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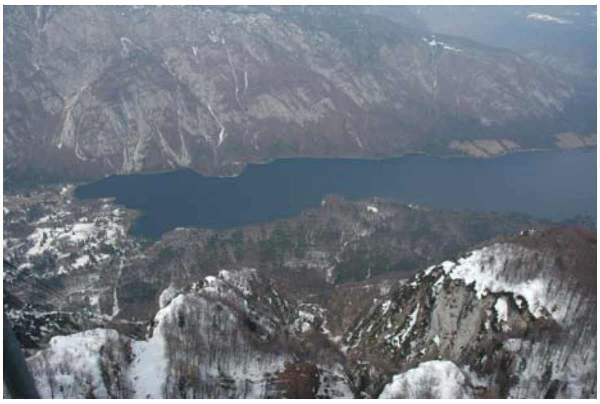

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FROM GEOMORPHOLOGICAL MAPPING TO RISK ASSESSMENT: A PROJECT OF INTEGRATED GIS APPLICATION IN THE WESTERN SWISS ALPS

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INTRODUCTION

This paper presents the general outlines of a PhD thesis to be carried out at the Institute of Geography of Lausanne University (IGUL under the supervision of Prof. Emmanuel Reynard (IGUL) and with the collaboration of Dr Eric Bardou (IGAR) and Dr Dominique Bérod (Roads and Watercourse Service, SRCE, canton of Valais).

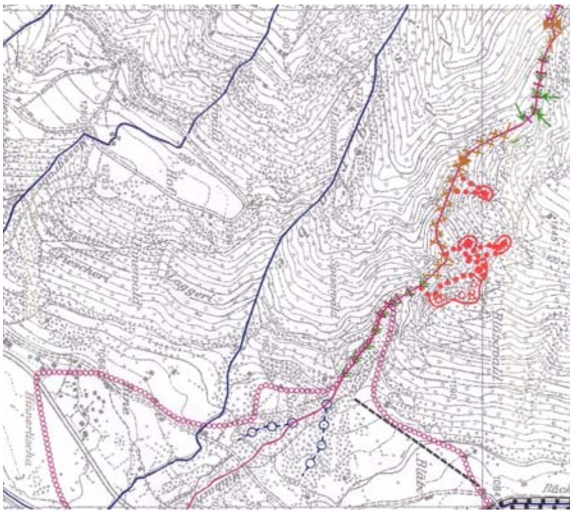
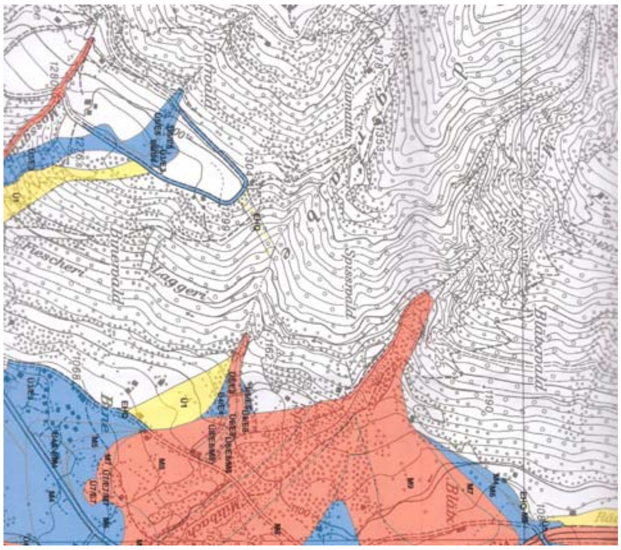
Overview of natural hazards in the Canton of Valais

In a context of rapid urbanisation and climatic changes, the occurrence of intense meteorological events will increase. Since 1987, the threats caused by hydrological phenomenon in Switzerland have become more and more serious, resulting in high damage consequences to the population and infrastructures (OFEE et SHGN 1991; OcCC 1998; OFEG 2002). Like the majority of alpine regions, the canton of Valais is particularly exposed to geomorphological hazards. Today, 300 avalanche couloirs, 29 dangerous glaciers and 260 rockfalls sites connected with living areas and communication infrastructures have been surveyed. Non exhaustive surveys, related to hydrological hazards, show that approximately 40 areas are exposed to floods and 235 areas could be reached by sediment laden floods. On the Rhone River plain, static floods with fine sediment deposition provoke costly damages (fig. 1), whereas in the lateral valleys dynamic floods, hyperconcentrated floods, debris flows, mud flows and landslides (OFEG 2002) are the most dangerous phenomenon for human life (fig. 2). Finally, the reaction of permafrost to climate change is still poorly known, but frontal slopes of some active rock glaciers, frozen morainic bastions and talus screes with permafrost conditions may collapse or produce debris flows (Lambiel 2006).

Figures 1 and 2. Static flood of the Rhone River in Saillon (top) and hyperconcentrated flow deposition in Baltschieder, October 2000. © OFEG (2002) and Planat.

Hazard mapping

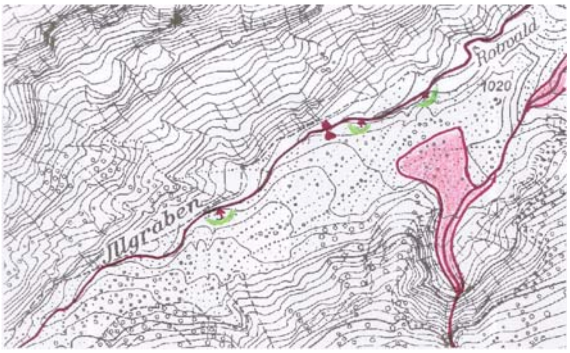
After the severe floods in Switzerland in 1987, the Swiss federal laws and ordinances on river engineering (LACE and OACE) and forests (LFo and OFo) were changed. They imposed the responsibility of establishing hydrological hazard maps on the Swiss cantons. These maps should become an obligatory tool for land planning (OFAT and al. 1997; ARE and al. 2005). The method applied by the federal authorities consists of three steps.
A "phenomena" map (fig. 3) is produced by using field geomorphological evidence (Kienholz and Krummenacher 1995; OFAT and al. 1997). A colour scheme is given to each morphogenic process. Different tones of colour or thicknesses of symbols allow the differentiation of the substratum type (rock or deposit formation), the depth of gravitational processes, and the evidence, relative age and size of processes. Then, based on this evidence, intensity maps are produced, either by numerical modelling and/or expert-system mapping.
The last step, called hazard map (fig. 4), is a much more synthetic map, which shows the different degrees of danger and is based on two main parameters: intensity and probability of hazard. Five colours are usually used: red (elevated danger), blue (medium danger), yellow (moderate danger), yellow-white stripes (area of residual risk management) and white (no danger).

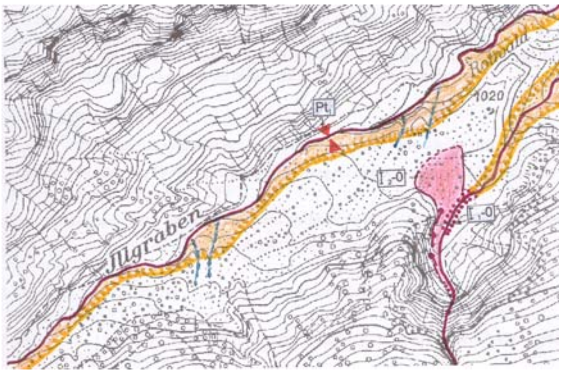



Figures 3 and 4. Examples of a phenomena map (left) and a hazard map (right). Source: SRCE, canton of Valais.

However, the variety of tools available leads to some inconsistencies in the field, especially when going from step 2 to 3. The recommended legend for mapping the phenomenon only gives a momentary vision of one single event. In theory, the phenomological map must be remade after each new event and all the maps should finally be superposed to have a global view of the flooded area.

There is, therefore, a need for more detailed information about volumes of potentially mobilised sediments, especially in densely populated mountain regions with a high potential of natural hazards. A better cartographic recognition of the slope system and especially the sediment transfer processes, linked with a specific legend, could improve the knowledge on hydrological hazards in the canton. There is also a lack of information because numerous basins are not yet mapped. Some important characteristics of an event / torrential system should be considered, like the integration of past events / history of the stream, distinction between punctual and potential sediment alimentation of a debris flow, distinction of the different processes in the deposition zone or distinction of different deposition landforms. Some aspects of the phenomena map have been deepened for free faces (Rouiller et Marro 1997) and debris flows (Liniger 2000; Zimmermann 2000; Bardou 2000, 2002). Experiences in debris flow mapping (Bonnet-Staub 2001; Bardou 2002) have shown that landforms related to debris flows are very active and may change very quickly over a short time and space scale, and that often potential sources of sediment could be surveyed before their outbreak. Figures 5 and 6 show an example mapped in a torrent in the central part of Valais. The catchment is known for its frequent debris flows and has been under survey for several years. Bardou (2002) has made a distinction between punctual and potential areal alimentation of a debris flow channel. The strict application of the recommended method (Kienholz and Krummenacher 1995) may result in a loss of information about the potential alimentation of the debris flows, coloured in beige.



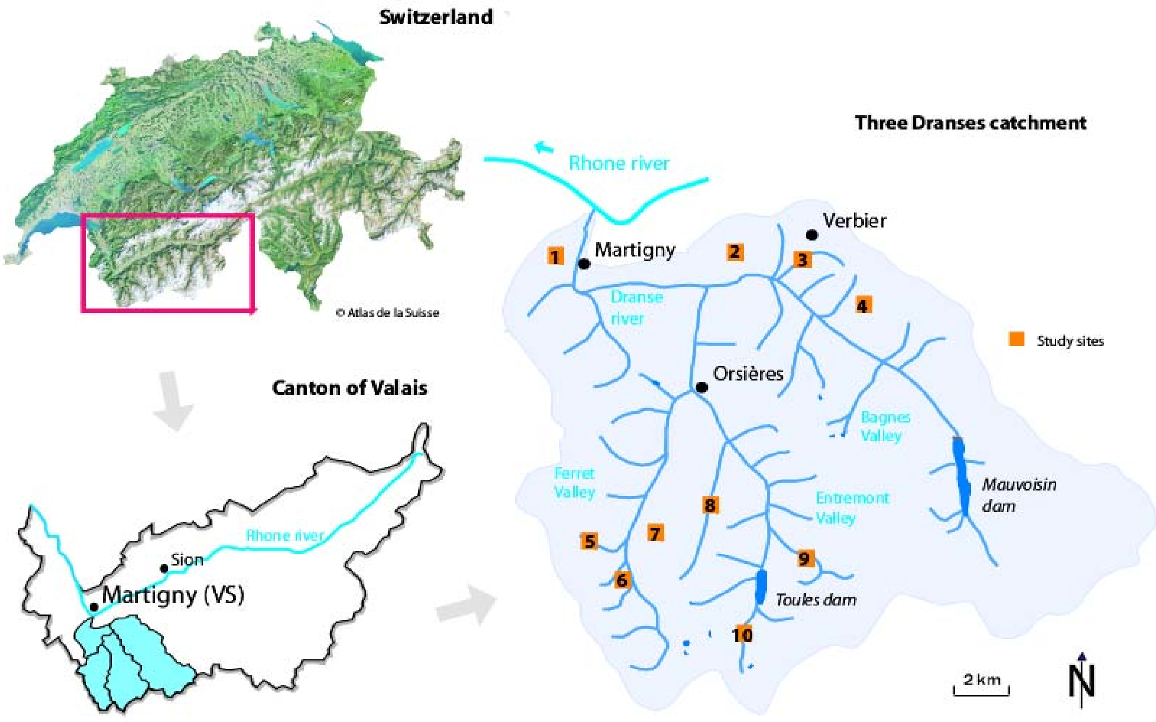


Figures 5 and 6: An example mapped in a torrent in the central part of Valais

Finally, protection works and hydropower exploitation has considerably modified hydrology and ecosystems of many alpine rivers and as the concessions are delivered for a long time period, the federal law on water protection (LEaux) has fixed a sanitation delay for 2012 to improve the situation of the rivers. In the canton of Valais, the Cantonal Energy Department has elaborated a directive to treat the legal tools and to establish an environmental diagnosis based on the Swiss graduated modular system (Theler 2004). There is, therefore, a need for an ecomorphological classification or typology of the rivers to be used for environmental assessment (OFEFP 1998a, b). The term “ecomorphology” designates the structural conditions of a waterway and its banks.

RESEARCH AREAS

The research focuses on the Dranses basin area (670 km^2), located in the western Swiss Alps, in the Rhone basin (fig. 7). The region was chosen because of the multiple levels of activity of its torrential systems and because of the number of studies already carried out until now (CRSFA 1996; Rouiller et Marro 1997; Lugon and al. 2000; OFEG 2002; Reynard and Mauch 2003; Theler 2003; Lambiel 2006). Today, ten potential study sites have been defined (fig. 7).



In the upper part of the **Ferret valley** basin, fluvial geomorphic processes are very active because of the crumbly lithology and the structural disposition of the slopes. Several alluvial fans are still in activity [5, 7]. In July 1990, a large debris flow occurred from the morainic bastion of the Dolent Glacier [6], damaging a small resort downstream (Lugon et al. 2000). In the **Entremont valley**, the all geomorphological context of the A Combe has already been studied (Summermatter 2002). Study of the periglacial settings and the debris flow activity was also made by our team in the torrent de la Croix and several other small flash flood type streams near Bourg St-Pierre. In the **Bagnes valley**, Verbier is one of the largest tourist ski resorts of the canton of Valais, with a very densely built area. The Torrent of Verbier [3] has overflowed several times due to the imperviousness of the soil. In the vicinity, the Merdenson torrent [2] is characterised by a high production of fluvial sediments, whereas the activity of the Lourtier Torrent [4] is highly influenced by the permafrost conditions in the upper area of the catchment and has already been studied by our team. (In the lower part of the Dranse basin, the intense activity of the lateral St-Jean Torrent [1] threatens the international St-Bernard road that links Switzerland and Italy. The Bagnes valley has also been selected for an intercantonal alarm and information system (IFKIS-MountainFloodWatch).

AIMS OF THE PROJECT

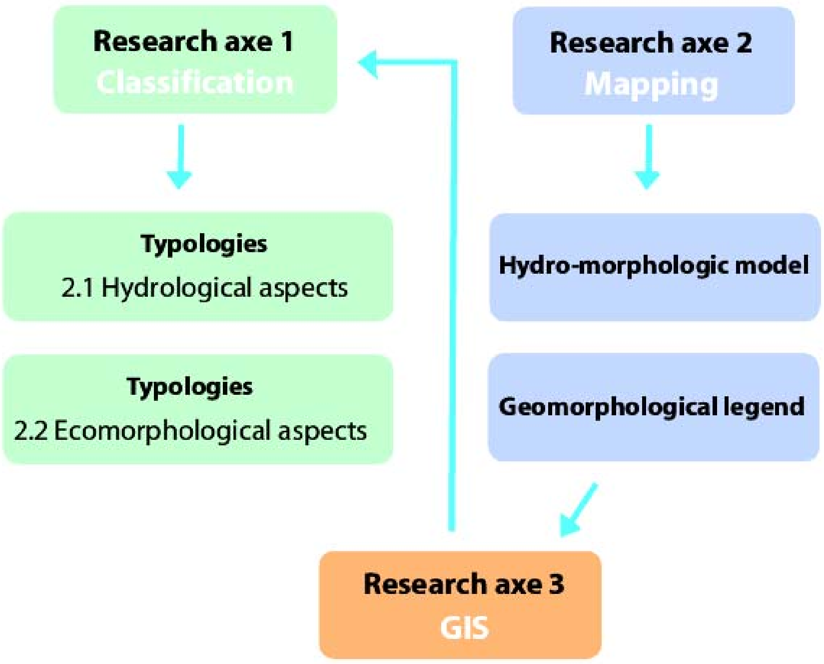
The aims of the thesis, that is planned to be undertaken between 2006 and 2009, are:

1. to classify the Rhone River sub-basins following their sensitivity to fluvial and torrential erosional processes and their ecomorphological situation (research axe 1);

2. to carry out a hydro-morphological mapping conceptual model at the catchment scale and to develop a specific geomorphological legend (research axe 2);

3. to test the method in several study sites by implementing the geomorphological legend in a GIS environment and by including different raster and vector data layers (e.g. permafrost distribution

modelling, lithologic and tectonic data, historical events lists, geophysical investigation data, dendromorphological and hydrogeological data, etc.) (research axe 3).



Watershed classification

The recurrence of large floods since 1987 in Switzerland has already allowed meteorological areas where precipitations are more important than others to be defined. The first research axe aims to highlight the catchments sensitive to hydrous erosion in the canton of Valais. The Rhone river basin is divided into about 50 sub-catchments by using the subdivision already established for the sanitation of rivers modified by hydropower infrastructures (MINERVE project, Boillat 2005). A classification has already been tested, based on two parameters: the Strahler order (that "translates" the hierarchy or the complexity of the hydrographical network) and the catchment surface. A more complex classification will be established, based upon several other parameters like slopes, slope cover and land use, floating wood, lithological and tectonic structures, rates of flow, permafrost distribution, glacier cover, etc.

A second classification will also be carried out and aims to define the ecomorphological conditions of the Rhone River sub-basins.

Geomorphologic mapping tools

The second research axe concerns geomorphology. Currently, geomorphologic mapping is one of the main research interests of the Institute of Geography at the University of Lausanne that has developed its own legend based on various European legend systems (Schoeneich 1993, Schoeneich et al. 1998). It was created to establish a simple, coherent and easily interpretable mapping system. The legend represents landforms by their genesis, then by their dynamics (distinction between erosion (white zones in the map) and accumulation landforms (coloured zones)). The geomorphological legend has been used in the Swiss Alps for twenty years (Schoeneich et al. 1998, Gentizon et al. 2000). In fact, the legend is mostly used for inventories and the management of landforms or nature and landscape protection and it is not sufficient to appreciate very dynamic processes like debris flows.

The second research axe aims at developing a conceptual geomorphic model (fig. 9) based on an “erosion system” from the top (rock escarpments, free faces in high altitude) downwards (alluvial fans, flood plain and scree cones, etc.). The aim is to consider the slope as a succession of connected reservoir subsystems varying in storage period and emptying velocity. These reservoirs depict glacial processes and landforms (till accumulation, morainic bastions, etc.), periglacial processes (permafrost creeping, rock glaciers, solifluction, etc.), gravitational processes (landslides, rock falls, etc.), fluvial processes (debris flows, alluvial fans, etc.) and snow processes (snow avalanche deposits). This methodological approach has already been tested to quantify the postglacial sediment filling of alpine valleys (Schrott et al. 2003).

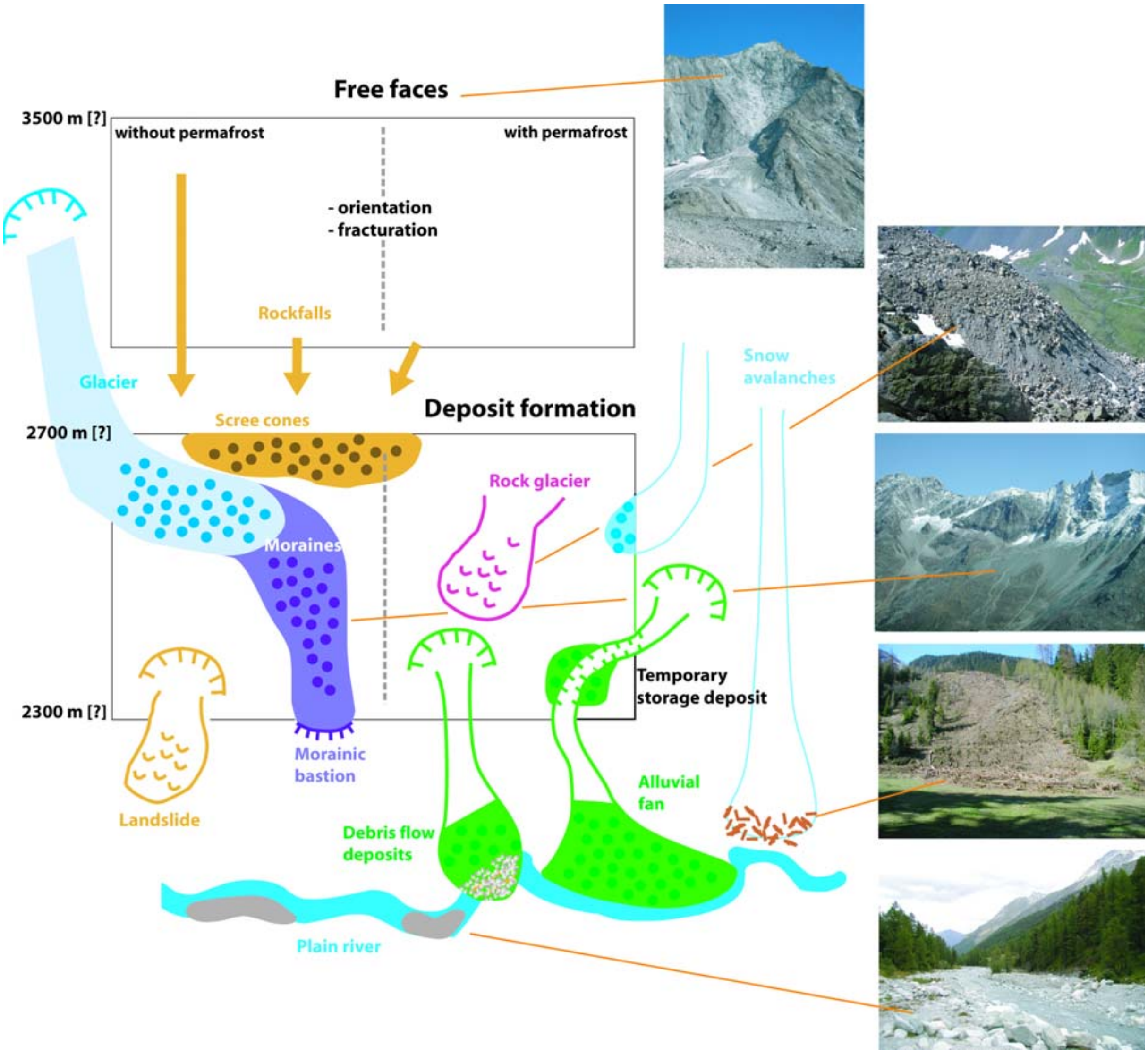


Figure 9 Conceptual approach of the slope system and development of a hydro-morphological model.

A specific, dynamic oriented geomorphological legend is then developed from the conceptual model. It integrates the dynamic character and the temporal evolution of landforms. It is also envisaged to integrate the problematic of floating wood. The legend will be able to complete some aspects of existing legends to consider all of the factors governing sediment transfers.

Implementation in a GIS system

The third research axe concerns geographical information systems (GIS). The GIS environment will be largely required, in particular for spatial analysis to classify the catchments (research axe 1), geomorphological legend implementation (research axe 2) and integration of non-geomorphological data (research axe 3). Implementation of geomorphologic maps in GIS has given good results, in particular in periglacial research fields (Gentizon et al. 2001). It allows several levels of information to be stored and provides a methodology of sorting in meta-data. Non-cartographic data (e.g. flood events, dendrogeomorphological data, forest quality and potential wood floating, geophysical profiles, etc.) should also be included in the database in order to serve as a tool for hydrological risk previsions.

PERSPECTIVES

The three main objectives of the study – catchment classification relative to the sensitivity to water erosion, a specific geomorphological legend developed for precise mapping at the catchment scale, integrated implementation of cartographic and non-cartographic data in a GIS environment – should contribuate towards a better prediction of natural hazards. More specifically, the study results will provide tools to be integrated in an alarm strategy at the catchment scale that is currently being developed by the cantonal authorities. Finally, as hazards maps will not be achieved before 2010, the authorities have shown some interest in using this future innovating mapping system.

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