EVARISK: methodology for the economic assessment of risk and protection efficiency evaluation

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Abstract: The primary evaluation of potential losses (incurred risk), resulting from one or successive natural or anthropogenic events, is rarely realised. Indeed, for lack of certainty on the event modes and delays, these evaluations have to be established for a series of scenarios corresponding to different conceivable hypotheses.

Yet, it is a really important element to come to a decision with regard to preventive action investments: these actions have a cost that should be compared with expected loss saving. The paper describes how to make a clear loses tool or balance for each scenario, using a regionalisation of hazard and a precise identification of the exposed elements. A methodology, commonly used in Switzerland, must be then applied to chose the most efficient solutions.

Résumé: L'évaluation préalable des pertes potentielles (risque encouru) qui pourraient résulter d'un événement ou enchaînement d'événements d'origine naturelle ou anthropique n'est quasiment jamais réalisée, et ce d'autant que, faute de certitude sur le mode et le délai de manifestation de l'événement, cette évaluation doit être faite pour une série de scénarios correspondant aux diverses hypothèses envisageables. Elle est pourtant un élément indispensable de la prise de décision en matière d'investissements en actions de prévention : ces actions ont un coût que l'on devrait chaque fois comparer à l'économie de pertes attendue.

On montre ici comment, à partir d'une régionalisation de l'aléa et d'une identification précise des éléments exposés, on peut établir un bilan éclairé des pertes pour chaque scénario. On applique ensuite une méthode couramment utilisée en Suisse de choix des solutions les plus efficaces.

Keywords: landslide, inundation, risk assessment, protection efficiency.

INTRODUCTION

Reliable evaluations of economic losses resulting from natural or human events are easy to establish, especially for insurance or reinsurance companies. But it seems more difficult to have available an estimated toll of losses due to a potential phenomenon. Yet, these tolls are the ones that could produce an economic quantification of incurred risk and that could be used as pertinent arguments in decision-making. In most cases, this risk is only assessed by a qualitative evaluation, using questionable empirical rules, which are based in the concepts of “hazard” and “vulnerability”.

Hazard in English, as “aléa” the equivalent in French, has a minor signification than “amenaza”, in Latin American, which is the most significant word compared with the two first ones. Threat is a concept of people’s imagination. Hwever, it could be a good thing to be really precise with the meaning of this term. For example, we could try to make precise the characteristics of an instability phenomenon or an expected flood, or understand how a chain of events and dysfunctions can lead from a simple breakdown to a disaster. However, this evaluation needs lots of experience and means. So hazard qualification stays generally very basic (especially in Risk Prevention Planning studies, PPR). To assess hazard, the French Environment Ministry recommends considering the occurrence frequency of an event and its intensity or magnitude. However, this method can be really subjective, and it can become very difficult to explain the hazard level chosen.

The word **vulnerability** is also a source of confusion. In a first comprehension, it can signify damage (for property), dysfunction (for activities) or harm (for people), resulting from the local manifestation of an event. So far, there are no reliable methods and means to assess vulnerability. So, it is often the importance of the considered element that we deal with and not really the vulnerability.

Risk is directly linked to threat and damage and it is not the product of hazard and vulnerability!

Considering the difficulty encountered to estimate these components, the assessment of risk cannot be really efficient. The only certainty we have is that if an important element is situated in a zone under high threat, the risk is high. Fortunately, it allows an identification of the most dangerous areas in a given territory and to evaluate a range of preventive solutions. However, this is completely inadequate in crisis situations and for decision-making. Yet, we can manage to do better risk assessments with acceptable cost and delay. To do this, data must be acquired and authenticated, some rules must be re-evaluated, and financial means must be redistributed.

In the following paragraphs, the exposed methodology is about natural phenomenon, but it can be applied as well to technologic risks.

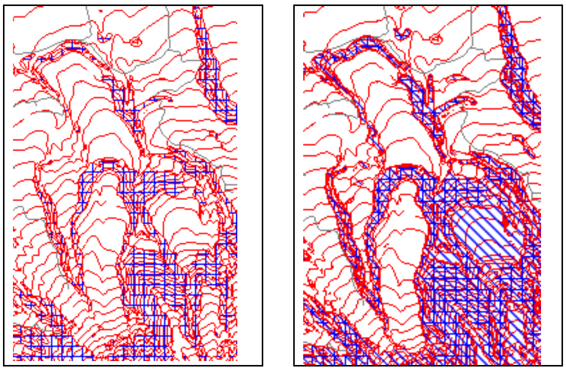
HAZARD: PHENOMENON CHARACTERISATION AND REGIONALISATION OF ITS EFFECTS

Characterisation methods adapted to the natural phenomenon

The available way to identify, localise and characterize hazard depends a lot on the considered natural phenomenon. Two kinds of factors have to be distinguished: *predisposition factors* (topography, nature and thickness of the superficial formations, vegetation, geological and structural elements) and *activation or worsening or triggering factors* (rain, civil engineering works, destruction by flooding, anthropic solicitations and run off or infiltrated water for landslide). This distinction between predisposition and triggering factors can also be made for volcanic phenomenon and earthquakes.

Unstable slopes

Slope instability is a complex natural phenomenon. Various methodologies are available to detect unstable zones. However, to do so, reference to a well-known event is always needed the characteristics of which can be very different from one geographic zone to another. However, in most cases, slope, nature and thickness of superficial formations and run-off and infiltration processes are to be considered.



Landslide hazard in intensive rain conditions

Landslide hazard in intensive rain conditions and post earthquake conditions

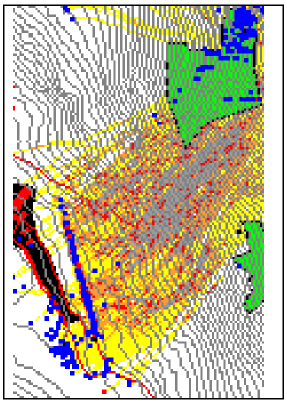
Figure 1. Hazard differences when different triggering factors are considered

To determine hazard, slope and the nature of superficial formations and their properties are usually combined using a geographical information system. However, this simple combination can lead to nonsense, whereas using a good algorithm and well-structured regionalized data can be very helpful to detect suspect zones. Figure 1 represents what has been done in Salvador using IRIS software (Unsteady Regionalized factor). It has allowed building up of “dynamic” hazard maps, taking into account both rainfall and earthquake conditions.

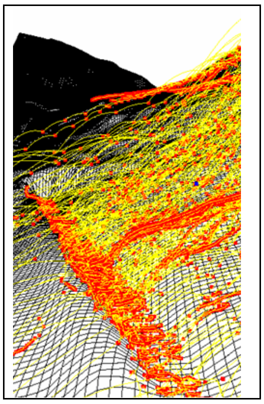
If we can define the regional geotechnical conditions and the ‘limits’ geometric conditions, it is also possible, on restricted zones or for linear projects (highways, roads, railways), to run systematically more complex calculations in three-dimensions, using the fundamental methods of soil mechanics (3D.PENT, GIPEA software).

Bursting and spreading rock masses

To solve these problems, failure locations and spreading zones on a slope are usually defined. In this note, we will not talk about the particular problem of the determination of failure zones for which specific means are at present time developed at GIPEA (3D.BLOC). Concerning the spreading zones, today, there are three-dimensional calculation models, based on DTM (Digital Terrain Models). From the initial failure locations (defined using deterministic methods like in 3D.BLOC system or semi-probabilistic methods), hundreds of thousands of simulations are run to calculate on each pixel height and velocity for each trial. The stop points are also determined. Bounce coefficient local variation is also taken into account, depending on the nature of the soil and land occupation.



Iso altitude of block flight, coming from a rock cliff



Simulation of the construction of an interception trench, in the same zone

Figure 2. Simulation of rock falls and the effectiveness of an interception trench

All these data are exported. Height and velocity maps can then be plotted as well as maps of the number of impact on each pixel. The same calculations can be run changing only the land morphology (using the DTM) in order to simulate the construction of interception works. The efficiency of these protection works can then easily been judged (Figure 2).

Floods

As with the previous phenomena, the flood hazard determination needs to combine:

- natural processes in order to appreciate the flood area morphology and deterministic processes using hydraulic models to estimate permanent predisposition factors. Field observations on remaining tracks of flooding can also be very helpful.
- probabilistic processes to forecast meteorological conditions evolution (worsening or triggering factors).

For a determined return period of these dangerous conditions, which means for a given flow, height, velocity and submersion durations are simulated. That needs a fine preliminary analysis of the land morphology and of the main obstacles (walls, bridges, river bed narrowing etc.), in order to select appropriate calculation point positions.

With experience and care, the simulation results can then be interpolated between calculation points. With a high resolution DTM (lasermetry), it is easy to determine water height for each pixel. It is more difficult to regionalize flow velocity and submersion duration, but it is possible to affect a value to each pixel, subject to use value classes in place of absolute values.

Proposed I_G values

Time / Height	Some hours to 1 day	1 to 7 days	More then 7 days
0 to 50 cm	1	2	3
50 cm to 3 m	3	4	5
More then 3 m	5	5	5

In order to take into account velocity in evaluation, the I_G factor have to be majored: $\mathbf{I_{GV} = I_G + A}$

Velocity (m/s).	<0,5	0,5< V< 1	1 <V < 3
A	0	1	2

Figure 3. Example of evaluation rules of flood local impact

The EVINOND software developed by GIPEA allows all these processing. It also allows considering the flood acceptability principles defined by Cemagref (Figure 3).

Georeferencing: how to use its resources

Through the three types of phenomena exposed above, we have tried to show that it is possible to develop a regional characterization of potential natural phenomenon processes and for quite a large area. Now, we are going to present an application of the EVARISK software applied to the example of flooding. Indeed, it is the phenomenon for which regionalization is the easiest to characterize (height, water velocity, duration of submersion). However, the same approach can also be applied to the spreading phenomenon of rock mass (using height and flight velocity, impact energy in each area point).

For landslides, it seems more difficult to quantify the corresponding phenomenon. Indeed, it is more their potential of activation than their mode of manifestation that is characterized. However, it could be of great interest to survey surface deformations, using monitoring techniques (mining subsidence for example) and using differential processing of DTM on recurring unstable zones, and so to forecast the long term potential evolution.

Towards new specifications for hazard map establishment

We have tried to show above that geomatic tools and methods can be very efficient in knowledge validation and structuring of the natural phenomenon manifestation (hazard). Obviously, field work remain essential, but it can really be eased and optimized, by a preliminary structuring of the whole available knowledge. So, it could be possible to eliminate a large amount of the subjectivity denounced here above, organizing at national (or international) level the acquisition and validation of pertinent data, and making them available for scientific, technical and operational prevention. These data could be detailed DTM, pairs of aerial photographs, orthophotographs, vectorized thematic maps, pertinent and well structured databases[1] on historic events etc. It would allow large savings and an increase of efficiency in natural hazard prevention.

VULNERABILITY: IDENTIFICATION AND LOCALIZATION OF THE EXPOSED ELEMENTS, OF THEIR EXPECTED DAMAGE[2] AND COST

Identification and localization of the elements at risk

Once the potential hazard area is determined, the elements at risk have to be identified, localized and characterized. This can be very difficult to do for large exposed areas and because both directly affected elements and those, which damage or dysfunction can be produce by the first one, have to be considered. Existing elements and regional developments have to be taken into account. Generally, property, activities and people are distinguished.

Typologies and their resolution

For lack of means and methods, we content ourselves with basic identification of these elements. Thus, for example, the definition level for land occupation planning (POS and PLU in France) is used with a resolution not really adapted to the aim of such evaluation[3]. In many PPR, no suitable resolution is available. So the elements identified are only the most important (hospital, school, aid centre, etc.) The risk assessed is then a function of this relative importance but not really of the true vulnerability of the considered element (Figure 4).

[1] Most existing historic databases on natural damaging events are limited to short descriptions without any back-analysis on the process interpretation. Geomatic potentialities could be of greatest interest for such reverse studies.

[2] Damage for property, dysfunction for activities, harm for people

[3] A risk study has been done on a French large city, based on only 15 categories of land occupation. In that condition, it seems difficult to make an explicit evaluation of the potential risk.

Information sources: from urbanism planning and air photographs to cadastral files and DGI and INSEE databases

Yet, there are many information sources available, which are more precise, especially with air photographs and cadastre. This one is established for financial aims. It is composed of two parts: the geographic elements (lots and buildings) and an important literal database.

The geographic elements are now georeferenced in most French communes (Figure 5). So, they can easily be introduced in the territorial information processing. The literal database is more difficult to use because, firstly, the law «informatics and freedom» protects it and, secondly, its very complex structure has been designed for fiscal use. This database, well developed, is really interesting for land management. So, it could be a good thing to complete it with all other interesting information that can freely be disclosed without any attack on property.

While waiting for this to happen, it is possible to find in the existing database relevant information that can be associated to geographical elements. However, it needs formal authorization and an important work of programming.

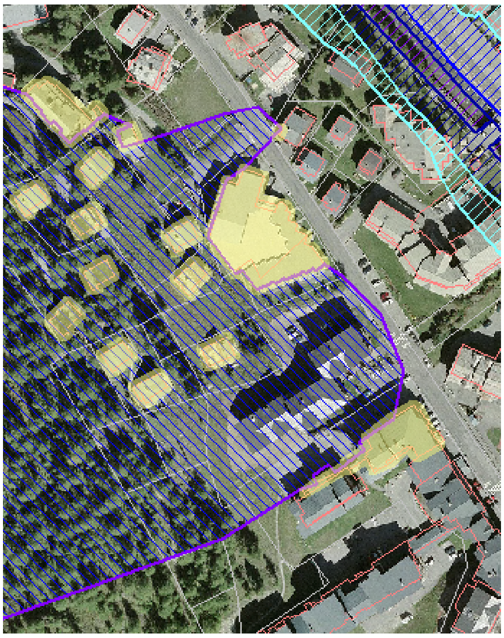


Figure 4. Identification of exposed buildings to avalanche corridor

Liste d'informations sur les bâtiments touchés

Id_bat_2003	Nom	Num_rue	Adresse	Nbr_chambre
58	Chalet Castor	24	Chemin du pe	4
59	Chalet Castor	30	Chemin du pe	8
60	Chalet Mousti	60	Chemin du pe	4
61	Hotel la Gelin	100	Chemin du pe	32
63	Chalet Caribo	229	Chemin du pe	4
64	Chalet Grizzly	235	Chemin du pe	3
65	Chalet Otari(T	257	Chemin du pe	4
66	Chalet Blanch	263	Chemin du pe	5
67	Chalet Elan(D	265	Chemin du pe	4
68	Chalet Raton	267	Chemin du pe	11
69	Chalet Coyott	298	Chemin du pe	6

Figure 5. Edition of relevant information for the prevention organization (EMMA, GIPEA)

Orthophotographic processing of air photographs is now generalized to almost the whole of France. With this processing, the information on land use can easily be identified, and so it can also be checked, updated and completed, especially concerning the nature and location of the elements at risk. It is also an excellent means of communication, for risk comprehension by the concerned societies.

Assessment of their vulnerability and their costs

Structural, functional and personal vulnerability

As explained above, the evaluation of vulnerability becomes easy only if the different elements are separately treated and according to the local form of future manifestation of the feared phenomenon. If all the necessary elements are available, work can be long and tedious. That is why it must be automated.

	factor	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Building year							
1950 to today	2			2	2	2	2
Before 1950	4	4	4				
Big wall materials							
Stone	2	2		2			
Concrete	2						
Millstone	1		1				
Bricks	1				1		
Chipboard	1					1	
Woods	0						
Others	0						0
Maintenance state							
Good	1	1	1	1	1		
Quite good	1						
Fair	0					0	
Mediocre	0						0
Bad	0			0			
Factors sum: S - 2		*5*	*4*	*3*	*2*	*1*	*0*

The possible values of this sum are the whole values from 0 to 5. The vulnerability of the concerned places is inversely proportional to these values. Below is the vulnerability expressed in relative values:

V_S		*0,5*	*0,6*	*0,7*	*0,8*	*0,9*	*1*
Vulnerability		*Very low*	*Low*	*Medium*	*High*	*Very high*	*Total*

Figure 6. Rules for the structural vulnerability assessment

Vulnerability (expected damage level), can be dealt with separately for structures (damages) (Figures 6 and 7), private or social activities (dysfunction level) and for people (sustained harm level).

Damage level or percentage depending on V_S and I_{GV}

V_S	0,5	0,6	0,7	0,8	0,9	1
I_{GV} de cadastral piece						
1	20	25	30	35	40	45
2	40	45	50	55	60	70
3	60	65	70	75	80	85
4	80	85	90	95	100	100
5	100	100	100	100	100	100

Figure 7. Estimation of damage levels

To do this, we have to learn lessons from real events and try to establish relationships between some descriptive elements of the event and some characteristics of the affected elements. These relationships are empirical but must be clearly explainable.

Economical value assessment

Here again, it is a difficult subject. As well as for the previous problems, the approach described only a starting point to a new method. Concerning property, evaluation means can be found in the literal database from the fiscal services (in French: DGI, Direction Générale des Impôts), subject to the maintenance of confidentiality and, consequently, to process information as a whole. In this way, a global land value can be estimated from the cumulative value of all buildings of one or several cadastral locations. This estimation can be more realistic with reference to local conditions, and, particularly, to land values in the commune being considered. In all cases, we have to provide ourselves with the means to realise automatically all these tedious operations.

Concerning activities and services, the DGI databases are less interesting than the INSEE (Institut National de la Statistique et des Etudes Économiques) ones. Indeed, these databases can normally provide information on the activity types for each establishment, with reference to the amount of production and employment classes.

Finally, economic estimation of personal injury asks a series of questions. It is proposed to refer to insurance company data.

EVARISK SOFTWARE

EVARISK is a GIPEA software. It has been developed to ease all the tasks in question in the previous paragraphs. It can be combined with the other GIPEA systems (3D.PENT, 3D.BLOC, EVINOND) and, in particular, it is also compatible with all the commercial SIG software.

Input data

First, to start the system, a file with the X, Y, height, velocity and duration parameters has to be prepared for the whole area concerned. The software described previously or their equivalent can be used. Secondly, the cadastral areas file, its associated database (DGI format) and the SIRENE file (from INSEE databases) have to be loaded. Then, the system counts the hits and locates them on a map, accessible by clicking on a button on the control screen (Figure 8).

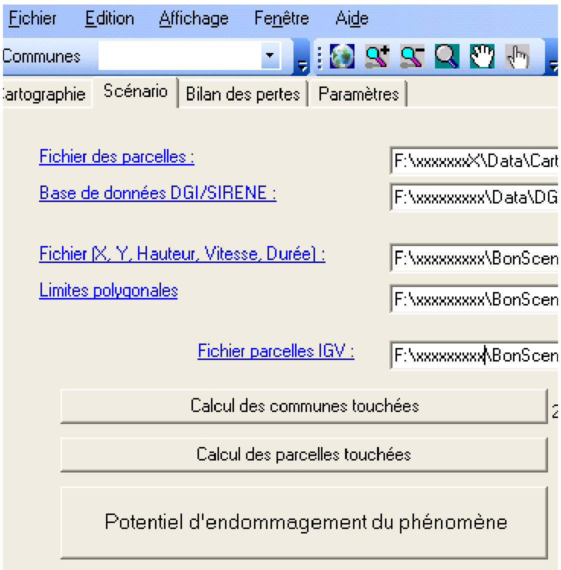


Figure 8. The EVINOND input screen

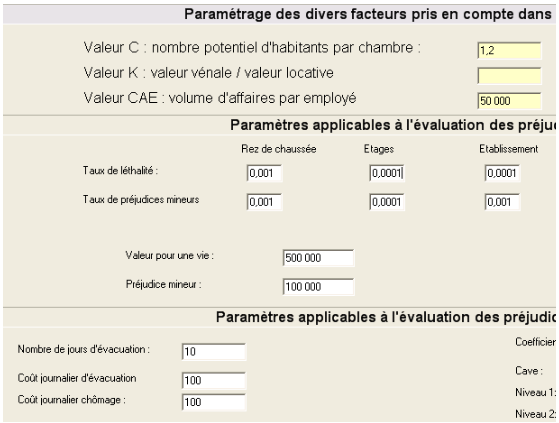


Figure 9. Parameter adjustment

The adjustable parameters

Another button permits access to the configuration unit, where some parameters are modifiable by the user (Figure 9).

The results screen

Typical results screens for residential properties and for commercial and industrial establishments are shown in Figures 10 and 11.

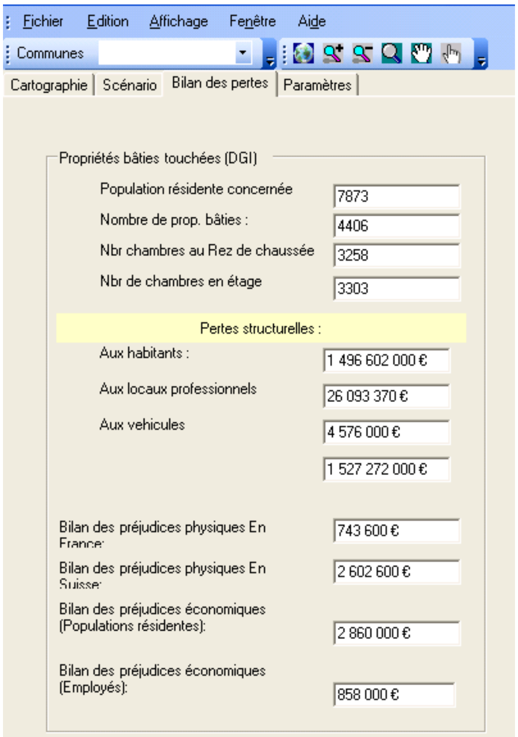


Figure 10. Assessment of the structural and associated losses for residential buildings

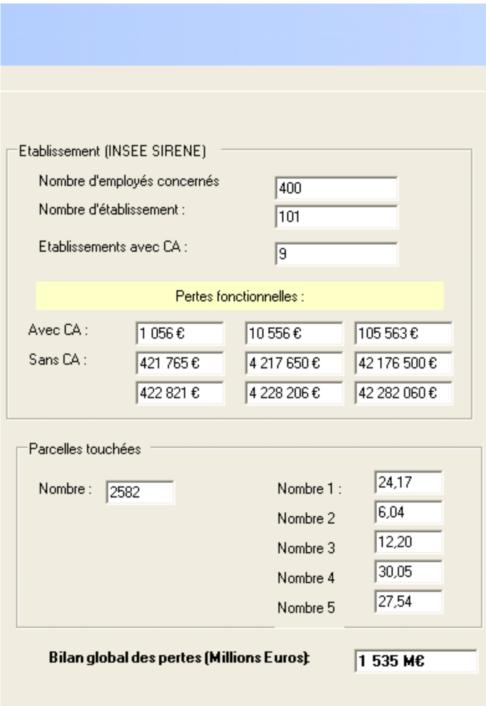


Figure 11. Assessment of structural and associated losses for commercial and industrial establishments

THE SWISS METHOD TO EVALUATE THE EFFICIENCY OF PROTECTIONS

Methodology principle

The methodology principle is to estimate an 'annual' cost of risk from a global evaluation of the potential losses and multiplying the corresponding amount by the probability that the expected event comes true in a given period. Thus, for an event that may occur in the next five years, with 100 expected losses, the estimated annual risk is 20. However, things are never so simple because there is a series of factors that can complicate things. For example, for an event divided in several phases with their own occurrence probabilities, a combination of estimations has to be done. This brings us to think about an event tree diagram.

The event tree diagram (Figure 12)

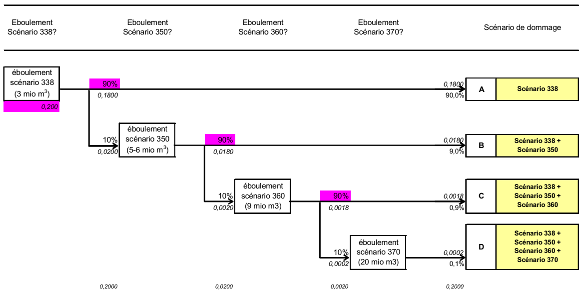


Figure 12. Example of an event tree diagram

This example is taken from the Sechilienne project where experts envisage four main scenarios corresponding to increasing seriousness and with very different possibilities of occurrence: if the first one can occur in the next five years, the second one has only a chance in ten to occur in the same year; the same rule can be applied on the other two scenarios.

The annual risk to take into account

The expected losses evaluation is respectively P1, P2, P3, and P4 for the four considered scenarios. So the annual risk is:

$$\mathbf{R_a = 0{,}18{*}P1+0{,}018{*}P2+0{,}0018{*}P3+0{,}00018{*}P4,}$$

Then, this calculated risk can be decomposed into the relative risk parts, in accordance with the loss categories (structural, functional, personal).

EVARISK permits this evaluation to be made easily:

- for each scenario, and for each considered condition (see below)
- for the reduction hypotheses corresponding to the conceivable protections. A residual risk can then be estimated (and consequently, the risk reduction generated by the protections) :

$$\mathbf{\Delta R = R_{before} - R_{\,after}}$$

The protection cost

The cost $\mathbf{K}_{(Pi)}$ for the several protections (P_i) has been estimated by the Project Coordinator. These investments are done once, at the beginning of work (except for a few program adaptations, which are not considered for long works).

The Swiss method advocates the transformation of the investment costs (**K)** as annual costs ($\mathbf{K_{a)}}$ as follows:

$$\mathbf{K_a = K_{ba} + K_u + K_r + (K - L_n) / n}$$

$$\mathbf{+ (K + L_n) * p / 2 * 100}$$

where:

K_a	*Annual costs*	*€/ year*
K_{ba}	*working expenses*	*€/ year*
K_u:	*annual maintenance cost, in % of K*	*€/ year*
K_r	*annual reparation cost, in % of K per year*	*€/ year*
K	*investment cost*	*€*
L_n	*residual value after working time*	*€*
n	*working time*	*year*
p	*interest rate = 3 %*	*%*

For each scenario, a 'risk,' or 'economic estimation of the expected losses,' $\mathbf{R_0}$ is evaluated. After completion of the prevention works, the residual risk $\mathbf{R_r}$ has to be estimated. The difference between these two elements is the value of risk reduction $\mathbf{R_v}$, which corresponds to the protection service.

The protection efficiency

The profitability or the efficiency of the investment is then expressed as:

$\mathbf{E = \Delta R / K_a}$

The whole process has to be adapted year after year, according to the evolution of the situation and parameters may be revised with regard to the elements cost, as well as the event occurrence probability. That is what the EVARISK system can do to help important decision-making.

APPLICATION TO THE PARTICULAR CASE OF SECHILIENNE

All the methods and tools described in this paper were applied in 2004 for a project of the Isère Departmental Directorate of Equipment, supervised by the French Environment Ministry. This project's aim was, first, the economic assessment of the risk resulting from the Séchilienne collapse and, second, to make proposals for risk reduction measures. The detailed results of this study are beyond the scope of this paper because they have not been published yet but a brief presentation of the conclusions is given.

Hypotheses on the conditions of event occurrence

The Séchilienne collapse has been known for many years and is under continuous monitoring by technical services of the Equipment Directorate. Some scenarios and scenario combinations for its future evolution (and its final collapse) have been defined by a committee of experts. Depending on the scenario, the results were a more or less important dam created across the Romanche Valley, then a water accumulation behind this dam. So, finally, a submersion wave discharge will occur as a consequence of the bursting of the dam. Four hypotheses have been retained corresponding to increasing seriousness (volume) with different occurrence probabilities. Hydraulic simulations have been done by SOGREAH. The results of these simulations have been used as input data for the EVARISK system.

Besides these elements, some other complementary conditions have to be taken into account, such as traffic cuts, the Romanche flow at the time of the event, the creation, or not, of a more or less important lake upstream from the dam or the preventive evacuation delay.

EVARISK has permitted the drawing up of the potential losses assessment for each hypothesis.

The various proposed solutions

The experts and the Equipment Directorate have studied, together, the possible defence measures to put in place. They can be divided into three main categories:

- works for reduction of the submersion wave (for the least serious bursting hypothesis but the most probable one)
- road deviations (more or less important)
- hydraulic galleries (for several discharge capacities of the upstream water)

The cost, the mode and the delay of realisation for these measures have been evaluated. A series of new hypotheses have again been done, according to the characteristics of the proposed solutions, to their mode of implementation and to their possible combination. All this has been taken into account in an event tree diagram.

The Swiss methodology proposes some rules for the evaluation of the cost depreciation. They have been applied in the Sechilienne project to calculate, for each case, the ratio 'annual cost of the protection measures/annual losses reduction.'

Thus, with this method, we have at our disposal not only all the detailed evaluation of potential losses for each scenario but also a list of possible solutions classified by efficiency.

EVALUATION AND PROSPECTIVES

In the above paragraphs, we have tried to show some of the possible progress with regard to risk prevention. In this section, we are going to see how to carry this out through projects.

PPR elaboration process

In France, for 20 years, a lot of effort and money has been invested for the elaboration of Risk Prevention Planning. Today, these efforts continue but with imprecise specifications, which lead to too much subjectivity and confusion in the 'hazard' assessment. Now, more rigour could be acquired if the essential data[4] (topographic, geological, hydraulic, historical data) could be collected, authenticated, structured and put at the disposal of specialists. The latter could then devote more effort to exploiting their experience in preparing diagnoses and prognostics rather than wasting their time collecting data. Moreover, the arguments used in information processes and negotiations with the concerned communities could be clearly expressed. Thus, the hazard characteristics, the identification of elements at risk and their vulnerability could be better defined and explained to people.

[4] However, providing that the prices and use fees of some providers or data administrators is controlled.

Precise economic assessment of incurred losses

In this paper, we have also exposed guidelines on how to make detailed economic assessments of potential losses for a given area, subject to having available structured data on the elements at stake. From this point of view, cadastre and its associated literal database are very interesting, even if it is difficult to have access it and if there are particular rules (private property law), to respect using them. It could be very interesting that an inter-ministerial collaboration allows, in a short time, free and simple access to some essential data.

Within the framework of INSEE works, it could be very useful to collect specific data that could be really interesting for the assessment of losses from natural dangerous events.

The presented methods are very interesting, especially for important problems, such as the Sechilienne one but they can also be applied to local problems or, at the communal level, for PPR, especially to ease the choice of priorities. Currently, there are almost no means to do so.

The possible improvement with regard to the risks repartition

The risks repartition is an essential element. It is one of the basic principles of insurance actions. We have seen that the mentioned methods could be a new key to the assessment of the several situations at risk. Up to now, only macro-economic approaches for risks, and especially for natural risks, are used. The proposed methods allow much more subtlety. The implementation of local micro-economic assessment is much more relevant for the optimisation of repartition strategies and also for regional development optimisation.

In the particular case of flood risk results could be the most conclusive in a short time. Indeed, flood phenomena are relatively easy to characterize and, moreover, large experience on damage, dysfunction and prejudice begin to take place.

The conceivable results of a strengthening of the international experience and the knowledge from various teams

Finally, it is encouraging to note that the presented work results from the coordination between two private PME from different countries. Now we hope to find some support to strengthen the methods mentioned in this note. There are still a lot of things to be done so that many scientific, technical, administrative and also political players can contribute to this strengthening.

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Some applications are available at GIPEA (gipea@gipea.fr)
Megève case in Haute Savoie: from a Prevention Natural risks planning to a real management system of communal risks.
EVINOND: management system for the assessment of flood damages and their acceptability
MARGUA: Risks and warning processes management for landslide threat in the volcanic site of the city of Guadalupe in Salvador
EMMA: Val d'Isère commune, realisation of a control board of the safety organization and the evacuation system of buildings and access obedient to avalanche risks.