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Geomorphologic risk assessment for EIA.

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Abstract
This paper deals with the interaction between geomorphologic processes and the socio-economic environment. Problems can not be solved any more one at a time, but require a more integrated and interdisciplinary approach to see how geomorphologic systems interfere with socio-economic systems. To foresee the consequences of new developments, physical models can be used during an EIA and play a central role in the risk assessment.

Keywords
Geomorphology, Environmental Impact Assessment, floods, landslides

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1. INTRODUCTION

Man's interaction with the natural environment is complex. On one hand, we try to isolate ourselves from the dynamics of the natural environment and create safe-havens where we can live and work without too much disturbance. On the other hand, we need the natural environment for its resources, for food, for recreation, etc. We appreciate the aesthetical beauty of the landscape but we loath the extremes in the natural processes that may harm our life, health or living conditions. The problem is that the socio-economic and the natural environment compete for space and interfere with each other. In those areas where the dynamics of both environments are high and space is scarce, this interference may have disastrous consequences especially when new projects are introduced – like constructing new infrastructure, expending residential areas or industrial zones. In the last decades, scientists have shown that such new projects may have unwanted negative consequences for both environments. The development of Environmental Impact Assessment (EIA) procedures for new large projects, now mandatory in many countries, reflects the awareness of this problem. A shortcoming of traditional Environmental Impact Assessments is that they tend to focus on the static elements of the environment and on a limited area surrounding a new project, and often disregard broader range or indirect effects. In most EIA studies, geomorphology has been analysed to evaluate the interaction between the project and geomorphologic assets rather than the interaction between geomorphologic processes and the new project. Studies on geomorphologic processes – in order to evaluate the geomorphologic hazards – are more complex and difficult (CAVALLIN & MARCHETTI, 1995).

2. GEOMORPHOLOGIC HAZARD VERSUS GEOMORPHOLOGIC RISK

A geomorphologic hazard can be described as the probability that a certain geomorphologic process will occur in a certain territory with a certain intensity in a given period of time. Geomorphologic hazards are natural events that can cause loss of life or damage to property.
The US-EPA (1998) defines risk as being dually composed by hazard and exposure.
Geomorphologic risk (R) is the expected number of lives lost, injured persons, damage to properties, or disruption of economic activities due to a geomorphologic hazard. It depends on the magnitude of the hazard (H), on the vulnerability (Vu) of the exposed element to that particular hazard and the value (Va) of the element (VARNES, 1984):

$$R = H \times Vu \times Va$$

Vulnerability is defined as the inability of an element or system to maintain its structure and pattern of behaviour in the presence of a geomorphologic hazard. Value in this context, not only implies economic value but can also be e.g. intrinsic-, scientific-, sentimental-, or ecological-value.
This definition shows that geomorphologic hazards are only a problem when they interfere with the socio-economic environment. Risk can increase due to an increase of the geomorphologic hazard (change in the geomorphologic systems) or due to an increase of the vulnerability and/or value of the exposed elements (change in the socio-economic environment) – see figure 1.
When there are no vulnerable elements or elements of value exposed to the geomorphologic hazard, the risk is negligible. Information on the vulnerability and the value of the elements exposed to a geomorphologic hazard has to come from experts outside the field of geomorphology, most notably from those working in the socio-economic environment. This implies that the study of geomorphologic risk has to be set in wider context. WHITE *et alii.* (1992) noted: "Traditionally natural sciences are concerned with the natural environment. Social sciences and applied sciences with the socio-economic environment. In reality these two components of our environment are inseparable; the natural environment cannot be fully understood in isolation from us and our interactions with it."

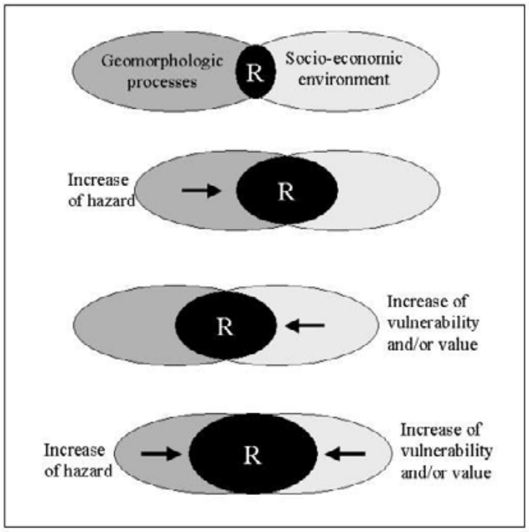

Fig. 1: Risk (R) exists where geomorphologic processes overlap with the socio-economic environment. Risk can increase due to an increase of geomorphologic hazards, an increase of the vulnerability and/or value or both.

One of the challenges of today is to bridge the gap between geomorphology and socio-economic sciences. This calls for a multi-disciplinary and integrated assessment where the owners of the problem get together to structure the problem in order to get a better understanding how geomorphologic hazards interfere with the socio-economic environment and thus affect the things that we care about. These *values* need to be identified and defined by all shareholders that are involved in the design, realisation and supervision of the new project, those that could be affected by it or its consequences and environmental scientists. The values can be related to *"human"* issues (life, health, well-being,...), *"economic"* issues (destruction, damage, loss of profit) and *"environmental"* issues (destruction, loss or degradation of habitats, aesthetic value). Values are fundamental to all that we do; and thus, values should be the driving force for our decision-making (KEENEY, 1996). In general, we want to avoid that geomorphologic hazards affect our values in a negative way.

3. RESPONSE TO GEOMORPHOLOGIC HAZARDS

The response to geomorphologic has evolved through time. The first and most practical response is the *avoidance* of geomorphologic hazards: Areas with dynamic geomorphologic processes are less suitable for settlements, etc. However, hazards cannot always be avoided, also because other – often conflicting – considerations are part of the location choice.
The second stage of response can be characterised as *solution-oriented*. The hazard is recognised as a problem that needs to be solved. Dikes are constructed, hill slopes are drained, rock-faces are

braced, etc. For centuries, engineers identified the problem and constructed protection works: For each specific problem a specific solution.
The third stage started in the 1980's when it became apparent that problems could not always be solved without considering external factors. The *integrated assessment* takes into consideration the various aspects of the problem, not only on the hazard side but also on the socio-economic side. Hazards are considered as part of geomorphologic systems that interfere with the socio-economic systems.
Some researchers (e.g. VAN LEUSSEN, 2002) identify a fourth development that they call *collaborative assessment*. Geomorphologic hazards are no longer identified as singular problems, but as part of a wider range of problems, all related to environmental issues. No single party is able to formulate the problem, let alone find solutions. Problem identification and solving has become a collaborative process. The challenge is to mobilise all parties that are affected by geomorphologic hazards and to move them towards collective actions and solutions. This could mean that the role of geomorphologists will change in the future.

4. LINKING GEOMORPHOLOGIC PROCESSES AND THE SOCIO-ECONOMIC ENVIRONMENT

Geomorphologic processes, such as rivers (fluvial processes), erosion and mass movements (slope processes) etc., are the dynamic actors that help to shape the landscape. Their rate of activity can vary greatly and when certain thresholds are surpassed these processes manifest themselves as geomorphologic hazards. How these hazards interfere with the socio-economic environment can be visualised in a conceptual model. On one side are elements of the socio-economic environment; on the other side are elements of the natural environment that are related to geomorphologic hazards. Lines and arrows indicate linkages between the elements. The result is an assemblage of possible relevant elements and their interaction in a general, conceptual manner, like shown in the example (fig. 2). The geomorphologic systems are in the lower part and the socio-economic systems are on the top. At the overlap between the two parts are the geomorphologic hazards. Geomorphologists can identify which elements control these hazards (hazard assessment) and collaboration with socio-economic scientists can reveal how these hazards eventually affect our values (risk assessment). The construction of the conceptual model serves the following purposes:

- It facilitates and structures the multi-disciplinary discussion between the owners of the problem (shareholders);
- It creates understanding of the complexity of the various systems (both geomorphologic and socio-economic);
- It forces the shareholders to explain the role of each element within the graph and to indicate its importance;
- It allows a preliminary assessment of how changes within the controls due to a new project may cascade though the systems and affect the values.

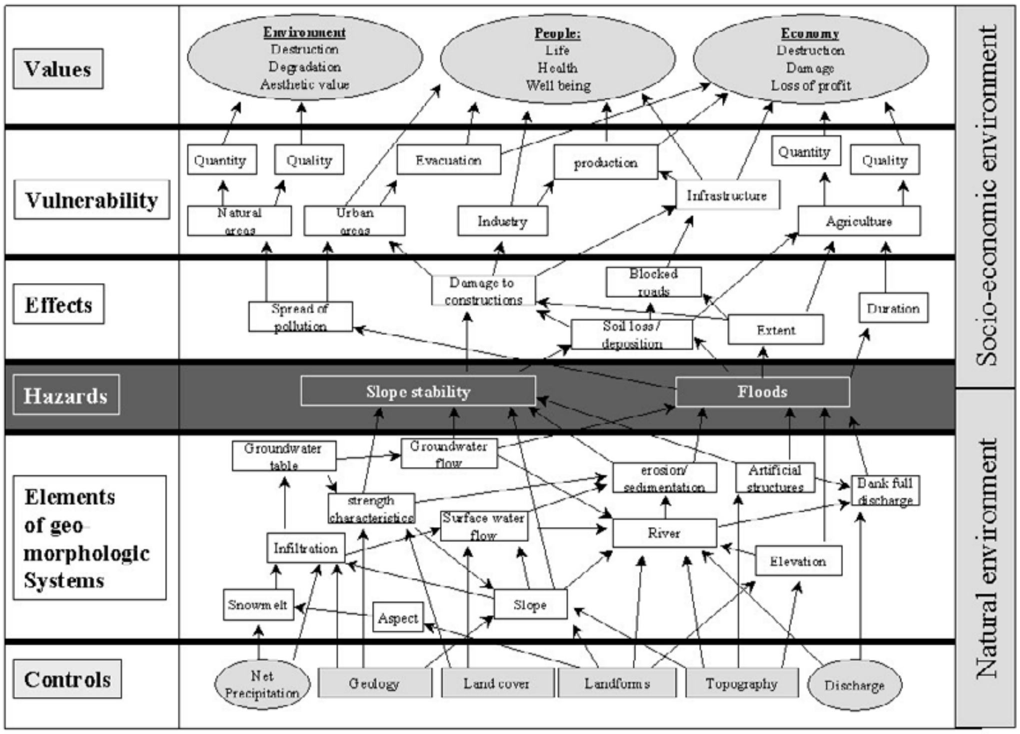

Fig. 2: An example of a conceptual model that illustrates how geomorphologic processes with their main control, manifest themselves as geomorphologic hazards that can interfere with the socio-economic environment and ultimately affect our values.

5. A NEW PROJECT AND GEOMORPHOLOGIC HAZARDS

The introduction of new elements within the geomorphologic and socio-economic systems could have consequences for our values. Major works can cause changes in the controls of geomorphologic processes, which could aggravate the geomorphologic hazards.
Hazardous geomorphologic processes can affect a new project and disrupt its function, cause damage or even its destruction. In this paper, these hazards are called *direct hazards*. Direct hazards will occur, regardless of the presence of the new project. How much the project is affected by a direct hazard depends on one hand on the magnitude of the hazard and on the other hand on the robustness of project’s design (or its vulnerability to that particular hazard).
The presence of the project may also trigger or activate dormant or non-active geomorphologic processes, which – in turn - may become geomorphologic hazards. Induced geomorphologic hazards are the result of interference between geomorphologic processes and a new project.
CAVALLIN *et alii* (1994) identified three different types of risk associated with direct hazards and induced hazards (figure 3):

- **risk:** the possibility that the project is damaged due to a geomorphologic process *(direct hazard);*
- **direct risk:** the possibility that the project changes the characteristics of a geomorphologic process *(induced hazard)* which in turn may damage the project;
- **indirect risk:** the possibility of damage to the surrounding environment due to changes in the characteristics of a geomorphologic process, caused by the project *(induced hazard).*

Traditional EIAs often fail to foresee the effects of these *induced hazards* that may have consequences for the project itself or the surrounding area. Figure 4 illustrates this for floods and mass-movements:

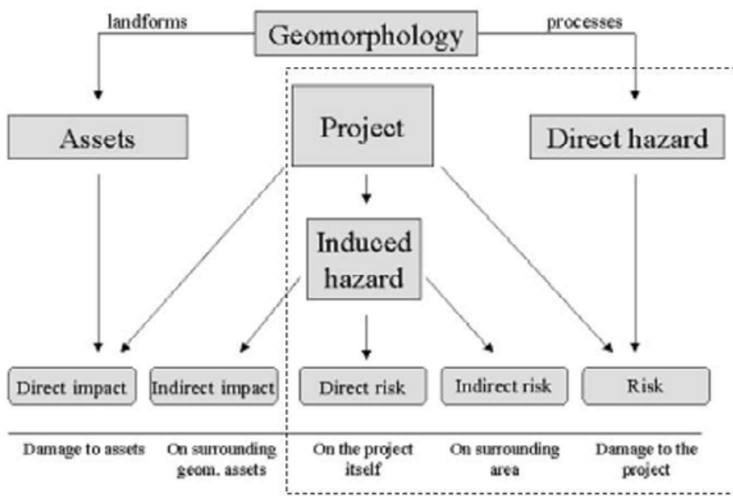

*Fig. 3: The interaction between geomorphology and a project (*CAVALLIN *et alii. 1994). This paper focuses on the part of the diagram indicated by the dashed box.*

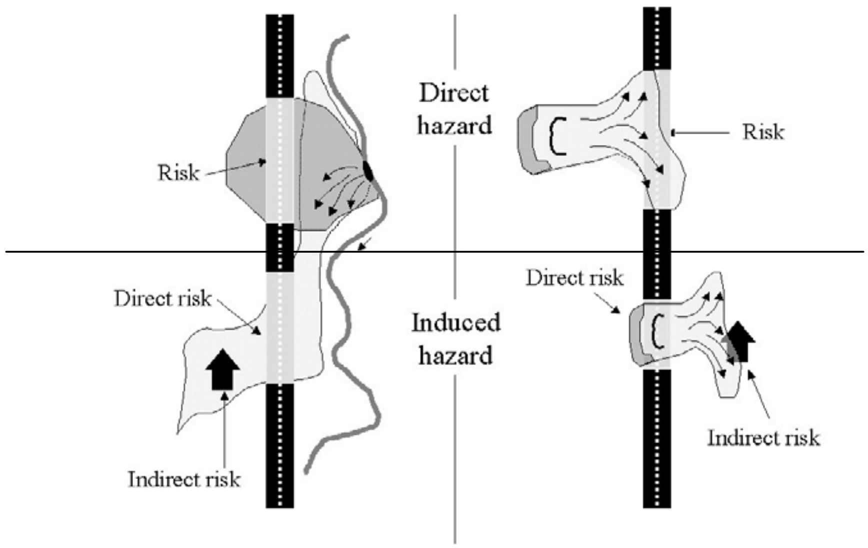

Fig. 4: The effects of direct and induced hazards.

<u>Floods</u>

Risk: A flood occurs and inundates the new motorway.

Direct Risk: To avoid inundation during a flood the motorway is build on an embankment that deviates the flood so that it inundates the motorway at an unforeseen location.

Indirect Risk: The motorway deviates the floodwater so previously unaffected areas are now inundated.

<u>Mass movements</u>

Risk: A mass movement occurs and affects the new motorway.

Direct Risk: The presence of the new motorway causes a mass movement that affects the motorway

Indirect Risk: The presence of the new motorway causes a mass movement that affects the surrounding area.

6. RISK ASSESSMENT FOR EIA: A THREE-STEP APPROACH

A geomorphologic risk assessment for Environmental Impact Assessment consists of three steps:

- Risk identification
- Hazard assessment
- Risk assessment

6.1 Risk identification

Risk identification implies that not only a potential geomorphologic hazard needs to be identified, but also if it could interfere with the socio-economic environment; In other words, could there be a problem? There are various ways to identify the potential geomorphologic hazards, e.g. through geomorphologic mapping by experts, historic analysis, statistical analysis or the application deterministic models. The aim is to estimate the probability of the occurrence of a certain geomorphologic hazard of a certain magnitude in a given area. What are likely locations of slope instability, or what could be the peak discharge of the river after prolonged precipitation? The use of statistical modelling for slope stability analysis is exemplified by e.g. FABBRI & CHUNG (1996), for flood prediction 1-D catchments models are often used, e.g. HEC (USACE, 1997) or LISFLOOD (DE ROO *et alii,* 2000). If geomorphologic processes become hazardous, an additional preliminary assessment should indicate if they would interfere with the socio-economic environment and what the potential consequences of a hazardous event could be.

6.2 Hazard assessment

Once a potential hazard is identified, it is important to know its characteristics. What is the extent of the inundated area of the 50-year flood or what is the potential run-out area of landslides? What are the controls of the characteristics of these geomorphologic hazards? The characterisation of direct hazards should not be too difficult. In the last decades, numerous methods have been developed to model the behaviour of many geomorphologic processes. Induced hazards are more difficult to foresee and qualitative assessments are usually not sufficient. The assessment of induced hazards requires more detailed and quantitative analyses that are able to predict how much the processes are disturbed, what elements within the various systems are affected and how the new project changes the characteristics of a geomorphologic hazard. Models are needed where the characteristics and accuracy of the boundary conditions and the input data determine the outcome of the computations. Such models show the effects of different boundary conditions or input data on the results. Deterministic models fulfil this requirement and make it possible to evaluate a series of "what if"-scenarios to assess the effect of a new project on the characteristics of the hazard. Such detailed analysis will result in the parameterisation of the geomorphologic hazard and comparison between several scenarios allows the evaluation of the consequences of a new project. If the characteristics are changed, this could have consequences for the project itself (direct risk) or for its surroundings (indirect risk).

Another important consideration for the choice of models is the output parameters from the models. These parameters should give a correct characterisation of the hazardous event. For instance, in the case of floods, it is not sufficient to know the extent of the flooded area; other parameters like inundation depth, flow velocity, warning time, duration, etc. are equally important to properly assess the hazard. The parameters should also be transparent and meaningful so that experts from other disciplines can also perceive their meaning during the risk assessment. LORENZ (1999) calls these parameters indicators: "Indicators describe the system or process in such a way that they have significance beyond their face value; they aim to communicate information of the system or process; the dominant criterion behind an indicator's specification is scientific knowledge and judgement". Indicators are the common language for the risk assessment.

6.3 Risk assessment
A geomorphologic risk assessment requires additional information on the vulnerability to a particular geomorphologic hazard of the various elements (land-use units) and on their value. The critical part of the risk assessment is to find vulnerability functions for each land-use unit. What are the levels of intensity or magnitude of the hazard where the land-use unit start to loose its ability to function as normal (lower level) and at what levels of intensity or magnitude is the land-use unit damaged beyond recovery so that it can be considered as total-loss (upper level), see figure 5.

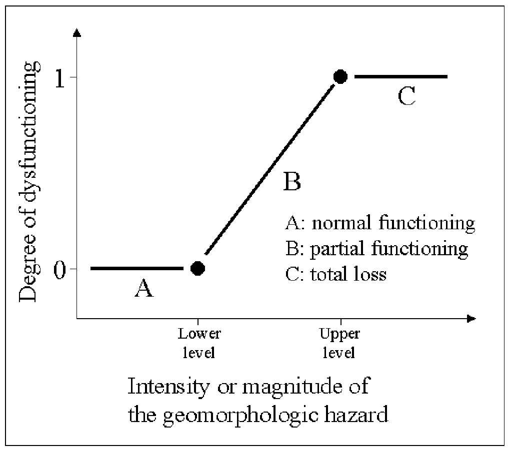

Fig. 5: Vulnerability functions: At what level of hazard starts the (partial) dysfunctioning of the exposed element and at what level is the element completely destroyed.

The intensity or magnitude of the geomorphologic hazard is characterised by the geomorphologic indicator, or by a set of indicators and its transformation into degree of dysfunctioning requires knowledge from various disciplines. For each element or land-use unit specific vulnerability curves are needed with their specific shape and critical levels.

7. CONCLUSION

When certain thresholds are surpassed, geomorphologic processes become geomorphologic hazards. Geomorphologic risk is the result of interference between geomorphologic hazards and things we care about. This implies that for a risk assessment, good knowledge of both the geomorphologic and of socio-economic systems is required. Risk assessment is truly a multi-disciplinary endeavour. On one hand, it is important to identify the controls of geomorphologic processes and on the other hand, it is needed to identify common values that should not be affected in a negative way by a geomorphologic hazard or its consequences.
Risk assessment has to be included in Environmental Impact Assessment procedures for new large projects, like the construction of new infrastructure. Important is that not only the direct

consequences of the new project are assessed, but also its indirect and broader range effects. In this paper is shown that the presence of a new project may induce new hazards, or change their characteristics in such a way that the geomorphologic risk increases. The first step towards a risk assessment is to identify potential geomorphologic hazards that could interfere with the socio-economic environment (*risk identification*). The second step, the hazard assessment, is to characterise and quantify the hazards and to predict how a new project will interfere with the geomorphologic processes; is there direct hazard and will there be induced hazards. The third step, the *risk assessment*, is to transform the hazard assessment into risk. This requires additional information on the vulnerability of all exposed elements and their value. This last step is the most difficult, because useful vulnerability functions are hardly available.

8. ACKNOWLEDGEMENT

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Summary
This paper describes the interaction between geomorphologic processes and the socio-economic environment. When geomorphologic processes become hazardous, they may have negative consequences for the things we care about, our so-called values. A geomorphologic risk assessment therefore consists of three components that need to be combined: 1) the characteristics of the geomorphologic hazards, 2) the vulnerability of the exposed elements to these hazards and 3) their value. As our society becomes increasingly complex, it is not sufficient anymore to analyse a singular problem and find a problem related solution. An integrated approach is required that considers geomorphologic risk as the interference of geomorphologic systems with the socio-economic systems. The introduction of a new element into the systems – like the construction new infrastructure – may have unforeseen and unwanted consequences. An Environmental Impact Assessment is the proper instrument to analyse how direct and induced hazards may affect the risk in the area surrounding the new project. Deterministic modelling, to consider and compare various scenarios, plays a central role in the risk assessment.

Riassunto
questo lavoro descrive le interazioni tra processi geomorfologici e ambiente socio economico. Infatti quando i processi geomorfologici creano situazioni pericolose, possono avere negative conseguenze per le cose a cui teniamo che vengono chiamate *valori*.
La valutazione del rischio geomorfologico comporta l'analisi di tre componenti che devono essere combinate insieme.
1) caratteri peculiari della pericolosità geomorfologica,
2) vulnerabilità degli elementi esposti,
3) valutazione del loro valore.
La struttura complessa della nostra società non permette di poter analizzare singolarmente i problemi ma invece richiede un approccio integrato che quindi consideri il rischio geomorfologico come integrazione tra aspetti geomorfologici ed economici. L'introduzione nel sistema ambientale di nuovi elementi, quali ad esempio la nuova arteria stradale, potrebbe avere conseguenze non previste e indesiderabili. La valutazione di impatto ambientale è quindi lo strumento più idoneo a analizzare come la pericolosità diretta ed indiretta indotta dai processi geomorfologici interagiscano con il nuovo progetto e con le aree limitrofe. I modelli deterministici bidimensionali permettono di poter realizzare scenari e di poterli confrontare tra loro, avendo così un ruolo predominante nella valutazione del rischio.