Simplified guide for closed/abandoned mining waste facilities risk assessment

GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

MINISTERIO DE AGRICULTURA Y PESCA, ALIMENTACIÓN Y MEDIO AMBIENTE

Instituto Geológico y Minero de España

DIRECCIÓN GENERAL DE CALIDAD Y EVALUACIÓN AMBIENTAL Y MEDIO NATURAL

SIMPLIFIED GUIDE FOR CLOSED/ABANDONED MINING WASTE FACILITIES RISK ASSESSMENT

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1. INTRODUCTION

The old waste storage facilities that have been closed or abandoned without any kind of restoration, or where the restoration has been incomplete or negligent, represent a permanent potential risk for the population and the environment, especially when they contain dangerous and contaminating substances. Furthermore, there are numerous references to damage caused by breach due to a loss of physical stability in these structures, whether active or abandoned (ICOLD, 2001). In Europe, accidents such as those at Baia Mare (Rumania), Aznalcóllar (Spain) or Ajka (Hungary) have led to greater social sensitivity to the risk that this kind of mining waste facility represents, as well as the development of a regulatory framework which governs their management and helps to prevent catastrophic accidents. The Directive 2006/21/CE of the European Parliament and of the European Council of 15th March 2006, on the waste management from extractive industries (hereinafter, the Directive), sets down that Member States must create and periodically update an inventory of the closed waste facilities, including the abandoned waste facilities located on their territory, which could have a grave environmental impact or which might become, in the medium or short term, a grave threat to human health or to the environment. These inventories should be drawn up by applying methodologies or procedures of risk evaluation. The transposition of the Directive was carried out in Spain by means of Royal Decree 975/2009, of 12th June, on the waste management of extractive industries and on the protection and rehabilitation of the space affected by mining activities. In accordance with this Royal Decree, the inventory of closed mining waste facilities will serve as a basis for drawing up a programme of measures in the scope of the state autohorities and those of the autonomous communities. In both sets of regulations, the requirements set down are established in terms of grave environmental impact or of threat, without directives being made on the manner of measuring the types of risk associated with mining waste or the levels of reduction that should be achieved.

The Directive defines an extractive industry waste facility as any area designated for the accumulation or dumping of wastes, whether in a solid or liquid state or in solution or suspension. The following form part of such facilities: mining tailing impoundments or other structures which serve to contain, hold back or confine the wastes or which have another function, as well as spoil dumps, heaps and tailings ponds. On the other hand, the working apertures filled with waste after taking out the mineral for purposes of rehabilitation and construction are not included in this category. On the other hand, the Directive does not provide an express definition of what is considered an abandoned mining waste facility, leaving the interpretation open for the member countries of the European Union (EU). In this Guide, only closed and abandoned waste storage facilities associated with mining activity which has ceased, with or without a responsible body or person identified, which might represent a risk to the health and safety of human beings and the environment are considered, according to the concept of "pasivo ambiental minero" (Arranz and Alberruche, 2008; Moreno and Chaparro, 2008; ASGMI, 2012) or that accepted by the Association of Ibero-American Mining and Geology Services (ASGMI, 2010).

The objective of this Guide is to show a simplified risk evaluation procedure (SRE) which makes it possible to set priorities of action, based on the risk that this kind of mining waste facilities represent, and which constitutes an instrument of support for the decision with regard to the measures which must be taken and their urgency.

The final result of the evaluation may serve as support for the taking of decisions with regard to the drawing up of plans or projects of restoration, rehabilitation or remediation which will deal with the most urgent situations, in a context of economic and material resources which, in the case of abandoned mines, are generally very limited.

1.1. BACKGROUND

The problem of abandoned mines in countries with a significant historical mining industry has made it necessary to develop policies and public actions in many of them, aimed at reducing and controlling the risk they represent. It can be said that the United States was a pioneer in the preparation of plans aimed at the recovery of these abandoned mining spaces, which in Anglo-Saxon terminology are known as *abandoned/orphaned mine sites* or *abandoned mine lands*. The law on the restoration of land altered by coal mining from 1977, known as the *Surface Mining Control and Reclamation Act* (SMCRA), already contemplated the creation of a fund for the rehabilitation of abandoned mine lands. Subsequently, the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) passed in 1980, entrusts to the *United States Environmental Protection Agency* (USEPA) the identification of land contaminated by different activities, and the evaluation and prioritisation by applying the *Hazard Ranking System* (HRS) method, and remediation according to the risk. For this purpose, the *Superfund was created* (modified in 1986 by the *Superfund Amendment Reauthorization Act*) which provided funds for the plan. In this context, the *Abandoned Mine Lands* programme was develped aimed at listing and recovering abandoned mining locations related with metals and phosphate mining (www.epa.gov/aml). Other initiatives are the so-called *Restoration of Abandoned Mine Sites* (RAMS) of the U.S. Navy Engineers (USACE), and the one run by the *U.S. Geological Survey* (USGS) known as the *Abandoned Mine Lands Initiative* (AMLI) (http://amli.usgs.gov). It is indispensable to mention the *Reclaimed Abandoned and Inactive Mines Scoring System* (RAIMSS) of the *Montana Department of Environmental Quality*, for the evaluation and prioritisation of hard rock mining sites with a view to their rehabilitation. RAIMSS is based on the HRS of USEPA adapted to the case of mining. The method considers the following as the main routes of exposure of the potential receptors: underground and surface water, the air, and direct contact (Montana Department of Environmental Quality, 1996).

Other countries that are very active in the inventory and characterisation of the risk of abandoned mining sites are: Canada, with a number of outstanding programmes such as the *National Orphaned/Abandoned Mine Initiative* (NOAMI) (www.abandoned-mines.org) or the *Northern Contaminated Sites Program* (NCSP), the *Aboriginal Affairs and Northern Development Canada* (AANDC) (Nahir *et al.*, 2006). Australia, where the *Abandoned Mine Sites* programme carried out by the *Department of Minerals and Energy* stands out. In Latin-America, the initiatives related with the mining environmental liabilities (PAM - pasivos ambientales mineros) stand out, such as those carried out by the Association of Ibero-American Geological and Mining Services (ASGMI) for the preparation of a manual for the inventory of abandoned and paralysed mines (ASGMI, 2010), or the Economic Commission for Latin America and the Caribbean (ECLAC) of the United Nations. A reference for this Guide is the "Manual for the evaluation of risks from shut down and abandoned mines" carried out by the National Geology and Mining Service of the Government of Chile (SERNAGEOMIN) and the German Federal Institute of Geosciences and Natural Resources (BGR) (SERNAGEOMIN-BGR, 2008). Also deserving mention is the recent work of IGT-

ONRM (2013), carried out in Cuba. African countries such as South Africa and Namibia have made inventories of abandoned or orphaned mining sites, through the *National Strategy for the management of Derelict and Ownerless Mines* (Department of Mineral Resources, 2009) programme and the *Geological Survey of Namibia* (SAIEA, 2010), implementing and adapting the method developed by SERNAGEOMIN-BGR (2008) in Chile, respectively.

In Europe there are a range of experiments related with the preparation of inventories of abandoned mining sites, applying methodologies of risk analysis for the purpose of establishing a hierarchy of these liabilities based on the threat that they represent for the population and the environment.

Among all of them, we might point out the following: In Ireland, the *Historic Mining Sites – Inventory and Risk Characterisation* project carried out by the *Environmental Protection Agency* (EPA) and the *Geological Survey of Ireland* and the *Exploration and Mining Division,* belonging to the *Department of Communication, Marine and Natural Resources* of the country (EPA-DCMNR, 2009). The method of evaluation of the risk is an adaptation of the *Reclaimed Abandoned and Inactive Mines Scoring System* (Montana Department of Environmental Quality, 1996). The final objective was a classification of the historic mining sites according to the risk that they involve for human and animal (livestock) health and the environment. It is also worth mentioning the Evaluation of Environmental Risk for the Rehabilitation of Abandoned Mines project conducted by the *Instituto Geológico e Mineiro of Portugal* (Santos Oliveira *et al.,* 2002). In the United Kingdom, the *Prioritisation of Abandoned Non-Coal Mine Impacts on the Environment* project carried out by the *Department for Environment, Food and Rural Affairs* (DEFRA), in collaboration with the English *Environment Agency*, carried out a prioritisation of the river basins and/or watercourses impacted by abandoned metals mining in England and Wales with a view to the planning of future programmes of remediation (Jarvis and Mayes, 2012; Mayes and Jarvis, 2012).

The ICWFAG (2010) group prepared a protocol for the pre-selection of closed mine facilities based on the analysis of risk, aimed at the preparation of the inventory required by Article 20 of Directive 2006/21/CE for all Member States of the European Union. This method was based on a prior documentary knowledge and a questionnaire. The method was governed by a principle of caution in such a manner that, in case of doubt or a high degree of uncertainty, it contemplated inspection on site. Some of the Member States have applied this Irish protocol to the preparation of the inventory of their facilities, adapting it to their own case by means of the extension and/or modification of the said questionnaire, as is the case of Finland and Hungary. Both countries have included the potential for generation of acid mine drainage (AMD) in it. It is advisable to warn that, for the application of that method of pre-selection, it was necessary to have prior inventories or documentary information which is not easily available in many countries. This was the case in the United Kingdom, where the preparation of an inventory of this kind of closed and abandoned mining waste facilities which represented a serious threat was selected using a questionnaire of its own with a single response (yes/no), which attempted to evaluate the gravity of the impact by means of the comparison of certain environmental or other kinds of parameters considered in the evaluation with the regulatory standards of environmental quality or official classifications (declaration of contaminated soils, etc.). The information was supplied by local authorities, or obtained from databases belonging to public bodies, research projects or earlier inventories (Potter and Johnston, 2012). In Italy, the *Istituto Superior per la Protezione e la Ricerca Ambientale* (ISPRA) carried out a hierarchical structuring of this kind of facilities (*Gerarchizzazione dei siti minerari censiti*), according to the risk to health and the ecological impact. For this purpose, they started with earlier inventories and the ARGIA methodology, designed for contaminated soils, was adopted. The evaluation of the risk due to failure of the structure (www.isprambiente.gov.it/it/banche-dati/strutture-di-deposito-di-tipo-a, consulted on 20/01/2014) was not contemplated.

Other European experiments to emphasise were: PECOMINES AND SAFEMANMIN (http://viso.jrc.ec.europa.eu/pecomines_ext/results/EUR21186EN.pdf) and (www.safemanmin.eu), respectively. The first was an initiative of the countries of central and eastern Europe which entered the EU in 2004. It has as its objective to set up an inventory of the waste facilities which might generate an impact, especially through acid waters, through questionnaires, expert opinion and the use of tele-detection at the regional level. The second, led by Rumania, established a hierarchical structuring of the waste facilities according to the risk to the population fundamentally.

In Spain, a number of autonomous communities (Galicia, the Basque Country, Castilla y León, Castilla-La Mancha, Extremadura and Andalucia, among others) made inventories of mining sites and/or more or less complex waste facilities and with different degrees of analysis or risk scenarios contemplated. In this regard, this Guide attempts to supply a single method of evaluation of the risk applicable to the whole of the Spanish state. The procedure which is proposed might be adapted to other countries and even to other types of environmental liabilities from mining, as well as the mining waste facilities, provided that the existing differences and the conditioning factors and the limitations associated with the available information on the numerous aspects which are considered by the methodology are kept very much in mind.

2. SIMPLIFIED PROCEDURE OF RISK EVALUATION IN CLOSED AND ABANDONED MINING WASTE FACILITIES

2.1. FOUNDATIONS OF RISK EVALUATION

In general terms, risk is the combined measure of the probability that an event will occur and of its more or less negative consequences. Therefore, it can be described as a concept which has two dimensions: hazard, or the probability of occurrence of a fact or event which might potentially cause loss or damage, and the severity of the consequences associated with that event; and the prediction of which involves implicitly a certain degree of uncertainty. In the field of health and the environment, risk is identified as the probability that a population or an ecosystem may present a greater incidence of adverse effects as a result of exposure to a hazard (USEPA, 2001).

The application of risk management to the facilities for storage of mining wastes has as its objective to facilitate the taking of decisions on the priorities for action and the measures of remediation and/or rehabilitation to be carried out, reducing uncertainty, by means of the application of systematic, transparent and well-structured methods based on the best available information. The final aim of this kind of procedure is the elimination or the reduction of the risks associated with the facilities to tolerable or acceptable levels. **Figure 1** shows the sequence of procedures in a risk management model (Standards Australia, 2004a, b; ISO, 2009):

- *Communication with and consultation* of the possible interested or affected parties throughout the process.
- *Establishment of the objectives and the strategic, organisational and administrative context* in which the risk management will take place.
- *Identification of risks*. This phase has as its purpose to identify what, why and in what way the potentially harmful events can occur.
- *Risk Analysis* in terms of consequences and probability (likelihood). At this stage, the rank or magnitude that the severity or gravity of the potential consequences may achieve is considered together with how probable it is that those consequences should occur. The combination of both factors enables the estimated levels of risk to

be determined. The purpose of this kind of analysis is "to develop an understanding of risk".

- *Risk Assessment* the purpose of which is the comparison of the estimated levels of risk among themselves and with levels of acceptability (*Risk Acceptability Criterion*), which makes it possible that the risks can be ordered, making it possible to identify the priorities of action and the design of the most effective mitigating measures. With regard to levels of risk, when they are unacceptable they must be eliminated or reduced to levels considered to be the minimum tolerable. The choice of these measures must be made following the ALARP criterion (*As Low as Reasonable in Practice*) or reduction of the risk to a level that is as low as reasonably feasible with the best available technology (BAT) criterion. If the risk level is low or very low, it might be considered acceptable and it might be proposed that no kind of action should be taken.
- *Treatment of the risks,* which consists of the implementation of the action strategy designed at the assessment phase. In the case of low priority risks, the response will be acceptance, control and monitoring. For other risks, the application of the specific proposed management plan.
- Monitoring and review of the operation of the risk management system and the changes which might affect it.

It is important to clarify what term, likelihood or probability, is translated by “probabilidad” in Spanish. The term probability employed in this guide should not be confused with a statistical probability of a risk. It is employed in a similar way that in the text of the Geological Survey of Namibia (SAIEA, 2010), and in works like those of Jonhson *et al*. (2007) and Jarvis *et al*. (2007). In addition, it would agree with the definition presented by Powter (2002): “Risk is a combination of two factors: the probability that an adverse event will occur (such as a specific disease or type of injury) and the consequences of the adverse event”.

As has been noted above, the prediction of risk implies a certain degree of uncertainty. For this reason, an exact determination of the probability and the severity will not be possible in most cases, nor will it be feasible to obtain absolute certainty. It is for this reason that risk analysis may be carried out with different degrees of refinement, depending on the data available. According to circumstances, the analysis may be qualitative, semi-quantitative or quantitative, or a combination of these. The complexity and the cost of these analyses follow an ascending order which goes from the qualitative to the quantitative. In practice, qualitative analysis is often used first to obtain a general indication of the level of risk, and subsequently it is possible to make a more detailed quantitative analysis, if there is information which makes it possible or resources are devoted to obtaining the information.

Figure 1. Components of risk management (from: Standards Australia 2004a, b).

In preliminary risk analyses, qualitative assessments are generally applied, using descriptive and qualifying scales which attempt to reflect relative positions on a scale or order to specify the hazard and the magnitude or severity of the damage. In these cases, the final risk assessment is generally reflected by means of double-entry matrixes which integrate both aspects. On the other hand, the quantitative analysis aims to understand with a certain degree of precision the probability/severity/risk relationship, with the use of numerical scales being common, the definition of probability as a frequency expressed by means of fractions or percentages and the application of more or less complex physical-mathematical models for the determination of risk.

2.2. DESCRIPTION OF THE SIMPLIFIED RISK ASSESSMENT METHOD (SRA)

A review of the initiatives which have been carried out internationally has shown that the methods based on risk evaluation by scenarios, making use of risk matrices, work very well to establish priorities of action on territories with abundant abandoned mines, emphasising the work carried out in Canada (above all in the northern territories) (Nahir *et al.*, 2006), in the United Kingdom (Johnston *et al.*, 2007; Jarvis *et al.*, 2007) and especially in Chile (SERNAGEOMIN-BGR, 2008), etc. It can easily be understood that in order for a methodology of risk assessment to be of use in relation to abandoned mines, it must be capable of contemplating the enormous variety of possible situations or scenarios of risk in all cases that might present themselves. A good way of achieving this is to draw up a list of possible scenarios of risk which includes the possible faults, events or processes, whether accidental, instantaneous or ongoing, temporary or permanent, linked to all the elements or components of a location or mining area, as is explained, for example, in SERNAGEOMIN-BGR (2008). In that piece of work, an attempt was made to ensure that each scenario should be precisely and concisely described, and this description was an important part of the assessment system from the moment at which it represented a scenario of typified and fixed risk. In reality, each one of the risk scenarios which may be defined represents a type of hypothetical individual scenarios, the severity and probability of whose occurrence would vary according to the specific case that is being examined.

The idea is that, once there is a battery of codified scenarios, for each mining structure the assessments are made on the severity and probability of occurrence of each and every one of them. If the probability and severity of all the scenarios corresponding to each of the places of study are assessed, the results can be reflected by locating the codes of the scenarios evaluated on what is called a **risk matrix** or matrix for assessment of the level of risk, which is one way of visualising both dimensions of risk at the same time and showing a classification thereof. If, furthermore, as is usual, traffic-light type colour codes are used (the more red implies a higher level of risk), the final result is a kind of covering letter of the location evaluated. In this way, it is possible to explore the result of evaluating a list of locations easily visualising those with the greatest problems, through the situation that the corresponding codes occupy on the matrices, as will be seen in the final chapter.

As has already been mentioned, the methods of environmental risk analysis which use risk assessment matrices may serve very well the objectives of establishing priorities of action, for territories with a large number of abandoned mining locations or mining waste facilities. The governing idea is that the prioritisation or hierarchical structuring of priorities of action must be based on the comparison of risk matrices obtained for all the locations in the inventory, that is to say, the position occupied in the different areas of colour by the typified scenarios which have been assessed for each location and the comparison between some locations and others. According to Pelletier & Dushnisky (1993), there are three methodologies of environmental risk assessment which are especially well adapted to mining operations: the *Failure Modes and Effects Criticality Analysis-FMECA*, the Event Tree Analysis and the *Fault Tree Analysis*). The type or the combination of assessment techniques which is best adapted to any particular application is, to a large extent, a result of the type of data in the projects or the realities that are being evaluated. The first of them supplies a structured approach for the identification of undesired events or situations, the consideration of the probability of occurrence and the estimate of its effects or consequences, which are quite well adjusted to the present case in abandoned mining areas. The procedure of Simplified Risk Assessment (SRA) which is proposed combines in reality elements from the methodologies denominated *Preliminary Hazard Analysis* and *Failure Modes and Effects Criticality Analysis-FMECA*), as they are described by Espí (2007). It consists of the following stages:

1. Identification of the situations which entail a risk or a **risk scenario**.
2. Identification of the possible affected persons, known as potential **receptors**.
3. Estimation of the hazard or **probability of occurrence** for each risk scenario.
4. Estimation of the **severity of the consequences** on the different receptors.
5. Application of the assessments to a **risk matrix** to distinguish risks by their level of significance, which makes it possible to catalogue the mining waste facilities and order them by priority of action.
6. Preparation of a prioritised list of mining waste facilities and/or the application of a methodology of **Detailed Risk Assessment (DRA).** It will normally be necessary to

make a risk assessment in greater detail or an ERD in those cases in which there is a high degree of uncertainty about the simplified assessment carried out earlier, or when the design of rehabilitation or remediation actions is contemplated.

The procedure which is proposed attempts to be coherent, to the extent that this is possible, with the text of Directive 2006/21/EC and the Decisions of the Commission which complement it, as far as the classification of wastes and of waste facilities is concerned. However, for the great majority of the existing abandoned mining waste facilities, the information that would be necessary to do so correctly does not exist, with the result that it would be absolutely necessary to carry out sampling and laboratory analysis campaigns adapted to the rules in each case, or to look for alternatives to this and to carry out the assessment by introducing a complementary term of **uncertainty**, which, together with the final results of the assessment will make it possible to establish the priorities or the subsequent research needs limited to those cases in which it is considered necessary. In order to carry out a risk assessment of mining waste facilities, it is necessary to start from an inventory which collects up-to-date and real information on their characteristics, in addition to another series of materials which may be of use to make the assessment: topographical maps, aerial images, geological maps, hydro-geological unit maps, information on geo-chemical aspects (reports, scientific articles, etc.), uses of the environment, distance to population centres, etc. There are, therefore, some basic needs for information which are considered indispensable to make the assessment of the different risk scenarios and which will be set out in detail below. Likewise, it is considered indispensable to have a minimum of analytical information on samples which may be considered representative of each waste facility.

Once the definitive list of priorities of action is obtained, it is feasible to analyse whether it is appropriate or otherwise to declare the mining waste facilities which occupy the highest positions, such as those of Category A, in accordance with the criteria set down in Directive 2006/21/EC, or whether they should be considered in the national inventories in accordance with the level of threat involved.

Normally, the establishment of priorities in the form of a list, drawn up using homogeneous information and following a risk assessment method on the basis of scientific and technical criteria, should emphasise the places where it is most urgent to act in accordance with this type of criterion. However, the decision-making process has no reason to finish at this point, and it may be necessary to combine these priorities with others set in accordance with another kind of reasons: social, territorial strategy, political, etc.

The fundamental criteria for risk assessment will be predominantly qualitative, conservative (pessimistic) and economising from the point of view of the acquisition of information, aiming to maximise the use of already existing data. Nevertheless, it is also worth pointing out that if it is decided to act on the locations which head up the theoretical list of priorities for action, it will be necessary to carry out new works of research in much greater detail, including obtaining new data, so as to quantify and define the objectives, as well as to design measures at the level required by a project of realistic remediation or rehabilitation. It is important to emphasise this last matter: it is not necessary for the risk assessment to know all aspects which may be relevant for a rehabilitation of each and every one of the locations or mining waste facilities, since there might be hundreds in a single inventory. What is necessary is to have uniform information on them (ideally an application form inventory), and to have a simple methodology, which is at the same time systematic, which will make it possible to set priorities even with the risk of making a mistake but which guarantees sufficiently well that the locations with the greatest problems are going to stand out and be located in "high positions in a hypothetical list of priorities".

2.2.1. Identification of risk scenarios

A methodology of risk assessment applicable to abandoned mining waste facilities must be capable of contemplating a great variety of possible situations or scenarios of risk in all cases that might arise. A good way of achieving this is to draw up a list of possible risk scenarios which includes possible failures, events or processes, whether they are accidental, instantaneous or ongoing, temporary or permanent, linked to all the elements and components of a location or mining area, following a model similar to that described in SERNAGEOMIN-BCR (2008). In that work, an attempt was made to ensure that each scenario was precisely and concisely described, with this description being an important part of the assessment system from the moment at which it represents a typified and set risk scenario. In reality, each one of the risk scenarios which might be defined represents a class of hypothetical individual scenarios, of which the severity and probability of occurrence will vary according to the particular case which is being examined.

The idea is that the risk scenarios considered should constitute a fixed set of typical scenarios which covers the possible effects which may arise and which turn out always or nearly always to be relevant, since they are storage or dumping facilities for mining wastes. It is useful to assign to these typified scenarios an alpha-numerical code, which facilitates systematisation and graphical expression. Once there is a battery of typical scenarios, for each mining structure the evaluations of severity and probability of occurrence of each and every one of them will be made. If the probability and severity of all the scenarios corresponding to each one of the places under study is evaluated, the results maybe set out locating the codes of the scenarios evaluated on what is called a **risk matrix** or a matrix of assessment of the level of risk, which is a way to visualise the two dimensions of risk at the same time and to show the classification of the risk (which is explained in the final section of this guide).

On the other hand, to systematise the set of typified scenarios which might be of use in the evaluation of each and every one of the mining waste facilities, it may be interesting to group them into categories. Separating the risk scenarios into classes avoids the evaluation of certain risks being diluted, and also enables the subsequent remediation actions to be better specified.

In the first place, it is worth distinguishing between those scenarios which might be described as risk scenarios due to *contamination* or which arise when three circumstances coincide:

1. There must be a **contaminant** present in concentrations such that it can generate undesired effects on the receptors.
2. There must be a **route of exposure** by means of which the receptor can enter into direct contact with the contaminant.
3. There must be at least one **receptor**.

This kind of risk requires a pathway or route of exposure (air or water and, through the influence of these, also the soil) so that the contaminating element can reach the receptors and produce the undesired effects. The absence of a route of exposure means that there is no risk.

After a review of the bibliographical references, the option has been taken to consider the following groups of scenarios of contamination to which an alphanumerical code has been associated, which appears in brackets:

- Generation of contaminating effluents with effect/impact to the surface waters (C1).
- Generation of contaminating effluents with effect/impact to underground water resources (C2).
- Mobilization of particulate material due to the action of the wind (C3).
- Emission of contaminating sediments due to erosion by water (C4).

It is advisable to give the warning that, according to the receptor, a certain material can be considered a cause of contamination or otherwise. Here, the term contaminant will be understood as all materials or components which may be dangerous, arising from human activity, of which the concentration is such that it involves an unacceptable risk to the environment, the population or economic activities: a siliceous, powdery material is not equally damaging for soil as for the plants where it is deposited, and it is not equally dangerous for people who may inhale it.

The contamination scenarios contemplated above must be evaluated for all the mining waste facilities about which it is intended to make a risk assessment. In the work for SERNAGEOMIN-BGR (2008), which was an important point of reference for this manual, other scenarios of risk deriving from the accessibility for persons to mining facilities in which there are process reagents (such as cyanide), remains of benefit processes (residues with mercury from the amalgamation process or arsenic compounds from roasting) are also considered; collections of concentrates, etc., which may be handled by persons who are unaware of the damage that they may cause. These kinds of scenario are beyond the scope of the consideration of the Directive, which limits the obligations of Member States to bearing in mind only the risks associated with dumps of wastes from extractive industries originating from the extraction and treatment and dumping in mining waste facilities, mining tailing impoundments and tailings ponds.

However, it has been verified that it may be necessary to consider another scenario, relating to the possibility that direct contact might arise through inhalation, accidental ingestion or contact with the skin, for those cases in which a high accessibility is perceived for persons, or in which it is noticed that the mining waste facilities are used for the conduct of a range of activities (recreational, sports or others). This scenario has been called:

- Direct contact arising from occasional access or from the development of activities (CD).

On the other hand, the risks associated with possible faults in the storage or containment structures for wastes may be considered. The possibility that there may be breaches of embankments or dykes depends in large part on the specific construction of each facility, its situation in the environment, the possible deterioration of its stability, etc. Due to the nature of the processes of breach of embankments and dykes, the effects generally show themselves rapidly, or even instantaneously. Once an embankment or dyke is broken, the displaced material can cover a varying area of land. The magnitude of that area affected determines the elements at risk or the receptors exposed, which may be as diverse as the wild flora and fauna present, crops and livestock, infrastructure, areas which underlie a range of economic activities and, of course, inhabited areas or those often visited by the population. In short, the risk assessment in this kind of processes depends on to what extent the facility is a source of potential risk or hazard and on the type of potential receptors which might be affected or affected by the effect, if it occurs. The systematic analysis of the possibility of accidental events such as, for example, the falling of people down the embankment of a mining waste facility has been rejected as a result of its very limited relevance. Nevertheless, the confirmation or the knowledge that such a circumstance arises with a certain frequency may constitute additional information that is capable of being considered additionally to the decision-making process based on the systematic risk assessment which is proposed here.

According to the typologies of mining waste facilities mainly present in Spain, two types of scenarios have been considered which are mutually exclusive, as they refer to two different kinds of mining waste facility: heaps and mining tailings impoundments.

The analysis of the risk scenario of a possible breach of what are known as leaching piles, which are very unusual cases in Spain, has been dispensed with. These scenarios are also associated with an alpha-numerical code which appears in brackets:

- Failure or breach of the slope at dumps containing waste rock or low-grade ore (FESC).
- Failure or breach of the dyke or the external embankment of mining tailing impoundments (FPRE).

Normally, as has been indicated, with this series of scenarios the majority of potential risks normally associated with mining waste facilities are covered. However, the possibility of defining and evaluating a different specific scenario from those mentioned above should not be disregarded and may in a certain case be important.

2.2.2. Evaluation of the probability of occurrence of the risk scenarios

A first step is to identify in a relatively simple manner those facilities which do not reasonably represent a problem whether due to their relatively limited importance, their location in very remote areas, as a result of evidence of recovery of the ecosystem without the intervention of man, etc. For this reason, for each one of the systems of evaluation of scenarios which will be proposed below, an attempt has been made to also emphasise the aspects the recognition of which makes it possible to identify those which offer few doubts about the unlikeliness of the occurrence of negative effects or about the limited severity of the consequences of such events, for which the work of ICWFAG (2010) has been useful. The qualitative or quantitative establishment of a measurement of the probability of occurrence of a particular scenario, independently of the consequences that it might have, is also known as the **hazard**. Hazard is a term which is usually more associated with the position or geographical location of the process which is being evaluated, which is fixed for a certain mining waste facility. The `probability of the occurrence of a certain scenario will vary according to the specific characteristics of the mining waste facility that is being evaluated and of the circumstances in which it is. For example, the probability that a movement of particulate material from the surface of a particular mining waste facility will take place will depend on the granulometry of the waste, the moisture content and the greater or lesser incidence of erosive winds in the place where it is located. The probability of occurrence will be determined by a function of these factors which may well be based on the mathematical models normally used to assess this process, but it is not necessary that they supply exact results. In a procedure of risk assessment such as that put forward here, it will be enough for the estimate of probability to be qualitative, as has already been explained. For this reason, the evaluation will take place through what have been called **probability indexes** (**I_P**), which make it possible to evaluate in qualitative terms how probable it is that a negative effect associated with the different scenarios will occur. The indices will be simple functions of all those factors (relevant elements, circumstances or conditioning factors which can be evaluated in relative terms) which contribute to modifying the degree of probability of occurrence of the scenario. These indices, according to the scenario to which they are applied, may have greater or smaller physical and mathematical foundations, and will include to a greater or lesser extent the appreciations of field or expert judgements, as well as the prior experience from other similar evaluation work, with the result that it is advisable to translate all the evaluations to a single non-dimensional numerical scale. The scale proposed is that shown in **Table 1**.

RATE	PROBABILITY INDEX VALUE (I_P)
VERY HIGH	≥4 (to 5)
HIGH	≥3 and <4
MEDIUM	≥2 and <3
LOW	≥1 and <2
VERY LOW	≥0 and <1

Table 1. Probability indexes (**I_P**) general rating scale.

2.2.3. Evaluation of the severity of the consequences of the risk scenarios

So far, it can be observed that the battery of scenarios proposed does not contemplate the receptors, despite the fact that it is necessary that they should exist so that it is possible to speak of risk. The receptors have to be identified considering their position with regard to the location of wastes which is being evaluated and by means of the estimate of the scope or area affected by the process or event which is at the origin of the risk scenario. It is possible to object that, among the negative effects of the breach of a mining waste facility and the liberation of wastes, processes of contamination can be included, which complicates the analysis, given that it would be necessary to think again of evaluations of the probability that processes of contamination associated with the new situation created will arise: wastes spread over a much larger area than they initially occupied. This turns out to be too complex for what is intended with the risk assessment that is proposed here, and it is better to assume that all the land affected by an accidental spill will be devastated by it or by the immediate cleaning work which will follow (which agrees with the experience of the last few years). In this regard, it is easier to value above all what might be affected (population, ecosystems, economic activities and goods) from the point of view of the severity. For this purpose, it is necessary to have a minimum knowledge of the distribution and characteristics of the possible receptors from the information gathered in inventories or visits to the site and with the support of cartographical information available of various kinds.

The scenarios can be differentiated by the consequences on three types of receptors:

- Effects, consequences or impacts on persons or the population (persons considered individually, inhabited areas, places of work or meeting places and towns and villages).
- Effects, consequences or impacts for the natural environment (terrestrial wild life, aquatic life, soils, sensitive areas, etc.).
- Effects, consequences or impacts on the socio-economic environment (goods, properties, cultural heritage and economic and social activities, such as agriculture, livestock keeping, recreation, tourism, etc.).

From the combination of the groups of scenarios set down in point **2.3** with these three types of final receptors the following **risk scenarios** arise**:**

- Effects on persons or the population deriving from the generation of contaminating effluents affecting surface water (C1PO).
- Effects on the natural environment deriving from the generation of contaminating effluents affecting surface water (C1NA).
- Effects on the socio-economic environment deriving from the generation of contaminating effluents affecting surface water (C1SE).

- Effects on persons or the population deriving from the generation of contaminating effluents affecting underground water resources (C2PO).
- Effects on the natural environment deriving from the generation of contaminating effluents affecting underground water resources (C2NA).
- Effects on the socio-economic environment deriving from the generation of contaminating effluents affecting underground water resources (C2SE).

- Effects on persons or the population deriving from the movement of particulate material due to the action of the wind (C3PO).
- Effects on the natural environment deriving from the movement of particulate material due to the action of the wind (C3NA).
- Effects on the socio-economic environment deriving from the movement of particulate material due to the action of the wind (C3SE).

- Effects on persons or the population deriving from the emission of contaminating sediments through water erosion (C4PO).
- Effects on the natural environment deriving from the emission of contaminating sediments through water erosion (C4NA).
- Effects on the socio-economic environment deriving from the emission of contaminating sediments through water erosion (C4SE).

- Effects on persons or the population deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore (FESCPO).
- Effects on the natural environment deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore (FESCNA).

- Effects on the socio-economic environment deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore (FESCSE).

- Effects on persons or the population deriving from failure or breach of the dyke or the external of mining tailing impoundments (FPREPO).
- Effects on the natural environment deriving from failure or breach of the dyke or the external of mining tailing impoundments (FPRENA).
- Effects on the socio-economic environment deriving from failure or breach of the dyke or the external of mining tailing impoundments (FPRESE).

Additionally, as has already been stated, another scenario will be added:

- Effects on persons or the population deriving from direct contact originating from occasional access or from the development of activities (CD).

The evaluation of the gravity or severity of the consequences, in each specific case, will vary according to the type of receptor. In fact, although any of the scenarios which are defined may hypothetically have effects on the three types of receptor, the normal thing is for the evaluation for each one of them to be based on different criteria, specific to each type. Some scenarios, due to their very definition, may have consequences that are comparatively much less important according to the three types of receptors. For example, flying dust is less pernicious for the population than for economic activities in the immense majority of cases. This fact, rather than being left out, may be reflected in the evaluation guide in the interests of making the evaluation method a systematic process. For each mining structure which is assessed, it is worth putting forward the demand of noting the result of the three assessments carried out for each scenario in the boxes reserved for the purpose in a kind of summary evaluation card, which may be very useful for subsequent approaches to remediation or rehabilitation.

The severity of the consequences will also be evaluated by means of what has been called **severity indices (I_S)**, which make it possible to evaluate in qualitative terms the gravity of a negative effect associated with the different scenarios arising. The indices will be simple functions of all those factors (elements, circumstances or conditioning factors, which can be evaluated in relative terms) which contribute to reducing or increasing the severity of the effects of each scenario. Depending on the type of effect and receptor, it may be convenient to analyse the severity of the damage according to such aspects as **exposure** and **vulnerability,** as will be shown in the following chapters. These indices of severity will also be assessed on a scale of zero to five (**Table 2**).

RATE	SEVERITY INDEX VALUE (I_S)
VERY HIGH	≥4 (to 5)
HIGH	≥3 and <4
MEDIUM	≥2 and <3
LOW	≥1and <2
VERY LOW	≥0 and <1

Table 2. Severity indexes **(I_S)** general rating scale.

The methodology designed must be capable of responding satisfactorily to the clearest requirement set down in the Commission Decision 2009/337/EC, that is to say, it must include in the category of maximum severity those cases in which there is "a grave hazard for human health" (Art. 1.). In Art. 4.2. it is expressed that “the risk of loss of human life or the hazard to human health is considered insignificant … if the people who might be affected … are not expected to be present in a permanent manner or for long periods of time in the potentially affected area". In relation with the environment and economic activities, it is not so simple to extract guidelines from the legislation, although it is possible to accept that maximum severity must recognise those kinds of damage which might be considered to be permanent or lasting, or when the environment affected cannot recover through small efforts of cleaning and restoration.

As will be seen at the end, the fact that both the probability index and the severity index of the consequences are valued in accordance with a scale of five intervals involves the subsequent adoption of a matrix of risks of five by five (five rows and five columns).

3. RISK ASSESSMENT FOR SCENARIOS OF CONTAMINATION

3.1. GENERATION OF CONTAMINATING EFFLUENTS AFFECTING SURFACE WATER (C1)

3.1.1. Probability index for the generation of contaminating effluents affecting surface water: I_P(C1)

The scenario which is contemplated here describes the risk situation associated with the verified existence of effluents of a contaminating nature, or with cases in which, due to the chemical nature of the wastes, it is considered probable that some drainage may arise (leaching or effluent) of water that is loaded with metals or other dissolved toxic elements which may be released from the mining waste facility to the exterior, thereby contaminating watercourses or masses of surface water. The elements of the hydrological system which will be considered in the evaluation of the risk will be all the watercourses, all those masses of natural water or wetlands (including the superficial ones of a seasonal nature) and reservoirs. They are evaluated by means of what has been denominated the probability index for the generation of contaminating effluents affecting surface waters I_P(C1)**.** This index is a function of three factors: a proximity factor depending on the distance at which the watercourses or masses of surface water are with regard to the mining waste facility evaluated (P_R); the toxicity or hazard of the wastes (F_{TOX}), established on the basis of chemical analyses, and the so called factor of the unprotected surface (F_{SD}), which makes reference to the size or surface of the mining waste facility, and to the existence or otherwise of any kind of cover of the wastes.

3.1.1.1. Wastes of an inert nature from extractive industries

The processes of contamination associated with mining wastes may arise if the wastes contain contaminating or toxic materials. For this purpose, a first aspect to be considered is the possibility that these wastes are not toxic or that they are inert. The Decision of the Commission, of 30th April 2009 by which the definition of inert wastes was completed in application of Article 22, section 1, letter f), of Directive 2006/21/CE of the European Parliament and of the Council on waste management from extractive industries establishes the criteria for the definition of these inert wastes. In Schedule I of Royal Decree 777/2012, of 4th May, on management of wastes from extractive industries and on protection and rehabilitation of the space affected by mining activities, the tables relating to the identification of these mining wastes that are considered inert are collected. On the basis of the above, it is obvious that one of the first tasks when evaluating the potential of contamination with a certain type of waste which is being evaluated is to verify whether it is so considered in the above-mentioned Schedule I. In this case, it can be accepted that the probability of it generating problems of contamination is nil or negligible with the result that it can be accepted that the probability index or $I_P(C1)$ of these wastes is zero.

3.1.1.2. Characterization of wastes by their toxicity: toxicity factor (F_{TOX})

Starting from the fact that a certain mining waste facility does not contain any of the wastes that have been catalogued as inert, it is necessary to evaluate the toxicity of the mining waste facilities by means of analytical methods, which must necessarily be simple and economic. There seems to be a consensus in the literature that the greatest risk for surface water systems is that a direct discharge of acid mine drainage (hereinafter, AMD) might occur onto a body of water located at a distance that is sufficiently small so that such contamination can be considered probable. Normally, and given the time that has passed since the abandonment of the majority of the abandoned mining waste facilities in this country, those wastes which have that capacity to generate AMD, are already doing so, with the result that the normal thing is that the waters from the washing thereof already have a charge of toxic elements deriving from the weathering of the surface.

The objective is to obtain a measurement of the simple toxicity by means of what has been denominated the **toxicity factor (F_{TOX}).** This factor is simply an indicator of the relative toxicity of the waste expressed on a scale of 0 to 5, and it will be the basis of classification of the mining wastes according to their contaminating potential for water.

Theoretically, the best and most direct way of verifying the capacity of the wastes to contaminate water occurs in those cases in which there is emergence at the foot of the embankment or run off from the wastes which have a pH, a degree of salinity or a composition in terms of trace elements of those that are considered toxic, which involves a clear threat for any system of surface waters which receives it. In principle, the sampling and analysis of this kind of water is the most direct measure which can be used for establishing the probability of the occurrence of phenomena of surface water contamination. At other times, the possibility arises of taking samples in the accumulations of supernatant water in the waste reservoirs. When both types of water exist: drainage at the foot or in the body of the embankment and supernatant, the first should be valued by preference since it has been seen that they may not have exactly the same characteristics.

One way of confirming a possible effect of acid mine water in the field is by using a joint measurement of the pH and of electrical conductivity (EC) in supernatant or leached water. The pH is a direct measurement of current acidity, while EC is correlated with the total amount of dissolved solids and with the content of sulphate ions, in the case of pyritic wastes which have undergone a process of oxidation. It can be considered with a good degree of certainty that a waste has a low probability of contaminating water (low toxicity) if the pH measurement and the electrical conductivity of the water samples satisfy the values expressed in **Table 3**. In this case, they will be assigned a toxicity factor value (F_{TOX}) equal to 0.5. Below, it is indicated how this toxicity factor intervenes in the calculation of the probability index of occurrence $I_P(C1)$. This way of assessing is reserved solely and exclusively for those cases in which there is no other information available, apart from the field measurements.

Supernatants or embankment drainages chemistry assessment	
Valuation criteria	**F_{TOX} value**
Electrical conductivity less than 400 µS/cm and pH between 6,5 and 8,5	0,5

Table 3. Toxicity factor (F_{TOX}) value assigned to supernatants or drainages from low toxicity mining waste.

Nevertheless, in the immense majority of cases it will be necessary to carry out chemical analyses of the water samples. The values obtained for concentrations of the elements of interest must be compared with the standard in **Table 4**, and the toxicity factor must be evaluated (F_{TOX}) in the way that is explained below.

When there are no supernatant or leached elements in the mining waste facility, it will be necessary to carry out the assessment using the analytical data of the wastes, by applying a single system of analysis to all of them. In principle, it would be possible to evaluate the toxicity from the samples which can be considered to be representative of a mining waste facility or from information published from which average values or ranges of the different parameters can be deduced. It seems that there is a consensus among the researchers in assuming that the surface samples represent the most active component from a geo-chemical point of view due to its greater exposure to rainfall and to the atmosphere and therefore to the alteration and solution of minerals. The great majority of the abandoned or orphaned mining waste facilities have been in this situation for sufficiently long so that the processes of change, especially in the surface layers, will have made their geo-chemical imprint. On the other hand, when it is intended to evaluate numerous structures, the taking of surface samples will not be excessively costly. It is recommended that the method of sampling described in Smith *et al*. (2000), Hageman & Briggs (2000) and Smith *et al*. (2002) should be followed. It appears to be well-accepted that it is the fraction of less than 2 mm that governs the chemistry of wastes, with the result that it will be this fraction, obtained by means of sifting, which will be used in the chemical analyses, independently of whether the separation is made in the field or in the laboratory. In the case of mining waste facilities of materials with pyrites, if possible, it may be of interest to obtain a sufficiently-large sample of material from a point located at a lower height (in contact with the natural ground), or where it is appreciated that there is a trail which announces the existence of drainage. It may be supposed that this material will be in some way impregnated with water from the leaching of the entire mass of waste.

An important first indicator of the chemistry of wastes is the pH (in suspension of solid material in water in a proportion of 1/1). This pH value, if it is greater than or equal to 11.5 is considered corrosive and a value of under 3.5 is considered toxic. However, the most practical thing, from the point of view of the effects on surface water, is to make tests which determine directly the quantities of soluble elements. In this regard, it must be emphasised that the most interesting work, in respect of prioritisation based on the toxicity of mining wastes in environments of abandoned mines use leaching tests with de-ionised water (USGS, 1999; USEPA, 2009). Of all possible leaching tests with water in the laboratory, the one that is most advisable is the one known as EN 12457-2 (*European Committee for Standardization*, 2002), which assesses the contents of soluble elements in a proportion of 1/10 (solid: de-ionised water).

It is proposed that the elements to be analysed should be those elements (metals and metalloids) that are potentially toxic collected in the Decision of the Commission of 30th April 2009: As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V and Zn. To this series of metals and metalloids contemplated above it is advisable to add Al and Se, which are toxic for aquatic life and are often present in rivers and streams affected by AMD. It is proposed that the evaluation of the results of the leaching tests should be carried out with regard to a water quality standard, such as that of water for human consumption or preservation of aquatic life, in a similar manner to how this is generally done with the generic reference levels in soils. This factor or index which will be identified as the **hazard average quotient** (**CPP_{LAB}**) is expressed in the following manner:

$$CPP_{LAB}=1/n \times \sum^{n} \frac{[X]_{LIX\text{-}LAB}}{NCA_X}$$

Where:

-$[X]_{LIX\text{-}LAB}$ is the concentration measured in the leaching resulting from applying to the waste the EN 12457-2 laboratory procedure (or other equivalent) for element X

-NCA_X is the maximum admissible content in the water or level of quality of water corresponding to element X

-n is the number of elements for which the concentration measured in the extract is greater than the level adopted as a standard, or the directly measured content in a sample of water from the waste taken in the field.

The levels adopted as a reference are shown in **Table 4**, together with other levels obtained from the references. For the definition of the standard with which the concentrations obtained are compared, the starting point was as regulated in Royal Decree 140/2003, on the quality of water for human consumption, and in Royal Decree 60/2011, by which the Environmental Quality Rules in the sphere of water policy were established. Furthermore, other international rules have been reviewed: those of the EPA in the United States, those of the WHO (World Health Organisation), those of the Ministry of the Environment in Ontario, as well as the work of Puura and D'Alessandro (2005).

	Standard adopted (a)	**Level for human water consumption (b)**	**NCA-MA (c)**	**OMS (d)**	**EPA *Primary Drinking Water* (e)**	**EPA *Secondary Drinking Water* (f)**	**EPA *Ambient Water Quality Criteria* (g)**
Al	**50**	200		200		50-200	
As	**10**	10	50	10	10		150
Cd	**0,25**	5		3	5		0,25
Co	**20(*)**						
Cr	**50**	50	50	50	100		
Cu	**10($)**	2000	30(¢)	2000	1300(§)	1000	10($)
Hg	**1**	1		1	2		
Mo	**70**			70			
Ni	**20**	20		20			
Pb	**10**	10		10	15(§)		
Se	**1**		1	10	50		
V	**6(#)**						
Zn	**120($)**		250(¢)	3000		5000	120($)
pH	**6,5-8,5**	6,5-9,5				6,5-8,5	

Tabla 4. Desirable levels of trace element concentration (in µg/L) and pH. Notes:

- Standard adopted.
- Chemical indicators from the Spanish Royal Decree 140/2003, about quality of human water consumption and the 98/83/CE Directive.
- Environmental Quality Standards in the field of water policy (Spanish Royal Decree 60/2011).
- Guideline values for naturally occurring chemicals that are of health significance in drinking-water (OMS, 2006).
- Maximum permissible levels in drinking water (National Primary Drinking Water Regulations, USEPA, 2009).
- Maximum permissible levels in drinking water (National Secondary Drinking Water Regulations, USEPA, 2009).
- Recommended aquatic life criteria for chronic exposition) (USEPA, 2002).

(*) There are no widely accepted international references. Suggestion of Puura &D'Alessandro (2005) is adopted.
(¢) Quality values for an intermediate salinity degree.
(#) The water quality objective for aquatic life of the *Ministry of Environment and Energy of Ontario* (2004) is adopted.
($) Quality values for an intermediate salinity degree.

Starting from data obtained at numerous mining waste facilities, it has been possible to draw up a graph (**Figure 2**) which makes it possible to transform the values of CPP_{LAB} into the so-called **toxicity factor (F_{TOX})**. It has already been mentioned that this factor is nothing other than an indicator of the relative toxicity of wastes expressed on a scale of 0 to 5. It has been considered that at any value of the hazard average quotient obtained from normalised laboratory test data greater than 400, the maximum toxicity classification (5) should be assigned to it, that is to say: $F_{TOX} = CPP_{LAB} \times 0{,}0125$, for $CPP_{LAB} \leq 400$, and $F_{TOX} = 5$, for $CPP_{LAB} > 400$.

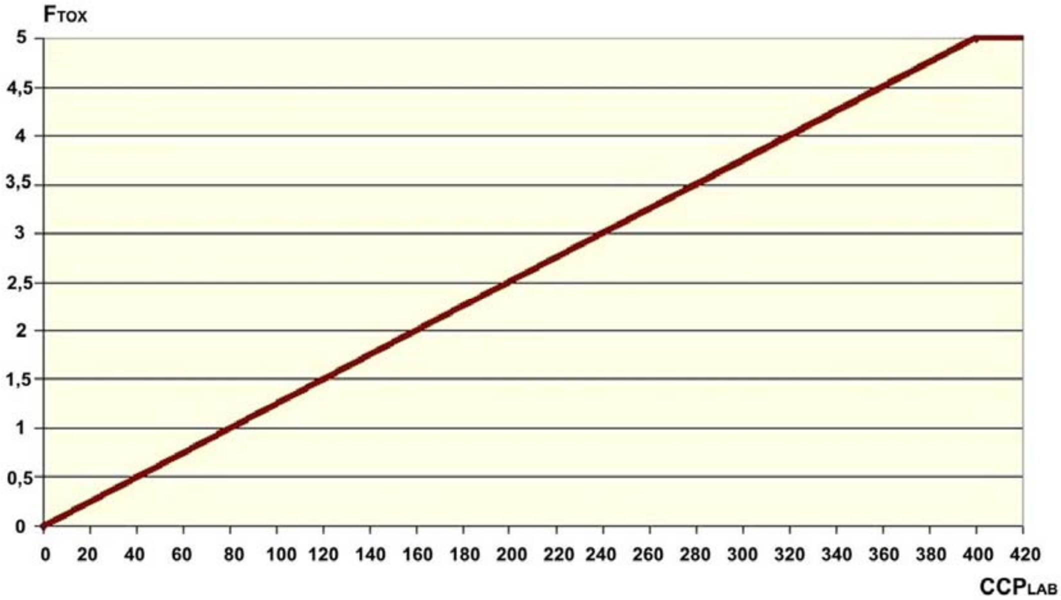

Figure 2. Toxicity factor (F_{TOX}) value allocation in accordance with the value of the hazard average quotient (CPP_{LAB}) calculated based on data from the EN 12457-4 laboratory test.

Another option to establish a measurement of the hazard of wastes is to use the so-called Field Leaching Test (FLT), which was developed by members of the US Geological Service to supply a rapid and economical measurement of the pH and the electrical conductivity, as well as to obtain a leaching on which it would be possible to measure contents of potentially toxic elements (Hageman & Briggs, 2000; Hageman, 2004). The method contemplates the extraction in water with an agitation time of only five minutes, assuming that the most reactive materials present in superficially altered wastes are relatively soluble components of the fine fraction (<2mm).

From the results obtained by means of the application of this field method to mining wastes, it is possible also to make an assessment with regard to the same standard of water quality which has been adopted as a reference. This factor or index will also be identified as the **hazard average quotient CPP_{ELC}**:

$$CPP_{ELC}=1/n \times \sum^{n} \frac{[X]_{ELC}}{NCA_X}$$

Where:

-$[X]_{ELC}$ is the concentration measured in the leaching resulting from applying the leaching test to the waste in the field for element X

-NCA_X is the maximum admissible content in the water or level of water quality corresponding to element X

-n is the number of elements for which the concentration measured in the extract is greater than the level adopted as the standard.

In like manner to what was done above for the results deriving from laboratory analysis, a graph has been prepared (**Figure 3**) which makes it possible to transform the values of CCP_{ELC} into the so-called **toxicity factor (F_{TOX})**. It has been considered that at any value of the hazard average quotient greater than 200, it should have the maximum toxicity classification (5) assigned, that is to say: $F_{TOX} = CPP_{ELC} \times 0{,}025$, for $CPP_{ELC} \leq 200$, and $F_{TOX} = 5$, for $CPP_{ELC} > 200$.

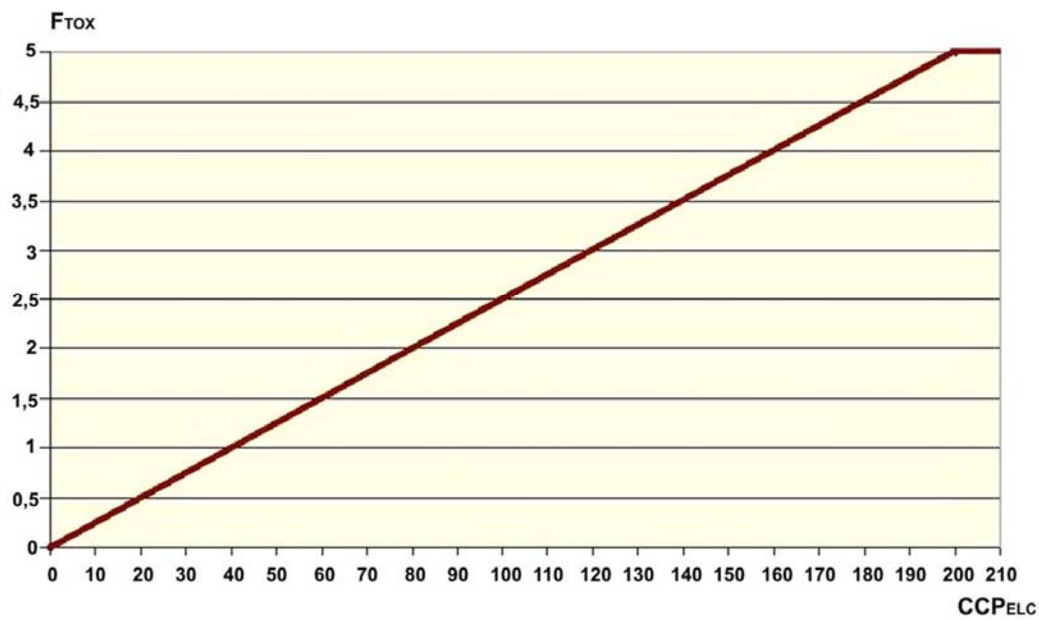

Figure 3. Toxicity factor (F_{TOX}) value allocation in accordance with the value of the hazard average quotient (CPP_{ELC}) calculated based on data from the field-leaching test.

Between the two strategies of assessment of the toxicity of the mining wastes the one that uses the laboratory tests must take priority given that it gives more reliable data as it is carried out in much more uniform conditions than those which predominate in the field testing campaigns. However, the second way of evaluating is still a good option for situations in which the lack of resources and time make it advisable to simplify the evaluation procedures.

3.1.1.3. Proximity of the watercourses or bodies of surface water to the mining waste facilities: proximity factor (P_R)

The probability that a receptor may be affected or reached by the contaminants depends in the first place on the route taken over the land by the water which has washed the wastes on the surface (run-off) and at a depth (emergences), following the line of maximum slope towards the closest watercourse or body of water. On other occasions, drainage from a mining waste facility will not reach any watercourse or mass of surface water, and will infiltrate the land, which will give rise to phenomena of contamination of soils and underground water. The processes of contamination of soil will be of very local importance while the processes of contamination of waters may have consequences at a much greater distance. The possibility of reaching a mass or water or watercourse depends to a large extent on the volume of contaminated water and the slope of the land. However, so as to simplify, it is more convenient to deal with criteria of proximity, with the certainty that at a lesser distance, downstream, it is more probable that the scenario that is being evaluated may arise, independently of the number of times it occurs within a certain space of time. The proximity between both things (the body of water and the mining waste facility) will therefore be a key element, given that if the distance is sufficiently large, the probability of the occurrence of the contamination taking place will be negligible or nil. The most convenient solution from all points of view is to evaluate this proximity via the measured distance in bird's eye view on topographical maps or aerial orthoimages in sufficient detail (preferably at a scale of 1:10,000 or larger).

In agreement with Turner *et al*. (2011), it is considered that the risk for watercourses or bodies of surface water is very high when the distance is less than 50 m On the other hand, when the distance is greater than 500 m, it is considered that the risk is very low.

These two magnitudes are proposed as the extremes of measurement of the distance between mining waste facilities and surface water after which the probability of an effect can be considered to be very high or very low. A **proximity factor (P_R)** is defined, with a value of between 0 and 1, which depends on the distance. The distance must be measured from the point of contact of the mining waste facility with the natural land located at a lower height to the watercourse or wet area, always in the most probable direction of circulation of water (maximum slope). This distance is in short the length of the journey or foreseeable or obvious route of the water. For the evaluation of this factor, two different types of case have been taken into consideration:

- On the one hand, the bodies of water (independently of the extent to which they are filled), permanent and intermittent watercourses of order 3 or greater. When establishing this criterion, a measure of ordering and hierarchy of the river courses based on the classic system of Strahler (1952) is being set, which consists of assigning the order 1 to the primary watercourses (which do not receive tributaries). The higher orders are assigned to sections of the watercourse that receive two or more flows of a lower order. An order 3 watercourse can be considered as important even if it is intermittent or is dry for much of the year. The proximity factor (**P_R**), in this case, can be valued using **Figure 4**. If preferred, it is possible to evaluate the factor as follows: $P_R = 1$, for $D \leq 50$; $P_R = (-0{,}0022 \times D)+1{,}1$, for $50<D < 500$; and $P_R = 0$, for $D \geq 500$.

- For those intermittent watercourses of a lower category, another formula of assessment supplied by **Figure 5** is proposed**.** For this kind of watercourse, it is considered that the maximum degree of effect may arise only at a distance less than that which was taken for permanent watercourses, and which is set at 30 m, and the upper limit is also less than that selected for permanent waters (300 m). If a certain mining waste facility is in a position to be able to affect several watercourses or masses of water, the closest will always be taken or the combination of distance and range which generates a larger proximity factor. When a certain mining waste facility is located in a valley, burying a section of watercourse, or when it makes contact with a watercourse or mass of water, it will be considered that the distance is zero and the **P_R** factor will reach its maximum value (1). If preferred, it is possible to assess the factor as follows: $P_R = 1$, for $D \leq 30$; $P_R = (-0{,}0037 \times D)+1{,}1$, for $30 < D < 300$; and $P_R = 0$, for $D \geq 300$.

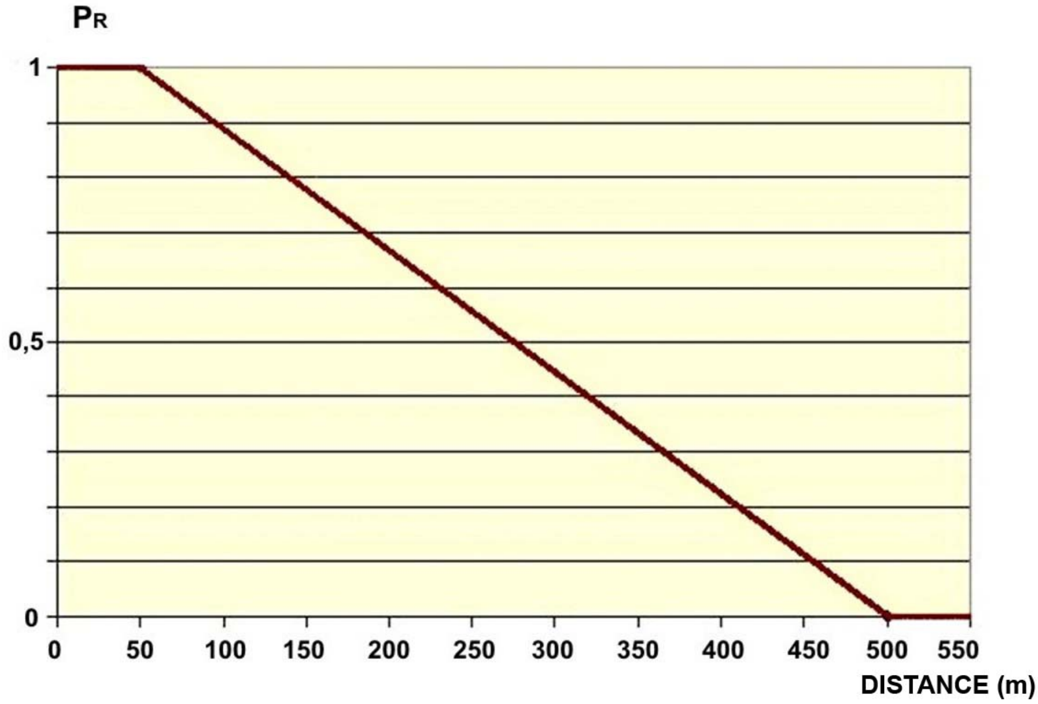

Figure 4. Proximity factor (P_R) value allocation for a body of water or a permanent stream or an intermittent 3rd or greater order stream in accordance with the distance (m) measured in the same direction of the water flow.

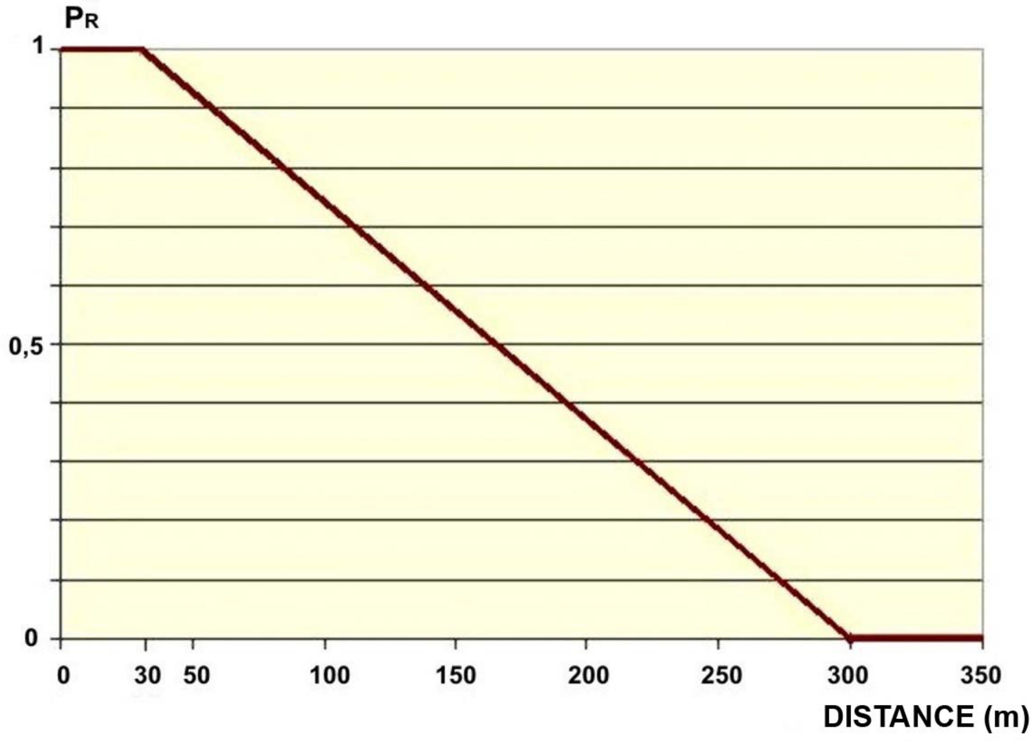

Figure 5. Proximity factor (P_R) value allocation for an intermittent less than 3rd order stream in accordance with the distance (m) measured in the same direction of the water flow.

The $\mathbf{P_R}$ factor may serve to rule out those cases in which it may be considered that the probability that negative effects may arise on the surface waters is negligible or nil, that is to say, when there is no watercourse or mass of water at a distance equal to or less than 500 m, or 300 m if they are intermittent watercourses of a lower order. In such a case, without need for carrying out subsequent assessments, the probability of generating contaminating effluents with effect on surface waters will be zero, that is to say, IP(C1) = 0.

3.1.1.4. Other factors which affect the probability of generation of contaminating effluents affecting surface waters: the unprotected surface factor ($\mathbf{F_{SD}}$)

Theoretically, the surface offered by the mining waste facilities to weathering processes and to infiltration in rainy periods determines the generation of run-off and/or percolation waters as well as the characteristics thereof. Clearly, dykes, especially if they have a steep slope, are surfaces which receive less infiltration than flat areas, which depends on the angle or inclination of the slope and on the formation of run-off. As it is not simple to establish to what extent the different parts of a certain structure may contribute to the contamination of the surface waters, whether by leaching or by run-off it is assumed that a valuation can be made on the basis of the total exposed area S_{EX}. From the measurement of the surface from a bird's eye view of the mining waste facility which is under evaluation it is possible to assign a **surface factor** (**F_S**) valued between 0 and 1 by means of the graph in **Figure 6**. It has been considered that the maximum value (1) must be assigned when a total exposed surface of the mining waste facility of 2 ha or greater is achieved. This is the same as using the following equivalences: $F_S = 0,5 \times S_{EX}$, for $S_{EX} \leq 2$, and $F_S = 1$, for $S_{EX} > 2$.

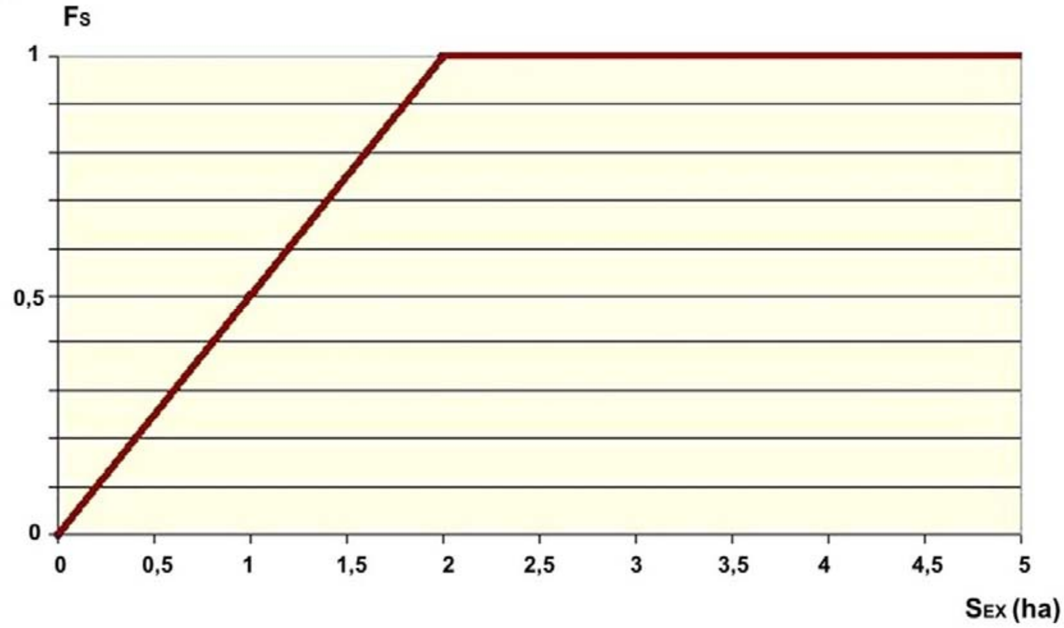

Figure 6. Surface factor (F_S) value allocation in accordance with the total surface of the mining waste facility exposed (S_{EX}).

It is normal that the abandoned mining waste facilities corresponding to authorised mines before the early 1980s were not subject to any kind of rehabilitation or remedial measures. Nevertheless, some of them were at a certain moment covered with other materials and, on occasion, revegetated. One of the many ways of classifying the materials used as cover is the one proposed by Perry & Bell (1985): the whole range of natural soils, synthetic materials, construction and demolition wastes, and natural soils whose properties have been emended or improved with the addition of other materials crushed limestone, steel wastes, organic material, etc.).

To the above-mentioned materials, it is necessary to add other products of quarries (gravel, aggregates, clays, etc.) and other mining wastes that are considered to be inert. The normal thing in abandoned mining waste facilities is that at most they have been subject to partial defensive practices: covered with soils or other earthy materials, covered with demolition waste or mining waste rock, in both cases treated or otherwise with a fragmentation method. Furthermore, most of the time, these covering operations are incomplete. However, a cover, even if it is simple, incomplete and often improvised, can have very beneficial effects from the point of view of the generation of contaminating effluents on surface water. In this regard, and even though it is complicated to establish valuations on the degree of protection that this type of cover supplies, it is proposed to analyse what has been called M_C or **covering material (Table 5)**. The staff who may have to evaluate any other possible covering material may establish those values that they consider necessary in view of those that are proposed as a guide in the above-mentioned table, playing with the characteristics and the thickness of the material. It is also possible to apply a multiplying factor of the protective effect of the cover if some kind of vegetation is present. This factor, which will be called **plant cover** (V_C), will be evaluated so that it increases the value of the cover according to the type of vegetation and the surface covered measured from above (the sum of the cover flush with the ground plus the projection of the crown). This evaluation is set out in **Table 6**.

In order to evaluate the level of surface vulnerability of the mining wastes, it is necessary to determine the **cover fraction** (F_C) in advance, which must cover, apart from the surface covered, also the materials and characteristics specific to the type of cover; for the calculation, the following formula will be applied:

$$F_C = (S_C/S_{PL}) \times (M_C + V_C)$$

Where:

- F_C is the **fraction of cover.**
- S_C/S_{PL} is the relationship between the surface covered (S_C) and the total surface (S_{PL}), measured from above.
- M_C is the value corresponding to the covering material, deduced from **Table 9.**
- V_C is the value assigned due to the presence of vegetation, deduced from **Table 10.**

Valuation of the waste-cover material		
Valuation criteria		
Type of material	**Thickness (cm)**	**M_C value**
Clays from quarries without coarse elements	<15	0,3
	>15	0,6
Clay soils with <10% of coarse elements	<25	0,5
	25-50	0,6
	>50	0,7
Stony soils (>30% of coarse elements)	<20	0,3
	25-50	0,4
	>50	0,6
Inert mining wastes or demolition wastes without fine elements (<20%)	<30	0,2
	30-60	0,3
	60-100	0,5
	>100	0,7
Inert mining wastes or demolition wastes with abundant fine elements or mixed with sand (>20%)	<20	0,3
	20-50	0,4
	50-80	0,5
	>80	0,6
Crushed rock with a predominance of elements with size smaller than coarse gravel and stones	<20	0,3
	20-40	0,4
	40-60	0,5
	>60	0,6
Crushed rock with a predominance of elements with size higher than coarse gravel and stone	<40	0,2
	40-80	0,4
	>80	0,6
Pads of vegetal material (straw, hay, etc.) or organic blankets	<10	0,4
	>10	0,7

Table 5. Valuation of the cover material (M_C) in accordance with the characteristics of the material employed. Particle sizes are defined as coarse elements (>2 mm), coarse gravel and stones (>20 mm). Lack of vegetation or sporadic and scattered vegetation is assumed.

Valuation of the vegetation covering the wastes	
Valuation criteria	
Existing vegetation type	**V_C value**
Arboreal vegetation of any density, with no or very limited significance undergrowth	0,2
Arboreal, shrubby or mixed dense vegetation	0,3
Dense grassland or pasture	0,1
Disperse herbaceous or o sub-shrubby vegetation (thyme or esparto fields), occasional herbaceous vegetation, or land without vegetation	0

Table 6. Values assigned to the vegetation factor (V_C), concerning the existing vegetation in the mining waste facility surface regardless, the plantation was natural or artificial. The covered surface estimation is performed by in-line measurement (adding the direct covered surface and the surface under foliage).

The degree of surface vulnerability of the mining waste facility will be proportional to the result of subtracting the value of $\mathbf{F_C}$ from 1. The scale of valuation will oscillate between 0 and 1; when the surface of the mining waste facility is completely covered or protected, it will be equal to 0; on the other hand, when there is no kind of surface cover, the value of $\mathbf{F_C}$ will be 0, with the result that the degree of vulnerability will be equal to 1.

Finally, the **surface vulnerability factor ($\mathbf{F_{SD}}$)** as a measure of the probability of infiltration and generation of leachings and run-offs, with a load of contaminants, can be calculated by applying the following formula:

$$\mathbf{F_{SD} = F_S \times (1\text{-}F_C)}$$

Where:

-$\mathbf{F_S}$ is the surface factor dependent on the area occupied by the mining waste facility.

-$\mathbf{F_C}$ is the cover fraction.

It can be verified that the F_{SD} factor is equal to the F_S factor (explained in the foregoing point) in those cases in which there is no kind of cover or when it can be considered irrelevant.

3.1.1.5. Calculation of the probability index of the generation of contaminating effluents affecting surface water $\mathbf{I_P(C1)}$

The probability index of the generation of contaminating effluents affecting surface water or **$\mathbf{I_P(C1)}$**, expressed on a scale of 0 to 5, will be calculated according to the following formula:

$$\mathbf{I_P(C1) = P_R \times F_{TOX} \times F_{SD}}$$

Where:

-$\mathbf{P_R}$ is the so-called **proximity factor** relative to the watercourses or masses of surface water.

-$\mathbf{F_{TOX}}$ is the so-called **toxicity or hazard factor** of the wastes.

-$\mathbf{F_{SD}}$ is the so-called **unprotected surface factor**, which makes reference to the size or area of the mining waste facility, and its degree of vulnerability according to the existence or otherwise of some kind of cover of the wastes. When it is evaluated on the basis of emergences at the foot, **Figure 13** is used (see below)**.**

3.1.2. Severity index of the generation of contaminating effluents affecting surface water I_S(C1)

The severity of the effects that drainage or contaminating effluent may cause to the environment, the people or the population and economic activities is derived from the consideration of the masses of water (temporary or permanent) which may be affected and their use. The severity of the damage to the surface water due to mining effluents is in accordance with the natural attenuation of the contamination load that the environment between the origin and the receiving mass of surface water represents. Hudson-Edwards *et al*., 1996, indicated how in water systems affected by acid drainage from mines, the concentration of contaminants in water and sediments tends to decrease with the distance from the sources of contamination as a consequence of chemical and hydro-dynamic processes. In general terms, in the present methodology a distance of 5 km downstream from the mining waste facility has finally been adopted for the evaluation of the possible damage to masses of water or watercourses except if there is information which makes it advisable to adopt another reference distance. The adoption of this distance is to a certain extent arbitrary. However, it is reasonable to accept that the attenuation has been total over it and also that the concentrations of metals or other existing solutes may be difficult to assign to the structure that is the object of evaluation. According to the circumstances which occur in the locations downstream from the mining waste facilities which are evaluated up to a distance of 5 km, a value of the **severity index of the consequences I_S(C1)** will be assigned**,** with a value of between 0 and 5.

3.1.2.1. Severity index of the effects on people and the population deriving from the generation of contaminating effluents affecting surface water: I_S(C1PO)

It is clear that the supply of water for human consumption is the most vulnerable in comparison with other uses of water, given that it goes hand in hand with a chronic exposure and involves a greater probability of generating systemic harm as it favours the entry into the organism, via ingestion, of dissolved toxic elements. Another important aspect in relation with this kind of use of water resources is its possible use for watering crops (especially horticultural crops or forage plants). The severity of the harm is evaluated via the so-called severity index of the effects on the population

Is(C1PO), which is made up of the following factors: population exposed (P_{EX}), vulnerability of the population (V_P) and the factor of exposure to the contaminant (F_{SUP}).

- *Population exposed (P_{EX})*

One of the factors which is involved in the severity index is that of the **population exposed (P_{EX})** to toxic elements, through the ingestion of contaminated water which has been taken from rivers, lakes or reservoirs affected by effluents from mining wastes. For this reason, it is necessary to know the number of points of extraction of water for the supply of the population (water for human consumption) present in the masses of surface water affected up to a distance of 5 km, in the direction of the water flow. The contingent of the population which might be affected is estimated in a similar manner to that proposed by EPA-Ireland (2009), from the number of persons per household, multiplied by the number of extractions of water, provided always that these were of a private nature and were not for supplies to towns and villages, it being understood that each one of them represents a place of residence. In Spain, according to the Census of Population and Households of 2011 by the National Statistical Institute, the average size of a family is 2.58 members; the resulting population value must be rounded up or down to a whole number. If there is extraction of water for the supply of a population centre, the demographic contingent of the said centre of population will be added to the population exposed which has already been evaluated. Although this is a very rough estimate of the total population exposed, the result of this calculation makes it possible to assess a degree of exposure with a view to defining priorities of action. Nevertheless, a very restrictive criterion is set so that if more than 50 persons are supplied, the risk is very high (value 5) or nil (value 0) when there is no extraction of water, in the reference spatial framework.

The intermediate values are established in a manner which is directly proportional to the increase or reduction in the number of persons potentially supplied with surface water, and this can be assigned directly from **Figure 7.** This is the same as considering that P_{EX} is equal to the number of persons supplied divided by 10, when this final number is ≤50. The existence of a "protected area" for the extraction of water for human consumption, which supplies over fifty persons" (Register of Protected Areas) in the mass of water affected, up to a distance of 5 km from the mining waste facility evaluated, will make it possible to directly assign the maximum value to this factor.

Figure 7. Exposed population factor (P_{EX}) value allocation in accordance with the number of people supplied with surface water.

It can be observed that the main source of information for the evaluation of the majority of the factors that define the severity index is the Register of Water. In this register, the rights to the private use of the water is registered, the management of which depends on the organisations in the basin, that is to say, the hydrographic confederations in the masses of inter community underground water, and the regional water administrations (water agencies) in the intra community administrations, in accordance with the Regulations on the Hydraulic Public Domain (HPD) (Spanish Royal Decree 849/1986). Apart from this, another source of information which may be valuable is the Catalogue of Private Water: an inventory of water use classified as private by the Water Act 1879, the owners of which opted to keep them under the same regime and not to include them in the previous register. Finally, if it is considered necessary, there is the possibility of consulting the persons competent in the matter at the affected local authorities.

- *Exposure factor (F_{SUP})*

The **exposure factor (F_{SUP})** may turn out to be a good indicator of the distribution of the concentration of the contaminating solutes in the mass of surface water, to which potential receptors are exposed. This factor tends to decrease with the distance from the point of emission or the waste mining waste facility, according to the efficiency of the complex processes of dilution and natural attenuation of the system. There is not a single model of distribution of the contaminant load based on ranges of distances, oriented to the evaluation of the probable effects on the health and the environment. Nevertheless, accepting the high degree of uncertainty of the model proposed, it has been decided in general and given the preliminary nature of the risk assessment to adopt the criteria adopted at CCME (2008), which is that the greatest concentrations arise at the point of discharge to 100 m downstream, assigning to this range the maximum value of the exposure factor (F_{SUP}). On the other hand, from 5000 m it is considered that the attenuation is total, or rather that the concentrations of metals or other solutes may be difficult to assign to the structure that is the object of valuation. The determination of the **exposure factor for surface water (F_{SUP})** can be carried out directly from the graph in **Figure 8**. The result is the same as that of applying the following equalities: $F_{SUP} = 1 + (-0{,}0002 \times D)$, for $100 < D \leq 5000$ m, $F_{SUP} = 0$, for $D > 5000$ m, and $F_{SUP} = 1$, for a distance $D \leq 100$ m.

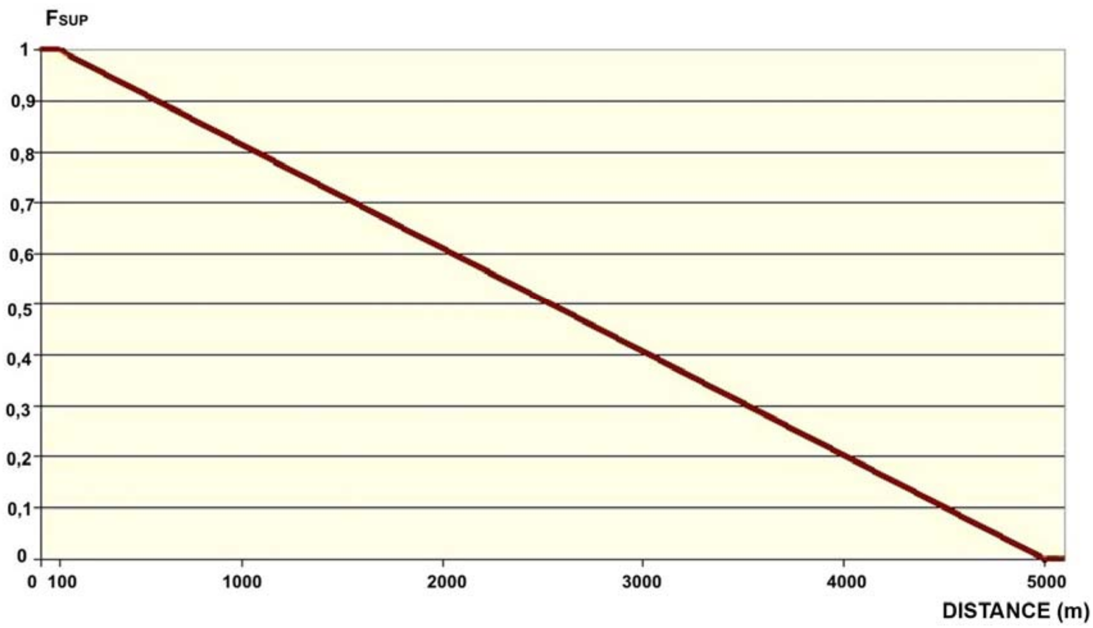

Figure 8. Value allocation for the pollutant exposure factor (F_{SUP}) depending on the distance to the surface water bodies.

- *Factor of vulnerability of the population (V_P)*

The **vulnerability factor of the population (V_P)** is closely linked to the type of use that is made of the surface water resources. Associated with this, a time of exposure and a dose are implicit from the point of view of the risk to health of people, which are highly dependent on the characteristics of the use of the water. Bearing in mind both considerations (exposure and potential dose), and by way of an operational criterion, in **Table 7** the valuations of large use groups are collected in accordance with the Regulation of the HPD. It is a matter of an open list which makes possible the inclusion by the evaluator of other uses of water which are not considered in the groups already defined.

As has been mentioned, the supply of water for human consumption represents the greatest vulnerability in comparison with all other possible uses of water. Another use which may be problematic is the irrigation of crops. Aquiculture may also be considered to be a use which causes a high degree of vulnerability, bearing in mind that fish farming is aimed at human consumption. With the same criterion, those river segments declared angling reserves may be considered as being of high vulnerability. Those areas devoted to bathing in rivers and masses of surface water (lakes and reservoirs) have also been considered to be areas of high vulnerability and have been regulated by Directive 2006/7/CE of the European Parliament and Council, of 15th February, relating to the management of quality of bathing waters and which has been transposed into the Spanish legal system by Royal Decree 1341/2007. The location of the bathing areas can be carried out through the National Information System of Bathing Waters "Nayade" on the internet (http://nayade.msc.es/Splayas/home.html), or alternatively by consulting the Register of Protected Areas, as is indicated by the Water Framework Directive (2000/60/CE), and/or Hydrological Plans of the river basin organisations. Nevertheless, if the evaluator has certain knowledge of the fact that, not in a sporadic way or rarely, the local population carries out such activities as bathing or fishing for their own consumption in a mass of surface water affected by effluents from mining waste facilities, the vulnerability assigned to these uses, although these river sections or masses of water are not included in any register of protected areas or of bathing sites, or are not declared fishing areas by the Administration will be considered. In **Table 7,** an evaluation for purposes of orientation is set out on the **vulnerability factor of the population V_P**, according to the use made of the water.

Assessment of the population vulnerability in the event of ingestion or direct contact with polluted surface water from mining wastes effluents.	
Valuation Criteria	**V_P value**
Water uses of very high vulnerability: Water supply for population (private water wells and human water consumption catchments, providing water to more than 50 people or population centres).	5
Water uses of high vulnerability: Irrigation (orchards, other crops and pastures) and farming uses (troughs). Aquaculture, fishing preserves and recreational uses (bathing areas).	4
Water uses of moderate vulnerability: Recreational use (sport fishing). Water for parks irrigation, etc.	3
Water uses of low vulnerability: Industrial use (energy generation, cooling, etc.), water for golf links irrigation, navigation and transport by water, etc.	2
Water uses of very low vulnerability: Other uses of low exposure.	1

Table 7. Valuation criteria of the exposed population vulnerability (V_P) depending on the surface water use.

The severity index of the harm to persons and the population which is proposed for a risk scenario due to contaminations of the surface water by effluents from mining waste facilities depends on: the population exposed and the ratio of exposure, or concentration of contaminants, according to the distance at which the point of removal or extraction of water with the most vulnerable use and the closest one to the point of emission is (**Figure 9**). This index is expressed by the formula:

$$I_S(C1PO) = 0{,}5\ P_{EX} + 0{,}5\ (F_{SUP} \times V_P)$$

Where:

-**I_S(C1PO)** is the Severity Index of the effects on people or the population deriving from the contamination of surface water by effluents proceeding from the mining wastes.

-**P_{EX}** if the factor of the population exposed as it supplies itself, for its own consumption, with water extracted from masses of surface water.

-**F_{SUP}** is the exposure factor of the population exposed at the point of extraction with the most vulnerable use of water and the closest to the mining waste facility.

-V_P is the factor of vulnerability of the population exposed as a function of the type of use considered most vulnerable.

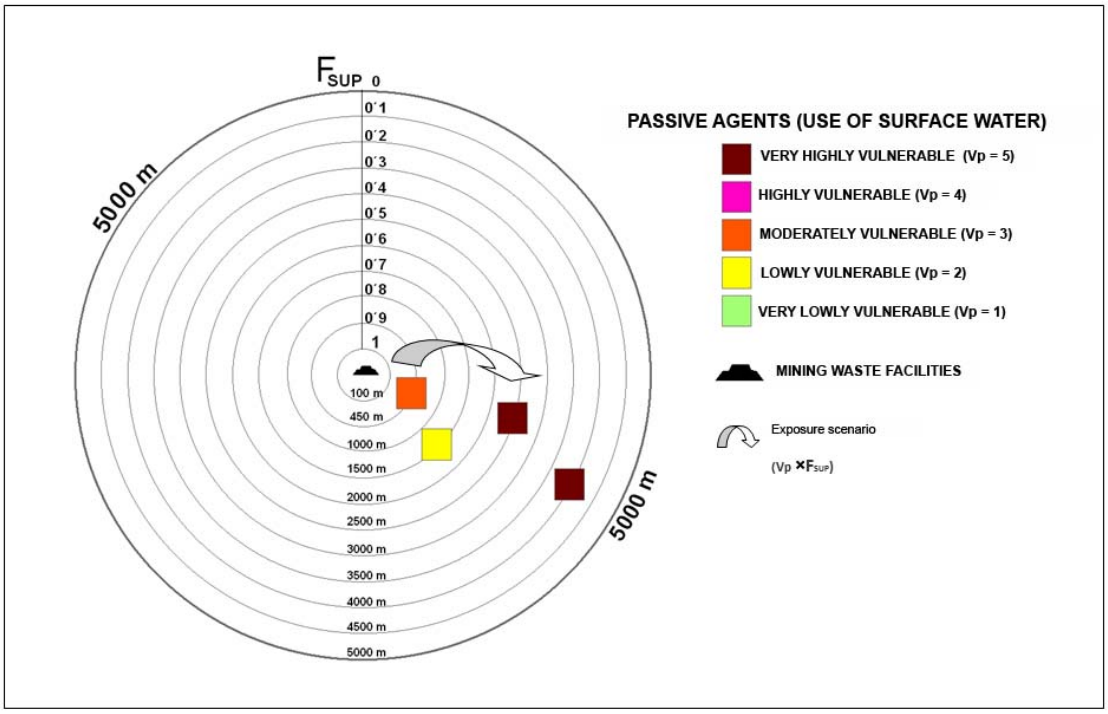

Figure 9. Selection criterion for the exposure scenario ($V_P \times F_{SUP}$): the most vulnerable water use and pollutant concentration linked to the distance (downstream and in the same direction of the water) to calculate the severity index for the impact of polluted surface water in the population (Is(C1PO)).

3.1.2.2. Severity index of the effects on the natural environment deriving from the generation of contaminating effluents affecting surface water: I_S(C1NA)

The so-called acid drainage from mines (ADM) is the type of effluent generated by mining wastes with the greatest potential for harm to aquatic ecosystems. This kind of drainage might be classified as a multifactorial contaminant, as its impact on the biocenosis is due to the acidification, salinisation, toxicity of metals, precipitation (coloidal and/or particulate) thereof and sedimentation (Gray, 1997). In general, the degree of damage (severity and duration of harm) to the biota will depend on: the chemical nature of the drainage (pH, total acidity and concentration of metals); the frequency and volume of the discharges; the size and characteristics of the receiving flow, especially its capacity for neutralization (a function of the pH and the alkalinity); dilution (this latter factor, depending on the flow of the contaminating current and on the volume of the mass of water receiving), and the hardness of the water in the receiving system, which has an influence on the eco-toxicity of the load of metals. Of like importance are the tolerance of the species affected and other ecological and environmental factors (IGME, 2010). The impact on aquatic ecosystems is evaluated through the severity index of the effects on the natural environment deriving from the generation of contaminating effluents affecting surface water. This index is a function of the vulnerability factor of the ecosystems (V_E) and of the exposure factor to the contaminating effluents (F_{SUP}).

- *Vulnerability of the ecosystems (V_E)*

It will be generally considered that the vulnerability will be inversely proportional to the degree of deterioration of the ecosystems affected. The ecological deterioration, recognised by quality standards of the masses of surface water, will depend in large part on the concentrations of toxic solutes to which the natural resources and ecosystems are exposed, and on their susceptibility to these contaminants. With a view to the definition of the **ecological vulnerability factor or that of the eco-systems (V_E)** the following are considered sensitive areas, as regards the masses of surface water, and according to the criteria of preservation of a natural resource or of purely ecological conservation: wetlands of international importance (Ramsar Convention) or catalogued in the National Inventory of Wetlands (INZH), and protection areas of the Natura 2000 network, the conservation of which is closely linked with the masses of surface water. All these areas that are considered sensitive are registered in the Register of Protected Areas (RPAs), as is set out in Art. 6 of the Water Framework Directive (2000/60/CE), of which the management also corresponds to the above-mentioned basin organisations, and are contemplated in the corresponding hydrological plans. Any other kind of protection of which the conservation might depend, in large part, on the surface water resources and which has not been considered in the previous register might also be included in the maximum category of valuation. It is clear that by virtue of the value of the resource and the merit of conservation, these areas present the highest degree of vulnerability and a greater foreseeable impact in case of being affected.

On the other hand, the Water Framework Directive, with regard to the protection of the masses of surface water, contemplates the evaluation and classification of the ecological state thereof as an expression of the quality of the structure and the operation of the aquatic ecosystems associated with these masses of water. Based on biological (aquatic flora, benthonic invertebrate fauna and ichthyofauna), hydro-morphological (hydrological regime and connection with masses of underground water; continuity of the river and morphological conditions) and physical and chemical (Directive 2000/60/CE, Appendix V of the Directive) indicators and the application of metrics and biological indices and those of another kind, proposes an evaluation and classification of the masses of surface water into five classes: very good condition (unaltered areas or with very limited alteration), good, acceptable, deficient and bad (it shows grave alterations of biological indicators) condition.

The Hydrographic Confederations and Water Agencies of the Autonomous Communities, in accordance with the above-mentioned regulations have incorporated Networks of Biological Control which supply information about the ecological state of surface water. If in the mass of water affected there were not to exist any nearby station belonging to this kind of network, it is possible to get information through publications or studies carried out by universities and research organisations which will make it possible to evaluate this ecological condition, provided always that it is considered necessary. In **Table 8,** the criteria proposed as a guide to the evaluation of the **vulnerability factor of ecosystems are indicated (V_E).**

- *Factor of exposure (F_{SUP})*

The **exposure factor (F_{SUP})** or concentration of the load of contaminants to which the different ecosystems or elements of the environment are exposed, is valued as a function of the distance to the mining waste facility, in a similar manner to how it was valued in relation to the population. The assessment of this factor is carried out by selecting, in **Figure 8**, the corresponding value F_{SUP} for a given distance.

Assessment of the ecosystem vulnerability in the event of surface water pollution due to mining wastes effluents emission.	
Valuation criteria	**V_E value**
Resources and ecosystems of very high vulnerability Sensitive areas (environmental protection of resources and ecosystems). Surface water bodies of very good ecological status.	5
Resources and ecosystems of high vulnerability Well-preserved wetlands but not included in Ramsar Convention nor in national inventories. Surface water bodies of good ecological status.	4
Resources and ecosystems of moderate vulnerability Surface water bodies of moderate ecological status.	3
Resources and ecosystems of low vulnerability Surface water bodies of poor ecological status.	2
Resources and ecosystems of very low vulnerability Surface water bodies of bad ecological status.	1

Table 8. Criteria for the evaluation of the ecological vulnerability (V_E) in accordance with the degree of protection and the ecological status of the water resource.

The index of severity of the damage to the environment **I_S(C1NA)**, in this risk scenario, is going to depend on the concentration of contaminants which will be a function of the distance at which is the most vulnerable aquatic ecosystem and/or natural resource up to a maximum distance of 5 km downstream, and closest to the point of emission, and its degree of sensitivity (**Figure 10**). This index is expressed by the following equation:

$$\mathbf{I_S(C1NA) = V_E \times F_{SUP}}$$

Where:

-I_S(C1NA) is the Severity Index of the effects on the environment deriving from the contamination of the surface water, due to effluents from the mining wastes.

-V_E is the ecological vulnerability factor according to the most vulnerable resource or ecosystem exposed, located at a maximum distance of 5 km in the direction of water flow.

-F_{SUP} is the exposure factor to which the different natural resources and most vulnerable ecosystems, and the ones closest to the mining waste facility are exposed.

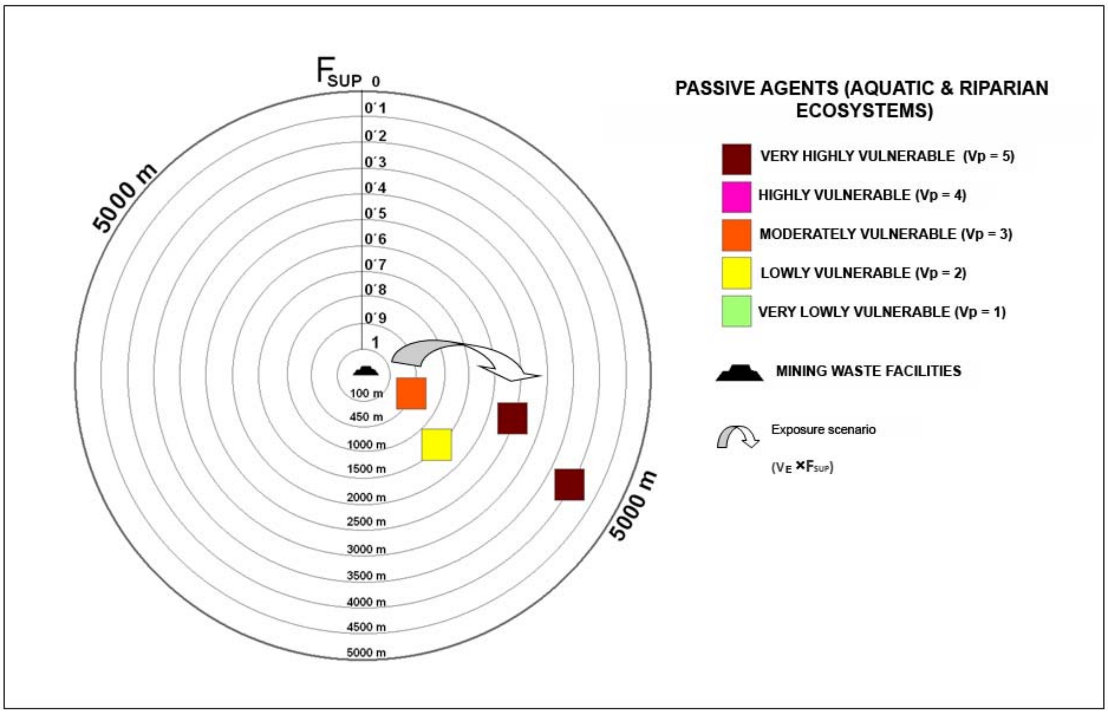

Figure 10. Selection criterion for the exposure scenario ($V_E \times F_{SUP}$): the most vulnerable resources or ecosystem and pollutant concentration linked to the distance to calculate the severity index for the impact of polluted surface water in the environment (Is(C1NA)).

3.1.2.3. Index of severity of the effects on the socio-economic environment deriving from the contamination of the surface water resources due to contaminating effluents: Is(C1SE)

The degree of impact on the elements of the socio-economic environment is going to depend on the local socio-economic structure and the degree of vulnerability of the different sectors of activity, and the elements of property which might be affected. The gravity of the damage will increase according to the economic weight of the sector involved or the social value of the potentially damaged elements. The severity of the consequences of the contamination of the surface water resources may also be evaluated in terms of loss of opportunity, if this represents a limitation for the conduct of those economic activities with the greatest potential or which it is desired to develop. Let the deterioration of water quality with regard to the standards demanded for certain uses serve as an example, such as for instance the economic impact involved in agricultural areas specialising in intensive irrigated agriculture. Given the preliminary nature of the methodology of risk analysis proposed, and the level of knowledge necessary to evaluate the economic structure, its potentiality and priority of use, making it advisable that the determination of the index of severity of the effects on the economic activities for this scenario **Is(C1SE)**, should only be carried out when the socio-economic damage is great and easily noticeable. In most cases, it will be considered that the valuation of the severity associated with this scenario **need not** be valued.

3.2. GENERATION OF CONTAMINATING EFFLUENTS AFFECTING UNDERGROUND WATER RESOURCES (C2)

3.2.1. Index of probability of the generation of contaminating effluents affecting underground water resources I_P(C2)

This scenario describes the situation of risk associated with the verified existence of effluents of a contaminating nature, or where, due to the chemical nature of the wastes, it is probable that some drainage of water loaded with metals or other dissolved toxic elements which may be released from the mining waste facilities towards the subsoil will take place, contaminating the underground water resources. Its evaluation is carried out by means of what has been called a probability index of the generation of contaminating effluents affecting underground water resources I_P (C2)**.** This index is a function of three factors: an intrinsic vulnerability factor to the contamination of the mass of affected underground water (FV); the toxicity or hazard factor of the wastes (F_{TOX}), and, therefore, of the effluents generated; and the so called unprotected surface factor (F_{SD}) with influence on the generation of toxic effluents and the possibility of infiltration.

3.2.1.1. Existence of aquifers and susceptibility to contamination: vulnerability factor (F_V)

The first question to settle in relation with the probability of contaminating the underground water resources is the existence of any underground water mass which might be affected. For this purpose, it is necessary to consult existing documentation which will make it possible in some way to recognise this: by means of their inclusion on geological or hydro-geological maps, the known location of wells and springs, quotation in scientific articles or the identification in studies of a more local nature. If after this investigation, the conclusion is reached that there are no aquifers which might be impacted by the mining wastes and that, therefore, there is no possibility that a process of contamination of these resources might be started, it is possible to ignore directly this risk scenario making a record of the decision, or what is the same thing, assigning a nil value to the index **I_P(C2).** On the other hand, if there is an aquifer or mass of underground water located under the mining waste facility or in the immediate vicinity of the embankments in a downstream position from the mining waste facility up to 50 m), the probability of the generation of contaminating effluents affecting underground water resources **I_P(C2)** must be evaluated**. For this purpose**, it will be necessary to determine in the first instance the susceptibility of the mass of underground water exposed to this type of contamination or the **factor of vulnerability (F_V).**

The evaluation of the vulnerability of the underground water resources to pollution, deriving from the presence on the surface of mining waste facilities, starts from the premise that the physical environment offers a certain degree of natural protection (Zaporozec, 1994). The term "vulnerability" is opposed conceptually to that of natural protection (Zwahlen, 2004), with the result of greater vulnerability as the natural protection of these resources decreases. In any case, any aquifer exposed is vulnerable to a greater or lesser degree (NCR, 1993). The probability of an adverse effect on the masses of underground water due to effluents or contaminating leachings from the mining wastes will be a function of the capacity of attenuation of the overlying strata or the non-saturated area by processes of physical retention and chemical reactions; of the inaccessibility of the saturated area, from the hydraulic point of view, to the penetration of the wastes; and of the nature, toxicity, concentration, mobility and persistence of the contaminating load and its interaction with the environment. Currently, there is a great variety of methods for evaluating the intrinsic vulnerability of the aquifers to contamination which may be sorted into three large groups: simulation models, statistical methods and methods of indexes and superposition (Jiménez, 2009), with the latter being the ones that have had the greatest development and application. Among the indexed methods, we should emphasise the following: DRASTIC (Aller *et al*., 1987), GOD (Foster, 1987), SINTACS (Civita *et al*., 1990), AVI (Van Stempvoort *et al*., 1992), EKv (Auge, 1995), BGR (BGR, 1993), DRASTIC Reduced (DGOHCA-IGME, 2002; DGOHCA-CEDEX, 2002), or in the specific case of karstic aquifers, the methods known as EPIK (Doerfliger & Zwahlen, 1997) and COP (Vías *et al*., 2006). All these methodologies, oriented towards the determination of the intrinsic vulnerability, might serve for the evaluation of this risk scenario. As almost always, the choice of the method will depend in large part on the availability of information.

The Reduced DRASTIC method (DGOHCA-IGME, 2002; DGOHCA-CEDEX, 2002) has been applied to the evaluation of the intrinsic vulnerability of masses of Spanish inter-region underground detrital and mixed water by the General Directorate of Water (DGA) of the Ministry of the Environment and the Rural and Marine Medium and the Geological and Mining Institute of Spain (from now on IGME), in the framework of the Granting of Management for the Conduct of Scientific and Technical Work of Support for Sustainability and Protection of Underground Water. Activity 9 (Resolution of 30th October 2007, BOE nº 267), in accordance with the requirements of the Water Framework Directive. This methodology proposes a reduction in the number of parameters of the original DRASTIC method, developed by Aller *et al.*, 1987, for the Environmental Protection Agency in the United States. Just like the DRASTIC method, it starts from the premise that the contaminant enters from the surface dragged down by infiltration of rainwater, being diluted in water and acquiring its own mobility, viscosity and density. A simplification adopted by the reduced method is the consideration, solely, of the upper aquifers to which it is possible to attribute a free hydraulic regime, assuming that the confined aquifers are much less vulnerable. Of the seven original parameters, in the Reduced DRASTIC method only four variables have been considered: the plant soil factor (S), the lithology factor of the unsaturated area (L), the thickness of the unsaturated area factor (E), and the net recharging factor (R). Each factor is evaluated in terms of lesser to greater vulnerability, from 1 to 10, except the reload which is valued from 1 to 9. The method proposes an index of vulnerability weighted according to the relative importance of each factor, finally obtaining an aggregate value of intrinsic vulnerability, applying the formula: $V= 3S+4L+5E+R$. The values of the index are comprised between 16 and 156, and are grouped in 10 classes of vulnerability numbered from 1 to 10 (**Table 9**). All the methodology is supported by a Geographical Information System. The final results were the so-called “Maps of Intrinsic Vulnerability of the Inter-Regional Masses of Detrital and Mixed Underground Water”, present in each Hydrographic Demarcation.

The COP (Vías *et al.*, 2006) method has also been applied by the DGA and the IGME for the evaluation of the intrinsic vulnerability of masses of carbonated underground water in Spain, and is specific for carbonated aquifers. In the method, three variables are contemplated: the factor of concentration of flow (C), the factor of protection of the underground water (O), and the precipitation factor (P). The index of intrinsic vulnerability of the COP method is the product of the above-mentioned factors, in accordance with the following formula: $V = C \times O \times P$. This index varies between 0 and

15; values close to 0 indicate maximum vulnerability (minimum protection), while values of close to 15 correspond to the minimum vulnerability (maximum protection). The final index of COP is grouped into five classes which represent different degrees of vulnerability (**Table 9**). Just like the previous method, all the process of evaluation took place in a SIG environment, which made possible the automatic generation and in digital format of the so-called "Maps of Intrinsic Vulnerability of the Masses of Inter-Regional Carbonated Underground Water", in each Hydrographic Demarcation of the country in which they are present.

METHOD VULNERABILITY CLASS	REDUCED DRSATIC		COP
	Index range	**Index value**	
Very low vulnerability	**16-30**	**1**	**4 - 15**
	30-44	**2**	
Low vulnerability	**44-58**	**3**	**2 - 4**
	58-72	**4**	
Moderate vulnerability	**72-86**	**5**	**1 - 2**
	86-100	**6**	
High vulnerability	**100-114**	**7**	**0,5 - 1**
	114-128	**8**	
Very high vulnerability	**128-142**	**9**	**0 – 0,5**
	142-156	**10**	

Table 9. Inherent vulnerability of groundwater bodies to pollution.

The intrinsic vulnerability maps of the masses of inter-regional detrital, mixed and carbonated underground water made by the DGA and the IGME, may constitute the basis for the valuation relative to vulnerability in the index of probability of occurrence which analyses the effect on underground water resources, especially when information or a study in greater detail is lacking. If a decision is taken to use those maps, it will be necessary to bear in mind that the implementation of the procedure of evaluation was carried out in the geographical information system ArcGIS 9.2, and that the application of the algebra of maps was carried out in a raster model due to the greater potential for analysis, with the resolution of a pixel of 25 m x 25 m, in a UTM projection and ED50reference system. What is more, the themed layers were subsequently transformed into *shape format*, of a vectorial nature. The evaluations and description of the procedure are collected, in a detailed manner, in the corresponding technical reports which accompany the maps as a report (DGA-IGME, 2009), for each one of the inter-regional Hydrographic Demarcations. Consultation of the maps and/or the obtaining of the themed information in digital format can be carried out through the Documentation Centre of the IGME. Apart from these matters, for its proposal of use in risk analysis, other aspects must be borne in mind:

- In these maps, the intrinsic vulnerability of the mass of underground water, defined by the Water Framework Directive as a clearly differentiated volume of underground water in an aquifer or aquifers is represented.
- The application of two different methods, Reduced DRASTIC and COP, obliges one to make an integration of the resulting indices, the values of which must be grouped in five classes of vulnerability unified in the so-called **factor of vulnerability** (**F_V**, valued from 0 to 1). This change of scale is established in a graphic form in **Figures 11** and **12.**
- For the determination of the value of the vulnerability factor at each mining waste facility which affects a mass of inter-regional underground water, it is necessary to proceed to the superposition thereof on the intrinsic vulnerability map, in such a manner that the final value will be the average of the vulnerability values, the result of the integration described above, with weightings for the area occupied in the area in which the intersection occurs of the facility and the affected mass of water.

On the other hand, with regard to the inter-regional masses of underground water the management of which depends directly on the respective Autonomous Communities, it is possible that they have developed vulnerability maps or other themed information which will help in evaluation. It is a good idea to insist that one of the limitations in the use of the existing maps for the valuation of intrinsic vulnerability is the possibility that there are aquifers of little importance that are not included or valued, which could supply a number of nearby towns and villages. For this reason, it is important to investigate this possibility in advance and, if so, to analyse the possibility of applying some of the generic methods described, without losing sight of the fact that their importance will normally be local.

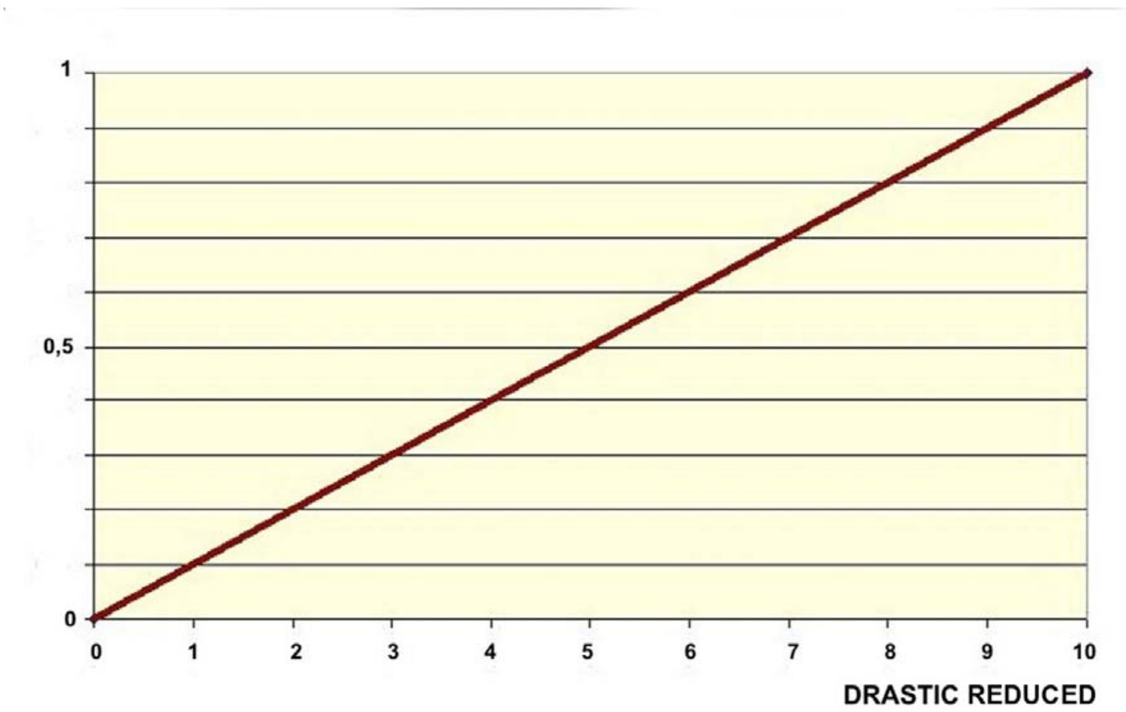

Figure 11. Vulnerability factor (Fv) in accordance with the value of the reduced DRASTIC index (for detritic and mixed water bodies).

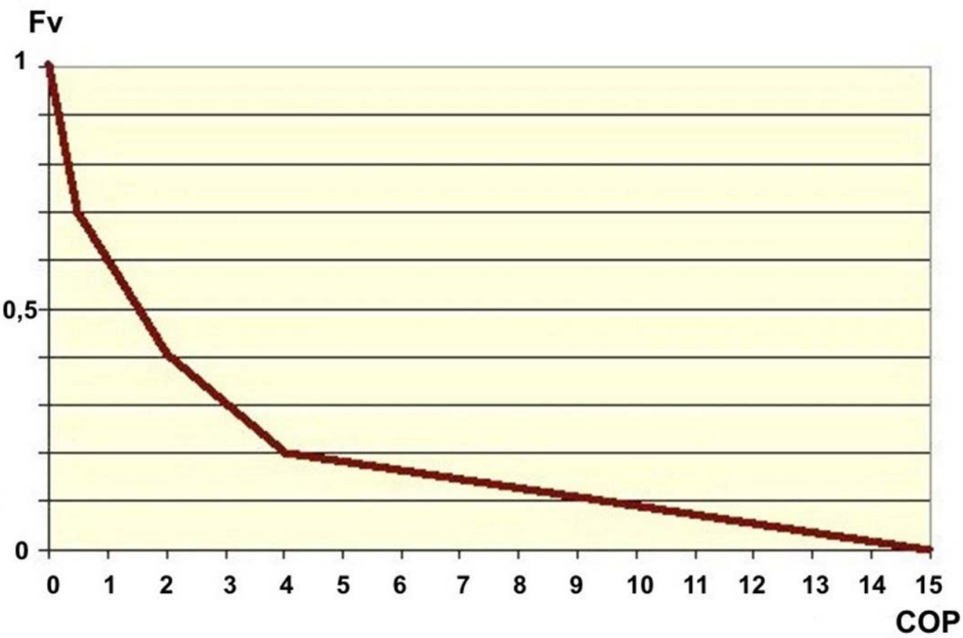

Figure 12. Vulnerability factor (Fv) in accordance with the value of COP index (for carbonated water bodies).

3.2.1.2. Characterization of wastes by their toxicity: toxicity factor (F_{TOX})

Just like what happens with surface water, the processes of contamination of underground water take place if there are contaminating or toxic materials. For the evaluation of the toxicity everything that has been said about drainage and toxicity of the wastes as elements of judgement of the probability of generation of contaminating effluents with effects on the surface waters is perfectly valid. The process of evaluation, as has already been explained, includes in the first place verifying whether the type of mining waste which it is desired to evaluate is included among those considered inert (Appendix I of Royal Decree 777/2012). If it is not included in these tables, the waste must be evaluated by following the methodology set out in section **3.1.1.2.**, until the value is obtained of what has been called $\mathbf{F_{TOX}}$**,** whether using analytical data of water or of waste.

3.2.1.3. Influence of the area occupied and without protection from the mining waste facilities on the probability of generation of contaminating effluents: unprotected surface factor (F_{SD})

Another factor to consider is the area occupied by the mining waste facility without any kind of protection or sealing, and which has come to be called in the proposed method of assessment the **unprotected surface factor (F_{SD}).** The probability of generation of contaminating effluents and their infiltration is increased the greater the unprotected surface area of a mining waste facility which stores non-inert wastes. For the determination of this factor, the surface area occupied by the facility or the area factor (F_S), and the surface protected by a covering and the degree of protection or fraction of cover (F_C).

- *Area factor (F_S)*

The total area occupied measured from above $\mathbf{S_{PL}}$ may be a good indicator of the probability of generation of contaminating effluents. Using the measurement of the area occupied by the mining waste facility which is under consideration, it is possible to assign an **area factor** ($\mathbf{F_S}$) valued between 0 and 1 by means of the graph in **Figure 13**. It has been considered that the maximum value (1) must be assigned when it reaches a total area occupied by the mining waste facility of more than 10 ha. That is to say, $F_S=S_{PL}\times0,1$, for $S_{PL}\leq10$ ha and $F_S=1$, for $S_{PL}>10$ ha.

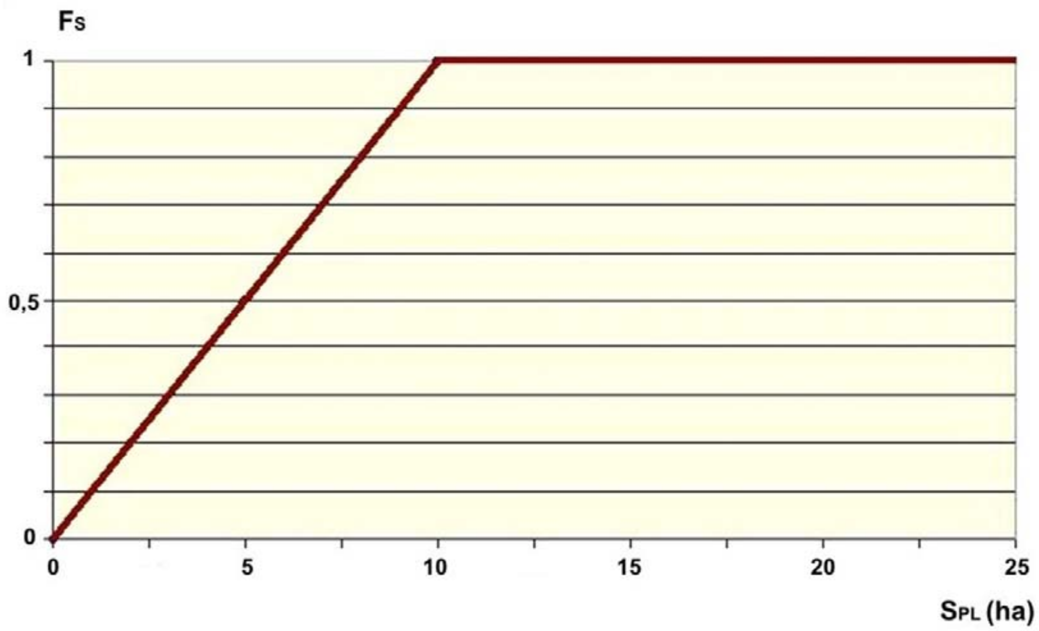

Figure 13. Surface factor (F_S) value assignment depending on the floor plan area (S_{PL}), measured in Ha, of the mining waste facility.

- *Cover fraction (F_C)*

It has already been mentioned that some abandoned mining waste facilities may be covered with other materials and, on occasion, replanted. The covering materials which tend to appear in this kind of facilities are normally: natural soils from the surroundings, natural soils whose properties have been emended, synthetic materials, construction and demolition wastes, quarry products (gravel, aggregates, clay, etc.) and other mining wastes or waste rocks that are considered inert. It is likewise common that the covering is incomplete and does not extend to the totality of the area of the mining waste facility. In any case, these coverings, even when they are simple and incomplete, may have beneficial effects from the point of view of the generation of contaminating effluents given that they retain water, preventing some of the percolation, or making the entry of air more difficult. It is for this reason that the existence of covering must be considered when making an evaluation of risk. In this regard, and even if it is complicated to establish valuations of the degree of protection that this kind of cover supplies, it is proposed that the valuations set out in **Tables 5 and 6 for** what has been called **M_C** or **covering material** should be considered. The staff who have to evaluate any other possible covering material can establish the values that they consider necessary in view of those that are proposed as a guide in the above-mentioned table, playing with the characteristics of the material and its thickness. A multiplying factor of the protective effect of the covering can also be applied if any other kind of vegetation is present. This factor, which will be called **plant cover** (**V_C**), will be evaluated so that it increases the value of the cover according to the type of vegetation and the area covered measured from above (the sum of the cover at ground level plus the projection of the crowns).

The **cover fraction** (**F_C**) considers, apart from the surface covered, the specific materials and characteristics of the type of cover; for calculating them, the following formula will be applied:

$$\mathbf{F_C = (S_C/S_{PL})\times(M_C+V_C)}$$

Where:

- **F_C** is the **cover fraction.**
- **S_C/S_{PL}** is the relationship between the area covered (**S_C**) and the total area (**S_{PL}**), measured from above.
- **M_C** is the value corresponding to the covering material, deduced from **Table 9.**
- **V_C** is the value assigned according to the presence of vegetation, deduced from **Table 10.**

The degree of lack of surface protection of the mining waste facility will be proportional to the result of subtracting from 1 the value of **F_C**. The scale of valuation will oscillate between 0 and 1; when the surface of the mining waste facility is completely covered or protected, it will be equal to zero; on the other hand, when there is no kind of surface cover the value of F_C will be 0, with the result that the degree of defencelessness will be equal to 1.

- *Calculation of the unprotected surface factor (FSD)*

The **unprotected surface factor (**F_{SD}**)** as a measure of the probability of infiltration and generation of contaminating leachings, will be calculated using the following formula:

$$\mathbf{F_{SD} = F_S \times (1-F_C)}$$

Where:

-F_S = Surface factor dependent on the surface occupied by the waste mining waste facility.

-F_C = Cover fraction.

3.2.1.4. Calculation of the probability index of the generation of contaminating effluents affecting underground water resources $I_P(C2)$

As has already been explained, the index of probability of the generation of contaminating effluents affecting underground water or **$I_P(C2)$** will be zero when there is no mass of underground water which might be affected, after an analysis of the existing information (references or maps) or of speaking to the inhabitants of the area where the mining waste facility is located. For all other cases, **$I_P(C2)$** will be calculated according to the following formula:

$$I_P(C2)= F_V \times F_{TOX} \times F_{SD}$$

Where:

-F_V is the so-called **vulnerability factor** depending on the intrinsic characteristics of the aquifers or masses of underground waters.

-F_{TOX} is the so-called **toxicity factor** of the wastes.

-F_{SD} is the so-called **unprotected surface factor**, which makes reference to the size or surface area of the mining waste facility, and its degree of defencelessness according to the existence or otherwise of some kind of cover of the wastes.

The value obtained from applying the foregoing formula gives results comprised between zero and five.

3.2.2. Severity index of the generation of contaminating effluents affecting the underground water resources $I_S(C2)$

The severity of the damage, in the case of contamination of these water resources, is closely linked with a probable loss of the current or potential use due to the deterioration in the quality of the water. The gravity of the effects will be greater when these resources are scarce and with priority protection, such as those used for drinking water supply, or when the degree of contamination makes its use in economic activities of importance for local development non-viable, or when it becomes a serious threat due to its toxicity to the health of the population exposed and of the ecosystems depending on them. In the specific case of underground water, the severity of the damage may be aggravated, even further, due to the high economic and technical cost involved in the recovery of a contaminated aquifer with the result that this kind of impact may in practice be considered irreversible.

3.2.2.1. Index of severity of the effects on persons and the population deriving from the generation of contaminating effluents affecting underground water resources: I_S(C2PO)

The route of exposure of persons to contamination, in this risk scenario, just as with surface water, is mainly due to ingestion of water and agricultural produce irrigated with water from contaminated wells or springs, and, to a lesser extent, due to contact and dermal absorption through the domestic use of the water (personal hygiene) or with recreational purposes (swimming-pools etc.).

The severity index of the damage to the population is obtained as in other severity indices applied to contamination scenarios through the evaluation of: the population exposed (P_{EX}) and the degree of vulnerability of the population (V_P), and exposure to the contaminant.

- *Exposure factor to contaminated underground water (F_{SUB})*

Mining waste facilities constitute specific sources of contamination of water resources. Unlike other sources of diffuse contamination, in this case the contaminants appear very localised, affecting a more limited and specific area of the mass of water. On the other hand, the concentrations of contaminants may be very high in the recharging area, moving slowly in the saturated area, and in the direction of the flow of water, undergoing, at the same time, a process of attenuation due to dilution and dispersion. From all of this, it can be deduced that the "concentrations of exposure" will decrease with distance from the mining waste facilities. For the calculation of the distance of the final extent of the contaminating plume, from which it is considered that its potential capacity for contamination is very limited, it is necessary to make a hydro-dynamic and hydro-geological analysis of the behaviour of the underground flow and of the contaminants, which requires deep and detailed knowledge of transit times, which will affect the distance in metres according to the particular case. In the literature and among the different methodologies which have dealt with the evaluation of risk in abandoned mine workings or soil contamination, there is no consensus for pre-setting this distance, in such a manner as to serve as a spatial framework of reference for all the process of evaluation of the damage. Finally, an arbitrary distance of 1 km has been adopted, just like the criterion followed by the Irish Environmental Protection Agency. It is worth remembering that the mining waste facilities tend to be located in spaces highly impacted by mining activity, with a high concentration of mining structures (mining waste facilities, mining tailing impoundments, pitheads, cuttings, etc.) which represent specific focuses of contamination, and it is very difficult to assign the degree of responsibility for a possible or verifiable deterioration of underground water; it is for this reason that it may turn out to be acceptable to have a buffer distance of 1 km around the mining waste facility under evaluation.

The **exposure factor (F_{SUB})** may be a good indicator of the distribution of the concentrations of contaminating solutes in the mass of underground water, to which the potential receptors are exposed. This factor tends to diminish with distance from the point of issue or the mining waste facility. As occurred with the effects deriving from the contamination of surface water, there is no unanimity in establishing a model of distribution of the contaminating load based on ranges of distances in metres, oriented to the evaluation of the probable effects on health or the environment. The distances which are used for the delimitation of protection perimeters around points of extraction of drinking water might serve as references but, in general, they generally refer to transit times (one day for the immediate area, 50 days for the nearby area, and ten years for the distant area (Martínez and García, 2003). Taking into consideration some of the criteria followed in methodologies of risk analysis applied to contaminated soils (Alberruche *et al*., 2014), a theoretical and qualitative model of distribution of the contaminating load is proposed in which the contamination plume has its maximum concentrations at between 0 and 100 m, diminishing in directly proportional manner with distance up to 1 km, where this exposure factor (F_{SUB}) is considered to be equal to 0. The values of the $\mathbf{F_{SUB}}$ factor are assigned. Taking **Figure 14** as a reference for values of distance (D) greater than 100 m the following calculation formula will be applied: F_{SUB}= -0,0011× D+1,11 for values of D less than or equal to 100 m , F_{SUB} will be assigned a value of 1.

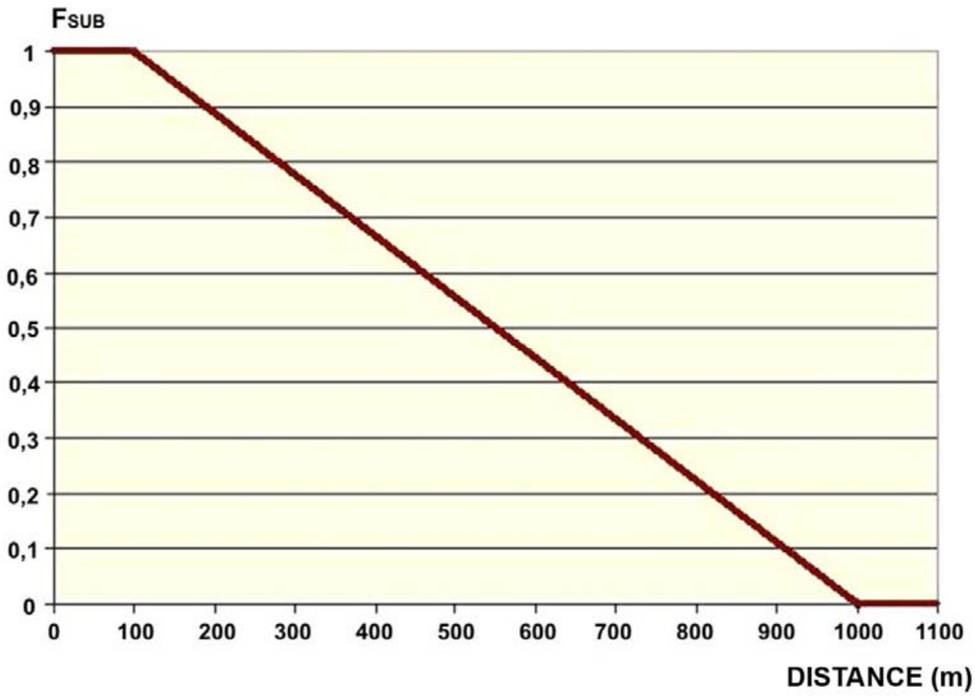

Figure 14. "Exposure to pollution" factor (F_{SUB}) value allocation in accordance with the distance and the pollution distribution in the groundwater body.

- *Population exposed (PEX)*

Just as the matter was set out in the analysis of the severity of the consequences associated with the contamination of surface water, one of the factors involved in the calculation of the severity index is the **population exposed ($\mathbf{P_{EX}}$)**, through the ingestion of contaminated water taken from the subsoil. For this purpose, it is necessary to know the number of wells and springs devoted to the water supply of the population (water for human consumption) within a radius of 1km, or alternatively, in the direction of the predominant flow of underground water up to that reference distance, if this is known through piezometric maps or hydrogeological research.

The contingent of the population which might be affected is estimated from the number of persons per household multiplied by the number of points of extraction of water, it being understood that each of them represents one household. In Spain, according to the 2011 Census of Population and Households of the National Statistical Institute, the average size of a family is 2.58 members; the resulting population value exposed must be rounded off to a whole number. Furthermore, a very restrictive criterion is established in such a manner that with over 50 persons the risk is very high (value 5) or nil (value 0) when there is no extraction of the water (well or spring). The intermediate values are established in a directly proportional manner to the increase or reduction in the number of persons potentially supplied with underground water, and it can be assigned directly using **Figure 15.** The existence of a "protected zone for taking water for human consumption, which supplies over 50 persons" (Register of Protected Zones), in the spatial area of reference, will make it possible to assign directly the maximum value of this factor. For population values of less than or equal to 50 persons, the P_{EX} index will be calculated by dividing this value by 10.

Figure 15. "Exposed population" factor (P_{EX}) value allocation according to the number of people potentially supplied with groundwater.

The main source of information for the evaluation of the majority of the factors which define the severity index is, again, the Register of Water, the management of which, depends on the river basin organisations or on the regional hydraulic administrations (water agencies), in accordance with the Regulation on the Hydraulic Public Domain (Royal Decree 849/1986), and the Register of Prohibited Zones. Apart from the foregoing, another source of data is the Catalogue of Private Water, which is an inventory of water use classified as private by the Water Act 1879, the owners of which opted to remain under this regime and not to include them in the foregoing register.

- *Factor of vulnerability of the population exposed (V_P)*

The **vulnerability factor of the population (V_P)** is closely linked with the type of use which is made of the underground water resource. Associated with it, and implicit from the point of view of the risk to the health of persons, there is a duration of exposure and a dose, both of which are dependent on the characteristics of the use of the water. Considering the exposure and the potential dose, and by way of an orientative criterion, in Table 10, the evaluations of the so-called **vulnerability factor of the population V_P**, are set out with an attempt being made to reflect the large groups of uses, in accordance with the Regulation of the Hydraulic Public Domain. This is a non-exhaustive list which makes possible the inclusion of new water uses in the groups already defined by the evaluator. Extraction of water for supplying human consumption is emphasised and those which supply an average volume of at least 10 m^3/day, as well as, if applicable, the corresponding protection perimeters; and future extractions of water for supply declared to be of special protection. Likewise, areas of withdrawal and their protection perimeters of mineral and thermal waters are emphasised.

Assessment of the population vulnerability in the event of ingestion or direct contact with polluted groundwater due to mining wastes effluents emission.	
Valuation criteria	**V_P**
Water uses of very high vulnerability: Water supply for population (private water wells and human water consumption catchments, providing water to more than 50 people or population centres), mineral water for human consumption, etc.	5
Water uses of high vulnerability: Irrigation (orchards, other crops and pastures) and farming uses (troughs), recreational uses (bathing areas), thermal waters (health resorts), etc.	4
Water uses of moderate vulnerability: Water for parks irrigation, etc.	3
Water uses of low vulnerability: Industrial use (energy generation, cooling, etc.), water for golf links irrigation, etc.	2
Water uses of very low vulnerability: Other uses of low exposure.	1

Table 10. Criteria for evaluate the exposed population vulnerability (V_P) depending on the groundwater use.

- *Index of Severity of the damage to the population deriving from the contamination of underground water by effluents from mining wastes, Is(C2PO).*

Finally, the severity index of the harm to the health of people which is proposed for a risk scenario due to contamination of underground water by effluents, is dependent on: the population exposed and the ratio of exposure, or the concentration of the contaminant, according to the distance at which the extraction point is with the most vulnerable use, and the closest to the point of emission (**Figure 16**). This index is expressed by the formula:

$$\mathbf{I_S(C2PO) = 0{,}5\ P_{EX} + 0{,}5\ (V_P \times F_{SUB})}$$

Where:

-I_S(C2PO) is the Severity Index of the effects on persons or the population deriving from the contamination of underground water by effluents from mining wastes.

-P_{EX} is the factor of the population exposed as it supplies itself with water extracted from aquifers.
-V_P is the factor of vulnerability of the population exposed according to the type of use considered most vulnerable.
-F_{SUB} is the exposure factor of the population exposed at the point of extraction with the most vulnerable use of water closest to the mining waste facility.

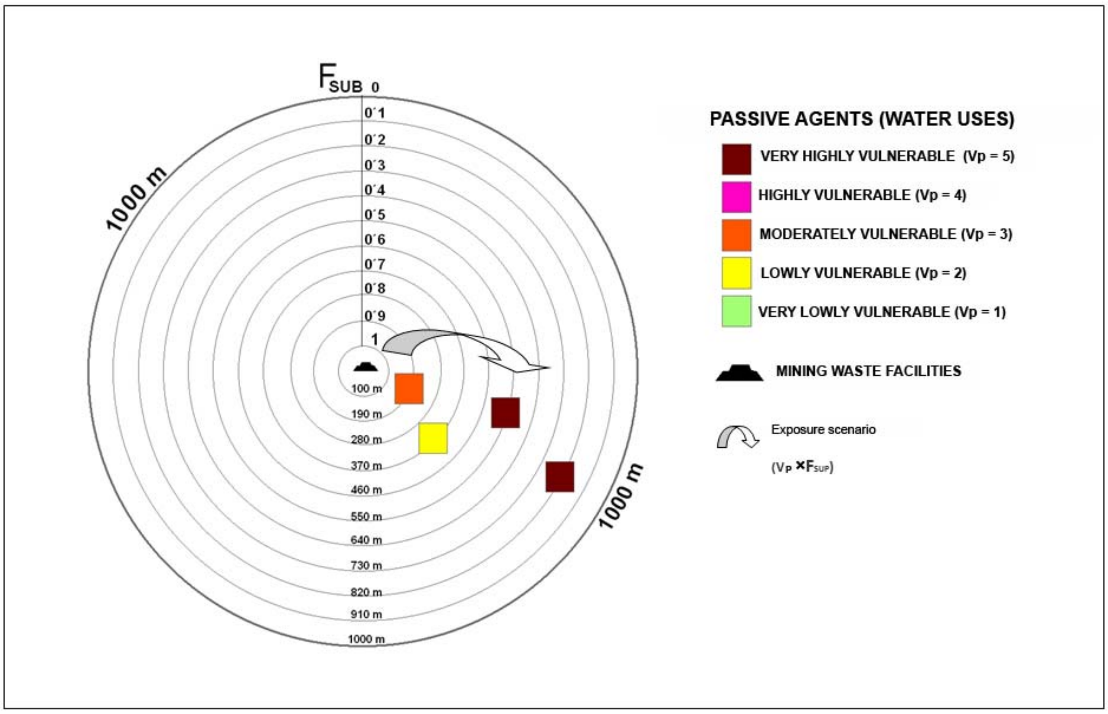

Figure 16. Selection criterion for the exposure scenario (V_P×F_{SUB}): the most vulnerable water use and pollutant concentration linked to the distance to calculate the severity index for the impact of polluted groundwater in the population (Is(C2PO)).

3.2.2.2. Index of severity of the effects on the natural environment deriving from the generation of contaminating effluents affecting underground water resources: I_S(C2NA)

Underground water is, in itself, a non-renewable natural resource. On the other hand, there are many ecosystems (mainly wetlands and river systems) which present a close and dependent interrelationship with underground water resources, which makes clear their ecological value and the effects that a deterioration in quality would cause to the environment. The severity index of the effects on the natural environment deriving from the generation of contaminating effluents affecting underground water resources Is(C2NA), will be a function of the vulnerability factors of the ecosystems (F_V) and exposure to contaminated underground water (F_{SUB}).

- *Exposure factor to contaminated underground water (F_{SUB})*

The **exposure factor (F_{SUB})** or concentration of the contaminating load to which the different ecosystems or elements of the environment are exposed is valued as a function of the distance to the mining waste facility, in accordance with the same theoretical model of distribution used to evaluate the I_S(C2PO) index, see **Figure 14**.

- *Vulnerability factor of the ecosystems (V_E)*

With a view to the definition of the **ecological vulnerability factor or that of the ecosystems (V_E)**, sensitive areas which are the object of environmental protection, the following are considered, as regards masses of underground waters: wetlands of national importance (Ramsar Convention) or those catalogued in the National Wetlands Inventory (NWI), either hypogenic or mixed; and areas under the Natura 2000 network, the conservation of which is closely linked to masses of underground water. All these areas that are considered sensitive are registered in the Register of Protected Areas (RPA) and are contemplated in the corresponding hydrological plans. Any other kind of protection where conservation might depend, to a large extent, on underground water resources and where they were not considered in the previous register will also be included in this category. It is evident that, by virtue of the value of the resource and the merits of conservation, these areas present the greatest vulnerability and a greater foreseeable impact in case of being affected.

Apart from the wetlands defined as sensitive areas, those wetlands whose ecosystems present good conservation despite not having been included in any of the previous types of protection are also considered highly vulnerable.

The ecosystems associated with river segments inter-related with masses of underground water by diffuse connection, such as is the case of those effluent flows which run over highly permeable detrital alluvial sediments, or by specific connection through springs, show also a high ecological vulnerability, especially, if they present good conservation or a very good or good ecological state, in accordance with the Water Framework Directive. The DGA and the IGME, within the framework of the Management Grant for the conduct of Scientific and Technical Work in Support of Sustainability and Protection of Underground Water, have carried out an "identification and characterization of the inter-relationship which is presented between underground water, river courses, discharges by springs, wetlands and other natural ecosystems of special interest regarding water" in each of the inter-regional masses of underground water, and have prepared the corresponding maps, which may be consulted at the IGME Documentation Centre.

In **Table 11**, the criteria proposed for the evaluation of the **vulnerability factor of ecosystems (V_E)** are indicated**.** As a general criterion when assigning the different degrees of vulnerability, susceptibility is considered inversely proportional to the degree of deterioration of the ecosystems affected.

Assessment of the ecosystem vulnerability in the event of groundwater pollution due to mining wastes effluents emission.	
Valuation criteria	**V_E**
Resources and ecosystems of very high vulnerability Sensitive areas (environmental protection of resources and ecosystems).	5
Resources and ecosystems of high vulnerability Well-preserved, hypogenic and mixed wetlands not included in Ramsar Convention or in national inventories. Well-preserved riparian ecosystems interconnected with groundwater bodies.	4
Resources and ecosystems of moderate vulnerability Surface water bodies of moderate ecological status. Slightly disturbed riparian ecosystems interconnected with groundwater bodies of moderate ecological status. Slightly disturbed hypogenic and mixed wetlands. Water for irrigation of woody and herbaceous crops and pastures.	3
Resources and ecosystems of low vulnerability Disturbed riparian ecosystems interconnected with groundwater bodies of poor ecological status. Disturbed hypogenic wetlands.	2
Resources and ecosystems of very low vulnerability Highly disturbed riparian ecosystems interconnected with groundwater bodies of bad ecological status. Disturbed mixed wetlands.	1

Table 11. Ecological vulnerability (V_E) assessment according to the value of the resource and the groundwater ecological status.

- *Calculation of the severity index of the damage to the natural environment deriving from contamination of underground water, by effluents from mining wastes, I_S(C2NA).*

The index of severity of the damage to the natural environment **I_S(C2NA)**, in this risk scenario, will depend on the concentration of contaminants which will be a function of the distance between the ecosystem and/or the most vulnerable natural resource within a radius of one kilometre (or a similar distance in the direction of underground flow) and closest to the point of emission, as well as its degree of sensitivity (**Figure 17**). This index is expressed by the following equation:

$$\mathbf{I_S(C2NA) = V_E \times F_{SUB}}$$

Where:

-I_S(C2NA) is the Severity Index of the effects on the natural environment deriving from contamination of underground water, by effluents from mining wastes.
-V_E is the ecological vulnerability factor according to the most vulnerable resource or ecosystem exposed, within a radius of 1 km (or within that distance in the direction of flow of the water).
-F_{SUB} is the exposure factor or concentration of exposure to which the different natural resources and most vulnerable ecosystems, and those closest to the mining waste facility are exposed.

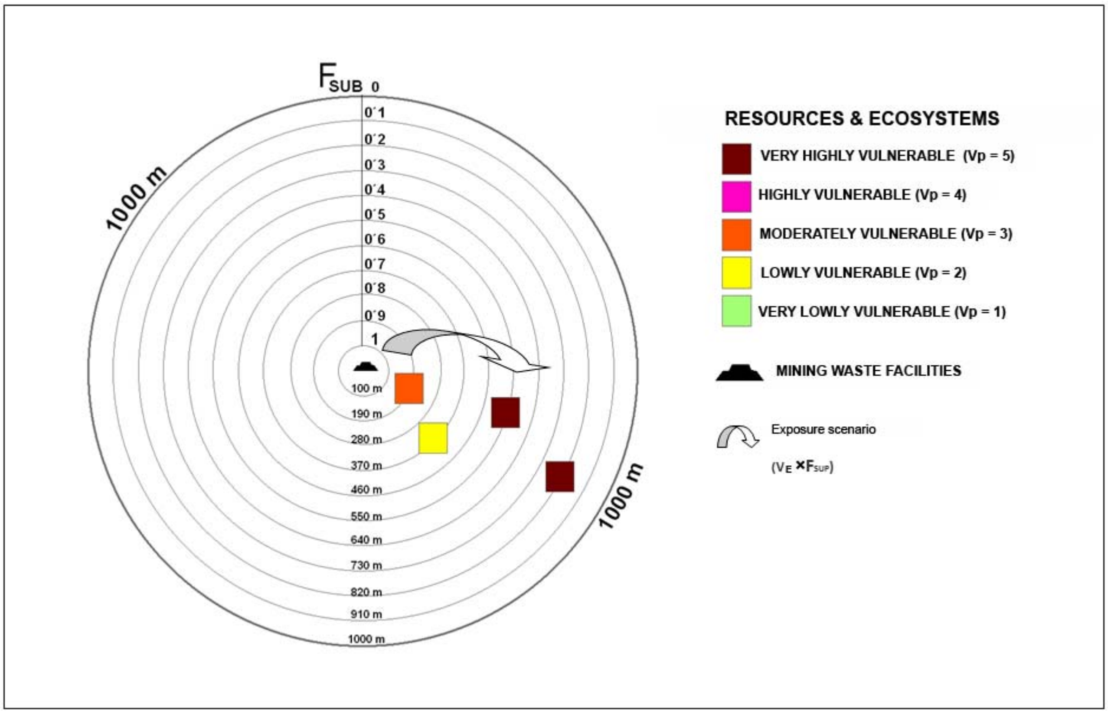

Figure 17. Selection criterion for the exposure scenario ($V_E \times F_{SUB}$): the most vulnerable resource or ecosystem and pollutant concentration linked to the distance to calculate the severity index for the impact of polluted groundwater in the environment (Is(C2NA)).

3.2.2.3. Severity index of the effects on the socio-economic environment deriving from the generation of contaminating effluents affecting underground water resources: Is(C2SE)

The severity of the effects on the socio-economic environment will depend on the local socio-economic structure and the degree of vulnerability of the different sectors of activity and property elements which might be affected; the seriousness of the damage will increase according to the economic weight of the sector involved. The severity of the consequences of contamination of underground water resources may also be evaluated in terms of loss of opportunity, if the contamination may mean a limitation on the development of those economic activities with the greatest potential for development or which it is desired to promote. In areas with scarce water resources, strongly dependent on underground water for supply, which have experienced significant urban and tourist growth, as is the case of the Mediterranean coast, lack of water which satisfies the standards of quality for human consumption has exercised and exercises a restrictive role. In those agricultural areas specialising in intensive irrigated agriculture, the deterioration in quality of water, with regard to the demands of its use, may cause serious damage or limit the development of the sector.

Given the preliminary nature of the methodology of risk analysis which is proposed and the level of knowledge necessary to manage to evaluate the economic structure, its potential and priorities of use, it is advisable that the determination of the index of severity of the effects on the economic activities for this scenario **Is(C2SE)**, should only be carried out when the socio-economic damage is high and easily observable. In the generality of cases, it will be considered that the evaluation of the severity associated with this scenario **should not be valued**.

3.3. MOBILISATION OF PARTICULATE MATERIAL BY THE ACTION OF THE WIND (C3)

3.3.1. Index of probability of the mobilization of particulate material by the action of the wind I_P(C3)

One of the great problems associated with mining areas and in particular flotation waste mining waste facilities and abandoned mining waste facilities with abundant fine materials on the surface, is the pick-up and dispersal of particulate material by the action of the wind or wind erosion. The contaminating substances potentially present in that material removed by the wind may represent direct damage by contamination of soil, water and nearby crops, or damage to the vegetation and inhalation, ingestion or skin contact effects for persons and animals (Blight, 2007; Oblasser and Chaparro, 2008).

This type of erosion, apart from favouring the dispersal of contaminating particles, may also increase the risk of mechanical instability of these storage structures (Espinace *et al*. 2006). This is a phenomenon which may arise in any kind of climate and environment although in all cases a number of factors must be present, such as: the presence of fine material, loose and dry, the existence of extensive areas with a not very rough surface, without plant cover or any other kind of protective covering and the predominance of strong winds (FAO, 1979). Nevertheless, it is in arid and semi-arid climates where the consequences of this phenomenon are generally most important and where it is most probable that the above-mentioned factors may occur.

The mining waste facilities, vulnerable to wind erosion, constitute a primary source of emissions of dust and consequent dispersal of contaminants via the air. The presence of forms of deflation and wind corrosion in dykes or embankments of mining waste facilities, and of wind deposition (dunes, ripples, etc.) on the storage structures for mining wastes and in their environment, are clear evidence of exposure and vulnerability to wind erosion (**Figure 18**). In these cases, it is possible to state, with a high degree of certainty, the high probability of a risk scenario due to movement of particulate material due to the action of the wind. The existence of research studies, analytical data from the field on concentrations of particulate or epidemiological material, in-depth interviews which make clear the disturbance to the towns and villages located in the area of influence together with any other type of information, with scientific rigour, which make it possible to confirm the impact of dispersal of contaminants via the emission of dust from mining waste facilities, will be enough to assign a high probability that this kind of risk scenario will arise.

Figure 18. Evidences of the emission of particulate material by wind erosion in mining tailing impoundments.

The absence of information or the scarcity of signs of erosion and/or deposits of wind sediments which are evidence of the dispersal of wastes by wind, will make it necessary to carry out an estimate of the probability of occurrence of this scenario of environmental contamination. Bearing in mind the empirical model of the equation of the loss of soil due to wind erosion (WEQ: *Wind Erosion Equation*) developed by Woodruff & Siddoway (1965), an index has been designed which evaluates the probability of occurrence of this kind of risk scenario according to the susceptibility to erosion of wastes (E_e), the climatic factors which control the water content of the material or the aridity factor (F_{AR}), and the capacity for erosion or speed of the wind (V_V), the surface exposed or surface factor (F_S) and the degree of cover or protection of the cover to the action of the wind or the defencelessness factor (F_{SD}). The definition of all of these and their mode of evaluation are described below.

3.3.1.1. Characterization of wastes according to their susceptibility to wind erosion: wind erosion factor (E_e)

The erodability expresses the susceptibility of the wastes to wind erosion and this is a parameter which depends on the intrinsic characteristics of the material and most especially on its texture and granulometry. This factor can be estimated in the first instance from the determination of the content of fine materials or the percentage of material with a size of less than 75-80 µm present in the waste (Alberruche *et al*., 2014), by means of the evaluation of granulometric curves obtained according to a range of methods: sieving, sedimentation and X-ray sedigraph, laser diffraction, microscope or monitoring of the electrical field (Coulter), among others. If materials predominate with upper granulometries (coarse grain), the erodability factor or susceptibility to erosion is less, and it becomes zero with wastes with a total absence of fine material.

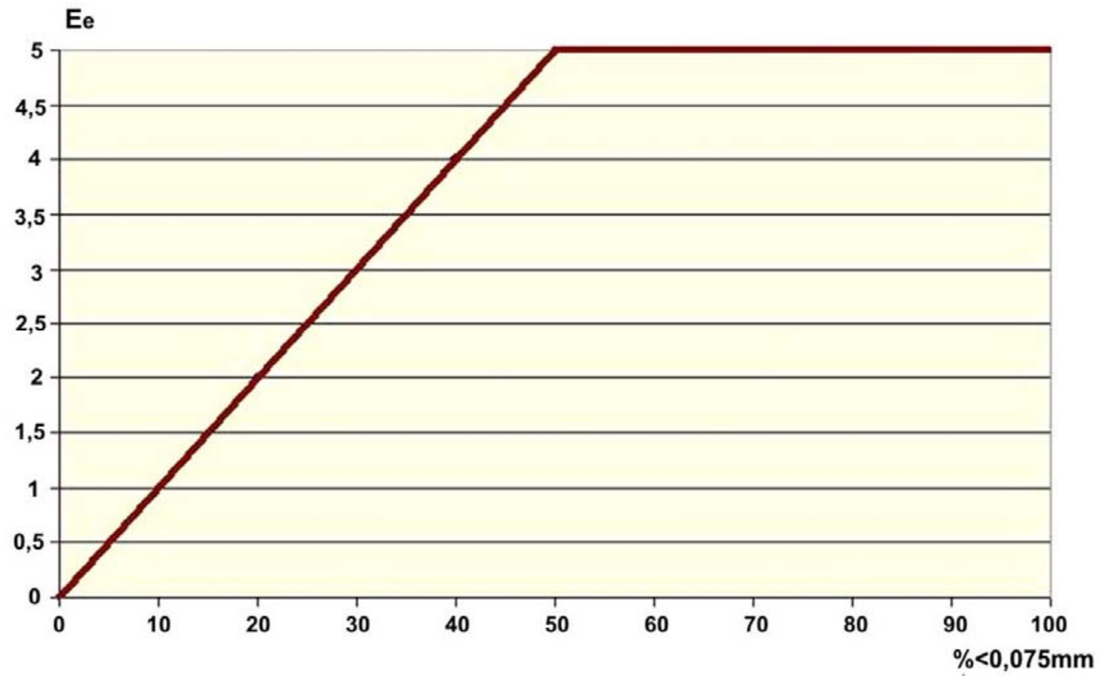

Figure 19. "Wind erodibility" factor value allocation according to the content of particles size lower than 75 µm (0,075 mm).

The **wind erosion factor** (**E_e**) is evaluated by assigning it a value equal to 5 when 50% of content is achieved or exceeded in particles of a size of less than 75 µm. The clays present in mining wastes, except for rare exceptions do not form stable aggregates with the result that in modern practice they can be considered capable of erosion. For the assignation of the values of factor E_e the graph from **Figure 19 can be used**. It can be verified that the use of the graph supplies values of E_e equal to those which arise from dividing by 10 the percentage of particles of a size of less then 75 µm, when this latter value is <50%, and equalling 5 when the content in particles of a size of less than 75 is ≥50%.

There is the possibility that there are data on granulometry of some mining wastes but they are expressed using the classic USDA texture triangle (USDA, 1999). The texture triangle makes it possible to assign the texture classes to the classification of the Department of Agriculture of the United States, according to the percentages of sand (0.05-2 mm), mud (0.002-0.05 mm) and clay (< 0.002 mm). It must be borne in mind that normally the information on granulometry expressed by the USDA system, refers to the fraction of fine soil (<2mm), with the result that it is generally accompanied by the content datum of coarse elements (>2mm). If this is not so, this information cannot be used except if it can be stated with certainty that the content in coarse elements is zero or negligible, as occurs with the majority of flotation mining wastes. Another aspect to be considered is that among the limits set down for the definition of the different granulometric fractions in the USDA systems, the size of 75 µm is not used. This value falls right in the middle of the interval which includes in the American system very fine sand (0.1-0.05 mm). For this reason, the most practical thing is to consider that the sum of the fractions of USDA mud and clay, that is to say those of less than 0.05 mm (50 µm) are the part which can be eroded, if anything increased or rounded upwards.

On the other hand, it is clear that the erosion factor of the wastes is going to be very much affected by the existence of crusts of oxidisation or the presence of some kind of cementation between particles which supplies cohesion to the materials, in which case, there is a great reduction in the process of abrasion due to the limited amount of abrasive particles and to the mechanical resistance of the crusts of oxidisation to the action of the wind. This circumstance has been considered to be an element of protection from erosion and it has been contemplated in the so-called vulnerability factor $F_{DS,}$ the evaluation of which is looked at below. Although the salt efflorescences present on the surface of many mining waste facilities show a high susceptibility to wind erosion and dispersion, they cannot be considered in the index of probability of occurrence unless all available information on the mining waste facilities which are evaluated has been obtained in the summer, without recent rainfall. However, in cases where its presence is important and significant, it may be of interest vis-à-vis the evaluation of the severity of the damage to the health of persons and of the environment given the high metal content which they generally present.

3.3.1.2. Water content of the surface wastes dependent on the climate: aridity factor (F_{AR}).

The susceptibility to erosion and fugitive emission of particulate material due to the action of the wind may be affected by the water content of the wastes, which depends on the type of material stored and its capacity to retain water, the ombroclimate of the geographical area where the mining waste facility is located and the age thereof. The water increases the cohesion between particles, which is commonly known as apparent cohesion, with the result that faster and more turbulent winds would be necessary in order to overcome these forces of cohesion (Espinace*et al.*, 2006). The **aridity factor** (**F_{AR}**) aims to evaluate the time that the wastes remain damp or dry throughout the year due to the effect of the local climatic conditions. The local mining waste facilities in areas with arid and semi-arid climates are the most susceptible to wind erosion (Blight, 2007). For their evaluation, the **De Martonne aridity index** (**Ia**) has been applied and which is calculated according to the following equation:

$$\mathbf{Ia = P/(T+10)}$$

Where:

- Ia = The De Martonne aridity index
- P = Average annual precipitation in mm
- T = Average annual temperature in ºC.

This index has been used to distinguish different climatic zones according to their value: hyperarid, arid, Mediterranean-type semiarid, sub-humid, humid and hyperhumid (**Table 12**). The values of the parameters which are operative there, average annual precipitation (mm) and temperature (ºC). These can be obtained from the location on the corresponding map which is accessible via the web at the following address: http://sig.marm.es/geoportal/.

Climate classification according to the De Martonne aridity index (Ia).	
Climate zones	**Ia value**
Desert (hiperarid or extremely arid)	0 – 5
Semi desert (arid or steppe-like areas)	5 – 10
Semi-dry (dry sub-humid)	10 – 20
Mildly wet (moist sub-humid)	20 – 30
Wet	30 – 60
Very wet (humid)	> 60

Table 12. Climate classification according to the De Martonne aridity index (Ia).

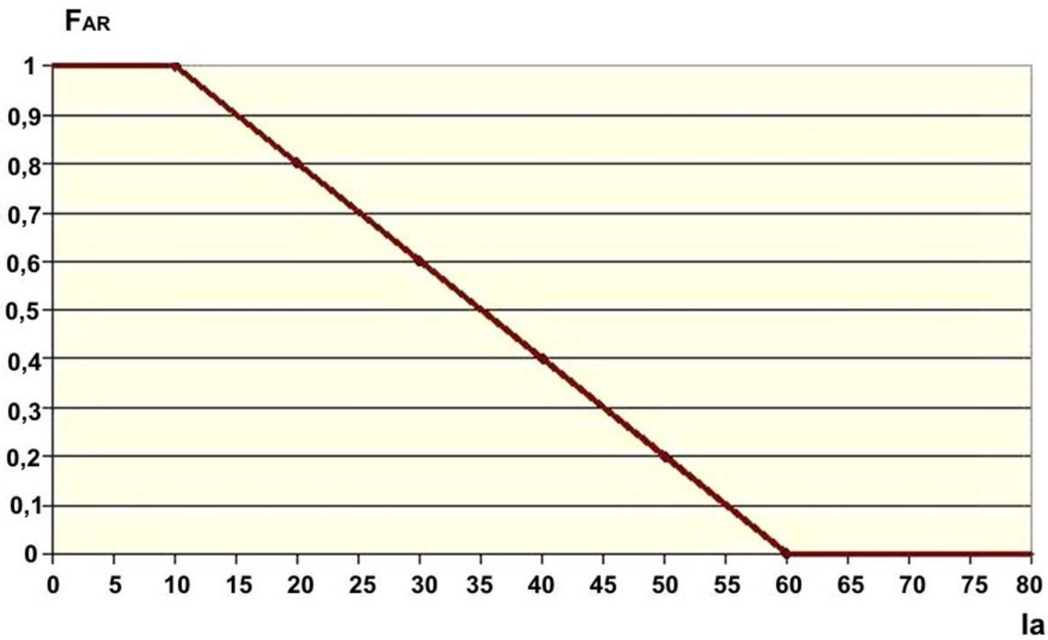

Figure 20. Aridity factor (F_{AR}) value allocation according to the De Martonne aridity index (Ia).

According to the values calculated or known of the De Martonne Index (Ia) for a certain geographical location, the value of the aridity factor (F_{AR}) will be assigned in accordance with the following criteria: when Ia is less than 10 (desert-like and semi-desert-like climates), F_{AR} will be equal to 1; when Ia is greater than 60 (hyper-humid or perhumid climates), F_{AR} will be equal to 0. For the assignation of the values of the factor in any other case, the graph from **Figure 20** can be used, or alternatively it can be calculated by means of the formula $F_{AR} = -0.02 \times Ia + 1.2$ when $10 \leq Ia < 60$.

3.3.1.3. Wind erosion: velocity factor of the wind (V_V).

The capacity for erosion and transport of particles from the surface of the soil increases with the speed of the wind (Blight, 2007; Lian-You *et al.*, 2003). The erosive power of the wind increases exponentially with velocity (Ben Salem, 1991). There is a critical velocity or minimum velocity to initiate the movement of particulate material the threshold of which will depend on the capacity for erosion and moisture content of the wastes and on the roughness of the surface of the mining waste facilities when they do not have a protective covering, among other factors. In Alberruche *et al.* (2014), a review of the scientific and technical bibliography has been made, including some methods of estimations of the fugitive emission of dust applied in mining, evaluation of environmental impact and contaminated soils. Taking this review as a base, the following criteria of valuation for the **wind velocity factor** (Vv) have been applied: if the average annual velocity of the wind (Vm) in the area where the mining waste facility is located is equal to or greater than 3 m/s, the Vv factor will be equal to 1. For values of Vm of less than 3m/s, the Vv factor is assigned using the graph from **Figure 21**, or is calculated using the expression: Vv=Vm×1/3.

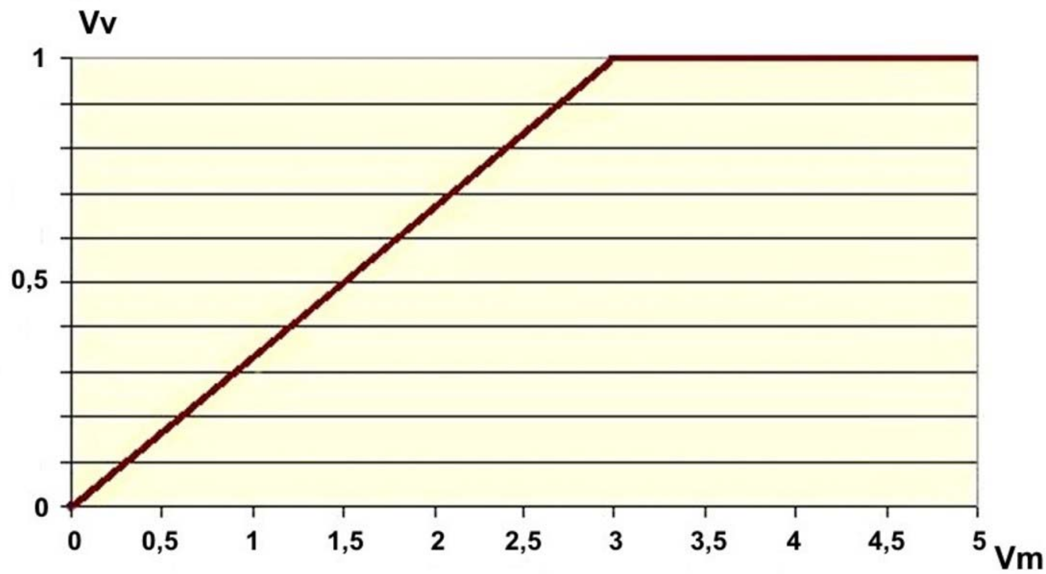

Figure 21. "Wind speed" factor (Vv) value allocation according to the mean wind speed (Vm) measured at the nearest weather station.

The National Wind Map developed by the National Renewable Energy Centre (CENER) (http://www.globalwindmap.com/VisorCENER/), supplies the average annual wind speed at a height of 10 m, on all of mainland Spain and the Balearics. At some points, furthermore, this cartographic tool offers graphic information on wind roses (distribution of velocities and of frequencies of directions) and histograms of distribution of wind velocities by ranges (%) **(Figure 22**).

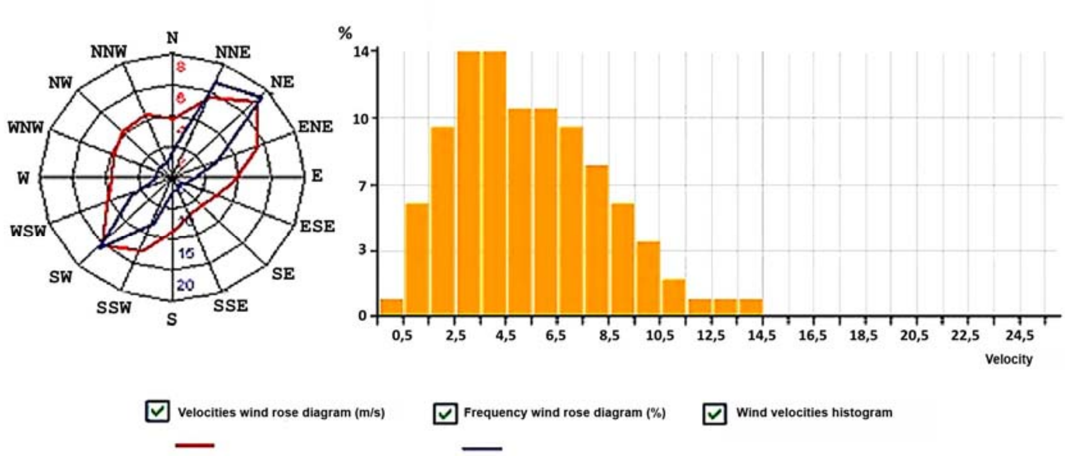

Figure 22. Wind roses (showing speed in m/s and frequency in %) and mean speed histograms in Portman Bay (Murcia, Spain) obtained from the Spanish Wind Map (CENER).

3.3.1.4. Surface exposed to the action of the wind: surface factor (F_S)

SERNAGEOMIN-BGR (2008) emphasise the existence of a direct relationship between the size of the mining waste facility with regard to the emission of dust and the distance of dispersal which might be achieved from it. It is evident that the probability of emission of particulate material increases the greater the surface exposed to the erosive action of the wind. The **exposed surface** (**S_{EX}**) is formulated as the aggregation of the total surface of embankments and/or dykes (S_T) and platforms or vessels (S_P), respectively.

$$\mathbf{S_{EX} = S_T + S_P}$$

Where:

S_{EX} = Total surface exposed or occupied by the mining waste facility.

S_T = Total surface exposed on embankments and/or dykes calculated according to the following equation

S_P = Total surface exposed on platforms or vessels, or flat surfaces.

Thus:

$$S_T = \sum_{i=1}^{n} \frac{S_{Ti}}{\cos(\theta)_{Ti}} \qquad\qquad S_P = \sum_{i=1}^{n} S_{Pi}$$

Where:

S_{Ti} = Surface of each embankment or dyke measured from above present in the mining waste facility.

θ_{Ti} = Angle of each embankment or dyke present in the structure.

$\mathbf{S_{Pi}}$ = Surface of each platform or vessel measured from above present in the mining waste facility.

Once the total surface exposed (S_{EX}) of a certain mining waste facility is known, it is possible to assign a value known as the **surface factor ($\mathbf{F_S}$)** in accordance with the following criteria: $F_S = 1$ for $S_{EX} \geq 2$ha. This maximum value has been assigned bearing in mind the average size of the storage facilities for mining wastes in our country. $F_S = S_{EX} \times 1/2$, when $S_{EX} < 2$ha. The SF values can also be extracted directly from the graph in **Figure 23**.

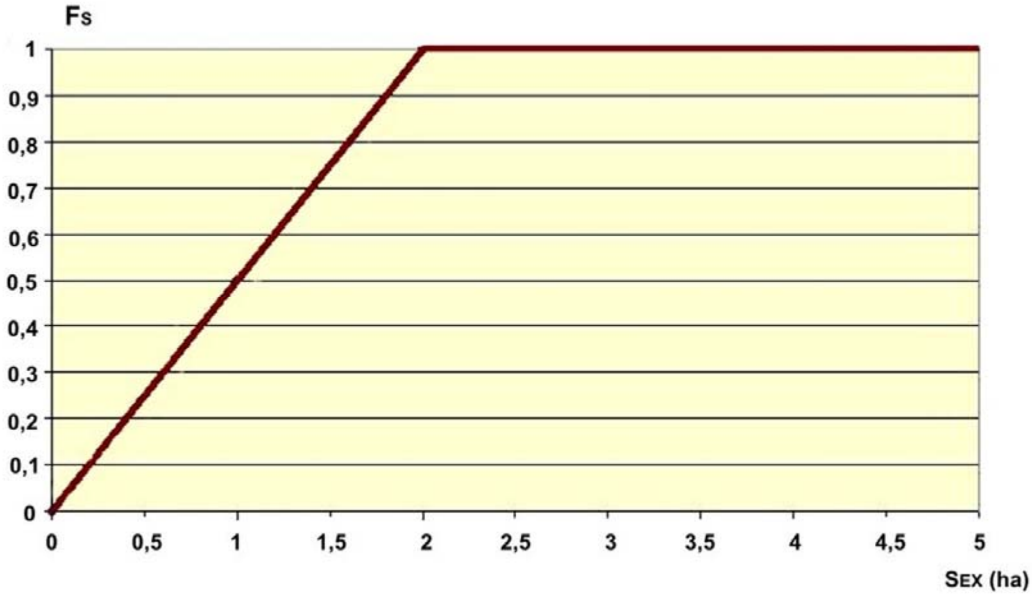

Figure 23. Surface factor (F_S) value assignment depending on the floor plan area (S_{PL}), measured in Ha, of the mining waste facility.

3.3.1.5. Degree of protection of the surface of the mining waste facility against wind erosion: vulnerability factor (F_{DS})

The existence of surface treatments with chemical or mechanical stabilisers or putting a layer of rocks or fragments of rock, compacted soil, etc. on the surface of the mining waste facilities and most especially on the embankments together with phyto-stabilisation and the implementation of a covering of spontaneous or induced arboreal, shrub or herbaceous vegetation or even the simple presence of a layer of mulch, considerably reduce losses of particulate material due to erosion, giving greater resistance to wind action or favouring dissipation of wind energy or its power of erosion (Blight, 1981; Espinace *et al*., 2006). As regards the protective nature of vegetation, Shi *et al.* (2002) make clear how an increase in plant cover exponentially reduces wind erosion.

The vulnerability factor (F_{DS}) represents an assessment of the level of protection or lack of it of the mining waste facility against wind erosion. It is possible that there is a single typology or the combination of different typologies of protective coverings on a single mining waste facility, in which case they must be considered as a whole, and evaluated in terms of the percentage of occupation with regard to the total surface area exposed at the facility (S_{EX}). The vulnerability factor, so called because it reaches its maximum value (F_{DS} = 1), when all the exposed surface is completely unprotected or without any kind of surface cover, will be applied whenever the unprotected terrain is not greater than 2 ha. In **Table 13,** the criteria of valuation of this factor are specified combining the proportion covered by a material spread over the surface to which is added the surface occupied by the vegetation at ground level or measured from above. The vegetation of a woody type may not be covering the soil at ground level but it has an effect on the reduction of the speed of the wind, with the result that the cover of the projection of the crowns is considered to be equivalent to the protection by ground level cover. Also included in the surface considered protected is what is covered with hard crusts of oxidisation (these being understood as those which can only be broken with pointed or cutting instruments) as well as the surface occupied by sheets of permanent water in the settling ponds of pools or reservoirs of mining wastes.

Assessment of the cover of the facility or the protection against wind erosion	
Valuation criteria	**F_{DS} value**
Unprotected surface, without vegetation cover or surface crusting.	1
< 20% of vegetation cover and/or protective treatment or surface crusting	0,8
20–40% of vegetation cover and/or protective treatment or surface crusting	0,6
>40–60% of vegetation cover and/or protective treatment or surface crusting	0,4
>60–80% of vegetation cover and/or protective treatment or surface crusting	0,2
> 80% of vegetation cover and/or protective treatment or surface crusting	0

Table 13. "Lack of protection against wind erosion" factor value allocation (F_{DS}).

3.3.1.6. Calculation of the index of probability of the movement of particulate material through the action of the wind I_P(C3)

In conclusion, the probability of occurrence of the movement of particulate material by the action of the wind in each storage structure for mining wastes **I_P(C3)** will be obtained from the use of the following equation:

$$\mathbf{I_P\ (C3) = E_e \times F_{AR} \times V_V \times F_S \times F_{DS}}$$

Where:

-**E_e** is the wind erosion susceptibility, dependent on the characteristics of the waste.

-**F_{AR}** is the aridity factor of the climate, which governs the time that wastes are dry throughout the year.

-**V_V** is the velocity factor of the wind.

-**F_S** is the surface factor of the mining waste facility, which depends on the total exposed surface of the mining waste facility.

-**F_{DS}** is the degree of lack of plant cover or other kind of protection of the surface of the mining waste facility (including the surfaces with the presence of surface crusts or permanent sheets of water).

The value obtained from applying the above formula gives results comprised between zero and five.

3.3.2. Index of severity of the movement of particulate material by the action of the wind $I_S(C3)$

3.3.2.1. Index of severity of the effects on persons and the population deriving from the movement of particulate material by the action of the wind: $I_S(C3PO)$

The severity of the damage deriving from the movement of particulate material (PM) from the surface of abandoned mining waste facilities, is a function of: the quantity, composition, size and toxicity of the particles to which the potential receptors are exposed; the duration of the exposure, and the vulnerability of the exposed receptors (population, ecosystems and economic activities). The seriousness of the damage may be expressed as a combination of the factors of **exposure**, or contact between the receptor with a certain quantity or concentration of mining dust for a certain period of time, and **vulnerability,** which responds to individual and inherent characteristics of each of the receptors. Conceptually, there are clear differences between the terms exposure and concentration: high concentrations of dust do not necessarily mean a high exposure since it is necessary furthermore that the receptor should be exposed to these concentrations for a minimum period of time, and the exposure is greater the more prolonged this period of time. Another concept which should not be confused with the foregoing terms is that of the dose, which makes reference to the quantity of particles which come into contact with the receptor and which, therefore, is going to depend not only on the different factors which determine the exposure but also on the characteristics and specific conditioning factors of each receptor, that is to say, on his/her vulnerability.

The majority of the research into particulate material concentrates on the effects that the inhalation of particles may have on the health of persons, without forgetting that there are other routes of exposure to the dust of a mining origin which include the ingestion of particles, absorption through the skin and exposure of the eyes. In a risk scenario of inhalation of particulate material moved by the action of the wind, the fine dust and particles of less than 10 μm diameter (PM_{10}) are of special interest, with the result that this is a habitual index for measuring air quality (Pope, 1989; Pope *et al*, 1991; Hall *et al*, 1992). The fraction habitually recognised as fine silt and clay from soils and mining wastes is within the range PM_{10}. The size, density and shape of the particles carried play a fundamental role as they exercise powerful control over:

- The proportion of suspended material and the time it remains in suspension, that is to say, the patterns of aerial transport and dispersion. The particles that are smaller than 100 μm in diameter have a lower velocity of terminal fall than the vertical component of the fluctuating turbulent wind, with the result that these particles may be transported in suspension and travel long distances in the direction of the wind, increasing the area of exposure and the potential number of receptors.
- The probability of inhalation, degree of penetration and pattern of deposition in the respiratory system (Fourie, 2007). The UNE (EN 12341, 1999) regulation considers all particles that can penetrate the respiratory system through the nose or the mouth with a size of less than 30 μm (PM_{30}) *inhalable*.

The particulate material may be classified according to the size and capacity of penetration in the human respiratory apparatus, that is to say, in epidemiological terms and in accordance with Standard UNE (EN 12341, 1999), into:

- Fine particles, which correspond to particulate material with an aerodynamic diameter of less than 2.5 μm ($PM_{2,5}$); it is considered the breathable fraction which can penetrate into the alveolar or gaseous exchange region.
- Coarse particles with an aerodynamic diameter of between 2.5 μm and 10 μm (PM_{10}-$PM_{2,5}$), also denominated the tracheo-bronchial inhalable fraction. The particles of less than 10 μm (PM_{10}) or the thoracic inhalable fraction, and especially the $PM_{2,5}$ or alveolar fraction, constitute the particulate material which carries the greatest risk to the health of persons.
- The extra-thoracic inhalable fraction has an aerodynamic diameter of more than 10 μm, and is retained generally in the upper parts of the respiratory apparatus (nasal cavities, pharynx and larynx); these larger particles are exhaled or alternatively are ingested. As has been indicated above, this regulation considers the fraction of less than 30 μm (PM_{30}) inhalable with the result that the particulate material with diameter greater than that size does not appear to be significant in a risk scenario of inhalation of contaminating particles and the type of exposure by ingestion or direct contact is more probable, in this case.

Epidemiological studies have made clear the adverse effect of particulate material on the populations exposed (Schwartz, 1996; Dockery & Pope, 1996; Brunekreef & Forsberg, 2005; Viana, 2003). Recent research has shown that fine particles ($PM_{2,5}$) have a greater impact on the health of human beings in terms of mortality, due to cardiovascular and respiratory reasons than coarse particles (PM_{10}-$PM_{2,5}$) (WHO, 2004, 2006). Inhalable dust emitted by mining wastes, and by extractive activity in general, is made up in a great percentage of particulate material of aerodynamic sizes of between 10 µm and 2.5 µm or a coarse fraction (WHO, 2003; WHO, 2006a). The capture of particulate material would make it possible to know whether the maximum values set by the regulations for these fractions are exceeded and in what size, and would also make it possible to determine their chemical composition and toxicity. Nevertheless, given the preliminary nature of the risk analysis in this methodology, it is not possible to put forward this kind of studies in the area of influence of the mining waste facilities which are the object of evaluation.

The evaluation of the severity of the damage from fugitive dust to the population has taken place according to the application of a multi-parametric index in which the size of the exposed population (P_{EX}), their degree of vulnerability (V_P), and the degree of exposure to the particulate material (F_{PM}) are considered. Bearing in mind also the effect of the contaminating capacity or toxicity of the fugitive dust (F_{CO}). The assessment of each of these factors is described below:

- *Factor of exposure to the particulate material (F_{PM})*

The determination of the degree of exposure to the particulate material, taking into consideration the empirical knowledge and the criteria applied in methodologies of risk analysis in mining and contaminated soils, has been done starting from a theoretical and qualitative model of distribution of the concentrations of dust as a function of the distance to the source of the contamination, and of the predominant wind direction (when this information is available). When the frequency of the directions in which the wind blows is not known, the ranges of distance correspond with the radii of the different muffling strips or areas around the mining waste facilities with different concentrations of particulate material. A conservative criterion is therefore adopted when accepting the possibility of including an area of exposure which, with a certain probability, is not to be found in the direction of predominant dispersal of the fugitive dust moved by the action of the wind. In **Figure 24,** a method of evaluation of the **factor of exposure** to particulate material (**F_{PM}**) according to the distance is shown, which varies in a different way according to the values considered: less than or equal to 100 m, between 100 and 1000 m, between 1000 and 3000 m, and more than 3000 m. That is to say, F_{PM}=1 for D≤100; F_{PM}= (1000-D)×1/1500, for 100<D≤1000; F_{PM}=0,6-0,0002D, for 1000<D≤3000, and F_{PM}=0, for D>3000.

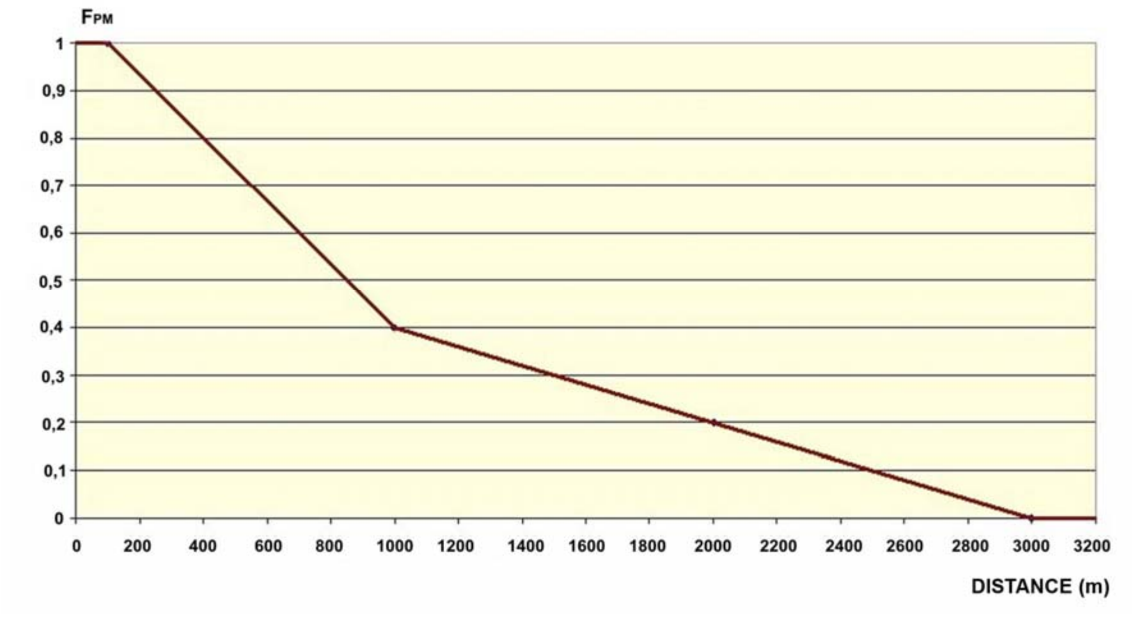

Figure 24. Value allocation for the "Exposure to dust emissions" factor (F_{PM}) in accordance with the distance from the source.

- *Factor of exposed population (P_{EX})*

Another fundamental factor for the evaluation of the severity of the damage to human health due to inhalation of fugitive dust from mining wastes is the number of persons or the size of the population exposed at a certain distance. Bearing in mind the model of dispersion adopted and described above, the population located within a radius of 1 km around each of the mining waste facilities, or in the direction of the prevailing winds if this information is available, will be considered, in such a manner that the greater the demographic pressure, the greater the exposure and the severity of the damage. The selection of intervals of population has attempted to include the statistical distribution of the Spanish population. In this regard, Zoido and Arroyo (2001) classify the Spanish boroughs on the basis of their size of population into: rural with fewer than 2000 inhabitants, intermediate with between 2001 and 10000 inhabitants; and urban with more than 10000 inhabitants. For the determination of the population exposed, statistical sources can be used such as the Nomenclator (Gazetteer) published by the National Statistical Institute (INE), which collects the list of population units smaller than the borough (singular population entities, population centres and disseminated) and their demographic contingent. It is necessary to identify those localised units in the area of influence defined and add their corresponding populations for the purpose of assigning their value to the **exposed population factor** (**P_{EX}**), in accordance with the criteria collected in **Table 14**. These units, with their graphical expression in the basic or topographic cartography, make clear the type of population and distribution of the population in the area. It is possible to have access to this information via the web using the following address www.ine.es/nomen2/index.do.

Assessment of the population exposition to particulate material from mining waste facilities.	
Valuation criteria	**P_{EX} value**
Population > 10000 inhabitants	5
Population between 5001 and 10000 inhabitants	4
Population between 2001 and 5000 inhabitants	3,5
Population between 1001 and 2000 inhabitants	3
Population between 501 and 1000 inhabitants	2,5
Population between 101 and 500 inhabitants	2
Population between 1 and 100 inhabitants	1
Uninhabited	0

Table 14. "Exposed population" factor (P_{EX}) value allocation according to the number of inhabitants within a radius of 1 km from the mining waste facility.

- *Factor of vulnerability of the exposed population (V_P)*

The other fundamental factor for the evaluation of the severity of the damage is expressed by the degree of vulnerability of the receptors to the contamination by particulate material. The susceptibility, perception and acceptability of the presence of dust differs depending on the use of the land, and on the intrinsic characteristics and socio-economic conditioning factors of the exposed population.

The duration of the exposure contributes to increasing the severity of the consequences. From the point of view of public health, the effects of chronic exposure to the dust, or exposure of long duration, and whose consequences are an increase in the death rate due to cardio-respiratory diseases and lung cancer are more significant (WHO, 2003, 2004). Nevertheless, acute episodes of exposure to very high concentrations of particulate material in a short period of time can also cause adverse effects on the health of the exposed population. Both types of exposure, acute and chronic, involve increases in hospital admissions for respiratory and cardio-vascular illness, and these are the main causes of increases in mortality (Dockery & Pope, 1996; WHO, 2003; Inza, 2010). The duration of the exposure is a factor which is closely associated with the use of the land. For this reason, the determination of the vulnerability of the receptors can be linked to it. Thus, the high vulnerability which is assigned to residential use is justified, to a large extent, by its association with a chronic and long-duration exposure of the population.

On the other hand, the intrinsic susceptibility of the persons subjected to the exposure to particulate material is going to have a notable influence on the severity of its effects on their health and well-being. Numerous studies have been carried out indicating that children, the elderly and persons with cardio-respiratory illnesses are population groups which are intrinsically more sensitive to atmospheric contamination (WHO, 2004). Apart from these, there are other groups which also show greater susceptibility to air pollution as a result of social or environmental factors or of personal behaviour such as the daily practice of sports or open-air activities, in parks and children's play areas, etc.

Taking into consideration the criteria set out in relation to the duration of the exposure and the susceptibility of certain groups of the population, it is possible to establish an order of uses of the land according to the degree of associated vulnerability. In **Table 15**, by way of an orientative criterion, the valuations of large groups of uses are gathered according to their vulnerability or sensitivity to exposure to dust. This is an open list which makes possible the inclusion of new uses of the land in groups already defined by the evaluator. It is clear that hospitals, old people's homes and residential areas, especially those made up of slums of a marginal nature, are highly vulnerable due to the intrinsic characteristics of the population and the duration of the exposure associated with these uses. In Zota *et al*. (2011), it is indicated how the presence of storage structures for mining wastes in the vicinity of residential areas contributes to increasing concentrations of dust and heavy metals in the interior of human dwellings. Attention is also drawn to the high vulnerability of parks and children's play areas and schools, and the uses of a recreational and/or sporting nature in the open air among others. Likewise, industrial areas or large commercial areas could have assigned an intermediate degree of vulnerability, by virtue of the time that the population remains in these areas and the fluctuation of the persons exposed. Agricultural and farming activities of an extensive nature involve in general limited labour with the result that, although it is an open-air activity, they might be thought to be of lower susceptibility as compared with other uses such as those described above; however, a greater intensity of production and the demand for a larger number of workers exposed would justify the evaluator increasing their vulnerability to exposure to particulate material. Finally, those uses with limited exposure would be classified as of very low vulnerability. In this way, it is proposed that the so-called **factor of vulnerability of the population** (**V_P**) should be evaluated following the orientative criteria set out in **Table 15.**

Assessment of the population vulnerability against dust emission from mining waste facilities.	
Valuation criteria	**V_P value**
Very highly vulnerable land uses: residential areas, hospitals, geriatric centres, etc.	5
Highly vulnerable land uses: parks, play areas for children, schools, recreational and outdoor sports uses, etc.	4
Moderately vulnerable land uses: industrial areas, shopping centres, etc.	3
Lowly vulnerable land uses: extensive farming activities, etc.	2
Very lowly vulnerable land uses: communication routes, etc.	1

Table 15. Criteria for evaluate the exposed population vulnerability (V_P) depending on the land use.

- *Factor of contaminating capacity of the dust (F_{CO})*

Mining is an important source of metal emissions to the atmosphere in the form of particles (Nriagu & Pacyna, 1988; Nriagu, 1989), and there is evidence that soluble metals may be a significant cause of toxicity by exposure to particulate material (WHO, 2003). For the determination of the toxicity of the particulate material, it is necessary to know the chemical composition of the mixture. For this purpose, there are several options:

- The characterisation and determination of the components present in a sample of mining wastes without granulometric discrimination, supposing that this composition is similar to that of fugitive dust caused by the action of the wind.

- The determination of the metals present in the wastes in the fraction equal to or less than 75 µm, which is capable of entering into suspension due to the action of the wind.

In both cases, the elementary analysis can be carried by means of portable or laboratory spectrometers using X-ray fluorescence (XRF). In the second option, the degree of uncertainty is significantly reduced by limiting the analysis to the fraction with the greatest susceptibility of generating dust. The valuation of the F_{CO} factor can be carried out using the values obtained from the so-called **IC**, which will be explained below. Another possibility is the comparison with Generic Reference Levels from soils for urban use in the Autonomous Community or setting of the mining waste facility, considering that if it exceeds any of those established for As, Cd, Cr, Ni or Se, the F_{CO} valuation must be 5 and 0 in the case of "inert" particulate material. The toxicity is incorporated into the severity index as an amplifying factor of the damage, up to a maximum value of 1.05 when the toxicity is considered very high or when the concentrations, if they are known, set down by the quality regulations of European and/or Spanish air for one or more elements is exceeded.

- *Calculation of the Severity Index of the effects on the population by mobilisation of particulate material by the action of the wind, Is(C3PO).*

The severity index of the damage to the health of persons, in a risk scenario due to the inhalation of particulate material, which is proposed depends on: the population exposed and the ratio of exposure or concentration of contaminants according to the distance at which the most vulnerable use and the nearest use or that of the worst scenario of exposure (**Figure 25**) are located. This index is expressed by the following formula:

$$\mathbf{I_S(C3PO) = [0{,}5\ P_{EX} + 0{,}5\ (V_P \times F_{PM})] \times (1+F_{CO}/100)}$$

Where:

-I_S(C3PO) is the Severity Index of the effects on persons or the population deriving from the mobilization of particulate material by the action of the wind.

-P_{EX} is the factor of the population exposed within a radius of 1 km of distance from the mining waste facility.

-F_{PM} is the factor of exposure to concentrations of particulate material of the population, according to the distance at which the most vulnerable use or the worst scenario of exposure ($V_P \times F_{PM}$) is located with regard to the mining waste facility.

-V_P is the vulnerability factor of the population exposed according to the most sensitive or vulnerable type of use exposed, or that of the worst scenario of exposure.

-F_{CO} is a factor of capacity of contamination associated with particulate material on the basis of analysis of total contents in elements. It operates as an amplifier which is a function of the degree of toxicity of the particulate material, taking the value 0 for inert wastes, and a maximum value of 5 for those considered to have a very high toxicity.

All possible values of **I_S(C3PO)** will be kept in the interval between zero and five, for which this last value will be assigned provided that it exceeds it.

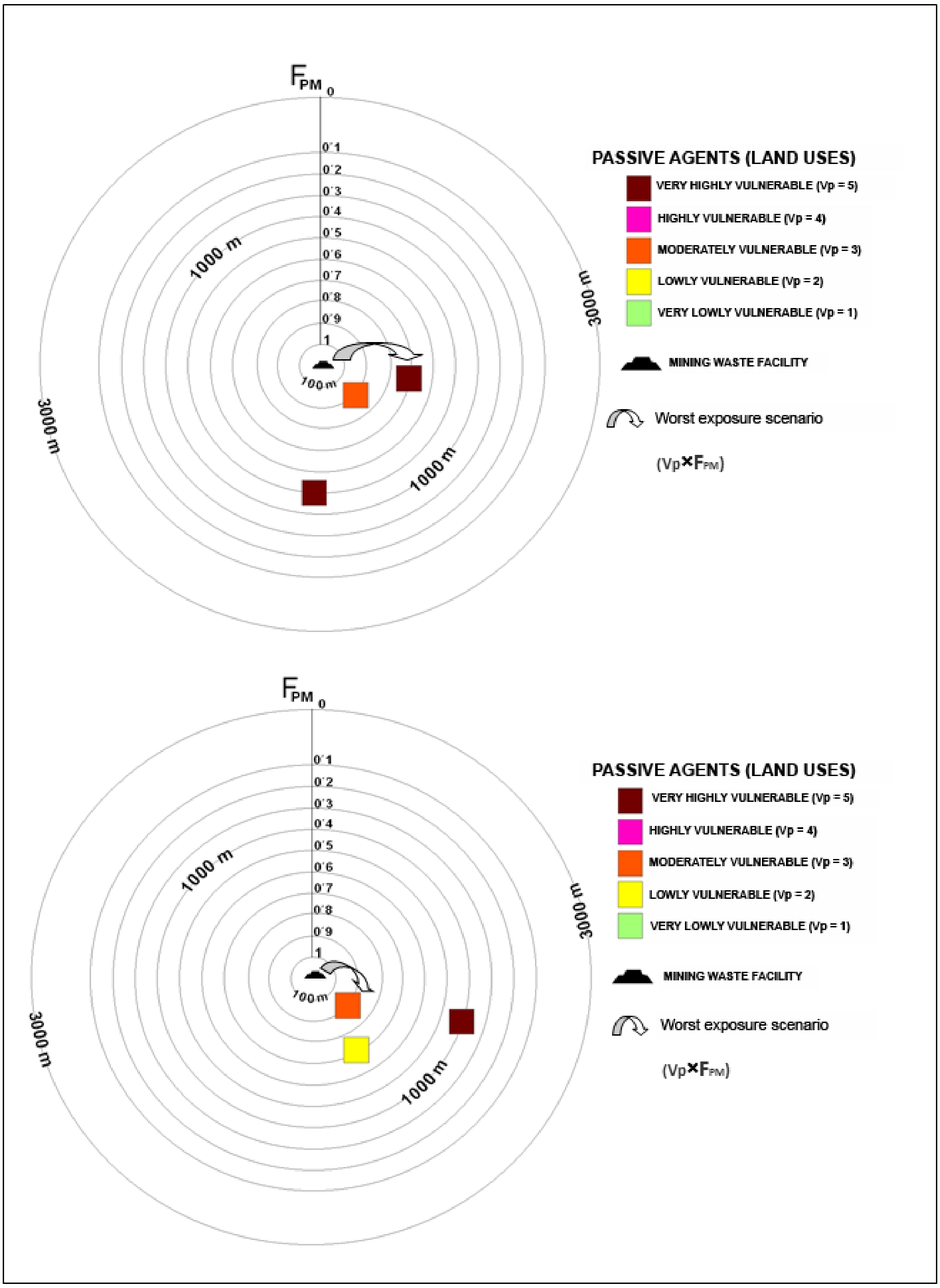

Figure 25. Selection criterion for the worst exposure scenario ($V_P \times F_{PM}$) to calculate the severity index for the impact of particulate material dispersion from mining waste facilities in the population (Is(C3PO).

3.3.2.2. Severity index of the effects on the natural environment deriving from the mobilization of particulate material by the action of the wind: I_S(C3NA)

The mobilization of particulate material from the surface of the mining waste facilities may also have direct and indirect effects on the nearby ecosystems. The deposition of the mineral dust on the leaves of plants may impede some of the processes which take place in photosynthesis due to the blocking of the stomata, reducing their capacity for gaseous exchange (carbon dioxide/oxygen) and the capture of water and light. Bergin *et al*. (2001) state that aerosols diminish the quantity of photosynthetically active radiation for the process of photosynthesis; all of this limits the development and growth of plants (Viana, 2003). Plants exposed to high concentrations of dust may undergo an increase in diseases and cellular deterioration of the leaves (MPCA, 2001). The deposition of particulate material on the soil may alter its properties and inhibit functions such as the taking up of nutrients by plants (Viana, 2003). On the other hand, the dust from mining wastes and the metals present may be inhaled, ingested or may come into direct contact with the fauna. The sedimentation of such dust may cause acidification and contamination with metals of the soils and surface waters, affecting the land and aquatic animal communities. The metals contained in mining dust may also be captured by the vegetation through the stomata on the leaves or from the soil. Furthermore, the bio-accumulation of metals may increase the vulnerability of the fauna and flora to other environmental stresses.

The degree of damage that ecosystems may undergo from exposure to the dust from mining waste facilities will depend on: the concentrations of particulate material to which they are exposed or the **exposure factor** (F_{PM}), and their susceptibility or **vulnerability to this contaminant** (V_E). The sensitive or most vulnerable areas are represented by the protected natural spaces (PNS), the spaces protected by the Natura 2000 Network, that is to say, Sites of Community Importance (SCIs), Special Areas of Conservation (SACs) and Special Protection Areas for Birds (SPAs), the habitats included in the Spanish Catalogue of Habitats in Hazard of Disappearance, as well as areas protected by international instruments (Wetlands of International Importance in accordance with the RAMSAR Convention; natural sites from the list of World Heritage and Biosphere Reserves declared by UNESCO; Bio-genetic Reserves of the Council of Europe; areas protected by the Convention for the protection of the marine environment of the north-east Atlantic (OSPAR); Specially Protected Areas of Mediterranean Importance (SPAMI); etc.). Also included as sensitive areas are the Important Areas for Birds of Spain (IBAS) and the wetlands included in the Spanish Inventory of Wetlands (IEZH), as well as other spaces that the competent bodies regarding the environment consider of special importance for the protection and conservation of the biodiversity and the natural heritage. In this way, it is desired to value the so-called **factor of vulnerability of ecosystems** (**V_E**) following the orientative criteria collected in **Table 16**. The evaluation of the **factor of exposure to particulate material** (**F_{PM}**) is carried out by applying the same criteria as in I_S(C3PO), as has been described above in section **3.3.2.1.**, using **Figure 24**.

Assessment of the ecosystem vulnerability against dust emission from mining waste facilities.	
Valuation criteria	**V_E value**
Sensitive areas (environmental protection).	5
River sections declared as areas of interest for fishes (salmonid and cyprinid waters). Well-preserved forests (evergreen and deciduous hardwood forest, coniferous forest).	4
Scrubs, holm oaks, woody crops (olive grove, fruit crops, vineyard, etc.)	3
Grasslands and pastures, arable crops, rivers and water bodies with disturbed riparian ecosystems.	2
Urban areas and very disturbed ecosystems.	1

Table 16. Criteria for evaluate the ecosystem vulnerability (V_E) against dust emission.

The severity index of the damage to the environment, in a risk scenario from mobilization of particulate material from mining wastes, will depend on the concentration of exposure which will be a function of the distance at which the most vulnerable or most sensitive ecosystem, and the one closest to the point of emission is, and on the degree of toxicity of the material moved by the wind (**Figure 26**). This index is expressed by the following equation:

$$\mathbf{I_S(C3NA) = (V_E \times F_{PM}) \times (1+F_{CO}/100)}$$

Where:

-I_S(C3NA) is the Severity Index of the effects on the natural environment deriving from the mobilization of particulate material by the action of the wind.

.**-F_{PM}** the exposure factor of the ecosystems most sensitive to the particulate material emitted from mining waste facilities, according to the distance at which the most vulnerable use is located.

-V_E is the vulnerability factor of the natural environment according to the most vulnerable type of use exposed.

-F_{CO} is a factor of capacity of contamination associated with the particulate material on the basis of analysis of the total contents in elements. It works as an amplifier which is a function of the degree of toxicity of the particulate material, taking the value 0 for inert wastes and a maximum value of 5 for those considered to have a very high toxicity.

Just as in the evaluation of the severity of the effects on the population, the evaluation of the **toxicity factor or of the contaminating capacity (F_{CO})** can be made using the values obtained from the so-called **IC**, which is explained below, or by means of the comparison with Generic Reference Levels for soils for non-urban and industrial uses, considering that if any of the levels set down for As, Cd, Cr, Hg, Ni, Pb, Sb or Se are exceeded, the assessment must be 5. Those values obtained which are in excess of 5 will have that value assigned to them, with the result that all the possible values of **I_S(C3NA)** will be kept in the interval between zero and five.

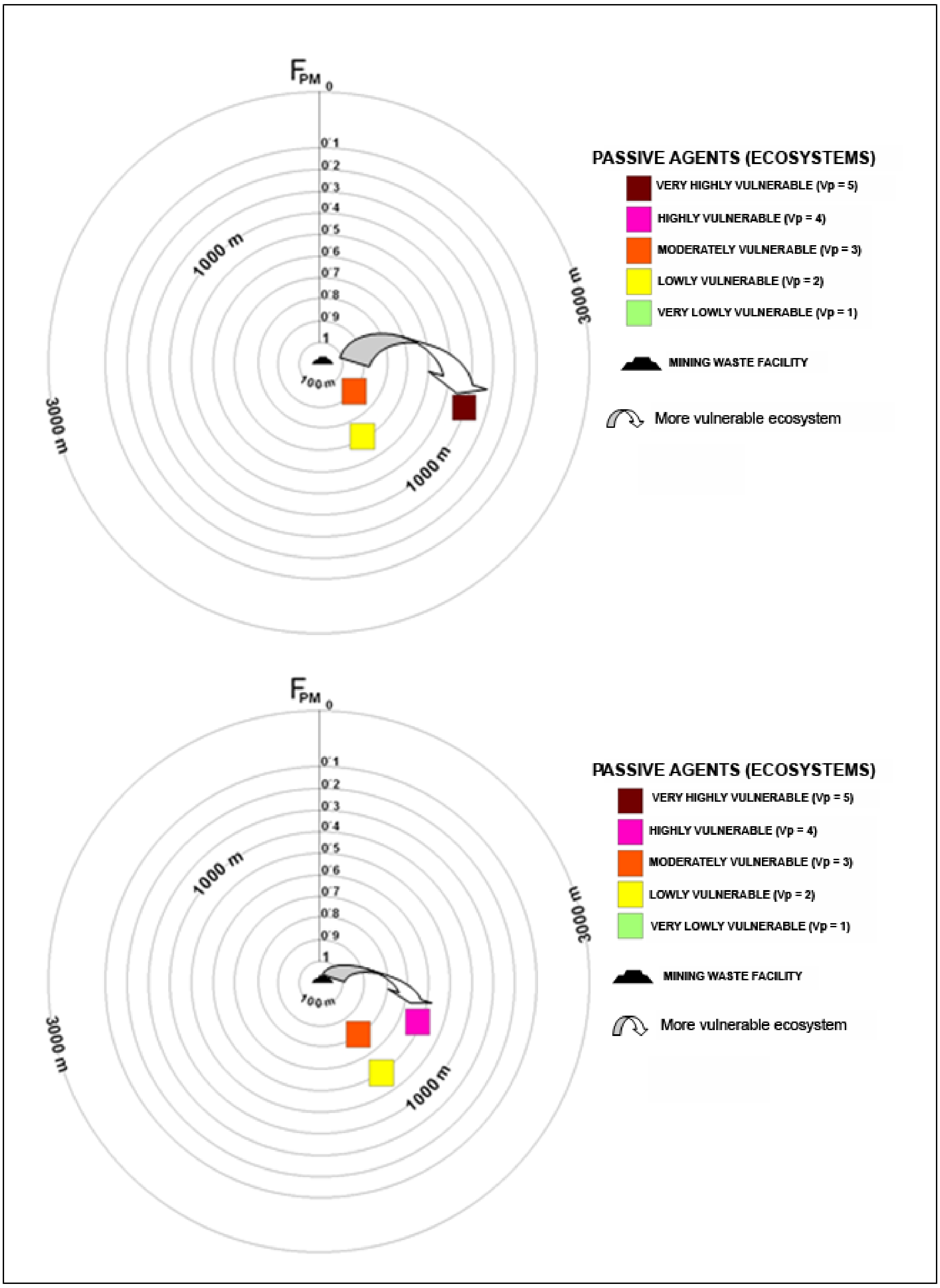

Figure 26. Selection criterion for the exposure scenario ($V_P \times F_{PM}$): the most vulnerable receptor or ecosystem (according to the land uses) and pollutant concentration linked to the distance to calculate the severity index for the impact of dust emission in the environment (Is(C1NA)).

3.3.2.3. Severity index of the effects on the socio-economic environment deriving from the mobilization of particulate material by the action of the wind: I_S(C3SE)

The severity index of the effects on the socio-economic environment deriving from the mobilization of particulate material by wind erosion is only calculated in those cases in which probable severe damage to economic activity or the cultural heritage is reliably established. An example is the location in the vicinity of mining waste facilities of uses that are highly sensitive and incompatible with the presence of contaminating dust such as high technology industries, food processing or agricultural or livestock use of high competiveness which represent, furthermore, the main or one of the main economic activities in the area; or the existence of nuisances and grave problems of visibility which reduce, in a significant way, the attractiveness for tourism or of the landscapes of some natural spaces of high scenic quality and represent a clear limitation for tourism or other urban uses with a high development potential in the area; or alternatively the corrosive action of the same is verified on elements to be conserved from the historical-artistic and cultural heritage .

The severity index of the damage to the socio-economic environment, in a risk scenario from mobilisation of particulate material from mining wastes, is going to depend on the concentration of exposure which will be a function of the distance at which the most vulnerable or the most sensitive element and the closest to the source of emissions is located (deduced from **Figure 24),** multiplied by a vulnerability factor ($\mathbf{V_{SE}}$) assigned directly by the evaluator**:**

$$\mathbf{I_S(C3SE) = V_{SE} \times F_{PM}}$$

In most cases, it will be considered that the valuation of the severity associated with this scenario should not be evaluated.

3.4. EMISSION OF CONTAMINATING SEDIMENTS DUE TO WATER EROSION (C4)

3.4.1. Index of probability of the emission of contaminating sediments due to water erosion I_P(C4)

The movement of sediments from mining waste facilities may affect neighbouring properties and watercourses or bodies of water located in positions that are dominated topographically by them. The sediments emitted by water erosion from the surface of mining waste facilities take on greater importance in wet climates and during rainy seasons, while, during dry seasons and in dry climates, the processes of wind erosion tend to take on greater importance. Comparatively, the problems of water erosion are much more serious in mining reservoirs than in heaps. The trace elements moved as particulate material may be associated with oxides and hydroxides, organic material or may form part of the crystalline structure of different mineralogical species. Once moved and deposited on neighbouring land or in watercourses nearby, the bio-availability of the trace elements dispersed as particulate material will depend on the pH conditions, the content of organic material, potential redox and temperature of the soils and the receptor sediments (Alloway, 1995).

The scenario which it is desired to evaluate is not set out as a problem of loss of soils, but as a process of emission of sediments of a contaminating nature. For this purpose, a **probability index of the emission of contaminating sediments through water erosion I_P(C4)** has been defined. A first aspect which it is necessary to evaluate is the contaminating potential of these sediments, considering the chemical nature of the wastes (F_{CO}). This aspect is complemented with a valuation of the capacity of emission, contemplating the footprint that the erosive processes have left on the banks of the mining waste facilities as an indicator of the susceptibility to water erosion (E_E). Other factors which have been considered are: the aggressiveness or eroding power of the rain in the area where each mining waste facility is located (F_{ER}), the surface of the banks of the mining waste facilities (F_{ST}), and the existence of elements of protection from the erosion or the emission of sediments (F_{SD}).

3.4.1.1. Contaminating potential of the sediments moved by water erosion from mining waste facilities: contamination factor (F_{CO})

In the first place, it will be determined whether the mining wastes are included in Schedule I of the Royal Decree 777/2012, of 4th May, on management of the wastes of the extractive industries and on protection and rehabilitation of the space affected by mining activities, where the tables relating to the identification of the mining wastes that are considered inert are collected. If the waste subject to evaluation can be considered inert, it will be directly assumed that the value of **I_P(C4)** is zero. In other situations, the evaluations of the toxicity or contaminating potential of the sediments emitted from mining waste facilities must arise from the study of the contents of potentially harmful substances for the environment or human health in the wastes and especially As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, V and Zn, which make up the set of metals and metalloids contemplated in the Decision of the Commission 2009/359/CE of 30th April 2009 plus Se. These contents must be sufficiently low so that the possible risks to human beings and the ecological ecosystems are insignificant both in the short and in the long term. It is considered that the contents in wastes of that series of elements are insignificant if they do not exceed the minimum national values for those locations defined as non-contaminated or the pertinent natural national levels. With this premise, the background levels for the soils fixed for each geological environment or autonomous community have been established, making comparisons between the total contents of elements measured in the wastes or sediments and which correspond to those soils. The background levels may be defined as the concentration of a substance, present systematically in the natural environment, which has not been influenced by local human activities. In theory, these values should make it sufficiently possible to detect the presence of unnatural concentrations in soils and sediments. Although there is no information relating to background levels of trace elements. Although there is no information relative to the background of trace elements of all the autonomous communities, thee are numerous published works which make it possible to obtain guides of background values for soils in many places (an example are those quoted in Table 33, or the work of López Arias and Grau Corbí, 2004).

The obtaining of the total contents of elements in the wastes is normally done by carrying out an acid digestion with subsequent measurement by spectro-photometry, or directly on the samples of waste by X-Ray Fluorescence (XRF). The comparison of the total contents of elements with the background levels in soils is made easier using what is called the **contamination index (IC)**, obtained by means of the addition of the fractions formed by the concentrations of the elements measured in the wastes with regard to the background levels of the soils in the environment for all the elements considered. This average quotient is similar to other indices used to analyse the levels of contamination by heavy metals in soils and sediments, such as the so-called *hazardindex* (Lim*et al.*, 2008), the *enrichmentindex* (Ferreira da Silva *et al.*, 2005) or the *pollution index* (Hakanson, 1980; Jung, 2001). When there are no reference values of any of the elements considered, when there is no information on the concentration of a certain element in the waste, or when the concentration of a certain element in the waste is less than the level used as a reference, this element will not be considered in the calculation. In this way, the formula may have a varying number of summands. One example of the application of the index is shown in **Table 17.**

$$IC = 1/n \times \quad \Sigma^{n} \frac{[X]}{NF_X}$$

Where:

-[X] is the average concentration measured in the waste of element X

-NF_X is the background level in soils corresponding to the element X in the area where the mining waste facility which is being evaluated is located.

Theoretically, an index of this style, if it is greater than 1, implies that there may be an enrichment or artificial contamination with regard to the natural levels of trace elements considered or measured. Hakanson (1980) proposed that when this quotient reached a value of between 3 and 6, it should be considered that the site housed a "considerable" degree of contamination, and a “high” degree of contamination for a quotient over 6. Abrahim (2005), used a modified index of the proposal made by Hakanson (1980), considering that for values of over 16 one might speak of a very high degree of contamination. Adopting the foregoing criteria, a graph has been drawn up which makes it possible to assign the values of what has been called the **factor of contamination**

(F_{CO}), from the values of the index of contamination (assigned directly by means of the graph in **Figure 50**), or assigning values by means of the following formula:

$F_{CO} = IC \times 5/16$, for $IC \leq 16$, siendo $F_{CO} = 5$ si $IC > 16$

MINING TAILING IMPOUNDMENT **ELEMENT (µg/g)**	**San Cristóbal W tailing dam (Mazarrón, Murcia, Spain)**	**Soil background level in Murcia, Spain (Martínez-Sánchez *et al.*, 2007)**	**La Económica tailing dam (Toledo, Castilla la Mancha, Spain)**	**Soil Background level in Castilla la Mancha, Spain (Jiménez-Ballesta *et al.*, 2010)**
As	450,0	8,1	70,8	16,1
Cd	3,09	0,12	8,31	4,4
Co	4,7	7,7	13,0	20,8
Cr	27,8	44,6	93,4	113,4
Cu	45,4	18,7	54,3	27,0
Hg	4,45	0,05	--	--
Mo	1,64		1,2	2,0
Ni	12,7	16,8	30,8	42,6
Pb	1967,4	9,8	1008,0	44,2
V	35,4	--	33,6	123,2
Zn	4524,0	55,2	2623,0	86,5
IC	**75,9**		**12,3**	

Table 17. Trace element content (obtained by means of the application of an acid attack to a composed sample and measured by IC-MS) and Pollution Index (IC) calculation in two Spanish mining tailing impoundments.

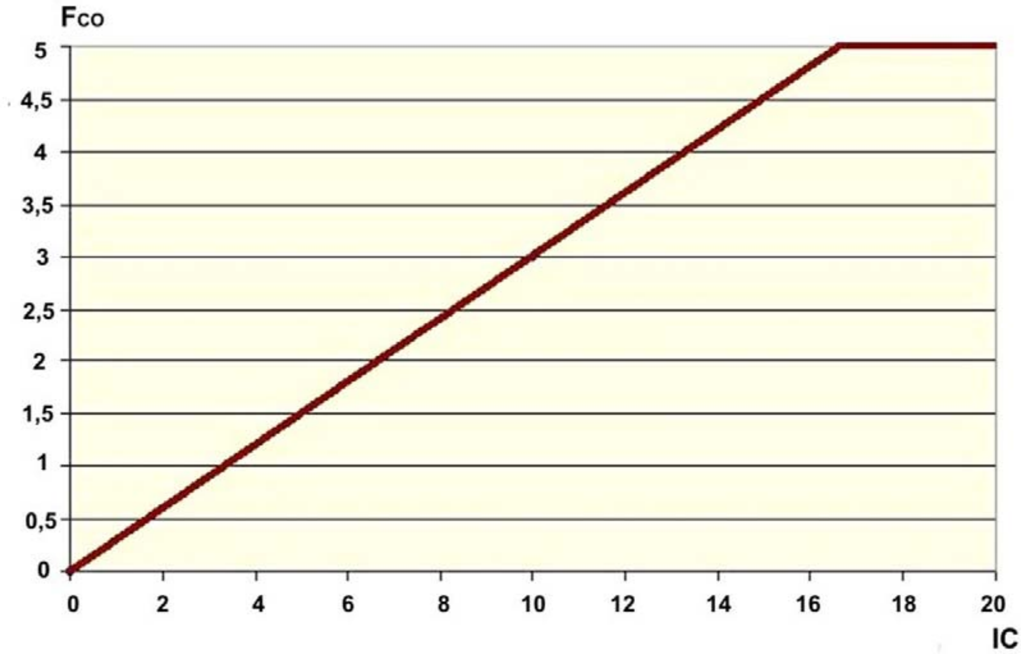

Figure 27. Pollution factor (F_{CO}) assignment according to the pollution index (IC) value, calculated based on trace element content data.

3.4.1.2. Characterisation of the erosive state of the mining waste facilities (E_E)

Except in those cases, which are normally exceptional, in which the time that has passed has been very short, the normal thing is that the erosion evidences developed clearly reflect the susceptibility to erosion of the mining waste facility which is being evaluated in the place where it is located, showing a characteristic combination of forms of erosion (laminar, in trails, tunnels or in ravines). It is also common that different forms of erosion can be appreciated on a single embankment, varying from simple sheet erosion in the upper part of the slope of embankments to erosive processes of enormous intensity. For all the foregoing reasons, in a way the erosive state in which a certain embankment is expresses the result of the action of the different erosion factors over time.

The idea is to assimilate the walls of mining waste facility to what has been called units of response to the erosion, in accordance with Märker *et al*. (1999). One more extensive and detailed justification may be found in Alberruche *et al*. (2014). These units of response to erosion recognise those divisions of the natural land which behave in a homogeneous manner in line with the erosion processes and in a different way with other units, as a consequence of the nature of the factors involved in the erosive process:

susceptibility to erosion, plant cover, slope, etc. From the point of view of the erosion of soil, these methods of classification recognise the severity of the processes of erosion. However, such classifications are also valid to express the probability of occurrence associated with the characteristics of the land, from the point of view of the emission of sediments. The gradation between the least serious state (absence of erosion or so-called layer erosion) and the most serious (generalised processes of gullying and tunnel erosion) is shown in **Table 18**, by means of which it is possible to assign a value of what has been called the **erosive state (E_E)**, according to the characteristics observed in the signs of erosion on the slope. If it is considered, in certain cases, that the value of the factor which is assigned must take on an intermediate value in comparison with those proposed in the above-mentioned table, this can be done according to the judgement of the evaluator. In **Figure 28,** two embankments are shown of reservoirs of floating wastes in a different erosive state.

Assessment of the erosive status of the embankments of mining waste facilities.	
Valuation criteria	**E_E value**
Lack of laminar erosion or concentrated surface runoff evidences.	0
Noticeable laminar erosion. Very few trails and/or evidences of anastomosed flow.	0,2
Few trails. Very few small gullies (<1m).	0,4
Frequent trails. Few small gullies.	0,6
Abundant trails. Frequent gullies (at least one >1 m). Some tubification evidences.	0,8
Abundant trails and small or large gullies. Frequent tubification evidences. Failing blocks or shallow landslides evidences.	1

Table 18. Erosive status (E_E) value assignment according to the presence of erosion evidences in the embankments of mining waste facilities.

Figure 28. Erosion evidences in embankments of mining tailing impoundments. Upper: El Soldado Mine, Villanueva del Duque, Córdoba, Spain. Bottom: Cerro de San Cristóbal, Mazarrón, Murcia, Spain.

3.4.1.3. Aggression or erosivity of the rain: erosivity factor (F_{ER})

Once the recognition of the existing features of erosion is established, it is necessary to also recognise that the rates of erosion of two slopes which show similar forms of erosion may be different according to the aggression of the climate in the area where they are located. Furthermore, the evaluation of the probability of occurrence of the processes of emission of sediments is not of interest so much at the level of particular events, where an annual balance may be more useful, assuming that the periods of normal erosion are as important as the extreme periods, given that in some way they are prepared, by supplying material available for erosion. In this regard, the value of the erosivity index of rainfall (R of the USLE), which is relatively constant for each geographical area given that it is an annual average value, may make it possible to qualify the tendency to erode of a certain mining waste facility, according to the average characteristics of the rain in the place where it is located.

The information on the values reached by the R factor of the USLE in Spain (measured in $hJ \times cm \times m^{-2} \times h^{-1} \times year^{-1}$) are collected on the maps of "Aggressiveness of the rain in Spain" (ICONA, 1988). The R factor is visible directly on the corresponding maps or by consulting the tabulated values which can be found on the above-mentioned monograph. Another option is the consultation of the R factor on the corresponding map which is accessible on the web via the following address: http://sig.marm.es/geoportal/.

The information on the erosion associated with the climate of the place in which a mining waste facility is located will serve to vary the value assigned to the erosive state, by means of a factor which has been called the **erosion factor** (**F_{ER}**), valued according to the values of the R factor (**Table 19**). It can be verified that, in Spain, according to the ICONA study (1988), the R factor varies between a maximum of 540 en Grazalema (Cadiz) and a minimum of 35-50 in areas of the Duero basin (Zamora, Palencia) and of the Ebro (Logroño, Zaragoza).

Rainfall erosivity factor assessment in mining waste facilities placements	
Valuation criteria	**F_{ER} value**
USLE R factor greater than 400	1
USLE R factor between 200 and 400	0,9
USLE R lower than 200	0,8

Table 19. Erosivity factor (F_{ER}) value assignment according to the USLE R factor value.

It can be observed that, although one of the factors of the USLE is being used, it is not being given as much importance as it has in the formula of the USLE. The idea is to add only a slight adjustment to the qualification obtained for the erosive state, using for the purpose the option which is most easily available.

3.4.1.4. Surface of the embankments of the mining waste facilities: embankment surface factor (F_{ST})

The problem of emission of sediments from a surface which is periodically undergoing erosive processes will be larger the greater the size thereof. The surface of the embankments of a mining waste facility may be measured easily from a bird's-eye view from the measurements of aerial images with the help of some of the existing applications of viewing, such as for example SIGPAC or IBERPIX, which include surface measuring tools. As was explained in the section devoted to wind erosion, the approximate measurement of the surface area of an embankment from the measurement of the surface in horizontal projection or from a bird's eye view is obtained by including the average angle of the slope, in the following manner:

$$S_T = \sum_{i=1}^{n} \frac{S_{Ti}}{\mathrm{Cos}(\theta)_{Ti}}$$

Where,

-S_T = Total exposed surface on embankments and/or dykes:

-S_{Ti} = Surface of embankments or dykes measured from above,

-θ_{Ti} = Angle of each embankment or dyke present in the structure.

We have considered, so as to simplify, that in the case of embankments made up of berms or built with a number of increases in height, the area which has been denominated $\mathbf{S_{Ti}}$ refers to the surface which surrounds or comprises each section of slope and the upper flat berm or surface. The angle in such cases is taken as the average angle, that is to say measured from the lower base to the upper crown. Once the total surface area of the embankments of a mining waste facility is known, it is possible to assign a certain value, the **embankment surface factor ($\mathbf{F_{ST}}$),** which is taken from the graph in **Figure 29.** Taking into consideration the case of Spain, the criterion of assignation to this factor of the maximum value when the value of 2 hectares is reached or exceeded. This is the same as assigning a value of $F_{ST} = 1$ for values of $S_T > 2$ ha, and calculating $F_{ST} = 1/2 \times S_T$, for values of $S_T \leq 2$ ha.

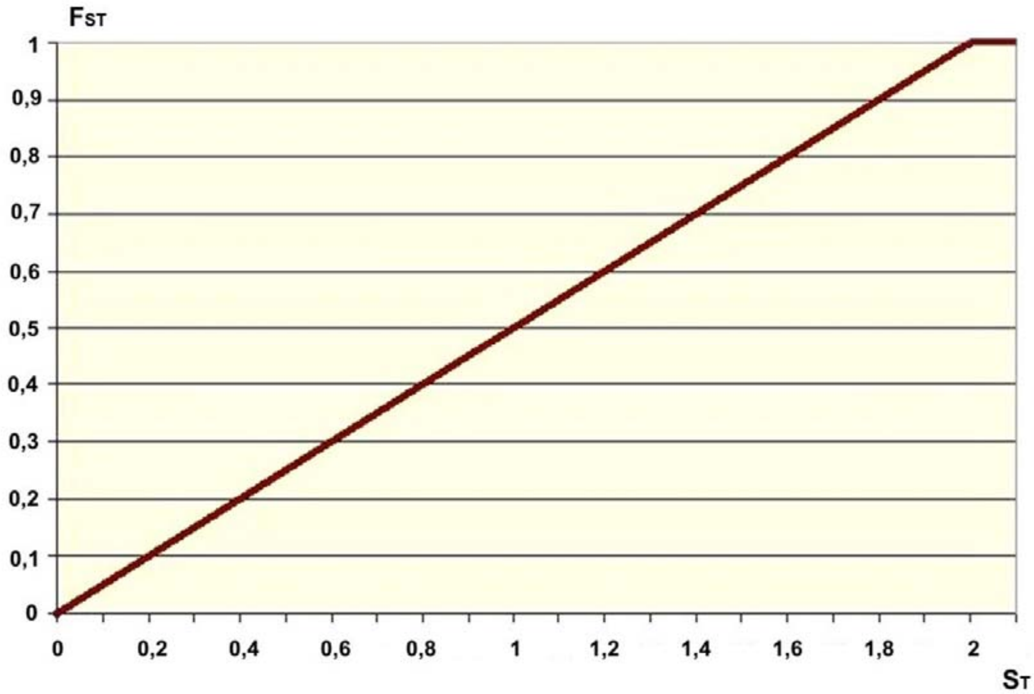

Figure 29. "Embankments surface" factor (F_{ST}) value allocation depending on the total surface of embankments (measured in Ha) of a mining waste facility.

3.4.1.5. Elements of protection from erosion or emission of sediments: VM factor

On occasion, it is possible to find dykes of mining waste facilities which have been covered with materials which limit the processes of erosion. Among the materials which may be among those which it is most common to find on embankments which it is desired to protect are the classical mulching and the nets or pre-fabricated organic blankets. The objective of the mulching is that a surface cover simulates the protective effect of a plant layer. The possibility that cases such as those that have just been described should appear is incorporated in the calculation of the probability of occurrence by means of a factor inspired by the so-called **VM factor** or erosion control factor (Israelsen & Israelsen, 1982), as is set out in **Table 20**.

Valuation of the materials protecting the embankment´s surface against erosion	
Valuation criteria	**VM value**
Embankments´ surface nearly or completely bare	1
Less than 50% of the embankments´ surface with vegetation cover	0,9
Slightly dense herbaceous vegetation and/or sub-shrubby vegetation, with scarce plant debris or waffle. Vegetation cover greater than 50%.	0,7
Diverse size mixed vegetation and thin layer of plant debris or waffle. Vegetation cover greater than 50%.	0,5
Mixed vegetation covering more than 50% and a large layer of plant debris or waffle.	0,3
Herbaceous vegetation (grass) covering less than 50% of the embankment´s surface.	0,5
Herbaceous vegetation nearly or completely covering the embankment´s surface.	0,1
Arboreal vegetation covering less than 50% of the embankment´s surface.	0,8
Arboreal vegetation covering between 50 and 80% of the embankment´s surface.	0,2
Arboreal vegetation covering more than 80% of the embankment´s surface.	0,05
Crushed rock or stony mining wastes with a predominance of elements with size higher than coarse gravel and stones covering less than 50% of the embankment´s surface.	0,4
Crushed rock or stony mining wastes with a predominance of elements with size higher than coarse gravel and stones covering between 50 and 80% of the embankment´s surface.	0,2
Crushed rock or stony mining wastes with a predominance of elements with size higher than coarse gravel and stones covering more than 80% of the embankment´s surface.	0,1
Organic blankets or nets completely covering the embankment´s surface.	0,05

Table 20. Value assignment to the VM factor depending on the embankment´s cover.

The values proposed must be considered to be for orientation only. When situations are recognised which are not correctly specified by any of the descriptions from **Table 20,** the evaluator may try to find an intermediate situation or ask questions in this regard so as to be able to assign a VM factor that he/she considers appropriate.

On the other hand, the existence of barriers, ridges, dykes, masonry walls or dry stone walls and any structure which retains sediments, as well as strips of vegetation, may limit, often totally, the emission of sediments. The existence of such structures, therefore, operates as an element which reduces the process. If there is no maintenance of such structures, they will have a limited lifetime, unless other aspects such as the presence of vegetation makes it possible to predict a reduction in the emission of sediments over time. For this reason, provided it is possible to state that the presence of such elements impedes totally the emission of sediments from the base of the embankments and that they are located at less than 20 metres from the foot, they may be assimilated to values of the VM factor equivalent to zero.

3.4.1.6. Calculation of the probability index of emission of contaminating sediments due to water erosion $I_P(C4)$

As a conclusion, the probability of occurrence of the mobilization of contaminating sediments due to water erosion in each storage structure for mining wastes $\mathbf{I_P(C4)}$ will be obtained from the application of the following equation:

$$\mathbf{I_P(C4) = F_{CO} \times E_E \times F_{ER} \times F_{ST} \times VM}$$

Where:

-$\mathbf{F_{CO}}$ is the **contamination factor** associated with the sediments generated in the facility starting with the knowledge of the total content of elements of the waste (taking value 0 for inert wastes).

-$\mathbf{E_E}$ is the so-called **erosive state.**

-$\mathbf{F_{ER}}$ is the **erosion factor,** associated with the climatic erosion of the place where the structure is located.

-$\mathbf{F_{ST}}$ is the **surface factor,** depending on the total area of the slope of the mining waste facility.

-**VM** is the so-called **erosion control factor,** which evaluates the defence from the existence of some kind of cover on the slope of the mining waste facility.

3.4.2. Severity index of the generation of contaminating sediments due to water erosion $I_S(C4)$

Before beginning, it is advisable to warn that the proof of the presence of high total contents in trace elements in sediments and soils does not make it possible to discriminate the mineral phases present. In fact, such a measurement does not make it possible to distinguish which elements have been moved as particulate material or have been precipitated, co-precipitated or have been adsorbed. As has already been mentioned, furthermore, the availability of the trace elements dispersed as particulate material will depend on the pH conditions, the content in organic material, potential redox and temperature of the receiving soils and sediments. The possible effect on soils arises when the sediments from mining waste facilities reach parcels of land located in positions below or in positions located on the edges of rivers of more or less size. In general terms, it can be assumed that the effects of the metals moved as particulate material over the soil will not be serious except in specific cases, given that these are solid materials in which the availability of the contaminating elements will normally be low and depending on the characteristics of the receiving medium. In any case, this type of effect is limited to strips of a limited size.

The effect on surface water is an aspect of more concern than the effect on neighbouring soils. From the moment at which a channel, irrigation channel or watercourse is reached in such a manner that the surface run-off is channelled towards the natural system of drainage or nearby masses of water, the possibility of effects due to sediments of a contaminating nature must be thought of, understanding always that these refer to those which hold large amounts of heavy metals. It is advisable to bear in mind that the sediments in watercourses and masses of water are seen as temporary drainage of metals, from where they can pass on into food chains, mainly through benthonic organisms (Diamond, 1995).

On the other hand, the descent in the content of one or another element with distance from the source of emission, does not follow a single pattern. The decrease in the content of metals and trace elements with the distance covered has been attributed to the following processes (Macklin&Smith, 1990): dilution due to the supply of uncontaminated sediments from other land and tributaries; deposition in nearby areas due to the size, shape and density of particles; covering with other kinds of sediment and solution or ingestion by aquatic life forms. In the work of Ferreira da Silva *et al.* (2005) the dispersion of metallic elements along the length of a stream in the Portuguese Iberian Pyrite Belt is shown, making reference both to elements that are dissolved and those deposited and it is deduced that a distance of 5 km might be a good choice for defining the distance when considering the possible downstream effects. Thus, just as in the scenario of contamination by dissolved contaminants, except if there is analytical information available or there is clear evidence that makes it advisable to choose another reference distance, the cases of possible effects and the use of surface water present up to a distance of 5 km will be analysed for the severity of the effects that the sediments eroded from mining waste facilities may generate for the environment, people or the village and the economic activities is derived from the consideration of nearby soils and masses of water which may be affected and of their use.

3.4.2.1. Severity index of the effects on people and the population deriving from the emission of contaminating sediments: I_S (C4PO)

The soils located in the vicinity of embankments of mining waste facilities and the plant cover that they have will be affected by the superficial run off up to a variable distance, according to the slope. The effects on the soils of the surrounding area are noticeable up to a few hundred metres (e.g.: Aslibekian & Moles, 2003). However, when concentrated drainage routes (streams, watercourses) are reached, the eroded particles containing trace elements which are exported from the mining waste facilities may cover several kilometres and be deposited in the watercourses and on the riverbanks in high concentrations.

- *Population exposed (P_{EX})*

It has been considered that, from the point of view of the effect on the population, it is enough to know the uses of the pieces of land in contact with the mining waste facilities, provided always that there is not any immediate concentration of the run off using the ditches beside tracks or natural watercourses. It will only be considered that the indirect effect on the population deserves to be considered if the run off loaded with contaminating sediments reaches fields of irrigated land or horticultural crops for direct consumption. The **population exposed (P_{EX})** in such a case will not generally be very big although, applying a very conservative criterion, it may be thought that it reaches fifty persons in any case.

When masses of surface water are considered, the routes of exposure of people to the contaminants in this risk scenario are mainly through the ingestion of the water, consumption of produce cultivated in soils receiving water which might carry contaminated material in suspension and, to a lesser extent, by contact and dermal absorption through use for recreational purposes (bathing or fishing areas, etc.). The **population exposed (P_{EX})** in such a case will be evaluated by the number of withdrawals of water for the purposes of supply to the population (water for human consumption) present in the affected masses of surface water up to a distance of five kilometres in the direction of flow of the water. The contingent of the population who might be affected can be estimated, as has already been noted, by using the number of persons per household multiplied by the number of extractions of water, provided always that these are of a private nature and do not correspond to supplies for centres of population, it being understood that each one of them represents one household. In Spain, the average size of a family is of 2.58 according to data from the census of 2011; the resulting value of population exposed must be rounded up or down to a whole number. If there is one extraction for supply to a population centre, the demographic contingent of that population centre will be added to the population exposed that has already been evaluated. Although this is a very rough estimate of the total population exposed, it does make it possible to evaluate a degree of exposure with a view to defining priorities of action. Nevertheless, a highly restrictive criterion is established in such a way that from over fifty persons supplied, the risk is very high (value 5) or nil (value 0) when there is no extraction, in the reference spatial framework. The intermediate values are set down in a form directly proportional to the increase or reduction of the number of persons potentially supplied with surface water and it can be assigned directly from **Figure 30**. The values obtained from the graph are equivalent to considering that P_{EX} is equal to 5 for a number larger than 50 persons, and P_{EX} is equivalent to the number of persons divided by ten for those cases in which the population affected is less than 50. The existence of a "protected area for the taking of water devoted to human consumption, which supplies over fifty persons" (Register of

Protected Areas) in the mass of water affected, up to a distance of 5 km from the mining waste facility evaluated will make it possible to directly assign the maximum value to this factor.

Figure 30. "Exposed population" factor (P_{EX}) value allocation according to the number of people potentially supplied with surface water.

The main sources of information for the evaluation of the majority of the factors that define the severity index are the Register of Waters and the Catalogue of Private Waters. Nevertheless, another alternative is the conduct of interviews with a person responsible from the local authorities affected, who has knowledge of the matter, or directly with the local population.

- *Factor of exposure (F_{SUP})*

Exposure may be a good indicator of distribution of the concentration of contaminating materials present in the sediments of a mass of surface water, to which the potential receptors are exposed. Except if analytical information and/or field information which makes it possible to design a concentration model of the contaminants in the water which is more consistent with reality is available, it can be accepted, as in the *National Classification System for Contaminated Sites* (CCME, 2008), that the largest alterations arise at the point of discharge and up to 100 m downstream, assigning to this range the maximum value of the, **exposure factor (F_{SUP})**; while from 5000 m onwards it is considered that the attenuation, dilution, mixing or burial of the sediments is total, or, what is the same thing, that the concentrations which might be present in the form of particulate material may be difficult to assign to the structure that is the object of evaluation, in any case. The determination of the **exposure factor for the surface waters (F_{SUP})** can be carried out directly from the graph in **Figure 31**.

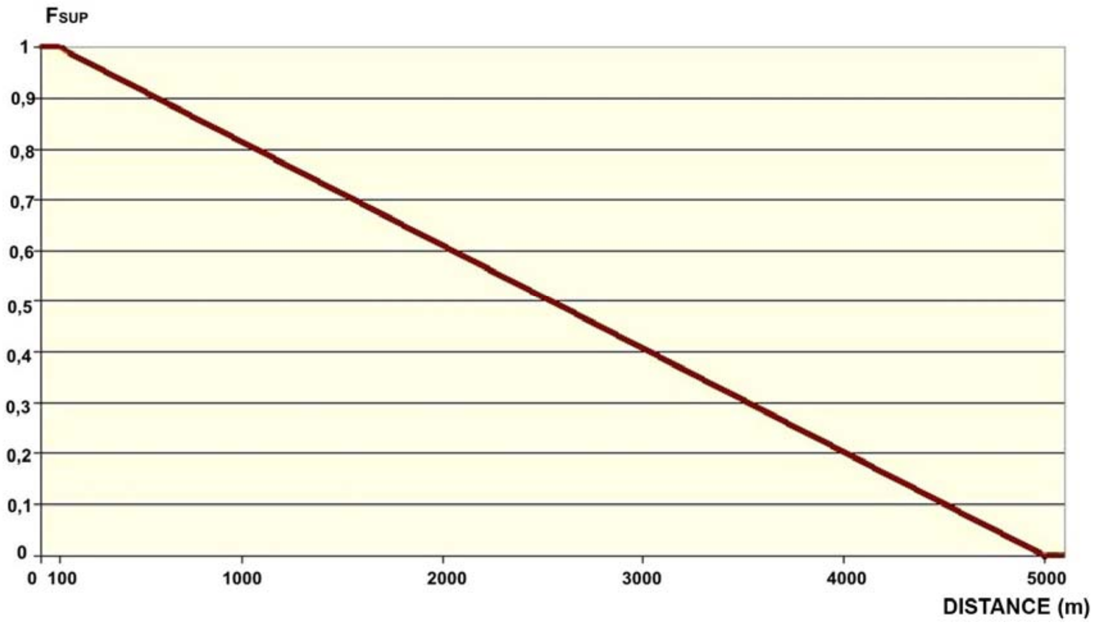

Figure 31. Value assignment to the "exposition to contaminated sediments (F_{SUP}) in accordance with the distance and the pollution distribution in the surface water body.

- *Vulnerability of the population (V_P)*

The **factor of vulnerability of the population (V_P)** is closely linked to the type of use which is made of the surface water resource, which has an associated time of exposure and a dose. These variables are highly dependent on the characteristics of the use of water. Bearing in mind both considerations (exposure and potential dose), and by way of a criterion for orientation, in **Table 21** the valuations of large groups of use are collected in accordance with the Regulations of the DPH. This is an open list which permits the inclusion of new uses of water in the groups which are already defined on the part of the evaluator. Another important aspect in relation with the type of use made of the water resource is its possible use for irrigation of crops. Numerous studies have shown that horticultural crops, particularly the cultivation of leaves (lettuce, cabbage, Swiss chard, etc.), accumulate larger concentrations of heavy metals if they grow in contaminated soils, which may arise as a consequence of irrigation with contaminated water. Aquiculture may also be considered a use which is highly vulnerable. Those sections of river that have been declared open for Angling can also be considered to be of high vulnerability. Areas devoted to bathing in rivers and masses of surface water (lakes and reservoirs), regulated by Directive 2006/7/CE of the European Parliament and the Council, of 15th February, relating to the management of the quality of bathing waters and which has been transposed into Spanish legislation by Royal Decree 1341/2007 have also been considered to be areas of high vulnerability. The location of bathing areas can be discovered using the National Bathing Water Information System "Nayade" on the internet (http://nayade.msc.es/Splayas/home.html), or alternatively by consulting the Register of Protected Areas, as is indicated by the Water Framework Directive (2000/60/CE), and/or Hydrological Plans of the river basin organisations. If the evaluator obtains information on the habitual conduct of activities such as bathing or angling for one's own consumption in a mass of surface water affected by run off from mining waste facilities, the vulnerability assigned to these uses, although these sections of river or masses of water are not included in any register of protected areas or areas for bathing, or have not been declared areas for Angling by the administration will be considered. In **Table 21,** the valuation finally adopted of the so-called **factor of vulnerability of the population V_P** is set out.

Assessment of the population vulnerability in the event of ingestion or direct contact with water contaminated by sediments released from mining waste facilities.	
Valuation criteria	**V_P value**
Water uses of very high vulnerability: Water supply for population (private water wells and human water consumption catchments, providing water to more than 50 people or population centres). Orchards or vegetable crops in direct contact with the embankments of mining waste facilities.	5
Water uses of high and moderate vulnerability: Irrigation (orchards, other crops and pastures) and farming uses (troughs). Aquaculture, fishing preserves and recreational uses (bathing areas, sport fishing).	3
Water uses of low and very low vulnerability: Industrial use, water for golf links irrigation, navigation and transport by water. Other uses of low exposure. etc.	1

Table 21. Valuation criteria of the exposed population vulnerability (V_P) depending on the land use and the surface water use.

Finally, the severity index of the damage to the health of humans which is proposed for a risk scenario arising from the contamination of surface waters by emission of contaminating sediments is dependent on: the population exposed and on the exposure, or concentration of contaminants, according to the distance at which the point of tapping or extraction of water is with the most vulnerable use, and the closest to the point of emission (**Figure 32**). This index is expressed by the formula:

$$\mathbf{I_S(C4PO) = 0{,}5\ P_{EX} + 0{,}5\ (V_P \times F_{SUP})}$$

Where:

-I_S(C4PO) is the Severity Index of the effects on humans or the population deriving from the effects on surface waters of the emission of contaminating sediments arising from mining wastes.

-P_{EX} is the factor of the population exposed as a result of being supplied, for their consumption, with water extracted from masses of surface waters.

-V_P is the vulnerability factor of the population exposed according to the type of use which is considered most vulnerable.

-F_{SUP} is the exposure factor of the population exposed at the point of extraction with the most vulnerable use of water and the closest to the mining waste facility.

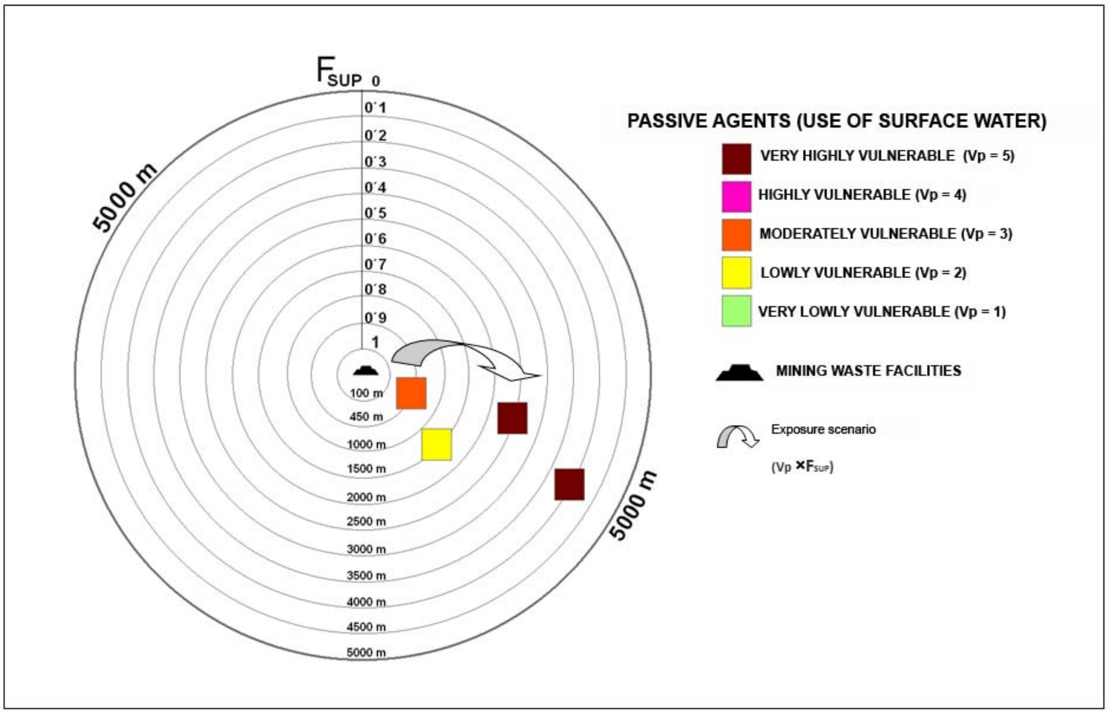

Figure 32. Selection criterion for the exposure scenario ($V_P \times F_{SUP}$): the most vulnerable water use and pollutant concentration linked to the distance (downstream and in the same direction of the water) to calculate the severity index for the impact of the emission of contaminated sediments in the population (Is(C4PO)).

The following index is also proposed, when it is only possible to prove a deposition of sediments on plots of land neighbouring the mining waste facilities, without watercourses or masses of water being reached:

$$\mathbf{I_S(C4PO) = 0{,}5\ P_{EX} + 0{,}5\ V_P}$$

Where:

-I_S(C4PO) is the Severity Index of the effects on humans or the population deriving from the effect on soils of emission of contaminating sediments arising from mining wastes.

-P_{EX} is the factor of the population exposed as it gains its supply, for its own consumption, from agricultural produce cultivated on affected soils.

-V_P is the factor of vulnerability of the population exposed according to the type of use considered most vulnerable.

3.4.2.2. Index of severity of the effects on the natural environment deriving from the emission of contaminating sediments: I_S(C4NA)

The addition of particles in suspension to surface water flows produces an increase in the turbidity of the environment and a reduction in the entry of sunlight, causing a reduction in the biological activity of plants, animals and aquatic micro-organisms, as well as effects on the photosynthesis of aquatic plants. It has already been mentioned that it is not possible to know at which moment the heavy metals moved as particulate material will become available. However, when the accumulation of sediments on the banks of streams becomes very large, the problems of toxicity will become perceptible at a certain moment. The severity index Is(C4NA) will be a function of the vulnerability of the ecosystems (V_E) and of the exposure to the contaminant (F_{SUP}).

- *Vulnerability of ecosystems (V_E)*

With a view to the definition of the **ecological vulnerability factor of ecosystems (V_E)** the following are considered to be sensitive areas that are subject to environmental protection, as regards the masses of surface water, and according to criteria of preservation of a natural resource or of purely ecological conservation: wetlands of national importance (Ramsar Convention) or those catalogued in the National Inventory of Wetlands (INZH), and the Natura 2000 network of protection, the conservation of which is closely linked to masses of surface waters. All these areas that are considered sensitive are registered in the Register of Protected Areas (RZP), as is set out in Article 6 of the Water Framework Directive (2000/60/CE) and are contemplated in the corresponding hydrological plans. Any other type of protected land, of which the conservation might depend, to a large extent, on surface water resources and which was not included in the previous register will also be included in this category. It is clear that by virtue of the value of the resource and of the merits of conservation, these areas present the highest level of vulnerability.

On the other hand, as has already been noted, the Water Framework Directive contemplates the evaluation and classification of the ecological condition of masses of surface water, which is an expression of the quality of the structure and the operation of aquatic ecosystems associated with these masses of water. Based on biological (aquatic flora, benthonic fauna of invertebrates and fish), hydro-morphological (hydrological regime and connection with masses of underground water; continuity of the river, and morphological conditions) and physical-chemical (Directive 2000/60/CE, Schedule V) indicators, and the application of metrics and biological indexes and those of another kind, it proposes an evaluation and classification of the masses of surface water in five classes, according to the degree of alteration with respect to unaltered natural conditions due to the activity of man: very good condition (unspoilt areas or those with little alteration), good condition, acceptable, deficient and bad (showing serious alterations of biological indicators). The Hydrographic Confederations and Water Agencies of the Spanish Regions, in accordance with those regulations, have incorporated Biological Control Networks which supply information about the ecological state of the surface waters. If there were no nearby station belonging to this kind of network, it would be necessary to collect information via publications or studies carried out by universities and research organisations which make it possible to evaluate that ecological condition.

In **Table 22**, the criteria proposed for the evaluation of the **factor of vulnerability of the ecosystems (V_E) are indicated.**

Assessment of the ecosystem vulnerability in the event of contaminated sediments emission from mining wastes facilities.	
Valuation criteria	**V_E value**
Resources and ecosystems of very high vulnerability Sensitive areas (environmental protection of resources and ecosystems). Surface water bodies of very good ecological status.	5
Resources and ecosystems of high vulnerability Well-preserved wetlands but not included in Ramsar Convention nor in national inventories. Surface water bodies of good ecological status.	4
Resources and ecosystems of moderate vulnerability Surface water bodies of moderate ecological status.	3
Resources and ecosystems of low vulnerability Surface water bodies of poor ecological status.	2
Resources and ecosystems of very low vulnerability Surface water bodies of bad ecological status.	1

Table 22. Criteria for the evaluation of the ecological vulnerability (V_E) in accordance with the degree of protection or the ecological status of the resources and ecosystems.

- *Exposure factor (F_{SUP})*

The **exposure factor (F_{SUP})** or concentration of the contaminating load to which the different ecosystems or elements of the environment are exposed is valued as a function of the distance to the mining waste facilities, in accordance with the technical model of distribution already enunciated in I_S(C4PO); the valuation of this factor is carried out by selecting, in **Figure 31**, the corresponding value, F_{SUP}, for a given distance.

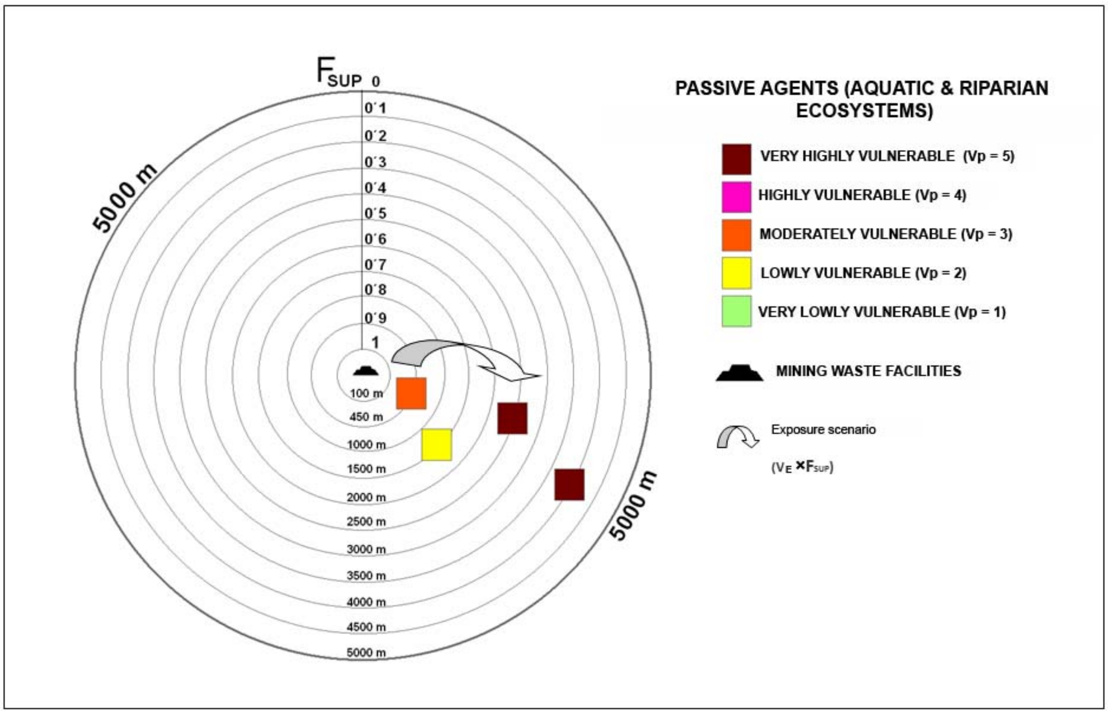

Figure 33. Selection criterion for the exposure scenario ($F_{SUP} \times V_E$): the most vulnerable resources or ecosystem and pollutant concentration linked to the distance to calculate the severity index for the impact of contaminated sediments in the environment (Is(C4NA)).

The index of severity of the damage to the natural environment **I_S(C4NA)**, in this risk scenario, will depend on the concentration of the contaminants which will be a function of the distance at which the aquatic ecosystem and/or the most vulnerable natural resource is up to a maximum distance of 5 km downstream and the closest to the source of the emissions and its degree of sensitivity (**Figure 33**). This index is expressed by the following equation:

$$\mathbf{I_S(C4NA)= V_E \times F_{SUP}}$$

Where:

-I_S(C4NA) is the Index of Severity of the effects on the natural environment deriving from the emission of contaminating sediments from the mining wastes.

-V_E is the ecological vulnerability factor as a function of the most vulnerable exposed resource or ecosystem.

-F_{SUP} is the exposure factor or concentration of exposure to which the different natural resources and most vulnerable ecosystems are exposed, and those closest to the mining waste facility.

3.4.2.3. Index of severity of the effects on the socio-economic environment deriving from the emission of contaminating sediments: Is(C4SE)

In environments that are not much affected by human activity, the effects on the socio-economic environment of the emission of sediments are normally negligible, if there are no areas of cultivation or artificial drainage systems in the vicinity of the mining waste facilities with the result that the determination of the index of severity of the effects on economic activities for this scenario, **Is(C4SE)**, will only take place when the socio-economic damage is high and easily determined. One example of this type of situations might be the observation of processes of serious silting of channels associated with transport infrastructures or those of another kind. In particular, it might be interesting to identify and value possible effects on the public land associated with roads and their functional elements and associated infrastructures. In most cases, it is considered that **it is not worth** carrying out the valuation of the severity associated with this scenario.

3.5. DIRECT CONTACT CAUSED BY OCCASIONAL ACCESS OR BY THE CONDUCT OF ACTIVITIES ON THE MINING WASTE FACILITIES (CD)

3.5.1. Probability index of direct contact caused by occasional access or by the conduct of activities, I_P(CD)

In certain cases, it is necessary to consider a scenario, relative to the possibility that a direct contact may occur for the persons, with the possibility of inhalation, accidental ingestion or skin contact. Abandoned mining waste facilities (especially mining tailing impoundments, due to their flat, clear surface) may be used for a number of different activities (recreation, sports or others). It is relatively normal to see marks from vehicles with or without a motor or even tracks for playing sport. This situation occurs particularly when these abandoned mining structures are in the vicinity of a village and there are no buildings or fences which prevent access. A detailed risk analysis ought to contemplate aspects related with the dose of exposure (according to the concentration and the bio-availability for each of the routes, characteristic of the potential receptors, etc.). The purpose of this methodology is, however, the realization of a preliminary evaluation, which does not prevent it being possible to consider the conduct of a more exhaustive risk analysis in those cases in which it is considered advisable. It is for that reason that the factors related with the doses of exposure have not been analysed. An **index of probability of direct contact caused by occasional access or by the conduct of activities, I_P(CD)**, **is proposed** which will depend on the concentration of toxic elements in the wastes, the degree of accessibility of the mining waste facilities, the distance to the nearest residential areas and the uses of the soil on the mining waste facility itself. These parameters are habitually used in the risk assessment associated with direct contact (EPA-Ireland; 2009; EEA, 2005).

3.5.1.1. Evaluation of toxicity relative to mining wastes: factor of concentration of direct contact (F_{CCD})

If it is a matter of a waste among those set out in Schedule I of Royal Decree 777/2012 (wastes from extractive industries considered to be inert), it can be stated that the probability of generating problems of toxicity by direct contact is nil or negligible, with the result that it can be assumed that the index of probability **I_P(CD)** will be zero.

On the other hand, the presence of components that are toxic for humans increases the potential for harm of the wastes, the characterisation and determination of the toxic elements present in the mining wastes, it is possible to do so by means of the analysis of the total composition. On the basis of the total contents measured in the wastes, a factor of **concentration of direct contact (F_{CCD}) is defined for** each one of the wastes evaluated. This factor functions in a manner similar to that relating to the contaminating capacity of the sediments generated by erosion, although it has been considered a good idea to simplify it. **For this reason,** it is proposed to bear in mind the analytical results relating to the elements As, Cd, Cr, Hg, Ni and Pb, to which Sb may be added if the information on this element is available. It can be seen that, of the metals enumerated in Directive 2006/21/CE of the European Parliament and of the Council on the management of waste from extractive industries, it is proposed to value only those which have been shown to represent a greater hazard for the human population (EPA-Ireland, 2009).

The total concentration of these trace elements is compared with the Generic Reference Levels (GRL) determined for each metal by each Spanish region for urban use according to the methodology defined in Schedule VII of the Technical Guide for the application of Royal Decree 9/2005, of 14th January, by means of which the relationship of activities which may potentially contaminate the soil and the criteria and standards for the declaration of soils as contaminated (MAGRAMA, 2007) are established. With the data on total contents of these elements, which are the ones considered to be of greatest environmental concern in scenarios of direct contact, a comparison will be made with the Generic Reference Levels of soils established for uses of the urban soil which it is advisable to apply in each case. The decision to use the Generic Reference Levels (GRL) is justified because these are established from considerations of risk, and are defined, according to article 2 of Royal Decree 9/2005, as: "the concentration of a contaminating substance in the soil which does not involve a risk greater than the maximum acceptable for human health", which, in the case of uses of urban soils, is set considering the possibility of accidental ingestion, inhalation or skin contact. In the first place, it should be verified whether they have been declared by the corresponding Autonomous Community and, if not, they must be established by the evaluator on the basis of bibliographic research. The concentration factor of direct contact is established in a simple manner, by assigning the value 5 for those cases in which it is greater than those of the Generic Reference Level of any of the elements commented on above, and the value zero in any other case. This last is the same as evaluating the index of probability of occurrence for direct contact or $\mathbf{I_P(CD)}$ as zero.

This methodology is similar to that used for the declaration of soil as contaminated (MAGRAMA, 2007), although this does not imply that the methodology proposed for preliminary evaluation of the risk by direct contact aims for the declaration of mining waste facilities as contaminated soils, because that is not the spirit of this work. The final aim is to obtain a wake-up call about those mining waste facilities that are accessible to the population which, owing to their concentration of certain metals, might involve a potential risk.,

3.5.1.2. Evaluation of the accessibility of the mining waste facilities: accessibility factor ($\mathbf{F_{ACC}}$)

One key element in evaluating the probability of occurrence of a risk scenario by direct contact is the accessibility of the possible receptors to the mining waste facility. These mining waste facilities are abandoned and on numerous occasions no fencing or warning signs has been put up. It is true that, on occasions, protection has been granted to certain elements of the mining heritage such as the declaration as a "Property of Cultural Interest" (as a Historical Site) of the “Mining Area of Riotinto-Nerva” in Huelva, and of the “Sierra Minera of Cartagena-La Unión” in Murcia. The declaration of these and other protected sites encourage the creation of an infrastructure devoted to visiting these spaces, such as footpaths, guided tours, viewing points, etc., which increases the possibility of direct contact.

An **accessibility factor ($\mathbf{F_{ACC}}$)** has been defined which evaluates these aspects. The criteria of valuation used were previously employed in the analysis of risk by direct contact associated with mining areas and contaminated soils (EPA-Ireland, 2009; EEA, 2005). It is proposed to assign to each category of accessibility a value of between 0 and 1, in such a manner that if there is no possibility of gaining access to the mining waste facility (inaccessible category) the accessibility factor and, as a result, the probability index of occurrence, will be nil. The value 1 is assigned to those mining waste facilities in which the accessibility is encouraged by the presence of certain elements such as the presence of footpaths, viewing points, notices, etc. The values of the accessibility factor are set out in **Table 23**. The evaluator may assign different values to those that are shown, in those cases in which the reality is not exactly in line with the descriptions in the table, and he will maintain coherence with the table.

Assessment of the accessibility to mining waste facilities.	
Valuation criteria	**F_{ACC} value**
Provided accessibility. Existence of elements that encourage the access (paths, posters, viewpoints), easy access ways (roads or tracks for motor vehicles).	1
Highly accessible. Without restrictions or disabilities (no fence, doors or signalling, no control access), easy access ways (roads or tracks for motor vehicles).	0,75
Moderately accessible. Fenced facility but without any access control, existence of footpaths.	0,5
Hardly accessible. Fenced facility, cut paths, cross-country access.	0,25
Non-accessible. Facility completely fenced, accesses cut and guarded, hard cross-country access.	0

Table 23. Accessibility factor (F_{ACC}) value assignment.

3.5.1.3. Proximity of mining waste facilities to residential areas: proximity factor to residential areas (P_{RR})

The proximity existing between the mining waste facility and the closest residential areas (understanding residential areas to be not only towns and villages but also housing estates and isolated houses) is an important element when evaluating the probability of occurrence of a risk scenario by direct contact, given that, if the distance is sufficiently large, the probability of occurrence of the contact occurring will be low. This is an element which has also been traditionally evaluated in scenarios associated with direct contact with mining waste facilities (EPA-Ireland, 2009) and with contaminated soils (EEA, 2005). This distance can be evaluated by means of direct measurement on topographical maps or orthoimages (there are a range of freely available tools and viewers such as SIGPAC which can be easily used).

A proximity factor **proximity (P_{RR})** to residential (inhabited) areas, which depends on the distance between the evaluated mining waste facility and the closest residential area, and to which values of between 0 and 1 are assigned according to the scale in **Table 24** is defined on the basis of the foregoing**.** The intervals of distance are a modification of the criteria used in similar methodologies (EPA-Ireland, 2009; EEA, 2005), while the values of the proximity factor assigned to each interval respond to the interest in maintaining the scale of values, in such a manner that the value of the index of probability remains within the range of values comprised between 0 and 5.

Assessment of the proximity factor (distance from the mining waste facility to residential areas)	
Distance (m)	**P_{RR} value**
< 250	1
250 – 500	0,8
500 – 1000	0,6
1000 – 2000	0,4
2000 – 5000	0,2
>5000	0

Table 24. Proximity factor (P_{RR}) value assignment depending on the distance from the mining waste facility to residential areas.

3.5.1.4. Calculation of the index of probability of occurrence of direct contact with effects on persons and the population of mining wastes: I_P(CD)

As has been explained above, the index of probability **I_P(CD)** will be zero when it is not considered that the wastes can have any negative effects on health ($F_{CCD} = 0$) or when there is no possibility of gaining access to the structure ($F_{ACC} = 0$), or when it is located at a distance of over 5 km from any populated area ($P_{RR} = 0$). In all other cases, the value of **I_P(CD)**, is expressed on a scale of between 0 and 5, and will be calculated according to the following formula:

$$\mathbf{I_P(CD) = F_{CCD} \times F_{ACC} \times P_{RR}}$$

Where:

- **F_{CCD}** is the so-called **factor of concentration of direct contact** relative to the potential of the waste to cause damage to the health.
- **F_{ACC}** is the so-called **accessibility factor** for mining waste facilities.
- **P_{RR}** is the so-called **proximity factor**, which makes reference to the distance to the nearest residential area.

3.5.2. Severity Index of the effects on persons and the population deriving from direct contact caused by occasional access or the conduct of activities, $I_s(CD)$

The severity of the harm deriving from direct contact with the mining waste facilities is a function of the time of **exposure** (contact of the receptor with the mining wastes during a certain period of time), and of the **vulnerability** of the receptors exposed (the population in this case). The time of exposure depends on the time of direct contact and has a clear influence on the severity of the harm, in such a manner that it contributes to increasing the severity of the consequences. In general, in terms of health, exposures of a chronic nature are more significant. The other fundamental factor for the evaluation of the severity of the damage arises from the degree of vulnerability of the receptors to the contamination by contact with the toxic components of the mining wastes. The different groups of population present an intrinsic susceptibility to exposure to contaminants, and the most sensitive groups are children, old people and sick people.

Both the exposure factor and vulnerability factor of the receptors can be linked to the use or occupation of the soil. For example, a nearby residential use is associated with a high degree of vulnerability because it is a chronic exposure of long duration. Other uses associated with high vulnerabilities are those devoted to the daily conduct of sports or open-air activities, parks and children's play areas, etc. It is for this reason that, with the aim of evaluating the severity of the consequences of direct contact according to the time of exposure and the vulnerability of the different groups of population as potential receptors, an ordering and evaluation of the different uses of the land in mining waste facilities or in the vicinity of mining waste facilities has been carried out, bearing in mind the time of exposure and the vulnerability of the receptors associated with each one of them. In **Table 25**, the evaluations of certain groups of uses of the land are gathered to make up an orientative list which can be adapted by the evaluator to other specific but unspecified cases.

Assessment of the severity associated to the land use developed on the mining waste facility surface in the direct contact scenario.	
Valuation criteria	**Is(CD)**
Land uses with a very high associated severity: marginalised population, illegal landfills, plays for children, etc.	5
Land uses with a high associated severity: intensive recreational use (sports activities).	4
Land uses with a moderate associated severity: residential areas, non-intensive recreational uses (paths, viewpoints).	3
Land uses with a low associated severity: agricultural, farming and forestry activities.	2
Land uses with a very low associated severity: other land uses (commercial, industrial, etc.). Other uses of low exposure.	1

Table 25. Assignment of the severity value depending on the land use for the direct contact scenario.

4. SIMPLIFIED RISK ASSESSMENT FOR SCENARIOS OF FAULT IN ROCK PILES

4.1. FAILURE OR BREACH OF THE SLOPE AT HEAPS CONTAINING WASTE ROCK OR LOW-GRADE ORE (FESC)

4.1.1. Index of probability of the failure or breach of the dump slope at a heap containing waste rock or low-grade ore heaps I_P(FESC)

Heaps are those which store materials from the layers of host rock and covering soil extracted in work of surface clearance and, in general, all those wastes known as mining waste rocks although on occasion they may include other refining wastes. The rigorous calculation of the probability of breach of a mining waste facility or of its geological hazard is not a simple matter and requires taking diverse aspects into account, such as the characteristics and anisotropy of the wastes, the changes undergone throughout the life of the structure, the variations in resistance with the levels of tension at each point of the final flowing surface, the effects of the shape, the condition of the substrate, etc. However, given the preliminary nature of the risk analysis which is proposed, it is not justified to undertake detailed stability studies. The stability of the mining waste facilities may however be evaluated in a qualitative manner through soundings of a number of factors with which it is related and which can be grouped as: intrinsic and constructive characteristics of the mining waste facility; characteristics of the substrate or foundation; evolution of the geotechnical behaviour of the mining waste facility; entry and accumulation of water in the mining waste facility and factors of seismic risk. A **probability index of the failure or breach of the dump slope of heaps containing waste rock or low-grade ore I_P(FESC)** has been defined and it is obtained by transforming the result of the sum of all the factors considered.

There are some simple methods for the auscultation of mining waste facilities, such as the so-called *Dump Stability Rating Scheme* (BCMWRPRC, 1991), which is also known in Spain as INESTEC (Junta de Andalucía, 2002). These methods are nothing other than processes of assignation of values to the different factors which have an effect on the stability of a mining waste facility. The values assigned are added together and the comparison of the total score obtained with a reference scale makes it possible to deduce a (qualitative) measure of the global stability. It is worth observing that the amplitude of the ranges of valuation of each factor is greater, the greater the importance or weight which is given to this factor. On the basis of this type of method of evaluation, a scoring scheme is proposed which is set out in **Tables 26** to **30**. By adding the values assigned to all the parameters evaluated, it is possible to obtain the value of the **hazard** (**Pe_{ESC}**) understood as the susceptibility to possible breach of the embankment.

Among the intrinsic and constructive characteristics of the mining waste facility, the following have been considered to be determinant (**Table 26**): the inclination of the slope in degrees (º), the maximum height of the mining waste facility, the system of dumping used in its construction, and the quality of the material, expressed in terms of resistance to alteration or degree of alterability, by the proportion or content of fine particles.

Assessment of the intrinsic and constructive characteristics of the heap	
Valuation criteria	**Factor value**
General slope gradient of the heap, measured in degrees (Θ)	
> 37	6
33-37	3
< 33	0
Maximum height of the heap (H)	
> 100 m	6
99-50 m	3
49-25 m	1,75
< 25 m	0
Mining wastes disposal system (Ver)	
Free dumping from wagon, dragline, cable, etc.	3
Free dumping from truck	1,5
Construction in lifts	0
Quality of the heap´s materials (Cal)	
Lowly durable materials. More than 25% of fine elements	4
Materials of variable durability. Fine elements content between 10 and 20%	2
Highly durable or erodes hardly rocks. Less than 10% of fine elements. Rocks that suffered spontaneous combustion.	0
Existence of operative drainage system (pipes, central drains) (Dr)	
No	3
Yes	0

Table 26. Value assignment to intrinsic and constructive characteristics of the heaps affecting the physical stability.

Slope refers to the general slope, that is to say, from the upper crest to the contact at the foot with the natural land surface, including the berms that there may be. The height and the slope of the embankment refer always to the general slope. The height of the mining waste facilities which have suffered breaches of the slope is enormously variable (McLemore, 2009): from 19 to 850 m, although there appears to be a general agreement that the probability is greater, the higher the slope is.

As has been indicated above, the construction method by free dumping generates a greater segregation of the material and less compacting. When the mining waste facilities are constructed by means of the dumping of successive layers, the base of each new layer will be supported by the lower layer, which gives greater stability to the structure.

Figure 34. Heaps from coal mining extraction showing different durability and fine elements content.

The physical and chemical alteration of the elements of a mining waste facility can affect the stability. Processes like changes of temperature, the effects of ice, hydrolysis and formation of new minerals and solubilisation modify the stability in a complex manner, which is relatively easy to study on the surface but is not at deeper levels. However, it is worth evaluating the types of rock present in terms of resistance to alteration and durability, and their influence on the degree of stability. Indeed, different lithologies may respond in a different manner under similar situations of alteration with consequences in the geo-technical properties. One is considering good quality materials when one speaks of resistant rocks, that are little changed and which contain less than 10% of fine particles (Junta de Andalucía, 2002). Mining waste facilities which store materials from weak rocks of little durability, such as slate which accompanies coal, mining waste rocks from coal mines mixed with colliery spoils, soft sedimentary rocks, etc., may on occasion include sizes of less than 10 mm in a proportion that is greater than 25%, which might be susceptible to liquefaction. Examples of materials of different durability and content in fines are shown in **Figure 34.**

On many occasions, the problems of stability are associated with deficient drainage of the foundations, the obstruction of springs and the infiltration of run off and rains, especially in periods of high intensity of rainfall. Especially when they occupy partially or totally watercourses or concentrated run off routes, the evacuation of these is important by means of diversions and perimeter channels. Starting from the internal heterogeneity which can be found in a mass of mining waste rocks, it is obvious that the entry or infiltration of water in the mining waste facility may increase the pore pressure in critical areas, reducing the resistance of the materials.

Other aspects of great importance are those that have to do with the foundation or substrate on which the mining waste facility is built. It has been affirmed that the condition of the foundation is the main factor which provides stability to a mining waste facility, due to the fact that it is the point of contact between the structure and the land (Junta de Andalucía, 2002): at least theoretically, if the foundation is flat, it is competent and has satisfactory drainage, the height that a mining waste facility can reach is practically unlimited, even if it is built by free dumping according to the angle of repose. The substrate can be classified according to the resistance of the material into three types: competent rock (highly resistant materials), rigid soil or soft rock (or rock which behaves in a similar way) not very consolidated soil (soft soils). Likewise, the slope of the foundation may be of great importance. In the case of land on a considerable slope, where the safety factor vis-à-vis breach is low, the possibility of landslides is very high. In **Table 27,** the criteria of evaluation of the characteristics of the substrate are recorded.

Assessment of the characteristics of the foundation	
Valuation criteria	**Factor value**
Slope of the foundation material, measured in degrees (Φ)	
> 25	6
20-25	3
15-20	1,5
<15	0
Type of foundation material (Sus)	
Unconsolidated or lowly consolidated soil	4
Stiff soil or soft rock	2
Competent rock	0

Table 27. Value assignment to the characteristics of the foundation affecting the physical stability of a heap.

On the other hand, the proven presence of signs or evidences of instability (traction cracks, settlement, undermining of the base, etc.) is an unavoidable element on which to form a judgement for evaluating the stability of a mining waste facility on the basis of recent visual inspections (**Table 28**).

Assessment of the geotechnical behaviour of the heap	
Valuation criteria	**Factor value**
Instability evidences (Ins)	
Existence of deep tensile cracks, settling of the ground, erosion of the base.	4
Some instability evidences (shallow cracks, local landslides, etc.)	2
No instability evidences	0
Erosive status: gully erosion (Car)	
Deep gullies	3
Some evidences of gully erosion	1,5
No evidences of gully erosion	0

Table 28. Value assignment to instability evidences on heaps.

As regards the presence and influence of water, it is proposed to value two factors, which have to do with the rainfall regime in the area in which the mining waste facility under evaluation is located (**Table 29**). The maximum rainfall in 24h is a much-used indicator of the intensity of rainfall in a particular place, to bear in mind in the design of the engineering works which must support flooding. A range of return periods are often used, which are established according to the importance and characteristics of the work. The maximum rainfall within 24 hours for a return period of 100 years can be obtained from the programme (MAXPLUWIN) of the publication "Máximas lluvias diarias en the España Peninsular" of the CEDEX (http://epsh.unizar.es/~serreta/documentos/maximas_Lluvias.pdf). The influence of the annual average rainfall has also been considered

Assessment of the water input and evidences of water content in heaps	
Valuation criteria	**Factor value**
Average annual rainfall measured in mm/year (P)	
>800	4
500-800	2
250-500	1
<250	0
Maximum probable rainfall in 24 hours for a return period of 100 years	
>150 mm	4
125-150	3
100-125 mm	2
75-100 mm	1,5
50-75 mm	1
<50 mm	0
System for perimeter rainfall deviation (Per)	
No deviation system	3
Partial and/or insufficient	1,5
Appropriate and in good condition	0
Evidences of water existence inside the facility (Aq)	
Evidences of water saturation. Existence of water in the embankment. Existence of non-occasional water content in the heap´s platform. Heap´s base in direct contact with rivers or streams. Existence of hydrophytic vegetation (junks, bulrushes, *Phragmites*).	6
Heap´s base located in a flood zone (excluding the cases above).	3
Dry or nearly dry facility	0

Table 29. Value assignment to the impact of the water content in a heap.

Finally, the effect of seismic movements on the stability of mining waste facilities may be evaluated by means of the known values of the so-called basic seismic acceleration (**a_b**) (**Table 30**). With regard to the seismic action that may arise in the construction and conservation of mining waste facilities, the Seismo-resistant Construction Regulation NCSE-02 (Ministry of Public Works, 2009) is applicable. A classification is made in this regulation of buildings based on the gravity of the consequences that might arise if there were an earthquake, in such a manner that mining waste facilities are considered constructions of special importance as catastrophic effects might arise as a result of seismic movements (Junta de Andalucía, 2002).

Seismic risk assessment	
Valuation criteria	**Factor value**
Basic seismic acceleration (a_b)	
• > 0,16	5
• 0,12-0,16	3
• 0,08-0,12	1,5
• 0,04-0,08	0,5
• < 0,04	0

Table 30. Value assignment to the impact of the seismicity on the stability of the heaps. Basic seismic acceleration data obtained from the seismic hazard map (Seismoresistant Regulation).

The sum of all the values of the parameters collected in **Tables 26** to **30** will have as its result the magnitude of what has been called the **hazard** (**Pe_{ESC}**). This value can be qualified according to what is shown in **Table 31**. It reflects the probability of occurrence of the scenario of breach of the embankment of the mining waste facility which is under evaluation in a range of between 0 and 61. With the aim of maintaining a common scale of valuation in all the parameters of evaluation of the risk that are considered, a transformation of the Pe_{ESC} values has been undertaken to a probability index of failure of the mining waste facilities (IpFESC) between 0 and 5 (**Figure 35**), which is equivalent to, when Pe_{ESC} varies between 0 and 50, IpFESC = $Pe_{ESC} \times 1/10$, and when $Pe_{ESC} > 50$, then IpFESC = 5.

Hazard factor score (Pe_{ESC})	
>40	Very high
30-40	High
20-30	Moderate
10-20	Low
<10	Very low

Tabla 31. Hazard factor scores (Pe_{ESC}).

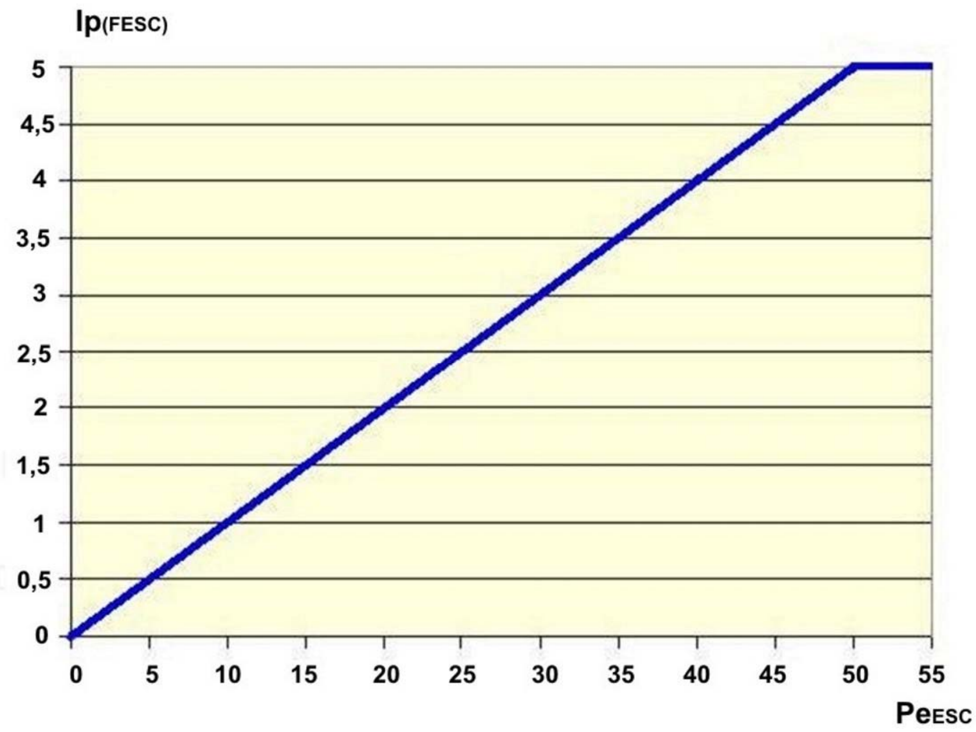

Figure 35. Probability index for the "failure on the embankment of a heap" scenario (Ip(FESC)), according to the hazard factor (Pe_{ESC}).

4.1.2. Index of severity of the failure or breach of the dump slope of heaps containing waste rocks or low-grade ore I_S(FESC)

In comparison with the mining tailing impoundments, fewer catastrophic cases are known associated with the breach or loss of stability of a heap. This is so because of the relatively poor mobility of the solid waste rocks from heaps as compared with the saturated wastes stored in tailing dams which can travel for distances of kilometres. Nevertheless, the destructive potential can sometimes be enormous, as can be seen from the lamentable case of Aberfan (Wales).

- *Determination of the maximum distance of movement of wastes released from heaps ($D_{máx}$)*

Due to the very nature of the processes of breaches of slopes, the effects are generally seen in a more or less rapid form. The speed of movement of the material which slides or flows is a parameter of great importance from the point of view of the severity of the possible consequences. There is unanimity in the scientific community as it is considered that the velocity of a landslide is one of the fundamental parameters when harm to persons arises, considering 5 metres a second a critical velocity above which it is difficult for a person to be able to escape (IGME, 2004). However, the making of predictions of the velocity of movement requires an analysis of a certain complexity, which cannot be achieved in preliminary studies of risk evaluation. One simpler approximation to the evaluation of the possible consequences is that it attempts to analyse the mobility of the mass of wastes in the light of accumulated experience in the study of landslides, scree flows. The work of Srour (2011), supplies instruments of graphic analysis which might be of use in establishing the maximum foreseeable distance of movement or the reach of the mining wastes in processes of breach of heaps, on the basis of empirical models developed by Golder Associates Limited (1995), Hungr (1995) and Corominas (1996), based on the carrying angle. The carrying angle, which represents the angle formed between the crest of the hypothetical surface of breach and the base of the mass that has moved, is highly dependent on the total mass of wastes displaced, which in turn depends in large part on the size of the structure. The relationship existing between the route and the relationship between the height or difference in height between the foot of the mass that has slid and the crown is used by Srour (2011) to prepare a number of graphs in which it is possible to analyse the probability of exceeding the values calculated according to the volume that has moved and the degree of confinement. Considering from a very conservative point of view that confined movements always occur and that all the volume of the structure moves, which is a long way from being true, it is possible to make estimates of the movement ($\mathbf{D_{max}}$) for different sizes of heaps in the case of no excess. In **Table 32,** values are offered for the maximum distance for different heights and volumes of heaps. The volume refers to the volume that has moved, and it might be supposed with a fairly conservative criterion that it is equivalent to the total.

With regard to the delimitation of the possible area of effects on a detailed cartographic basis, with a certain reach being known ($D_{máx}$), it can be done by projecting the contact of the base of the mining waste facility with the natural ground until that distance is reached, following the lines of maximum slope and bearing in mind the lateral confinement that the topography itself may cause. That area of effect determines the elements at risk or exposed receptors. The delimited area at risk will serve as a reference for the calculations of the respective indexes of severity of the effects on persons and the population, the natural environment and socio-economic effects deriving from the failure of this kind of structure. Given that the basis of calculation of the distance or reach is empirical, a certain degree of conservatism is advisable.

Value assignment to the maximum distance travelled by the mining wastes (D_{max}) in the case of breach of a heap.										
For a volume of 10.000.000 m^3										
H			30	40	50	60	70	80	90	100
D_{max}			390	520	650	780	910	1040	1170	1300
For a volume of 5.000.000 m^3										
H			30	40	50	60	70	80	90	100
D_{max}			330	440	550	660	770	880	990	1100
For a volume of 1.000.000										
H		20	30	40	50	60	70	80	90	100
D_{max}		180	270	360	450	540	630	720	810	900
For a volume of 500.000 m^3										
H		20	30	40	50	60	70	80	90	
D_{max}		160	240	320	400	480	560	640	720	
For a volume of 100.000 m^3										
H		20	30	40	50	60	70	80		
D_{max}		140	210	28	350	420	490	560		
For a volume of 50.000 m^3										
H	10	20	30	40	50	60	70			
D_{max}	60	120	180	240	300	360	420			
For a volume of 10.000 m^3										
H	10	20	30	40	50	60	70			
D_{max}	50	100	150	200	250	300	350			

Table 32. Value assignment to the maximum distance travelled by the mining wastes (D_{max}) in the case of breach of the heap, according to the mobilised volume (m^3) and the height of the heap (H) measured in metres.

4.1.2.1. Index of severity of the effects on persons and the population deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore: Is(FESCPO)

The most serious consequence of the failure of a heap is the loss of human life, therefore, the most important risk factor will be the **population exposed (P_{EX}),** up to the maximum distance of travel of the material that has slid ($D_{máx}$). The severity of the damage to the population at potential risk of being affected by the hypothetical failure will depend on the density of population or the human contingent exposed and their vulnerability, which will be a function of the patterns of activity and use of the land, including aspects relating to the protection given by the characteristics of construction inherent thereto (e.g. a residential area or a camp site). When designing the criteria of evaluation of this factor, some of the proposals used in the "Guía Técnica relativa a la Clasificación de Presas en función del Riesgo Potencial" (Technical Guide relating to the Classification of Reservoirs according to the Potential Risk, Ministerio de Medio Ambiente, 1996) have been taken into consideration. Likewise, in the above-mentioned guide, the following concepts have been considered:

-*Urban centre of population*, understanding as such, in accordance with the Spanish Statistical Institute (*Instituto Nacional de Estadística*, INE), the set of at least ten buildings which form streets, squares and other urban roads. Exceptionally, the number of buildings might be less than ten provided that the de iure population which inhabits the locality amounts to more than fifty inhabitants. The population centre includes those buildings which, although they are isolated, are at a distance of less than 200 metres from the external limits of the above-mentioned group, although in the determination of that distance any land occupied by industrial or commercial facilities, parks, gardens, sports areas, cemeteries, car parks and other such items must be excluded, as well as canals or rivers which may be crossed by bridges. In the technical guide, a serious effect on an urban population centre is when over five of the inhabited buildings might be affected.

-*Limited number of dwellings or isolated dwellings:* a limited number of dwellings is considered to be between one and five inhabited dwellings.

-*Incidental loss of human life*: This makes reference to an occasional and not foreseeable presence of population.

In the present methodology, the urban centre of population, from the point of view of the effects on the life of people is treated as a very vulnerable element and is considered to be one of the worst scenarios. A conservative criterion is applied when the total population of the place is considered, provided always that there are places of residence included in the area which might be affected by the movement of the wastes, although this area of effects includes marginally a small area of the urban centre of population. The loss of human life is without a doubt unacceptable, nevertheless, and given the necessity of establishing a prioritisation between risk scenarios, the possibility exists of carrying out a valuation of the centres of population according to their size or number of inhabitants, with the minimum value being 3.5 (high vulnerability) for centres with 50 inhabitants and 5 for those of an urban nature of over 10000 inhabitants (very high vulnerability), with different evaluations being set according to the different numbers of the population (**Table 33**). For the determination of the *de iure* population or the number of inhabitants of each centre, it is possible to go to a statistical source such as the Nomenclator (Gazetteer of the Spanish National Statistical Institute), which can be consulted on the internet at the following address: www.ine.es/nomen2/index.do.

Just like in the above-mentioned technical guide, the existence of one or several buildings for residential use and which do not collectively exceed a maximum of five dwellings, will be considered isolated housing. In Spain, according to the Census of Population and Housing of 2011, by the National Statistical Institute, the average size of a family is 2.58, as has been indicated above. The valuation assigned to urban centres and isolated dwellings is reflected in **Table 33**. When there is no nucleus of population, the value of the population exposed (P_{EX}) will be assigned according to the vulnerability of the type of occupation of the land, fundamentally. In **Table 34,** a list of uses according to their vulnerability is shown. This list is open to the addition of new criteria or the adaptation of those already set out in the cases of the area, by the evaluator.

Assessment of the population vulnerability in the case of failure or breach of the embankment at a heap	
Valuation criteria	**P_{EX} value**
Population centres: more than 10000 inhabitants	5
Population centres: between 5001 and 10000 inhabitants	4,75
Population centres: between 2001 and 5000 inhabitants	4,5
Population centres: between 1001 and 2000 inhabitants	4,25
Population centres: between 501 and 1000 inhabitants	4
Population centres: between 101 and 500 inhabitants	3,75
Population centres: between 50 and 100 inhabitants	3,5
Population centres with less than 50 inhabitants or isolated houses	3

Table 33. “Exposed population” factor (P_{EX}) value assignment in the case of failure or breach of the embankment at a heap.

Assessment of the vulnerability of the exposed population in risk zones derived from the failure or breach of the embankment at a heap	
Valuation criteria	**P_{EX} value**
Very highly vulnerable land uses: residential areas (marginalised population included), camping.	5
Highly vulnerable land uses: great commercial and recreational areas, schools, hospitals, industrial areas, high capacity pathways, high frequency passenger suburban trains, etc.	4
Moderately vulnerable land uses: parks, intensive recreational and sport use, areas of attraction for population (pilgrimages, etc.), moderate traffic density pathways, long distance (moderate frequency) passenger trains, etc.	3
Lowly vulnerable land uses: extensive farming activities, extensive recreational and sport use, low traffic density pathways, freight trains, low frequency passenger trains, etc.	2
Very lowly vulnerable land uses: scarcely frequented areas.	1

Table 34. “Exposed population” factor (P_{EX}) value assignment according to the exposed land uses vulnerability in the case of failure or breach of the embankment at a heap.

It can be seen that uses that are highly vulnerable to the failure or breach of a heap have been considered: large commercial stores, industrial estates, schools, hospitals, sports centres and all those other uses which involve an influx of population and a relatively high time of exposure. Those whose intrinsic and/or constructive characteristics make them especially vulnerable as they offer little protection as is the case of residential areas of a marginal nature (shanty towns) or camping areas located in the area of risk have been considered very specially.

With regard to the valuation of the road infrastructure that might be affected from the point of view of the evaluation of the damage to persons, it is recommended, whenever possible, to use as a criterion the annual average daily intensity (AADI) of traffic, measured in vehicles/day consulting for this purpose maps of intensities of traffic drawn up by the Autonomous Communities or the Ministry of Public Works. If this kind of information is not available, its ownership may constitute a criterion of classification of the road network. Thus the communication routes which make up the Network of General Interest to the State depending on the Central Administration are supposed to have a greater intensity of traffic, as they are made up of roads which link autonomous communities and connected the main population centres of the State, forming part in turn of the main international itineraries; the Network of Regional Roads follows in importance, and it is possible to make out a hierarchy (secondary roads of the first order, of the second order, etc.) which is also interpreted as a greater or lesser use by vehicles, and finally the Provincial network of Roads depending on the County Councils. In the case of high capacity roads (dual carriageways and motorways), state and regional roads it is taken for granted that they will bear high intensities of traffic. Other communication routes such as the railway are valued according to whether they are mostly used for passenger or goods transport, and the frequency of the journeys.

Agricultural (farming) and recreational activities, of extensive use, that is to say, with a low exposure to risk from the time and/or demographic point of view, are those that represent low vulnerability. The areas with a slight influx of population are considered to be of very low vulnerability, where human losses are incidental or scarcely foreseeable.

The evaluator will make a non-exhaustive list of the most significant elements exposed, assigning to the P_{EX} factor a value obtained from one of the foregoing tables. The final value of the P_{EX} factor will be that of the worst scenario considered, which means that, of the elements exposed (population centres or other uses of land), the one which involves the highest value of exposure for the population will be taken.

Finally, the index of severity of the effects on persons and the population deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore **Is(FESCPO)** will be assigned according to: the value of the population factor exposed

(**P_{EX}**) in the worst of the scenarios, in the area delimited as being of risk, in accordance with the following formula:

$$\mathbf{Is(FESCPO) = P_{EX}}$$

4.1.2.2. Index of severity of the effects on the natural environment deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore: Is(FESCNA)

The breach of a mining waste facility and the movement of a certain volume of material downstream, following the line of maximum slope, will have as its result the physical destruction or a severe impact on the ecosystems exposed by contamination depending on the toxicity of the wastes. It must be borne in mind that the possible processes of contamination associated with this kind of accident will complicate the analysis greatly, given that it will be necessary to think again regarding evaluations of the probability that processes of contamination associated with the new situation created arise: scattered waste in an area much larger than the one they originally occupied. For this reason, it is assumed that all the land affected by an accidental spill will be devastated by the spill itself or by the immediate cleaning work which will follow (which is in accordance with the experience of the last few years). The severity of the damage will be a function of the conservation values of the ecosystems affected and of their vulnerability. The most serious effects from an environmental point of view arise when there are sensitive areas in the zone considered to be probably affected or which might be reached by the material moved. The sensitive or most vulnerable areas are represented by protected natural areas, spaces protected by the Natura 2000 network, that is to say, Sites of Community Importance (SCIs), Special Areas of Conservation (SACs) and Special Protection Areas for Birds (SPAs), the habitats included in the Spanish Catalogue of Habitats in Hazard of Disappearance, as well as areas protected by international instruments (Wetlands of International Importance), in accordance with the RAMSAR Convention; natural sites from the World Heritage and Biosphere Reserve lists of UNESCO; Biogenetic Reserves of the Council of Europe; areas protected by the Convention for the protection of the marine environment of the North-east Atlantic (OSPAR); Especially Protected Areas of Importance for the Mediterranean (ZEPIM); etc.). Also included as sensitive areas are the Important Areas for the Birds of Spain

(IBAS) and the wetlands included in the Spanish Inventory of Wetlands (IEZH), as well as other spaces which the competent organisations in the matter of the environment consider to be of special importance for the protection and conservation of the biodiversity and the natural heritage. In **Table 35,** criteria of evaluation of ecological vulnerability are set out for orientation (V_E).

Assessment of the ecosystem and other exposed elements vulnerability in risk zones derived from the failure or breach of the embankment at a heap	
Valuation criteria	**V_E value**
Sensitive areas (environmental protection)	5
River sections declared as areas of interest for fishes (salmonid and cyprinid waters). Water bodies of good or very good ecological status. Well-preserved forests (evergreen and deciduous hardwood forest, coniferous forest)	4
Scrubs, holm oaks, woody crops (olive grove, fruit crops, vineyard, etc.), Surface water bodies of moderate ecological status.	3
Grasslands and pastures, arable crops, rivers and surface water bodies with disturbed riparian ecosystems and poor ecological status.	2
Urban areas and very disturbed ecosystems.	1

Table 35. "Ecological vulnerability" factor (V_E) value assignment according to the intrinsic vulnerability of the exposed ecosystems in risk zones derived from the failure or breach of the embankment at a heap.

Finally, the index of severity of the damage to the natural environment deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore (**Is(FESCNA)**) will be a function of the ecosystem or most vulnerable natural element exposed (**V_E**) in the area delimited as being at risk, in accordance with the following equation:

$$\mathbf{Is(FESCNA) = V_E}$$

4.1.2.3. Index of severity of the effects on the socio-economic environment deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore: Is(FESCSE)

The severity of the consequences is going to be a function of the destruction, or irreversible damage which might be caused by the slippage of the stored material due to breach of the heap, to the cultural heritage, especially what is classified as a Property of Cultural Interest (BIC) or any other figure of protection, to the main economic activities in the area of study and on services (hospitals, etc.) and essential infrastructure (water supply, energy, road communication, etc.).

In **Table 36,** general criteria of evaluation of the vulnerability of the elements of the socio-economic environment are set out (V_{SE}) of the elements exposed, as a function of their heritage value and priority nature from the social and economic point of view. Logically these criteria are of a generalist nature, with the result that, depending on the specific characteristics of the socio-economic environment affected, it will be possible to include new criteria, or even to alter the order and value of those already set out by the evaluator.

Assessment of the socio-economic environment vulnerability in risk zones derived from the failure or breach of the embankment at a heap	
Valuation criteria	**V_{SE} value**
Protected cultural heritage.	5
Priority economic activity for the area under consideration. Essential services (hospitals, etc.). Critical infrastructures (water and energy supply). Communication paths (roads or trains providing external interconnection, high capacity pathways, etc.).	4
Other secondary economic activities. Secondary communication paths, non-critical infrastructures, non-essential services.	3
Economic activities, services and infrastructure of minor importance.	2
Impact on elements without cultural or productive value or with little economic value.	1

Table 36. Value assignment to the "Cultural heritage, productive system, infrastructures and essential services" vulnerability factor (V_{SE}) in risk zones derived from the failure or breach of the embankment at a heap.

The index of severity of the effects on the socio-economic environment deriving from the failure or breach of the slope of dumps containing waste rock or low-grade ore

Is(FESCSE) will be a function of: the cultural heritage, economic activity, infrastructure or most vulnerable essential service exposed (**V_{SE}**) in the area delimited as at risk, in accordance with the following formula:

$$\mathbf{Is(FESCSE) = V_{SE}}$$

4.2. FAILURE OR BREACH OF THE DYKE OR THE EXTERNAL EMBANKMENT OF MINING TAILING IMPOUNDMENTS (FPRE)

4.2.1. Index of probability of the failure or breach of the dyke or the external embankment of mining tailing impoundments I_P(FPRE)

Processes of concentration of the mineral normally implies a reduction in the size of the grain of the material by means of crushing and grinding. The granulometry of the waste will depend on the demands of the mineralogical process used to concentrate or extract the minerals (IGME, 2004). After the concentration by flotation or another method, large quantities of waste of a fine granulometry are generated which are dumped in the form of a pulp or aqueous suspension in so-called mining tailing impoundments (also known as *colas* or *relaves* in Latin America). The reservoirs of fine mining-metallurgical waste are complex geo-technical structures. They present a number of constructive and functional aspects that are similar to reservoirs of loose materials, although they also present important and significant differences which make them more vulnerable due, among other factors, to the fact that the construction process is affected by the operating necessities of the mining operation. These mining waste facilities are characterised by being located wholly or partially above the height of the surrounding land, with the result that they require a retaining wall or structure for the wastes. The physical stability of the mining waste facility will depend on the integrity and state of conservation of the dyke. The area of the mining waste facility where the tailings are stored constitutes the basin of the reservoir. In **Figure 36,** a general basic diagram of a Mining tailing impoundment is set out with the different elements of which it is made up.

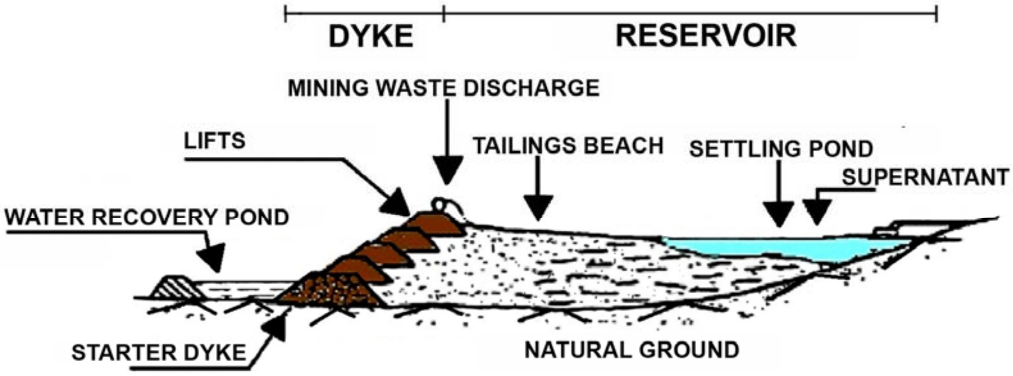

Figure 36. Mining tailing impoundment structure basic scheme (modified from: IGME, 1986).

The rigorous calculation of the probability of breach of a dyke is not something simple and would require taking into consideration numerous aspects and evaluating them via instrumental means and/or analytical data. However, given the preliminary nature of the risk analysis which is proposed, it is not justified to deal with detailed stability studies, with the result that the evaluation has to be based on a number of factors or parameters which may be considered to be key, such as:

- The **design and constructive characteristics of the dyke,** such as: typology and construction method, materials used and the geometry (height, slope of the embankment and length of the dyke). These characteristics will condition the geo-technical properties proper to the retaining wall.
- The state of conservation of the dykes, or **the degree of physical integrity of the mining tailing impoundment**. The cumulative damage due to the occurrence of extreme events, the effect of abandonment and the lack of maintenance of the installation together with the climatic inclemency, are going to result in: erosive processes (external and internal), structural changes or deformations of the retaining wall, which might compromise the general stability of the mining tailing impoundment.
- The **volume of wastes stored in the facility,** normally estimated in cubic metres, and which constitutes a critical factor in the magnitude of the damage associated with a process of breach.
- The **location**, which depends on the geological, geomorphological, hydrological, hydro-geological and geo-technical characteristics of the same, on the one hand, and

the **associated hazard to the location, that is to say, the natural risks associated with the place**, (seismicity of the area, floods, extreme climatic events, etc.). The location, therefore, will have a powerful influence on the stability of the structure as it constitutes the foundation on which the dyke is erected.

- The **water balance of the materials of which the dyke is made up**, due to the strong influence on the interstitial pressure or pore pressure to which the material is subject. The degree of saturation thereof will be powerfully controlled by the position of the settling pond, phreatic level and permeability of the slurry. Likewise, the state of conservation of the system of drainage (pipes, chimneys, spillways channels, perimeter channels for collecting run off, etc.) and their characteristics may have an influence on the state of the wastes.

A wider justification of the choice of these factors can be found in Alberruche *et al.* (2014). They must all be valued on the basis of the information obtained in field visits or in the records of an inventory, together with all that analytical information or of another type which is considered advisable. From the valuation of all the parameters, it is possible to obtain an **index of probability of the failure or breach of the retaining dyke or the external embankment of a mining tailing impoundments IP(FPRE)** which is obtained by transforming the result of the addition of all the factors considered.

The different factors are valued on different scales. The values assigned to these factors, for each one of the structures evaluated, are added together to obtain the value of what has been called **hazard (Pe_{PRE}),** understood as susceptibility to a possible break in the embankment. Those to which the widest ranges of evaluation correspond are those which are considered to possess the greatest weight or importance in the final calculation. As will be seen at the end of this chapter, as a function of the total score obtained on a scale or reference scale, it will be possible to finally assign a value for the global stability through the **index of probability of occurrence I_P(FPRE)**.

4.2.1.1. Design and construction characteristics of the dyke (DC)

The type of material used and the construction characteristics of the dyke are the main aspects which have been considered in the evaluation. In order to facilitate the analysis, the construction and dyke design characteristics have been subdivided into a number of sub-factors which are described below. The greater the value assigned to each of them, the greater is the hazard in the case of a possible failure or breach of the mining tailing impoundment. As will be seen, each one of the sub-factors is valued at a certain range of values. As has already been stated, a greater maximum value and a greater amplitude of the range of valuation of a certain sub-factor is equivalent to considering that this sub-factor has a greater weight or relative importance. In **Table 37,** the values of the different sub-factors are given. It can be observed that the sub-factor that has the greatest weight assigned is the angle of the embankment of the dyke.

- *Construction material of the dyke (Mat)*

The type of **construction material of the dyke (Mat)** will govern its geo-technical and hydro-geological properties and, therefore, its physical stability. The largest part of the abandoned mining tailing impoundments in this country have been built with the mining wastes themselves, by means of the system of hydraulic filling. The particular nature of this system is that the wastes undergo a process of classification by segregation of the solid particles according to their specific weight and distance from the point of dumping (Vick, 1990), in such a manner that the coarsest and/or heaviest material tends to be deposited in the vicinity thereof and the finer and/or lighter material is deposited in the most distant locations. However, this theoretical segregation of the material is not totally guaranteed, as is indicated by Oldeocop and Rodríguez (2006), since the effectiveness of the mechanism of classification by size appears to depend strongly on the solid/water relationship of the slurry which is dumped. On the other hand, the progressive construction of the dyke linked with the operational demands related with the fluctuations in the rhythm of production of wastes by the mine generates variations in the conditions of dumping and the inclusive changes in the location of the dumping points. As a result of all this, there are alternating levels of finer and more plastic materials between the sandy materials of the dyke. An improvement with regard to the foregoing procedure of dumping and natural decantation of the slurry for the construction of the dyke, with beneficial consequences on the stability, arose with the application of systems of cycloning. This system makes possible a greater control of the granulometry of the material of which the retaining structure is made up (IGME, 2004), as well as a reduction in the percentage of fine aggregates. The sands of the cycloning supply therefore a greater effective resistance and a high degree of permeability, two fundamental factors to guarantee the stability of mining tailing impoundments (USEPA, 1994).

The use of mining wastes of flotation as a construction material for the retaining dyke is fundamentally for economic reasons. The mining tailing impoundments may also be structures or civil engineering works of a conventional type, constructed above the surface of the land using an external dyke of soil or other material. The construction materials are very diverse, although three basic types may be considered in ascending order with regard to their resistance in the case of a possible breach: mining rubble, selected loan materials, with a higher or lower proportion of blocks, rubble and dykes of masonry or of mass concrete. This mode of construction is very rare in abandoned mining tailing impoundments in Spain. In principle, the retaining dykes built with these materials must be considered more stable than those built with the slurry itself, although it may only be because it is possible to suppose minimum work of calculation of the stability and a certain control of the construction. In **Table 37,** the values assigned to the **construction material of the dyke (Mat)**, in accordance with the influence which might be exercised on the probability of breach. It should not be forgotten that the assignation of these values is a response to the requirements of a preliminary procedure for the evaluation of the risk.

- *Method of construction of the dyke (M_c)*

The **method of construction of the dyke (M_c)** also has important implications for stability. According to the type of system of construction of the dyke by hydraulic refilling with its own wastes, there are three basic types of mining tailing impoundments: upstream, central line and downstream (**Figure 37**). These denominations refer to the direction in which the crest of the growth of the retaining dyke might move with regard to the initial dyke, as the structure increases in height.

The upstream method consists of building successive dykes, each one of which is slightly set back with regard to the previous one (IGME, 1986). Mining tailing impoundments built using upstream methods are the ones most at risk of suffering landslides with a breach of the surface of the dyke itself, as well as processes of liquefaction, piping and erosion due to excess. It also presents with regard to the other methods of growth with mining wastes a lesser capacity for storage of water, and a high degree of susceptibility to liquefaction in the case of seismic movements. There is a general suggestion that, in seismic areas, this method of construction should not be used (Vick, 1990; USEPA, 1994; ICOLD, 2001), and its use is currently prohibited in countries such as Chile, Peru, Argentina and Mexico. The great majority of abandoned mining tailing impoundments for flotation slurries in this country have been built using the upstream method.

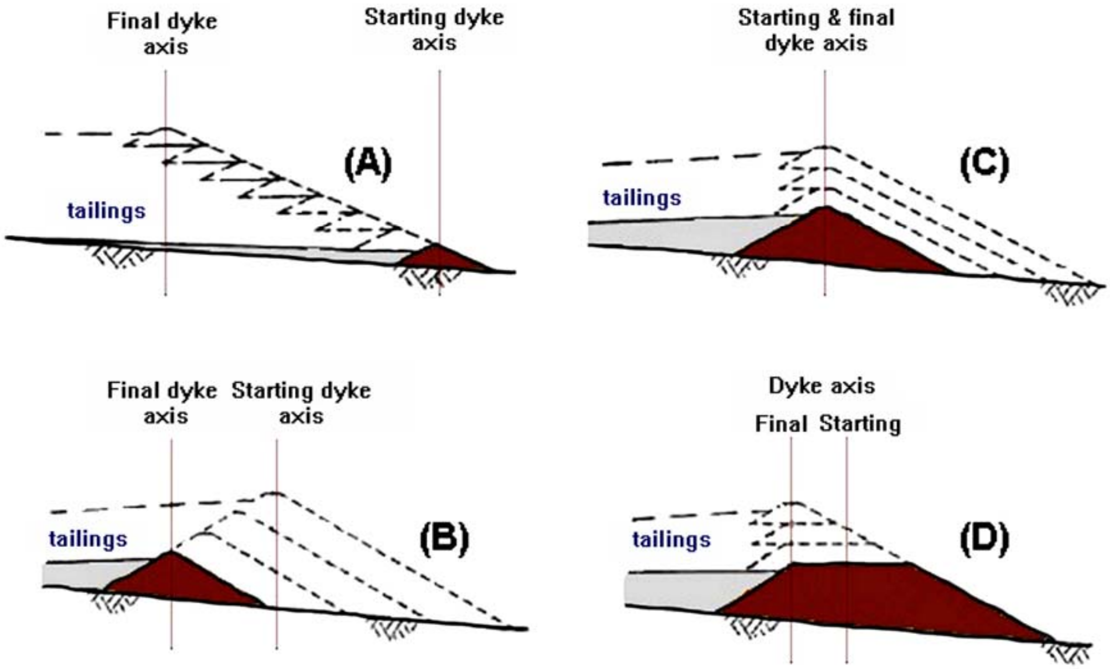

Figure 37. Types of mining tailing impoundments constructued through hydrulic filling using the mining waste themselves according to the regrowth system (modified from: Junghans and Helling, 1998). A) Upstream, B) Downstream, C) Centerline y D) Modified centerline.

The downstream method is so called because the successive phases of the construction of the dyke are based on the upper part of the slope situated in the downstream position with regard to the previous phase, changing the central line of the upper part of the mining tailing impoundment. The thickness of the retaining wall at its base increases with the height with the result that this type of mining tailing impoundment generally is more stable due to its great width and because it is based directly on the substrate (Junghans & Helling, 1998). The downstream method offers a degree of stability which it is not possible to obtain by means of the upstream method, due to the possibility of compactation and the facility to incorporate drainage which will facilitate the depression of the phreatic level, and the impermeabilisation of the face of the dyke which is in contact with the mining waste facility is normal. The procedure known as centerline or of centred construction combines some of the advantages of the other methods (with greater seismic stability than the upstream method and fewer requirements of volume of material in the growth with regard to the downstream method). The successive increases in the size of the dyke start from the axis of the starter dyke, extending downstream but keeping to the same vertical as at the beginning of the construction of the mining waste facility. One variation is the so-called modified centerline (**Figure 37**). In this method, what is done is an increase in the size of the retaining wall of the mining tailing impoundment in the same way as the centerline method but with a prolongation of the length of the wall of the downstream dyke (Junghans & Helling, 1998). In **Table 37,** the assigned criteria of evaluation of probability of occurrence of a breach according to the **method of construction of the dyke (M_c).**

- *Angle of the slope of the main dyke or the general slope if there are berms (Θ)*

The slope of the downstream embankment of the main dyke, or the general embankment if there are berms is another of the geometrical factors which influence stability. The embankments with a lesser slope will in general by more stable given that their support base on the ground in relation to their height will be greater (SERNAGEOMIN-BGR, 2008). In some cases of dykes built with mining wastes, it is observed that the slope of the embankment coincides with the angle of repose of the material, that is to say, the embankment is what results naturally from the dumping of the material with which the dyke is built. It is obvious that, in these cases, the safety margin of these embankments is foreseeably lower. Nevertheless, it is necessary to indicate that as a consequence of the mechanical processing of the prior milling, the granular washing wastes generally present angular shapes which gives them relatively high angles of internal friction, although with no or very low cohesion except with plastic material (IGME, 1986). With regard to the phenomenon of aging, there are a number of factors which contribute to the fact that abandoned mining tailing impoundments can maintain embankments with a steep slope relatively stable: the progressive consolidation of the slurry, the cementation by the precipitation of hydroxides or metallic oxyhydroxides or sulphate salts when they are not very soluble, or alternatively they may intensify the processes of suction as the wastes lose their moisture (IGME, 1986; Rodríguez et *al.*, 2011). In **Table 37,** the criteria of valuation are shown of the parameter **angle of the embankment of the main dyke or the general embankment if there are berms (Θ)**. For the establishment of these criteria, the criteria applied by González de Vallejo *et al.* (2004) in the analysis of potential movements of the hillside have, among others, been taken into consideration: slopes of less than 10º are considered stable; between 10 and 20º they are generally stable, when there are no movements of the hillside active nor old movements recorded, or moderately unstable with old movements; and of over 20º moderately stable if there are no movements recorded, or unstable if there has been any previous movement.

- *Height of the dyke or of the sum of the dykes (H)*

Another aspect of construction that is of importance from the point of view of stability is the **height of the reservoir or of the sum of the dykes (H)**, understood as the difference between the height of the crown and of the lowest point in contact with the base of the embankment and the foundations. It represents the sum of the heights of all the dykes when there are further episodes of construction (**Figure 38**). In accordance with the International Committee on Large Dams (ICOLD), and taking into consideration the classification of the ITC 08.2.01 for "mining tailing impoundments in processes of treatment from extractive industries" (repealed by Royal Decree 975/2009), it may be considered that a dyke with slurry is large when the height, understood as it has been defined above, is greater than 15 metres. The majority of mining tailing impoundments which have suffered a fault in their physical integrity in the historical record were of a height of more than 15 m (Rico *et al*., 2008). Those mining tailing impoundments with a height of between 10 and 15 metres are also generally considered large mining tailing impoundments provided that they fulfil one of the following conditions: length of the crown greater than 500 metres, capacity of the reservoir greater than 1,000,000 cubic metres and/or capacity of drainage greater than 2,000 cubic metres per second. In general, medium-sized mining tailing impoundments can be considered to be those where the height of the dyke is between 5 and 15 metres, which do not fulfil the conditions indicated above. The mining tailing impoundments with a height of less than five metres are considered small mining tailing impoundments apart from exceptions.

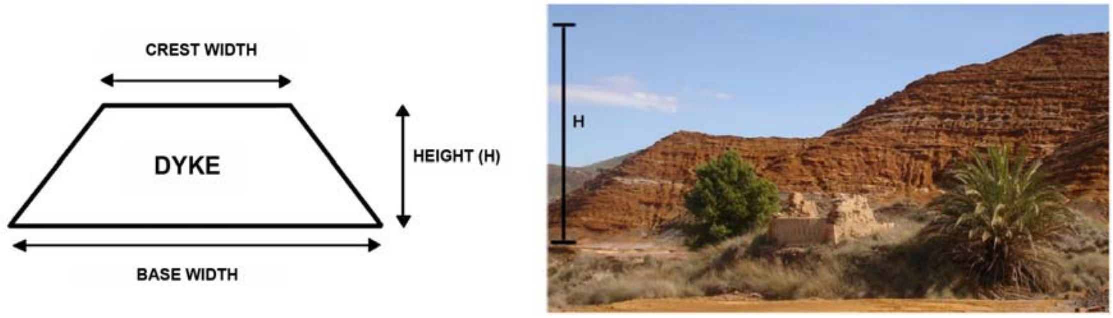

Figure 38. Height measure in heightening maining tailing impoundments.

The increase in height represents a greater load and, therefore, is a factor which increases the vulnerability of the mining tailing impoundment with regard to a probable break, especially in conditions of saturation. In **Table 37,** the criteria of valuation of the **height of the dyke or of the sum of the dykes (H)** parameter are shown, with the mining tailing impoundments of a height of over 30 m being considered the most vulnerable.

- *Length of the crown of the dyke (L_D)*

The increase in length of the crown of the dyke can also increase the possibility of a fault. As has been commented on above, one of the criteria that ICOLD uses for the definition of large mining tailing impoundments, together with the height and the storage or drainage capacity, is a length of the crown of over 500 metres. This criterion is what has been considered most unfavourable, with the maximum value of probability of breach being assigned for that parameter. The value given to the **length of the crown of the dyke (L_D)** parameter is also set out in **Table 37**.

The sum of the set of sub-factors considered up to here and estimated in **Table 60** constitute in turn the design and construction characteristics **(DC) factor**, that is to say:

$$\mathbf{DC = Mat + Mc + \Theta + H + L_D}$$

Where,

-Mat = Construction material of the dyke

-M_C = Method of extension of the dyke

-Θ = Angle in degrees of the dyke or general angle if there are berms

-H = Height of the dyke or of the sum of the dykes

-L_D = Length of the crowning dyke

The maximum value that can be reached by this expression is 80 points, for the hypothetical case in which all the sub-factors valued have the worst theoretical conditions from the point of view of the characteristics of the dyke.

Assessment of the "design" factor and the constructive characteristics of the dyke (DC) DC = Mat+Mc+Θ+H+L_D	
Valuaction criteria	**Factor value**
Construction material of the dyke (Mat)	
Flotation slurries	16
Cycloned flotation slurries	12
Selected loan materials	8
Selected loan material with blocks	4
Masonry or riprap	2
Mass concrete	0
Method of construction of the dyke (M_C)	
Upstream	16
Modified centerline	12
Centerline	8
Downstream	4
Conventional dyke of loose materials	2
Conventional dyke of masonry or mass concrete	0
Angle of the slope of the main dyke or the general slope if there are berms (Θ)	
More than 35º	24
Between 30º and 35º	16
From 20º to less than 30º	12
From 10º to less than 20º	6
Less than 10º	3
Dyke of masonry or mass concrete (independently of the angle)	0
Height of the dyke or of the sum of the dykes (H)	
More than 30 m	16
Betweeen 20 and 30 m	12
From 15 to les than 20 m	8
From 10 to less than 15 m	4
From 5 to less than 10 m	2
Les than 5 m	0
Length of the crown of the dyke L_D	
More than 500 m	8
Between 300 and 500 m	6
From 100 to less than 300 m	4
From 50 to less than 100 m	2
From 10 to less than 50 m	1
Less than 10 m	0

Table 37. Value assignment to the "design" factor and the constructive characteristics of the dyke (DC).

4.2.1.2. Volume of wastes stored (VOL)

It has already been commented that the volume of slurry stored is a criterion considered by ICOLD as a modifier of the classification of mining tailing impoundments. Those mining tailing impoundments with a volume of more than one million cubic metres are considered large mining tailing impoundments, in the case of mining tailing impoundments of between 10 and 15 m in height, or more than three million cubic metres when they are less than five metres in height. The storage volume depends on the adjustment between the size of the dyke and the original topography of the land where the mining tailing impoundment is located. In general terms, the greater the volume, the greater the probability of breach. The factor which has been called the **volume of waste stored (VOL)** is valued in **Table 38,** assigning a maximum value of five for this factor in those cases in which the value of two million cubic metres of volume is exceeded.

Assessment of the "stored material volume" factor (VOL)	
Valuation criteria	**Factor value**
Estimated volume of stored material measured in Mm^3 (Vol)	
More than 2	20
From 1 to 2	16
From 0,5 to less than 1	12
From 0,25 to less than 0,5	8
From 0,10 to less than 0,25	4
Less than 0,10	0

Table 38. Value assigment to the "stored material volume" factor (VOL).

4.2.1.3. Location (EMP)

It is clear that the location of the mining tailing impoundment is going to have a powerful influence on the stability. The topography, the size of basin upstream, the climatic conditions of the area, the geo-technical properties of the place and its seismicity are aspects of the location which must be considered in the evaluation of the stability and physical integrity of this kind of mining waste facility (Witt and Wudtke, 2005). The **location factor (EMP)** has been subdivided into two sub-factors, relating to the position occupied in relation with the surrounding topography and the characteristics of the substrate.

- *Typology of mining tailing impoundment according to the location (TEMP)*

The type of location of mining tailing impoundments in relation to the topography is an important aspect from the point of view of stability, especially as regards the form in which it places conditions on the supply of water that can be received externally, with the result that it has been decided to evaluate the **type of mining tailing impoundment according to the location (T_{EMP}).** In accordance with the classification of Vick (1990), mining tailing impoundments can be classified into the following typologies: *cross valley*, valley bottom without being superimposed on the watercourse, on the hillside and on the flat or exempt (*ringed-dyke*) and may be constituted by a single structure or multiple structures.

In cross valley mining tailing impoundments and in those located next to riverbeds, the influence that the external supply of water can have is much greater than that corresponding to locations on hillsides or on the flat. Cross valley mining tailing impoundments have been one of the most used typologies, as they supplied a maximum volume of storage with a minimum volume of dyke although this kind of location has serious disadvantages with regard to the control of the water when the hydrographic basin is significant (IGME, 1986). Cross valley dykes are particularly vulnerable to overflows and excesses of water arising from spates of water. They also present greater susceptibility to erosion in the areas of contact between the supports of the dyke and the sides on which they are built, and the liquefaction, due to the high volume of water that they receive from surface run-off generated in the watercourse located upstream from the mining waste facility (USEPA, 1994). Therefore, the control of the water flow is especially important and will depend on the existing infrastructures: drainage systems and scour outlets, overflow channels and channels for diversion of watercourses or perimeter channels for collecting surface run-off, etc., and of its degree of operativity or state of conservation. Mining tailing impoundments located beside watercourses but without interfering with the water flow (or with the water diverted on passing close to the foot of the dyke), represent a solution to the location when the watercourse situated upstream of the mining tailing impoundment is very large. However, this type of mining tailing impoundment is especially vulnerable to undermining of the foot of the dyke by river erosion and may give rise to the failure of the wall of the mining tailing impoundment due to washing away of the foot.

The supply of water in hillside mining tailing impoundments is the run-off water generated on the hillside from all points placed higher than the reservoir, and which comes directly from rainfall or snowfall. It is considered that the design on the hillside is optimal when the slopes of the land are less than 10º (USEPA, 1994). The exempt mining tailing impoundments located on the flat only receive a contribution of water from rain or snow which falls directly on them. On some occasions, they may be affected by a spate if they are located on a flood plain, in very open basins with flat valley floors. One not very frequent location is at a watershed. As is logical, this type of location is not capable of being affected by the surface run-off generated on neighbouring land. In the exempt mining tailing impoundments, the increase in the length of the dyke can also increase the possibility of failure (Robertson, 1987), and generally presents greater exposure to wind erosion (USEPA, 1994).

Another aspect that is intimately related with the location of the mining tailing impoundments is the original slope of the land under the dyke of the mining tailing impoundment. However, except when there are maps from before the construction of the structure which is being evaluated, it will not be possible to measure in a direct manner, in which case it can be assumed that it will be similar to what can be measured immediately downstream of the dyke on natural land. In general, we start from the principle that a location with a more abrupt topology will be more unfavourable from the point of view of safety, than gentler or flatter topographies. For this purpose, the conditioning factors of each type of mining tailing impoundment have been considered in terms of safety and, apart from the slope of the land, criteria related with the morphology and degree of encasement of the valleys have been added, it being understood that forms which fit in are indicative of more elevated slopes of the watercourse and a greater erosive capacity of the watercourses. In general, encasement is generally associated with abrupt topographies with steep slopes. The types of valleys proposed by Horacio and Ollero (2011) have been used in the definition of these criteria, based on a previous piece of work by Pardo-Pascual and Palomar (2002), which is based on the index of fitting in (relationship between the maximum width between slopes and the depth of the valley) and the width of the bottom of the valley (**Figure**

39). The sub-factor of the type of mining tailing impoundment according to its location (**T_{EMP}**) has been considered of enormous importance, which is reflected in the range used in its valuation, with a maximum of 80**.**

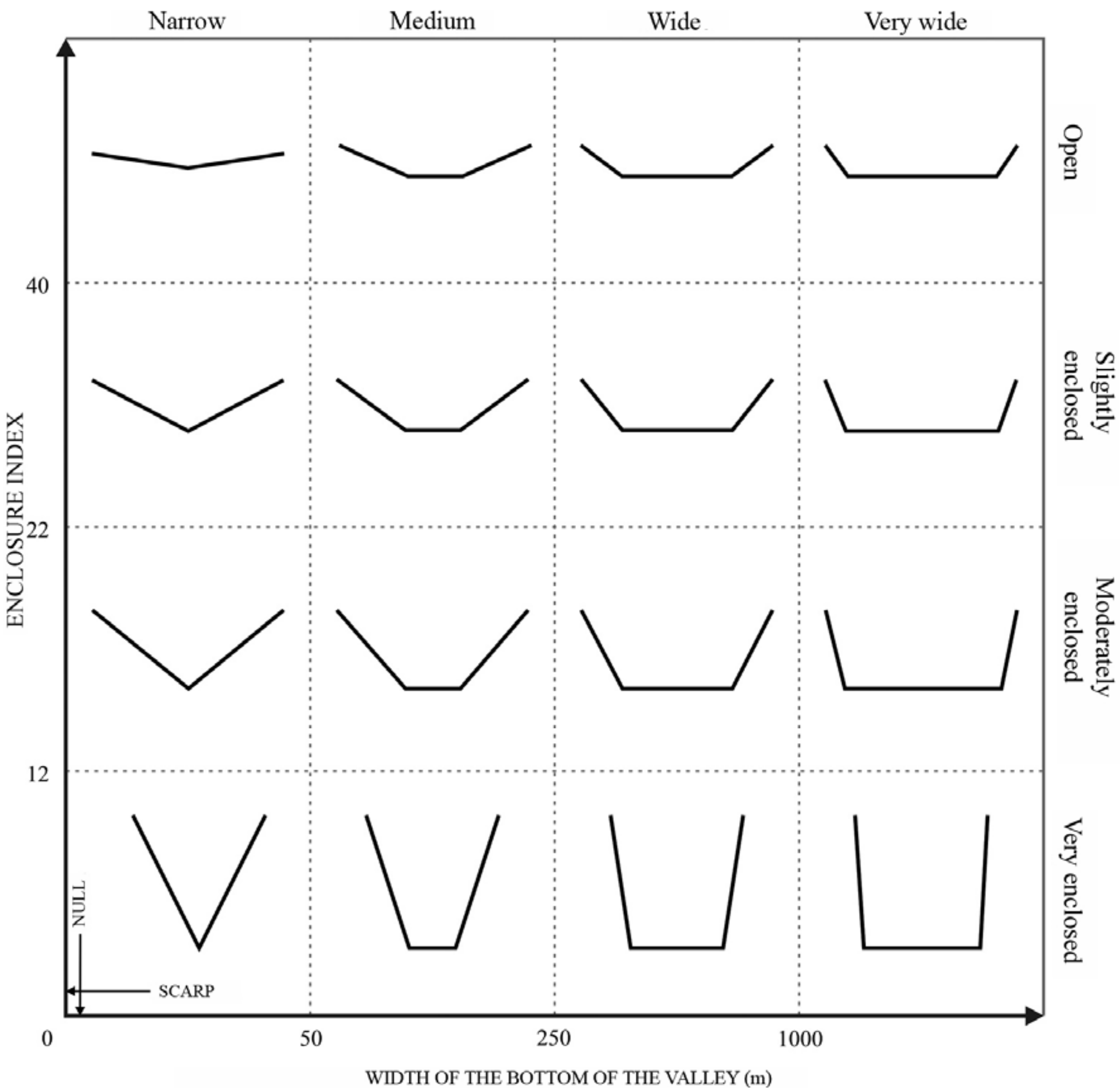

Figure 39. Classification of the valleys according to the morphology and the in-depth width (Horacio and Ollero, 2011; modified from Pardo-Pascual and Palomar, 2002).

In **Table 39,** the location is valued according to the type of mining tailing impoundment and the topographical and geo-morphological characteristics of the place**.**

The material on which a mining tailing impoundment is based is the so-called substrate or foundation material **(Sus)**. The problems associated with the material which serves as the base are very diverse. Most of them are common to the problems which might arise in dams for water reservoirs. At IGME (1986), it is indicated that the implantation of the dyke must be avoided on soft materials, which are compressible or degradable and which can by excessively deformed under the loads imposed or can reach conditions of breach. Bunches or lenses of soft material are especially dangerous as they can give rise to differential settling of the dyke and its consequent cracking. Likewise, it is advisable to avoid as a base old mining waste facilities of slurry and mined or karstified areas which might collapse under the load of the dyke or favour internal erosion. Also clay or limestone formations constitute a deficient foundation as under the load of the dyke high interstitial pressures might arise, with a considerable reduction in resistance to cutting. The foundation is therefore decisive from the point of view of the stability and in particular its resistance to the cutting strain, its compressibility and its permeability, as well as the hydraulic connections with regard to the environment (USEPA, 1994). There are many possible classifications of the geological materials for foundations, having opted for a simple classification which distinguishes between different types of materials on the basis of their resistance: unconsolidated soils, consolidated soils, soft rocks, altered rocks or unaltered hard compacted rocks or competent rocks (**Table 39**). The factor known as **location (EMP)**, which has been considered of maximum importance, is valued as the sum of the values assigned to the type of mining tailing impoundment (**T_{EMP}**), and the material of the substrate or the foundation on which the dyke is built (**Sus**): **$EMP = T_{EMP} + Sus$**

Assessment of the location factor (EMP) $EMP = T_{EMP} + Sus$	
Valuation criteria	**Factor value**
Type of mining tailing impoundment according to the setting-up location (T_{Emp})	
Cross valley	80
Valley-bottom in very narrow valleys	72
Valley-bottom in any other type of valley	64
Side hill with slopes higher than 30º	64
Side hill with slopes from more than 20º to 30º	56
Side hill woth slopes between 10º and 20º	48
Side hill with slopes lower than 10º	40
Ringed-dyked in the bottom of a wide and open valley	32
Ringed-dyked located in a watershed	16
Ringed-dyked located in a great extent plain, a moorland or similar	0
Material of the substrate or foundation (Sus)	
Unconsolidated or lowly consolidated soil	20
Consolidated soil	16
Soft rock	12
Compacted but altered and cracked rock	8
Compacted rock altered on the surface	4
Competent compacted rock	0

Table 39. Value asssignment to the “location factor” (EMP).

4.2.1.4. Physical integrity of the mining tailing impoundments (IF)

Theoretically, the stability of mining tailing impoundment must be maintained throughout their lifetime as this kind of mining waste facility must remain indefinitely. The problems of stability of a mining tailing impoundment are sometimes noted directly by simple observation of the effects which have arisen over time, and which may be the cause of new stability problems. The factor which has been called **physical integrity of the mining tailing impoundment (IF)** has as its object to make clear the observable weaknesses and instabilities in a certain mining tailing impoundment and their probable influence on a hypothetical breach. The presence of **processes of recognisable instability** through the development and extension of its effects make it possible to carry out direct evaluations on the implications which they might have for the probability of a break.

The type of effects which are evaluated are (**Figure 40**): failure or breach of the dyke because of landslides on the slope, the subsidence or collapse of the container, or any kind of instability tests of lesser importance (cracks, settling of the dyke, surface landslides, etc.). Likewise, the breach may be because of deep erosion due to regressive upward erosion, favoured by phenomena of excess or by processes of internal erosion, or also by extreme external water erosion. Some breaches of the dyke can be related with man-made activities, such as for example those caused by the extraction of sand in abandoned mining tailing impoundments, which have broken or the dyke has been undermined generating vertical or sub-vertical embankments which are badly fissured and unstable. In **Figure 41,** the subsidence of the container of a mining tailing impoundment in Portman (Sierra Minera of Cartagena-La Unión) can be appreciated, associated with a collapse due to internal erosion.

Figure 40. Picture 1: tailing flow slide in Luciana mining tailing impoundment (1960, Cantabria, Spain). This facility is currently abandoned. There were 16 mortal victims. Picture 2: tailing flow slide in El Descargador mining tailing impoundment (Sierra Minera Cartagena-La Unión, Murcia, Spain). Picture 3: failure due to headwater erosion in a mining tailing impoundment in Portman (Sierra Minera Cartagena-La Unión, Murcia, Spain). Picture 4: breach of the embankments of a mining tailing impoundment in El Soldado Mine (Villanueva del Duque, Córdoba, Spain) due to sand extraction for commercial purposes.

Figure 41. Subsidence occurrence in a mining tailing impoundment in Portman (Sierra Minera Cartagena-La Unión, Murica, Spain) due to an internal erosion collapse.

An important aspect to bear in mind is the erosion of the dyke, since this is a potential mechanism for long-term breach of abandoned mining tailing impoundments (ANCOLD, 2011). The presence of irrigation channels, erosion gullies and phenomena of tubification on numerous dykes of abandoned mining tailing impoundments is a clear reflection not only of the high degree of erodability and/or dispersivity but also of the accumulated effect of erosive processes during the time that has passed since the abandonment. It is also common that different forms of erosion can be appreciated on a single slope, varying from simple erosion through splashing, laminar erosion, to processes of gullies that are very well developed. In many cases, the existence of a deep erosion gully may be the result of the evolution of earlier processes of tubification in which the tunnels formed have collapsed, or as a consequence of cracking due to settling or another cause. In many cases, a process of accelerated growth of an erosion gully may cause the fall of a mining tailing impoundment by itself. Tubification, likewise, constitutes one of the main causes of failure of mining tailing impoundments (ICOLD, 2001). In **Figure 42,** examples are shown of forms of water erosion in dykes of mining tailing impoundments.

Figure 42. Water erosion evidences in embankments of mining tailing impoundments: a) splashing erosion; b) laminar erosion and tubification at the embankment´s base; c) gully erosion; d) laminar and gully erosion.

For all of the foregoing reasons, it has been considered that the **erosive state or degree of erosion of the dyke** at a certain moment is in turn a direct indicator of the degree of weakening of the resistance of the dyke. In this way, it is possible, by means of simple viewing, to obtain evaluations on the incidence of erosive processes on stability. The state of erosion or degree of erosion may be described as follows:

- Incipient: Evident laminar erosion. Some channels (<30 cm depth) and/or evidence of joint flow.
- Significant: Few water flows. A few small erosion gullies (from 30 cm to 1m in depth).
- Important: frequent water flows. A few small erosion gullies.
- Notable: Abundant water flows. Frequent erosion gullies (some large, of >1 m in depth). Some tubification phenomena.
- Extreme: Abundant water flows and erosion gullies, large and small. Frequent tubification phenomena. Some loosening of blocks or superficial landslides, normally associated with erosion gullies and tubification phenomena.

The factor which has been called **physical integrity of the mining tailing impoundment (IF)** is finally obtained by means of a table with double entries in which, on the one hand, the instabilities observed in the mining tailing impoundment are obtained and, on the other, the degree of erosion or erosive state of the dyke (**Table 40**). The total absence of signs of erosion and of instability would involve the assignation of a zero to the factor considered. With regard to the valuation, it is assumed that an embankment or dyke of a mining tailing impoundment which has achieved the state of erosion which has been qualified as extreme is in a situation of maximum propensity to suffer a breach, and it is only a question of time until one occurs. It is for this reason that the option has been taken to assign a maximum to this extreme situation, independently of whether it is accompanied or not by any evidence of instability. On the other hand, the valuation of the instabilities is not categorical, and assignation of another different value from what would be deduced from the table when expert opinion so advises is admissible; for example, depending on the dimensions and location in the structure, the presence of large cracks admits higher values when it is considered that they compromise the stability seriously.

EROSIVE STATUS OF THE DYKE	INSTABILITY EVIDENCES IN THE DYKE			
	NO EVIDENCES	SUPERFICIAL LANDSLIDES; SETTLINGS; WIDESPREAD CRACKS; OTHER DEFORMATION OR MINOR INSTABILITIES	SUBSIDENCE OR COLLAPSE OF THE CONTAINER	WIDESPREAD OR LOCAL BREACHES AT THE DYKE
Incipient	**16**	**32**	**48**	**80**
Significant	**32**	**48**	**64**	**80**
Important	**48**	**48**	**64**	**80**
Notable	**64**	**64**	**80**	**80**
Extreme	**80**	**80**	**80**	**80**

Table 40. Matrix for allocating values to the "physical integrity of the dyke" factor (IF).

4.2.1.5. Balance of moisture of the mining wastes and of the materials of which the dyke is made up (BH)

The hydraulic operation determines the conditions of stability of the mining tailing impoundments (Rodríguez *et al*., 2011). The stability of the dyke will depend in large part on the level of hydrostatic pressure or pore pressure of the material of which it is made up and on the wastes stored, which is intimately linked with the position of the phreatic level. The elevation of the phreatic level in the interior of a mining tailing impoundment depends in large part on the balance of inlets and outlets of flows of water in the mining tailing impoundment. In **Figure 43,** the conceptual model of the water balance of an abandoned mining tailing impoundment is shown. For the purposes of facilitating analysis, what has been called the factor of **balance of moisture of mining wastes and of the materials of which the dyke is made up (BH)** has been broken down into a summary of sub-factors which are described below. Again, the bigger the value assigned to each of them, the greater is the hazard of a possible breach or failure of the dyke. Each one of the sub-factors is valued in a certain range of values, that is to say: greater maximum values and a greater amplitude of the range of valuation of a certain sub-factor are equivalent to that sub-factor having a greater relative weight or importance. In **Table 41,** the values assigned to the different sub-factors are given.

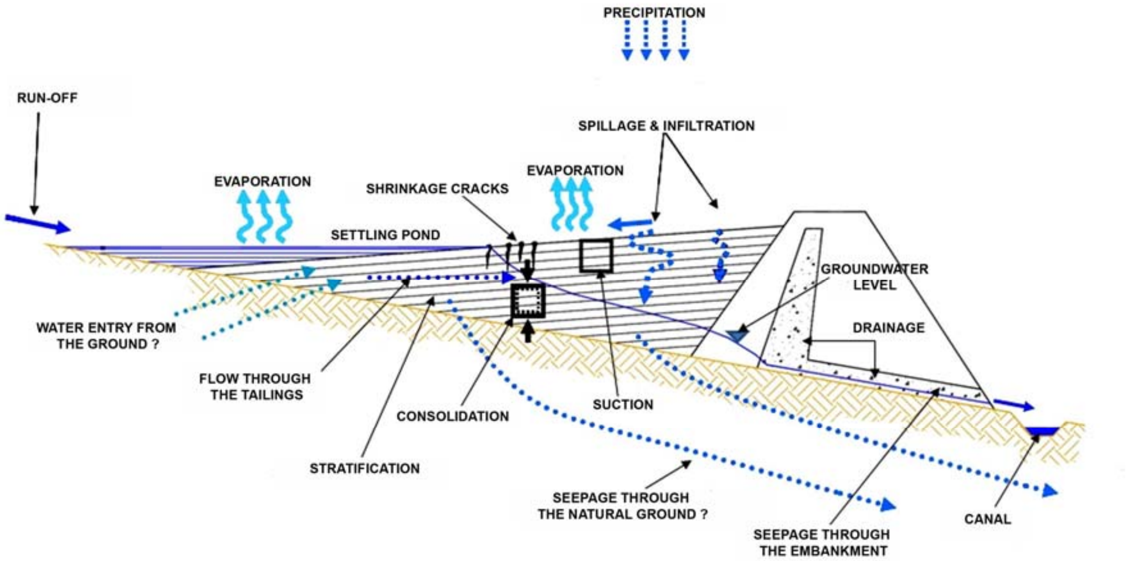

Figure 43. Schematic conceptual model showing the different components of an abandoned mining tailing impoundment (modified from Zandarin *et al.*, 2009).

- *Settling ponds* (L_d)

For all the reasons commented on above, a relatively simple way to evaluate indirectly the location of the phreatic level in the mining waste facility is through the relative position of the **settling pond** ($\mathbf{L_d}$). The settling pond is the most depressed sector of the mining tailing impoundment, with the result that in the majority of abandoned mining tailing impoundments rainwater and surface run-offs accumulate inside, at least seasonally. The identification and delimitation of the settling pond may be carried out on the basis of a range of evidence, among which the following should be emphasised: the existence of supernatant water, the presence of precipitates of salts in the most depressed area or on its edges, and the presence of phreatophytic vegetation, such as bulrushes (genus *Typha*) or reeds (genus *Juncus* and *Scirpus*) and especially (*Phragmites australis*), species which are characterised because they have a root system and part of the stem under water, during at least a part of the year. In **Figure 44,** some of these identifying characteristics of the settling pond are shown. The contribution of the sub-factor relative to the settling pond to the possibility of breach of the dyke will be evaluated taking into consideration the area occupied thereby, the permanent or intermittent nature and its relative position with regard to the dam wall. The importance of this last aspect is evidenced, for example, by means of the recommendation of the

Dams Safety Committee of New South Wales (Australia): in operative upstream mining tailing impoundments which do not have scour drainage, the settling pond should be located at a distance from the upper retaining wall at 10 times the height of the dyke (DSC, 2012). The European Commission (2009), in this regard, indicates that the width of beach or distance from the dyke to the lagoon should be at least superior to the height of the mining tailing impoundment.

Figure 44. Criteria for the identification and delimitation of the settling pond in mining tailing impoundments. Left: settling pond in El Gorguel mining tailing impoundment (Sierra Minera de Cartagena-La Unión, Murcia, Spain), with presence of supernatant, hydrophytic vegetation and precipitated salts. Right: settling pond with supernatant in a mining tailing impoundment in Rio Tinto (Huelva, Spain).

- *Position of the phreatic level in the dyke (Fr)*

Another sub-factor to be considered is the **position of the phreatic level in the dyke (Fr)**, as it determines in large part the degree of saturation of the materials: the higher it is, the greater the volume of material that will be found in conditions of saturation. In a way, this sub-factor is not totally independent of the foregoing one, with the result that an attempt has been made to make it the sum of both which determines the true importance of the recognition of the position of the phreatic level for the stability of a mining tailing impoundment, and they can be valued as a whole up to a maximum of 50 points (**Table 41**).

Assessment of the "wastes water balance" factor (phreatic water) (BH) $BH = L_d + Fr + Ia + P_{24} + Q_E + D_E + Rv$	
Settling pond (L_d)	**Factor valuation**
Settling pond covering more than 50% of the mining tailing impoundment container surface	
Settling pond with a permanent layer of water	30
Settling pond with an intermittent layer of water	27
Settling pond covering less or equal to 50% of the mining tailing impoundment container surface	
Permanent layer of water. Distance to the dyke less than once the height of the dyke.	30
Intermittent layer of water. Distance to the dyke less than once the height of the dyke.	27
Permanent layer of water. Distance to the dyke between once and twice the height of the dyke.	24
Intermittent layer of water. Distance to the dyke between once and twice the height of the dyke.	21
Permanent layer of water. Distance to the dyke more than twice the height of the dyke.	18
Intermittent layer of water. Distance to the dyke more than twice the height of the dyke.	15
Semi-drained settling pond	6
Lack of settling pond or completely drained lagoon.	0
Position of the phreatic level in the dyke (Fr)	**Factor valuation**
In the last third of the dyke (from the base)	20
In the second third of the dyke (from the base)	16
In the first third of the dyke (from the base)	12
In the base of the dyke	8
In the foundation, less than 5 metres in depth	4
In the foundation, more than 5 metres in depth	0
No phreatic level evidences or piezometric registers	10

Table 41. Value asignment to the "waste water balance" (BH) subfactors according to the settling pond and the phreatic level position in mining tailing impoundments.

- *Index of Aridity of De Martonne and $P_{24\ máx}$ for a return period of 100 years*

The climatic parameters are going to exercise a powerful influence, as well as due to the risk associated with flooding and spates. Rico *et al.* (2008) indicate that the majority of the incidents recorded in mining tailing impoundments in the world and in Europe have been related directly or indirectly with unusual events or periods of rain or snow. As a rule, it can be stated that long-term stability is more feasible the drier the climate, for a number of reasons: the climatic conditions favour the drying of the slurry and a descent in the phreatic level and the drying accelerates the consolidation of the slurry and increases the cohesion by suction, improving the parameters of resistance. Contrary to this, in humid or wet climates, the periods of rainfall will be more prolonged and, therefore, the rainfall or accumulated moisture will be greater. The **index of aridity of De Martonne (Ia)** relates the annual average values of rainfall and temperature. In **Table 42, the** contribution of the degree of aridity of the climate is evaluated for the possibility of failure of the structure according to the climatic area in which it is located, by means of the valuation of an associated sub-factor. On the other hand, the effect of extreme rainfall or storms in the unleashing of landslides or movements of flow is considered. For the determination of the probability of occurrence of this type of stormy events, a sub-factor associated with the **maximum probable rainfall in 24 hours** for **a return period of 100 years** has been considered, which can be classified as conservative with regard to other methodologies which advocate shorter return periods, generally ten years (SERNAGEOMIN-BGR, 2008). The evaluation of this parameter is not free of a certain degree of uncertainty due to the lack of data, although there are thresholds of intensity and duration of the rain for the unleashing of movements on the hillside, there are no specific references for mining tailing impoundments. In **Table 42,** the intervals defined for this parameter and its corresponding valuation with regard to the possibility of generating instabilities in mining tailing impoundments.

Assessment of the "wastes water balance" factor (climatic factors) **BH = L_d +Fr +Ia +P_{24} +Q_E + D_E +Rv**		
De Martonne aridity index (Ia)		**Factor valuation**
Climate zones	**Ia = P/(T+10)**	
Hiper-humid	> 60	10
Humid	30 – 60	8
Sub-humid	20 – 30	6
Semi-arid (Mediterranean type)	10 – 20	4
Semi desert (arid)	5 – 10	2
Desert (hiper-arid or extremely arid)	0 – 5	0
Maximum probable rainfall in 24 hours for a return period of 100 years		**Factor valuation**
> 150 mm		10
From 125 to less than 150 mm		8
From 100 to less than 125 mm		6
From 75 to less than 100 mm		4
From 50 to less than 75 mm		2
<50 mm		0

Table 42. Value assignment to "water balance" factor (BH) connected to climatic aspects with expected influence on the stability of mining tailing impoundments.

- *Volume of run-off (Q_E)*

In the balance of water of the cross valley mining tailing impoundments and those situated next to rivers or bases of valleys, the **volume of run-off (Q_E)** from the drainage basin upstream, has a fundamental role to play, with the result that a sub-factor has been associated with it which is valued by means of **Table 43**. The best way to minimise these volumes in this kind of mining waste facility is by means of location in areas at the head of the basin; this is a principle in which all the scientific literature coincides in this regard. At IGME (1986), it is recommended that the receiving basin should not exceed the area of the mining tailing impoundment by more than ten times. Vick (1990) advises that this value should be less than 5 to 10 times the area of the mining waste facility. The Ministry of Energy and Mines of the Republic of Peru (MINEM, 1997) is even more restrictive and proposes, as an empirical rule, that the relationship of the area of capturing the run-off waters with regard to the area of the mining tailing impoundment should be less than 3 and, under no circumstances, greater than 5. For a qualitative estimation of the maximum volumes of run-off which might enter this kind of mining waste facilities, the philosophy of the Rational Method has, in general terms, been followed by means of which the conversion of meteorological variables, mainly rainfall, in run-off water is carried out. In accordance with this method, the maximum volume (Qp) or volume of run-off water entering the system or basin will be the product of the intensity of precipitation (I) times the area thereof (A), and it can be reduced by a run-off quotient (C, between 0 and 1) which represents the proportion of water which is retained. Thus, in cross valley mining tailing impoundments and in those situated next to rivers, it is proposed to determine qualitatively the volumes of potential run-off by means of the application of a sub-factor which has been called **maximum volume of run-off which enters the mining tailing impoundment (Q_P)** deduced from **Table 43,** integrating the area of the drainage basin upstream and the effect of the vegetation, by way of a quotient of run-off according to the Rational Method, as a function of whether a certain threshold of rainfall in 24 hours for a return period of 500 years is exceeded, having proposed that of 200 mm. The return period of 500 years has been selected as it is used in the *Basic Directive of Planning of Civil Protection in the Risk of Flooding,* for the determination of the areas of exceptional flooding.

MAXIMUM VOLUME OF RUN-OFF (Q_p) For cross valley and bottom valley mining tailing impoundments			
(*I*) RAINFALL 24h $_{500\ years}$ < 200 mm			
(*C*) VEGETATION COVER (shrub and trees)	(*A*) UPSTREAM DRAINAGE BASIN SURFACE ÁREA		
	< 1 km^2	1–10 km^2	> 10 km^2
< 50 % of the surface	MODERATE	HIGH	VERY HIGH
≥ 50% of the surface	LOW	MODERATE	HIGH

MAXIMUM VOLUME OF RUN-OFF (Q_p) For cross valley and bottom valley mining tailing impoundments			
(*I*) RAINFALL 24h $_{500\ years}$ ≥ 200 mm			
(*C*) VEGETATION COVER (shrub and trees)	(*A*) UPSTREAM DRAINAGE BASIN SURFACE ÁREA		
	< 1 km^2	1 – 10 km^2	> 10 km^2
< 50 % of the surface	HIGH	VERY HIGH	VERY HIGH
≥ 50% of the surface	MODERATE	HIGH	VERY HIGH

Table 43. Maximum volume of run-off estimation in cross valley and bottom valley mining tailing impoundments according to the maximum probable rainfall in 24 hours for a return period of 500 years.

In mining tailing impoundments located on hillsides, it is considered that the probable volume of run-off will be low, except if the surface which drains into it is greater than ten times the area of the mining waste facility and the plant cover, shrubs or trees, is less than 50% of the draining surface, and an average value can be assigned in these cases. In exempt mining tailing impoundments, the volume of surface water is limited to rainfall or snow deposited directly on it, with the result that in all cases it will be considered a zero volume of run-off.

- *System of internal drainage and hydraulic infrastructures of evacuation, retention and diversion of the run-off (D_E)*

The mining tailing impoundments should have infrastructures of internal drainage and of evacuation, retention and diversion of the run-off water. The importance of the systems of drainage in abandoned mining tailing impoundments which have subsequently been restored, is recognised in the literature and in the practical experience as fundamental for guaranteeing the stability and reducing the risk of breach of the mining tailing impoundment. The internal scouring drainage systems have a fundamental role to play to guarantee the depression of the phreatic surface and this approximates to the dyke (USEPA, 1994; ICOLD, 1996). In **Figure 45,** different systems of basal drainage are shown according to the construction method of the dyke. It is necessary to remember that, in most abandoned mining tailing impoundments, these drainage systems undergo deterioration over time, so their functionality is reduced. In most cases, drains, wells and chimneys are destroyed or silted up.

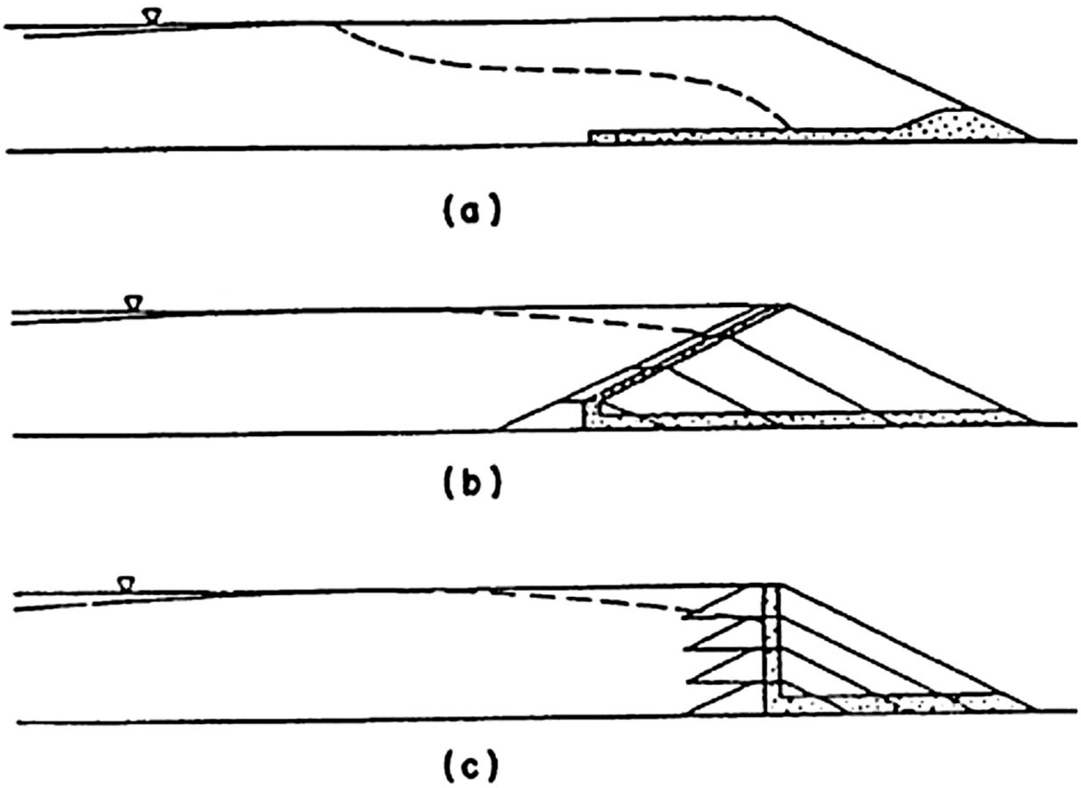

Figure 45. Bottom drainage systems in upstream, downstream and centerline mining tailing impoundments (IGME, 1986).

Other hydraulic structures of evacuation of the waters accumulated on the surface of the mining tailing impoundments are the overflow channels, which have as their main function to quickly unload the water from extraordinary rainfall or spates. The existence of a functional overflow channel with water flowing on the embankment of the dyke, or on the natural land that has been excavated on the ground or in rock, might be important for guaranteeing the stability of the abandoned mining tailing impoundments in the long term. In any case, construction with materials of low durability or the lack of maintenance favours deterioration and inoperability due to silting up or vegetation. The role of the **internal drainage systems and hydraulic infrastructures** for **evacuation, retention and diversion of run-off** (**D_E**) has been evaluated by means of the corresponding values assigned in **Table 44**.

Assessment of the "wastes water balance" factor (water inlets and outlets) **$BH = L_d + Fr + Ia + P_{24} + Q_E + D_E + Rv$**	
Volume of run-off which is added to the mining tailing impoundment (Q_E)	**Factor valuation**
Very high volume of run-off	10
High volume of run-off	8
Moderate volume of run-off	6
Low volume of run-off	4
Very low volume of run-off	2
Null volume of run-off	0
Systems of internal drainage and other infrastructures for evacuation , retention and diversion of run-off waters (D_E)	**Factor valuation**
Lack of internal drainage systems or non-operating drainage systems/AND/Lack of spillways or perimeter channels or they are not operational.	15
Lack of internal drainage systems or non-operating drainage systems /AND/Presence of partially operating spillways and/or perimeter channels.	12
Lack of internal drainage systems or non-operating drainage systems /AND/ Presence of operating spillways and/or perimeter channels.	10
Partially operating internal drainage systems/AND/ Lack of spillways or perimeter channels or they are not operational.	8
Partially operating internal drainage systems/AND/ Presence of partially operating spillways and/or perimeter channels.	6
Partially operating internal drainage systems/AND/ Presence of operating spillways and/or perimeter channels.	4
Operating internal drainage systems/AND/ Lack of spillways or perimeter channels or they are not operational.	2
Operating internal drainage systems/AND/ Presence of partially operating spillways and/or perimeter channels.	1
Operating internal drainage systems/AND/ Presence of operating spillways and/or perimeter channels.	0
Degree of plant cover (R_V)	**Factor valuation**
Without plants or small freight vegetation covering less than 25% of the surface	5
Small and medium freight vegetation covering between 25% and 50% of the surface	4
Small, medium and large freight vegetation covering between 25% and 50% of the surface	3
Small, medium and large freight vegetation covering between 50% and 75% of the surface	2

Assessment of the “wastes water balance” factor (water inlets and outlets) $BH = L_d + Fr + Ia + P_{24} + Q_E + D_E + Rv$	
Small, medium and large freight vegetation covering more than 75% of the surface	1
Nearly or completely vegetation cover dominated by trees	0

Table 44. Value assignment to the “water balance” factor (BH) connected to water inlets and outlets.

- *Plant cover (R_V)*

Finally, another aspect which has been taken into consideration in the valuations is the plant cover. It has been verified that the mining tailing impoundments which have a greater plant cover due to natural colonisation or reforestation present a lower degree of saturation than those without plant cover (Oldecop *et al*., 2011). The vegetation apart from being a protection factor against water erosion contributes to the elimination of the water present in the wastes, at least, in the levels close to the surface favouring the process of drying. In **Table 44,** the values which have been assigned to what has been called the **plant cover (R_V) sub-factor**.

- *Calculation of the balance of moisture of the materials of the dyke (BH)*

To sum up, the sum of the set of sub-factors considered, provides the value of the factor which has been called the **balance of moisture of the materials which make up the dyke** (BH), that is to say:

$$\mathbf{BH = L_d + Fr + Ia + P_{24} + Q_E + D_E + Rv}$$

Where:

-L_d = Settling pond

-Fr = Position of the phreatic level in the dyke

-Ia = Index of Aridity of De Martonne

-P_{24} = Maximum rainfall in 24 hours for a return period of 100 years

-Q_E = Volume of run-off which is added to the mining tailing impoundment

-D_E = Systems of internal drainage and other infrastructures for evacuation, retention and diversion of run-off waters

-Rv = Degree of plant cover

The maximum value which can be reached by this expression is 100 points, for the hypothetical case in which all the sub-factors valued involve the worst conditions from the point of view of the theoretical water balance for the structure that is being evaluated.

4.2.1.6. Hazard associated with the location (PEM)

There are a number of circumstances of a geological or anthropic nature, associated with the location, which might compromise the stability of mining tailing impoundments. Foremost among them are seismic hazard, that arising from movements of the terrain and the existence of overloads in the structure.

In areas of seismic activity, earthquakes are one of the main causes of breach of abandoned mining tailing impoundments. The greatest hazard for mining tailing impoundments caused by earthquakes derives from the possibility of dynamic liquefaction which may affect both the wastes and the natural saturated soils which might be located under a mining waste facility. The potential liquefaction depends on a number of factors such as: the granulometry of the wastes of which the dyke is made up, the relative density or the degree of compactation, the pressure of confinement at the moment of undergoing a dynamic requirement, the intensity and duration of the movement or shaking of the ground and the degree of saturation of the materials. Apart from the moisture content, which has already been analysed, the geographical location of the mining waste facility will therefore be a determining factor. This may be evaluated through the **seismic hazard (a_b).** On Spanish territory, it has been established by means of the map of seismic hazard, included in the Regulation on Seismic Resistant Building (NCSR, 2002). This map supplies, for each point of Spanish territory and expressed in relation to the value of gravity (g), the basic seismic acceleration (**a_b**), which indicates a characteristic value of the horizontal accelerations of the surface of the land, corresponding to a return period of 500 years. Vick *et al*. (1993) studied the effects of earthquakes on abandoned mining tailing impoundments built by the upstream method, finding that none underwent flow faults even with seismic accelerations of about 0.04g. The damage was limited to cracks and some local liquefactions in the container. These authors relate this fact with an improvement of the parameters of resistance which accompany the aging of a mining tailing impoundment and which has been described by a number of authors. In seismic areas, where earthquakes predominate with moderate accelerations which do not lead to a failure of the structure, the recurrence of an earthquake may nevertheless give rise to a cumulative damage (cracking, differential settling, etc.) and increase the vulnerability of exposed mining waste facilities. If it is considered necessary, it is possible to consult the detailed list of values of $a_b \geq 0{,}04g$, in all boroughs of the national territory, which is also included in the above-mentioned regulation. The values assigned to the seismic hazard of the location or seismicity of the area, expressed in the basic seismic acceleration (a_b) for a return period of 500 years, are expressed in **Table 45**. Likewise, at the location of a mining tailing impoundment in the nearby area (up to 5 km) to an active fault, a value of seismic hazard can be assigned that is very high. The information relative to these faults can be obtained by consulting the Database of active faults in the Quaternary Active Faults Database of Iberia (QAFI), using the link from IGME. (http://www.igme.es/infoigme/aplicaciones/qafi/).

The existence of masses of landslides or accumulations of scree to the sides, or at the tail of a mining tailing impoundment, may be destabilising elements which may increase the probability of breach. Likewise, on occasions, it is possible to observe the existence of different kinds of materials deposited on the slurry of a mining tailing impoundment: mining wastes dumped subsequently, other types of wastes, installations, etc., which may give rise to an overload and also favour a failure in the structure. The existence of this kind of circumstances is evaluated by means of the factors, **movements of the land (Des)** and **overloads on the mining tailing impoundment (Car),** which are valued in **Table 45.**

Assessment of the "hazard associated with the location" factor (PEM) PEM= the most unfavourable value	
Valuation criteria	**Factor valuation**
Seismic hazard in the mining tailing impoundment location (a_b, according to the basic seismic acceleration)	
More than 0,16	20
Between 0,16 and 0,12	16
Between 0,12 and 0,08	12
Between 0,04 and 0,08	8
< 0,04	0
Movements of the land. Slides running into the settling pond that may compromise the stability (Des)	
YES	20
NO	0
Overloads on the mining tailing impoundment (Car), according to the percentage of surface occupied by other wastes or facilities, etc.)	
75% - 100%	20
50% - 75%	16
25% - 50%	12
10% - 25%	8
< 10%	4
Without overload	0

Table 45. Assessment of the "hazard associated with the location" factor (PEM) in mining tailing impoundments.

The value of the factor of **hazard associated with the location (PEM)** is obtained by assigning the highest value obtained among the hazards considered: seismic, movements of the land (landslides on slopes of the container of the mining tailing impoundment) or the existence of overloads which may compromise the stability of the mining waste facility. Therefore, the maximum possible value is 20.

4.2.1.7. Calculation of the probability index of the failure or breach of the dyke or external embankment of mining tailing impoundments I_P(FPRE)

As has already been commented on, the values assigned to all the factors which have been described in the foregoing sections and set out in **Tables 37** to **45**, for each of the structures evaluated, are added together to obtain the value of what has been called **hazard (Pe_{PRE}),** which is understood as the susceptibility to possible breach of the embankment and/or the dyke. The maximum theoretical total which the value can reach is 400 points. The intervals of probability are shown in **Table 46.**

Valuation of the total hazard score (Pe_{PRE}) to assess the susceptibility to possible breach of the waste facility	
>300	Very high
225-300	High
150-225	Moderate
75-150	Low
<75	Very low

Table 46. Valuation of the susceptibility to possible breach of the mining tailing (Pe_{PRE}).

Furthermore, it is proposed to transform the value obtained for the hazard into a **probability index of occurrence of the failure of the structure (I_P(FPRE))** making use of the graph which is shown in **Figure 46.** The value obtained from applying this transformation gives results comprised between 0 and 5. In this way, it is kept within the scale proposed for the probability indices of each and every one of the risks evaluated. The assignation which is obtained from the graph is the same as by using the expression IpPRE = $Pe_{PRE} \times 1/75$, when Pe_{PRE} varies between 0 and 375, and IpESC = 5, when $Pe_{ESC} > 375$.

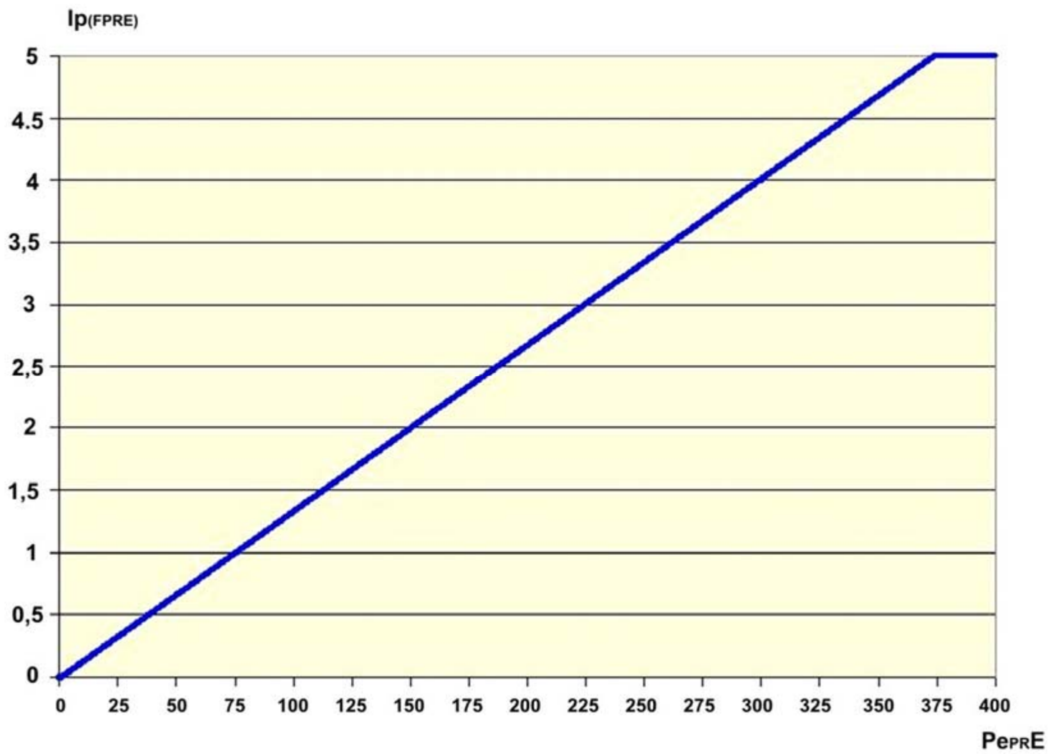

Figure 46. Probability index of occurrence of the failure of the structure (Ip(FPRE)) according to the hazard score (Pe_{PRE}).

4.2.2. Index of severity of the failure or breach of the retaining wall or the external embankment of mining tailing impoundments: I_S(PRE)

The behaviour of the slurry, once the breach has occurred, is enormously variable. In general, it is possible to state that the breaches that have turned out to be most destructive were: those in which the leak gave rise to the dumping of large volumes of slurry, the cases in which the slurry covered a long distance, and those that occurred with high advance speeds of the avalanche. All these conditions have been fulfilled when the liquefaction of the wastes has occurred. These phenomena have arisen in locations with a low slope of the land, with the result that the slope does not appear to be a determining factor in the development of the flow. Experience shows that these landslides continue until they reach flat land or a body of stabilised water. However, in SERNAGEOMIN-BGR (2008) it is stated that the most destructive flows of slurry are those that travel with very little advance warning along steep canyons that are narrow. In this way, the places with the greatest slope or difference in height will as a consequence have higher speeds of movement, with the result that the distance covered, the capacity of movement and, therefore, the destructive potential of the materials liberated will be theoretically higher in such cases. However, even when the encasement must have an influence on the route taken by the slurry once the dyke has broken, empirical analysis of the distances covered by different flows of slurry after the breach relate this only with the dimensions of the mining tailing impoundment. The severity of the consequences which are derived from the breach of a mining tailing impoundment is, according to this, affected by the scope or run of the mass of slurry and water on the land located downstream from the damming structure, given that the energy which drives them will be simply gravitational. In general, the route which will be followed by the tailings liberated is determined by the drainage network of the place. Rico *et al.* (2008) have developed a formulation to estimate the reach of a flow of mining wastes. In the above-mentioned work, it is made clear that, unlike what happens with mining tailing impoundments of water, the volume of material liberated reaches only a portion of the total stored. These authors propose the following empirical formula:

$$\mathbf{D_{max} = 1{,}61 \times (HV_F)^{0{,}66}}$$

Where:

-D_{max} is the maximum distance covered by the flow of slurry in kilometres

-H is the height of the mining tailing impoundment (in metres), independently of whether there is a protection (which is generally very small)

-V_F is the volume dumped (in millions of cubic metres) which in turn may be estimated by the expression: $V_F = 0{,}354 \times (V_T^{1{,}01})$

-V_T is the total volume of the mass of wastes stored in the mining waste facility.

This formulation may be considered to be a perfectly valid approximation for establishing a first classification of the levels of risk, considering that what is intended is not a quantitative and exhaustive evaluation, but a preliminary and qualitative evaluation of numerous mining tailing impoundments. For the evaluation of the severity of the possible effects on persons and the environment it will be necessary to analyse the possible presence of elements exposed to the hypothetical flood of slurry. In this regard, it may be useful to analyse the run and the area which is intuitively more probable to be affected, by means of the delimitation of the possible area of effects on a detailed map: with a certain scope known ($D_{máx}$), this may be done by projecting the contact of the base of the mining waste facility with the natural land until this distance is achieved, following the lines of maximum slope and taking into consideration the lateral confinement which the topography may give rise to. That area of effects determines the elements at risk or exposed receptors, which may be as diverse as the wild flora and fauna present, crops and livestock, infrastructure, surfaces which are used for a range of economic activities, and, of course, inhabited areas or those occupied by the human population. The area at risk, delimited in this way, will serve as a reference for the calculation of the respective indices of severity of the effects on persons and population, the natural and socio-economic environment deriving from the failure of this kind of structure.

4.2.2.1. Index of severity of the effects on persons and the population deriving from the failure or breach of the dyke or the external embankment of mining tailing impoundments: Is(FPREPO)

The most serious consequence of the failure of a mining tailing impoundment is the loss of human life, therefore, the most important risk factor will be the population exposed ($\mathbf{P_{EX}}$) within the area of risk delimited as is proposed in the foregoing point (up to a maximum distance, $D_{máx}$). The severity of the damage to the population with potential risk of being affected by the hypothetical breach of the embankment of a mining tailing impoundment, will depend on the density of population or human contingent exposed and their vulnerability, which will be a function of the patterns of activity and use of the land, including aspects relative to the protection given by the characteristics of construction inherent therein (e.g. a residential area or a camp site). In a similar manner to what was done in the foregoing chapter, some of the proposals used in the "Guía Técnica relativa a la Clasificación de Presas en función del Riesgo Potencial" (Technical Guide regarding the Classification of Dams according to the Potential Risk - Ministry of the Environment, 1996) have been taken into consideration; just as in the above-mentioned guide, the following concepts have been taken into consideration:

-*Urban population centre*, understanding as such and in accordance with the National Statistical Institute, a set of at least ten buildings which form streets, squares and other urban roadways. Exceptionally, the number of buildings might be less than ten provided that the *de iure* population which inhabits the locality amounts to more than fifty inhabitants. The population centre includes those buildings which, although they are isolated, are at a distance of less than 200 metres from the external limits of the above-mentioned group, although in the determination of that distance any land occupied by industrial or commercial facilities, parks, gardens, sports areas, cemeteries, car parks and other such items must be excluded, as well as canals or rivers which may be crossed by bridges. In the technical guide, a serious effect on an urban population centre is when over five of the inhabited buildings might be affected.

-*Limited number of dwellings or isolated residences*: Between one and five inhabited residences will be considered a limited number of dwellings.

-*Incidental loss of human life*, this makes reference to an occasional and unforeseeable presence of population.

In the present methodology, the urban population centre, is treated as a very vulnerable element. With a conservative philosophy, it is proposed to consider the total population of the centre, provided always that there are dwellings included in the area which might be affected by the movement of the wastes, although this area of effect includes marginally a small surface of the urban centre. The loss of human life is without a doubt unacceptable. Nevertheless, and given the need to establish a prioritisation between risk scenarios, there is the possibility of making a valuation of the population centres according to their size or number of inhabitants, with the minimum value being 3.5 (high vulnerability) for centres with 50 inhabitants and 5 for those of an urban nature of over 10,000 inhabitants (very high vulnerability), setting different evaluations according to the different intervals of population (**Table 47**). For the determination of the *de iure* population or number of inhabitants of each population centre, it is possible to have recourse to a statistical source such as the Nomenclator (Gazetteer - National Statistical Institute) which can be consulted on the Internet using the address www.ine.es/nomen2/index.do. The existence of one or several buildings devoted to residential use will be considered isolated dwellings if they do not together exceed a maximum of five places of residence. An average size of family of 2.9 has been considered according to census data from 2001, as has been indicated in earlier sections.

When there is no population centre, the value of exposed population (P_{EX}) will be assigned according to the vulnerability of the type of occupation of the land, fundamentally. In **Table 48** a list of uses according to their vulnerability is shown. This is a list that is open to the addition of new criteria or to adaptation of those already included to the areas own cases, by the evaluator.

Assessment of the population vulnerability in the case of failure or breach of the dyke or the external embankment at a mining tailing impoundment	
Valuation criteria	**P_{EX} value**
Population centres: more than 10000 inhabitants	5
Population centres: between 5001 and 10000 inhabitants	4,75
Population centres: between 2001 and 5000 inhabitants	4,5
Population centres: between 1001 and 2000 inhabitants	4,25
Population centres: between 501 and 1000 inhabitants	4
Population centres: between 101 and 500 inhabitants	3,75
Population centres: between 50 and 100 inhabitants	3,5
Population centres with less than 50 inhabitants or isolated houses	3

Table 47. "Exposed population" factor (P_{EX}) value assignment in the case of failure or breach of the dyke or the external embankment at a mining tailing impoundment.

With regard to the evaluation of the road infrastructures which might be affected from the point of view of the evaluation of the damage to persons, it is recommended, whenever possible, to use as a criterion, the annual average daily intensity (AADI) of traffic measured in vehicles/day consulting for the purpose maps of intensities of traffic made by the Autonomous Communities or the Ministry of Public Works. If this information is not available, it may be a criterion of classification of the road network as a function of its ownership, thus the routes of communication which make up the Network of General Interest to the State (RIGE) depending on the Central Administration is pre-supposed to be of a greater intensity of traffic, as it is made up of roads which link autonomous communities and connect the main centres of population of the State, forming part in turn of the main international routes; this will be followed in importance by the Network of Regional Roads, it being possible to distinguish in this network a hierarchy (secondary roads of the first order, of the second order, etc.) which is also interpreted as a greater or lesser transit of vehicles; and finally the Provincial Network of Roads depending on the *Diputaciones Provinciales*. The routes of high capacity (dual carriageways and motorways), belonging to the regions or the State, are understood to bear high intensities of traffic. Other routes of communication such as the railway will be valued according to whether the transport of passengers or of goods predominates and of the frequency of transit.

Agricultural (agricultural and farming) and recreational uses, of an extensive type, that is to say, of low exposure to risk from the point of view of time and/or demography, are those which show a low vulnerability. The areas with a low influx of population are considered as being of very low vulnerability, where human losses are incidental and not highly foreseeable.

Assessment of the vulnerability of the exposed population in risk zones derived from the failure or breach of the dyke or the external embankment at a mining tailing impoundment	
Valuation criteria	**P_{EX} value**
Very highly vulnerable land uses: residential areas (marginalised population included), camping.	5
Highly vulnerable land uses: great commercial and recreational areas, schools, hospitals, industrial areas, high capacity pathways, high frequency passenger suburban trains, etc.	4
Moderately vulnerable land uses: parks, intensive recreational and sport use, areas of attraction for population (pilgrimages, etc.), moderate traffic density pathways, long distance (moderate frequency) passenger trains, etc.	3
Lowly vulnerable land uses: extensive farming activities, extensive recreational and sport use, low traffic density pathways, freight trains, low frequency passenger trains, etc.	2
Very lowly vulnerable land uses: scarcely frequented areas.	1

Table 48. "Exposed population" factor (P_{EX}) value assignment according to the exposed land uses vulnerability in the case of failure or breach of the dyke or the external embankment at a mining tailing impoundment.

The evaluator will make a non-exhaustive list of the most significant elements exposed, assigning the to the P_{EX} factor the value according to the size of the population centre which might be affected or of the most vulnerable element exposed, always with a clearly conservative criterion. If a number of population centres might be affected, their inhabitants would be added together and the value of a population centre whose size would be that corresponding to the total population contingent exposed would be assigned, in accordance with the contents of **Table 47**. The final value of the P_{EX} factor will be that of the worst scenario considered, which means that of the elements exposed (population centres or other uses of the land) the highest value of exposure of population will be taken.

Finally, the index of severity of the effects on persons and the population deriving from the failure or breach of the embankment of mining tailing impoundments (**Is(FPREPO)**) will be assigned according to: the value of the exposed population factor (**P_{EX}**) in the worst of the scenarios, in the area delimited as being at risk, in accordance with the following formula:

$$\mathbf{Is(FPREPO) = P_{EX}}$$

4.2.2.2. Index of severity of the effects on the environment deriving from the failure or breach of the retaining dyke or the external embankment of mining tailing impoundments: Is(FPRENA)

The breach of the retaining structure of mining wastes and the mobilization of a certain volume of material downstream, following the line of maximum slope, will have as a result the physical destruction or a severe impact on the ecosystems exposed due to contamination depending on the toxicity of the wastes. The severity of the damage will be a function of the values of conservation of the ecosystems affected and of their vulnerability. The most serious effects from the environmental point of view will arise when there are sensitive areas exposed in the area considered to be probably affected or which might be reached by the mobilised material. The sensitive or most vulnerable areas are represented by the protected natural spaces, the spaces protected by the Natura 2000 network, that is to say, Sites of Community Importance (SCIs), Special Areas of Conservation (SACs) and Special Protection Areas for Birds (SPAs), the habitats included in the Spanish Catalogue of Habitats in Hazard of Disappearance, as well as areas protected by international instruments (Wetlands of International Importance in accordance with the RAMSAR Convention; natural sites on the list of World Heritage and Biosphere Reserves declared by UNESCO; Bio-genetic Reserves of the Council of Europe; protected areas from the Convention for the protection of the marine environment of the Northeast Atlantic (OSPAR); Specially Protected Areas of Importance to the Mediterranean (ZEPIM); etc.). Also included as sensitive areas are the Important Areas for the Birds of Spain (IBAS) and the wetlands included in the Spanish Inventory of Wetlands (IEZH), as well as other spaces that the competent organisations regarding the environment consider of special importance for the protection and conservation of the biodiversity and the natural heritage. In **Table 49,** criteria of evaluation of ecological **vulnerability** (**V_E**) are set out for orientation.

Assessment of the ecosystem and other exposed elements vulnerability in risk zones derived from the failure or breach of the dyke or the external embankment at a mining tailing impoundment	
Valuation criteria	**V_E value**
Sensitive areas (environmental protection).	5
River sections declared as areas of interest for fishes (salmonid and cyprinid waters). Water bodies of good or very good ecological status. Well-preserved forests (evergreen and deciduous hardwood forest, coniferous forest)	4
Scrubs, holm oaks, woody crops (olive grove, fruit crops, vineyard, etc.), Surface water bodies of moderate ecological status.	3
Grasslands and pastures, arable crops, rivers and surface water bodies with disturbed riparian ecosystems and poor ecological status.	2
Urban areas and very disturbed ecosystems.	1

Table 49. "Ecological vulnerability" factor (V_E) value assignment according to the intrinsic vulnerability of the exposed ecosystems in risk zones derived from the failure or breach of the dyke or the external embankment at a mining tailing impoundment.

Finally, the index of severity of the damage to the natural environment deriving from the failure or breach of the retaining dyke or the external embankment of a mining tailing impoundment (**Is(FPRENA)**) will be a function of the most vulnerable ecosystem or natural element exposed (**V_E**) in the area delimited as being at risk, in accordance with the following simple equation:

$$\mathbf{Is(FPRENA) = V_E}$$

4.2.2.3. Index of severity of the effects on the socio-economic environment deriving from the failure or breach of the dyke or the external embankment of mining tailing impoundments: Is(FPRESE)

The severity of the consequences will be according to the destruction, or irreversible damage which might be caused by a slide of the material stored due to breach of the mining tailing impoundment on the cultural heritage or any other protected area, to the priority economic activities in the area under study, and to services (hospitals, etc.) and essential infrastructure (water supply, energy, road communication, etc.). In **Table 50, the general criteria of evaluation of the** vulnerability of the elements of the socio-economic environment (**V_{SE}**) of the elements exposed, according to their heritage value and priority nature from the social and economic point of view. Logically, these criteria have a generalist character, with the result that depending on the specific characteristics of the socio-economic environment affected, new criteria might be included, or the order and value of those already exposed by the evaluator might be altered.

Assessment of the socio-economic environment vulnerability in risk zones derived from the failure or breach of the dyke or the external embankment at a mining tailing impoundment	
Valuation criteria	**V_{SE} value**
Protected cultural heritage.	5
Priority economic activity for the area under consideration. Essential services (hospitals, etc.). Critical infrastructures (water and energy supply). Communication paths (roads or trains providing external interconnection, high capacity pathways, etc.).	4
Other secondary economic activities. Secondary communication paths, non-critical infrastructures, non-essential services.	3
Economic activities, services and infrastructure of minor importance.	2
Impact on elements without cultural or productive value or with little economic value.	1

Table 50. Value assignment to the "Cultural heritage, productive system, infrastructures and essential services" vulnerability factor (V_{SE}) in risk zones derived from the failure or breach of the dyke or the external embankment at a mining tailing impoundment.

The index of severity of the effects on the socio-economic environment deriving from the failure or breach of the embankment of mining tailing impoundments (**Is(FPRESE)**) will be a function: of the cultural heritage, economic activity, the most vulnerable exposed infrastructure or essential service (**V_{SE}**) in the area delimited as at risk, in accordance with the following formula:

$$\mathbf{Is(FPRESE) = V_{SE}}$$

5. PREPARATION OF RISK MATRICES

The evaluation of the risk is based, as has already been explained, on the joint valuation of the two factors involved: the probability of occurrence of a risk scenario by contamination or by failure of the storage structure of the wastes, and the severity or gravity of the consequences which might be caused to the safety of persons, to the natural environment and economic activities. Once the probability and severity of all the scenarios corresponding to each of the places of study have been evaluated, the results can be set out by situating the codes of the scenarios evaluated on what is called the **risk matrix** or matrix of evaluation of the level of risk, in which both factors are combined, in such a manner that for each combination of values of probability and severity of the consequences a single value of magnitude of the risk arises. This is facilitated by the use of alphanumerical codes assigned to the different scenarios.

Given that the final objective of the risk assessment is to determine: those mining waste facilities which involve an unacceptable risk and on which it is necessary to act with urgency, those other tolerable risks on which it will be necessary to act with less urgency and those with which it is acceptable to tolerate with a certain supervision, it will be necessary to establish the areas of the risk matrix which involve a certain decision. It is usual to use the colours of the traffic lights (the more red, the higher the risk) to delimit the different areas of the matrix which correspond to different assigned levels of risk. For that delimitation of areas within the matrix, it is of great usefulness to verify the result obtained by making the evaluations of the different indexes of probability and severity vary, or by carrying out real valuations of known mining waste facilities. In any case, a matrix will not be completely valid unless each classification of risk assigned to each possible combination of probability/severity is analysed to ensure that the tool coherently reflects the perception of risk.

The number of rows and columns in a risk matrix may be different depending on the starting information and on the degree of refinement which is considered necessary to apply. Another aspect to be considered is that of the symmetry or asymmetry of the matrices. Symmetric matrices tend to be used, that is to say, that they have the same number of levels of probability and of severity. Thus, for example, in the work carried out in the United Kingdom (Johnston *et al.*, 2007; Jarvis *et al.*, 2007) matrices of three by three have been used, while in the territories of Northern Canada those of five by five have been preferred (Nahir *et al*., 2006; Robertson & Shaw, 2009). Curiously, in the work carried out in Chile (SERNAGEOMIN-BGR, 2008), asymmetric matrices of three by four were used, with the intention of emphasising a greater degree of severity for negative effects on persons.

Logically, the more probable an evaluated risk scenario is and the more severe its consequences, the greater the magnitude of the risk that must be associated with that scenario in particular. Inversely, the risks must be of lesser magnitude the smaller the probability of occurrence and the severity of the consequences of the scenario evaluated. In the matrix proposed, the level of risk increases from the lower left part of the matrix towards the upper right-hand corner. The idea is that, for each storage structure for mining wastes, a risk matrix should be worked out, in which all the scenarios of risk are included after having evaluated the corresponding indexes of probability of occurrence and of gravity of the consequences which it would have on the population, the natural environment and economic activities. The values obtained work as "coordinates" of probability and severity in the risk matrices, where the corresponding codes are located: C1NA, C1PO, C2NA,…,FPRENA, etc. In this way, it is possible to explore the result of evaluating a list of locations, easily viewing those with greater problems, via the location occupied by the corresponding codes on the matrices. This is made easier by the zones of different colours. Red and dark orange represent a very high and high risk, respectively. Light orange expresses a moderate risk and, finally, yellow and green represent a low and very low risk, respectively (**Figure 47**).

It is also proposed that the application of the described methodology makes it possible, in the final instance, to classify the mining waste facilities that are worthy to be included on an inventory of, that is to say, that "have a serious environmental impact or which may become, in the medium or short term, a serious threat to the health of persons or the environment" (Article 20 of Directive 2006/21/CE), but not only that, an order of priorities of action can also be established. The location of scenarios of risk in red or strong orange boxes, that is to say, with a very high or high risk, will classify the corresponding structure as being of high priority (**Figure 48**), from the point of view of the implementation of actions of remediation or rehabilitation, vis-à-vis those other structures whose risk scenarios are mostly located in green or yellow boxes, which will be classified as of very low or low priority.

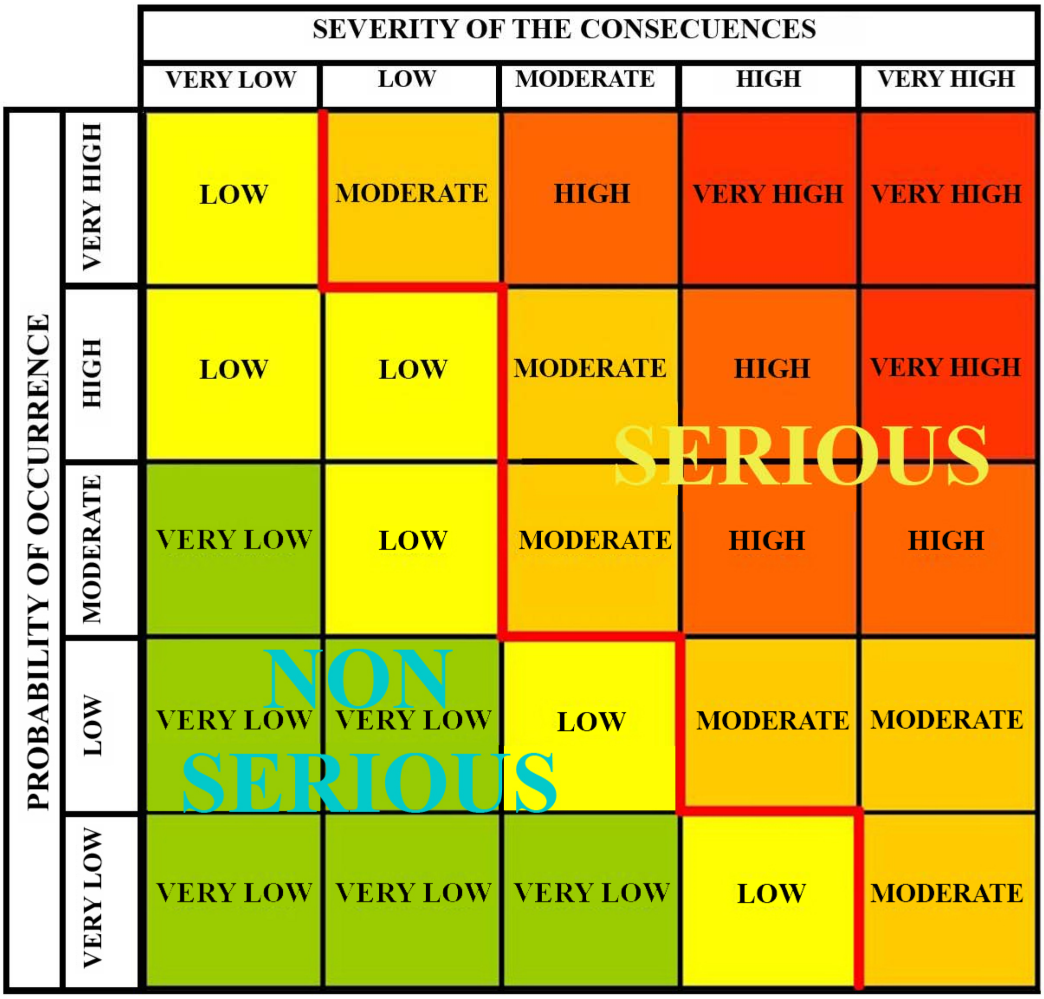

Figure 47. Proposed risk matix. The SERIOUS or NON SERIOUS qualifications are set in line with Article 20 of the Directive 2006/21/CE.

The level of risk assigned to a mining structure or mining waste facility will be that of the worst scenario of risk presented. In **Figure 49,** the risk matrix of a heap in which most of the probable risk scenarios present a very low magnitude of risk. However, the simple existence of a medium risk scenario due to breach of the dump slope, with the consequent damage to the natural environment (FESCNA), will be a sufficient criterion to assign a value of moderate risk (which implies a serious level of impact or threat), and it is advisable that the said structure should be considered in the inventories to which article 20 of Directive 2006/21/CE refers, although with a much lower order of priority to the example from **Figure 48**.

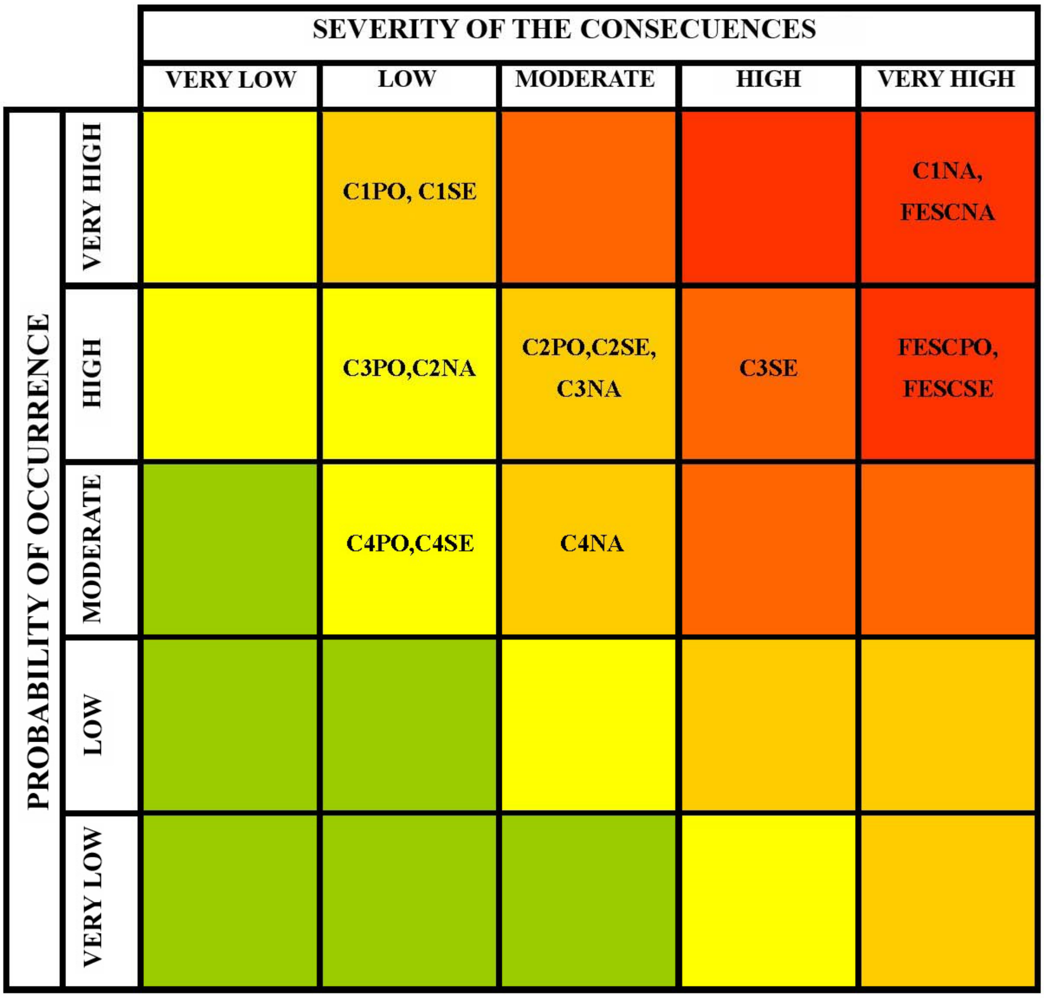

Figure 48. Hypothetical risk matrix of a mining waste facility of high priority according to its high risk.

The preparation of the risk matrices culminates the process of evaluation. In themselves, they constitute a tool which may be of great usefulness for the preparation of an ordered list of priorities of action for closed or abandoned mining structures, with a view to dealing with the elimination of those risks that are considered unacceptable, or alternatively, to reducing them to acceptable levels. However, as has already been mentioned, the establishment of priorities following this method of risk assessment, on the basis of scientific-technical criteria, does not have to be the end point of the process of decision making, and it may be necessary to consider other established priorities in accordance with another type of criteria: social, of territorial strategy, political, etc. Furthermore, as was stated initially, the management of risk does not end here, and it is desirable to implement strategies of action designed on the basis of the results of the evaluation phase for each concrete case. The taking of decisions may require acceptance, the design of control measures or the formulation of actions which imply a modification of the evaluation of the risk as far as possible or desirable.

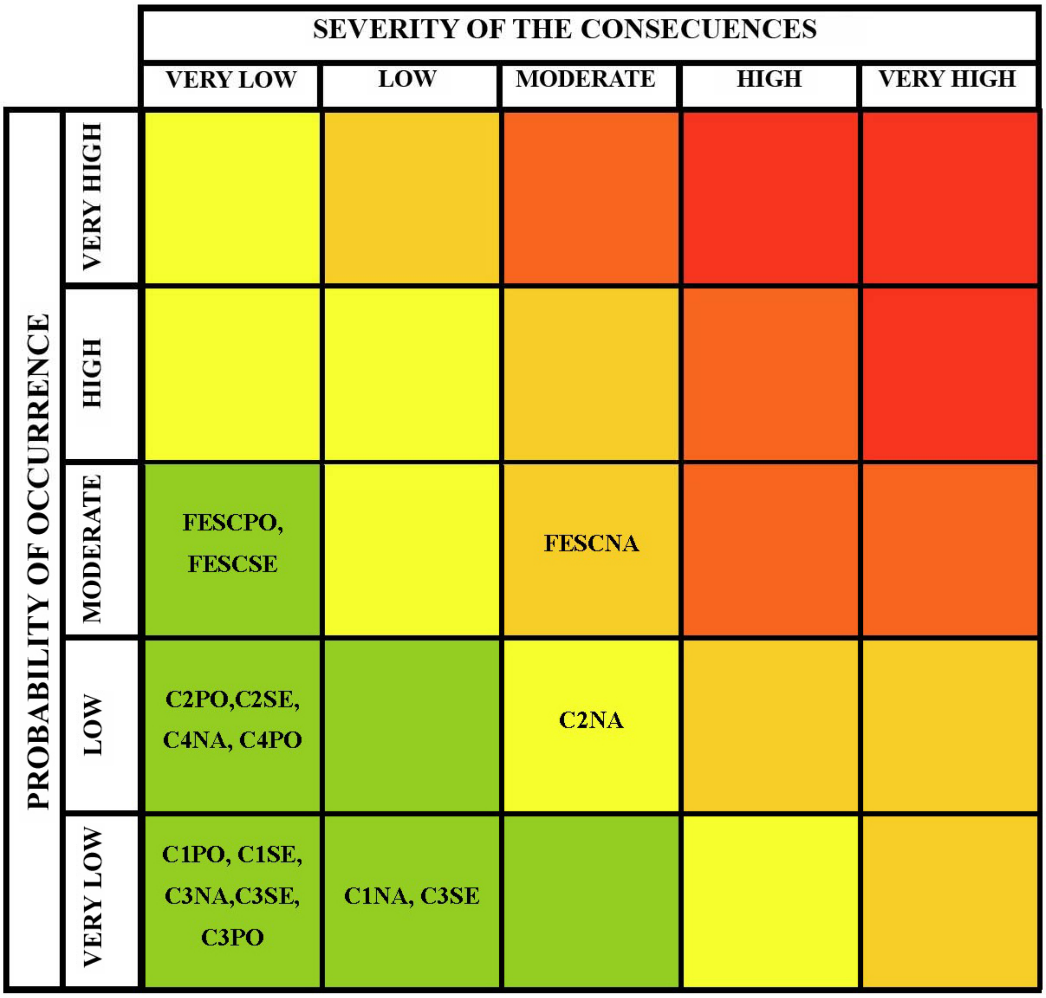

Figure 49. Hypothetical risk matrix of a heap with moderate risk.

6. LINKS TO APPLICATIONS AND SUPPORT INFORMATION FOR RISK EVALUATION ON THE WEB

There are in Spain a number of applications and thematic or cartographic information of a public nature and with free access from the web, which may be of use for the evaluation of the risk of mining waste facilities. The list of links which is set out below is not exhaustive and only mentions some of the most significant:

- *Ministerio de Agricultura, Alimentación y Medio Ambiente (www.magrama.es)*
  http://sig.magrama.es/geoportal/
  http://www.magrama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/cartografia_informacion_disp.aspx
  http://www.magrama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/servidor-cartografico-wms-/
  SIGPAC. http://sigpac.magrama.es/fega/h5visor/

- *Instituto Geológico y Minero de España (www.igme.es)*

- *Instituto Geográfico Nacional (www.ign.es)*
  http://www2.ign.es/iberpix/visoriberpix/visorign.html
  http://centrodedescargas.cnig.es/CentroDescargas/index.jsp

- *Confederaciones hidrográficas y agencias del agua*. La mayoría de ellas disponen de acceso a visores cartográficos dónde es posible localizar las zonas protegidas según la Directiva Marco del Agua (DMA) o descarga de información georreferenciada, y consultar los correspondientes planes hidrológicos.
  Confederación Hidrográfica del Cantábrico (www.chcantabrico.es)
  http://sig.chcantabrico.es/sigweb/
  Confederación Hidrográfica del Duero (www.chduero.es)
  http://www.mirame.chduero.es/DMADuero_09/index.faces
  Confederación Hidrográfica del Ebro (www.chebro.es)
  http://iber.chebro.es/geoportal/
  Confederación Hidrográfica del Guadalquivir (www.chguadalquivir.es)
  http://idechg.chguadalquivir.es/opencms/geoportal/es/
  Confederación Hidrográfica del Guadiana (www.chguadiana.es)
  http://www.chguadiana.es/Geoportal/
  Confederación Hidrográfica del Júcar (www.chj.es)
  http://aps.chj.es/idejucar/

http://aps.chj.es/down/html/descargas.html

Confederación Hidrográfica del Miño-Sil (www.chminosil.es)

http://siams.chminosil.es/visor/

Confederación Hidrográfica del Segura (www.chsegura.es)

http://www.chsegura.es/chsic/

Confederación Hidrográfica del Tajo (www.chtajo.es)

http://visor.chtajo.es/VisorCHT/

Augas de Galicia. Xunta de Galicia (www.augasdegalicia.xunta.es)

http://www.cmati.xunta.es/ide-dhgc/

Agencia Balear del Agua. Portal del Agua de las Islas Baleares

http://www.caib.es/sacmicrofront/home.do?mkey=m0808011112185729323&lang=es

SIG del cens d'aigües subterrànies. https://apps.caib.es/seraisubfront/

Agencia Vasca del Agua (www.uragentzia.euskadi.net/u81-0002/es)

Sistema de Información del Agua. *http://www.uragentzia.euskadi.net/appcont/gisura/*

Sistema de Información del Plan Hidrológico D.H. Cantábrico Oriental

http://www.uragentzia.euskadi.net/appcont/gisura/?appConf=configuracion_ph.json

Agència Catalana del l'Aigua. Consulta de Datos

http://aca-web.gencat.cat/aca/appmanager/aca/aca?_nfpb=true&_pageLabel=P3800245291211883042687

http://aca-web.gencat.cat/aca/appmanager/aca/aca?_nfpb=true&_pageLabel=P1232354461208201788774

Agencia del Agua de Castilla-La Mancha

http://pagina.jccm.es/agenciadelagua/index.php?id=11&p=11

Consejo Insular de Tenerife (www.aguastenerife.org)

Consejo Insular de Gran Canaria (www.aguasgrancanaria.com)

Consejo Insular de Fuerteventura (www.aguasfuerteventura.com)

Consejo Insular de Lanzarote (www.aguaslanzarote.com)

Consejo Insular de La Palma (www.lapalmaaguas.es)

Consejo Insular de la Gomera (www.aguasgomera.es)

Consejo Insular de El Hierro (www.aguaselhierro.org)

- *Instituto Nacional de Estadística. (www.ine.es)*

  Nomenclator http://www.ine.es/nomen2/index.do

- *Mapa eólico nacional.CENER (www.cener.com/es/energia-eolica/mapas-viento.asp.)*

  http://www.globalwindmap.com/VisorCENER/mapviewer.jsf?width=1293&height=983

- *Norma de construcción sismorresistente NCSE-02*

  http://www.fomento.gob.es/MFOM.CP.Web/handlers/pdfhandler.ashx?idpub=BN0222

- *Infraestructuras de Datos Espaciales de España*
- *http://www.idee.es/*
- *Sistemas de Información Territorial de las CCAA*
- *Programa M*AXPLUWIN Publicación "Máximas lluvias diarias en la España Peninsular" del CEDEX, accesible en Internet vía web (http://epsh.unizar.es/~serreta/documentos/maximas_Lluvias.pdf).

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