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VULNERABILITY MAPPING IN KARST AREAS AND ITS USES IN SWITZERLAND

KARTIRANJE RANLJIVOSTI KRAŠKIH PODROČIJ IN NJEGOVA UPORABA V ŠVICI

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Jean-Pierre Tripet & Nathalie Doerfliger & François Zwahlen & Cyril Delporte: Kartiranje ranljivosti kraških področij in njegova uporaba v Švici[1]

Švicarski državni hidrološki in geološki zavod razvija nov pristop k izdelavi zaščitnih con vodonosnikov na kraških področjih. Zaradi specifičnoh hidrogeoloških značilnosti kraških vodonosnikov so na krasu potrebni tudi posebni zaščitni ukrepi. Zaščitna območja, začrtana na podlagi obstoječih smernic, ki ne upoštevajo specifike kraškega prostora, so pogosto neprimerna. Nedavno predstavljena metoda "EPIK" temelji na kartiranju ranljivosti zbirnega področja vodnega vira in upošteva več faktorjev ranljivosti: epikras, zaščitni pokrov, pogoje infilracije in razvitost krasa. Kot praktični primer je predstavljeno območje Saint-Imier na področju Jure.
Ključne besede: kras, kartiranje ranljivosti, zaščitne cone, metoda EPIK, Švica, Jura.

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Jean-Pierre Tripet & Nathalie Doerfliger & François Zwahlen & Cyril Delporte: Vulnerability mapping in karst areas and its uses in Switzerland[1]

A new approach for delineating protection zones in karst regions based upon vulnerability mapping of catchment areas is being developed at the Swiss National Hydrological and Geological Survey. Due to the particular hydrogeological characteristics of karst aquifers, specific protection measures are required. Protection zones in karst delineated on the basis of existing guidelines generally do not take into consideration hydrogeological factors, and therefore provide only limited efficiency. The newly proposed "EPIK" method is based on vulnerability mapping of the catchment area of the source, where various objective vulnerability factors are taken into consideration: epikarst (E), protective cover (P), infiltration conditions (I), and karstic network (K). A field application on the case of Saint-Imier pilot area is presented.
Key words: Karst, vulnerability mapping, water protection zones, EPIK method, Switzerland, Jura.

[1] *This text is an extended summary of an article published in BRGM 3, 1997*

INTRODUCTION

The basis for surface water and groundwater protection in Switzerland is set out in the Federal Law on Water Protection. The 1971 law has been totally revised and a new Federal law, which came into effect in November 1992, places more emphasis on the protection of natural waters from a quantitative and qualitative (preventive measures) stand-point. The regulations related to the implementation of the new law are still in preparation and new guidelines have to be established. The responsibility for the enforcement of the law rests largely with the Cantons, the Federal Authorities having mainly a co-ordinating role.

The cantons define the protection zones for the public drinking sources. The necessary investigations and the payment of possible compensation are the responsibility of the owner of the waterworks. The regulations impose the delineation of three different zones: S1 to protect the waterworks structure against damage and prevent the direct entry of pollutants into the groundwater; S2 to protect against microbiological and non-degradable pollutants and to allow adequate time and space for the necessary action in the event of an accident; S3 to provide additional safety. The three zones are subject to specific land-use restrictions relating to the protection objectives: in S1, practically no activity is allowed; in S2, there is less restriction but, among other things, construction works are not permitted; in S3, quarrying and waste disposal are forbidden and industrial plants are subject to restriction.

In order to assist the enforcement of the new Law on Water Protection, the Swiss National Hydrological and Geological Survey, SNHGS, of the Swiss Agency for the Environment, Forests and Landscapes, SAEFL, is carrying out a number of studies aimed at improving groundwater protection in karst areas. For example, SNHGS, together with another unit of SAEFL and the University of Neuchâtel, is developing a new approach based on vulnerability mapping of the catchment areas of sources for delineating protection zones in karst regions. The aim of this paper is to explain the rationale for the choice of this approach, present an outline of the method and comment on the first field applications.

IMPORTANCE OF THE PROTECTION OF KARST WATER IN SWITZERLAND

Groundwater from karst aquifers plays a major role in the water supply of large regions in Switzerland, and consequently in their development and economy, particularly in the Jura range, the northern slopes of the Alps and some areas of southeastern Switzerland (Austroalpine area). In these mountainous regions, agricultural and forestry activities are common, and in many cases, industry and tourism are very important for the economy. Karst groundwater provides a major part of the public drinking water supply to a number of communities; in the Canton of Neuchâtel, for example, karst waters from springs and wells provide nearly 2/3 of the drinking water supply.

Karst waters in Switzerland are often of high enough quality that only simple water treatment is needed before its use. However, quality is often impaired during flood periods; for example, an undesirable increase of turbidity or organic matter content is common. Moreover, groundwater in karst areas is particularly sensitive to human impacts. This vulnerability is related to the specific character of groundwater flow in karst aquifers, which is highly heterogeneous in space and variable in time.

Therefore, in Switzerland, as in many other regions where karst water is a natural resource justifying protection, specific protection measures are required due to the particular hydrogeological characteristics of karst aquifers. Protection zones delineated in karst areas on the basis of existing guidelines generally do not take hydrogeological factors into consideration and consequently provide only limited efficacy. In view of the need for a new approach, a critical review of the hydrogeological factors controlling the distribution and natural movement of groundwater in karst aquifers has been carried out, the results of which are summarized in the next section.

HYDROGEOLOGICAL FACTORS AND DELINEATION OF GROUNDWATER PROTECTION ZONES IN KARST REGIONS

Karst aquifers have distinct characteristics and a specific hydrological regime. Common characteristics of karstic drainage basins include: little or no surface drainage, swallow holes and sinking streams, an underground karstic network of open joints or conduits, and groundwater discharge through point sources. The hydrological regime is governed by highly heterogeneous flow conditions: high hydraulic conductivities in open joints and conduits contrasting with low conductivities in more compact rock on the one hand, and point infiltration (e.g. through swallow holes) and diffuse percolation of meteoric water on the other. As a result, the specific regime of karst springs shows marked flood peaks of short duration followed by a slow depletion curve.

Based on these criteria, a conceptual model of a karst aquifer (Fig. 1) was established comprising a network of connected joints and conduits ("karstic network") in a more compact, less pervious fissured rock. During flood periods the neighbouring fissured medium is recharged by the karstic network, whereas during low-water periods, it is drained by the network.

The sensitivity (or "vulnerability") of a groundwater source to human impacts depends on the purification capacity of the aquifer and on the travel time of the groundwater. Due to the extremely heterogeneous hydrological behaviour of groundwater flow in karst environments, the water reaching a source represents the mixing of different components with varying respective volumes and aquifer-residence times. For instance, field studies in Switzerland (Tabular Jura) have shown that diffuse percolation of rain water directly into the more compact rock represents more than half the total aquifer recharge; this recharge component is subject to natural self-cleaning processes which, depending on the regional conditions, can be significant. The other recharge component is point infiltration directly into the karstic network (DOERFLIGER & ZWAHLEN 1999). As a result, the residence time of groundwater is not a direct function of the distance between a given point of the catchment and the source. The concentric protection zones in porous media, with the degree of restriction and control on development decreasing with distance from the source, are not applicable to karst aquifers.

For these reasons, a specific approach for delineating groundwater-protection zones in karst areas based on vulnerability has been proposed in Switzerland. This strategy has also been considered and recommended in the framework of a research programme of the European Commission, COST Action 65 (HOETZL *et al*. 1995). An outline of the "EPIK" method developed in Switzerland is given in the next section.

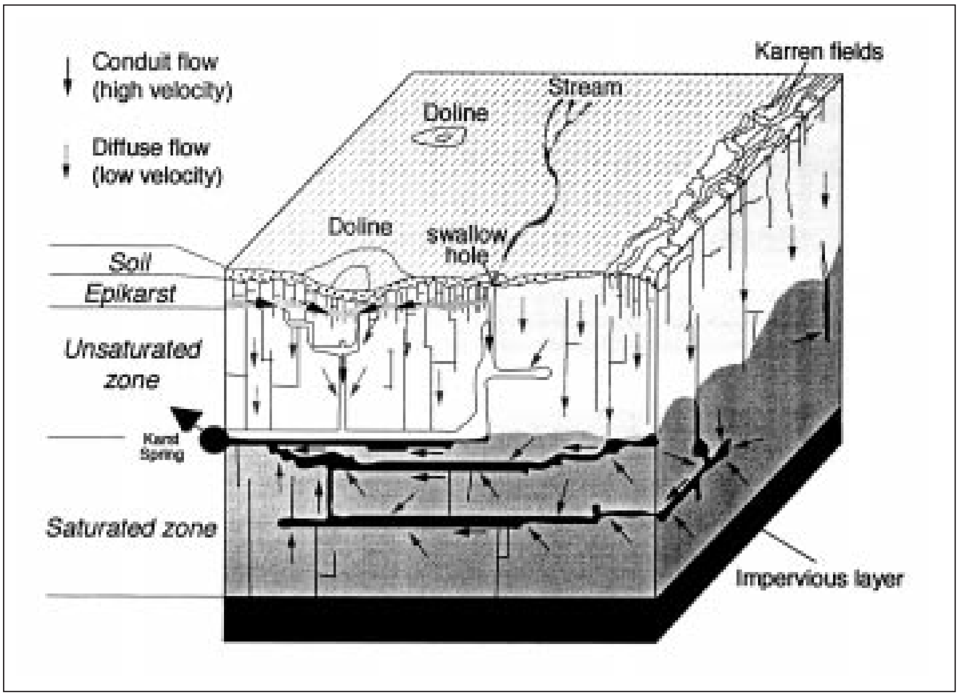

Fig. 1: Conceptual model of a karst aquifer (low-water conditions).
Sl. 1: Konceptualni model kraškega vodonosnika ob nizki vodi.

VULNERABILITY MAPPING IN KARST AREAS, THE "EPIK" METHOD

Outline of the method

The EPIK method, developed by the University of Neuchâtel at the request of the SNHGS and SAEFL, takes into account the most recent knowledge of flow conditions in karst aquifers. The source protection zones delineated on this basis take into consideration hydrogeological factors and follow objective criteria so as to provide a groundwater protection strategy applicable to land-use planning.

The method is based upon vulnerability mapping of the catchment area of a source (spring or well), taking various objective factors into consideration. Vulnerability is defined here as the intrinsic property of an aquifer (geological, geomorphological and hydrogeological characteristics), which determines the sensitivity of groundwater to contamination by human activities. Both point and diffuse contamination are taken into account, as are the various types of contaminants at a global scale.

An analysis of the hydrodynamic behaviour of karst aquifers has shown that vulnerability as defined above depends on the following four factors: the epikarst ("E", an intensively karstified and highly permeable near-surface zone), the protective cover ("P"), the infiltration conditions ("I", diffuse or point) and the karstic network ("K"). The evaluation of these factors makes it possible to characterize the vulnerability.

Four successive steps are used for vulnerability evaluation and mapping, and for delimiting the groundwater protection zones:

1. Delineation of the catchment area of the source (spring or well).
2. Evaluation of the vulnerability factors (E, P, I and K) for each surface unit of the catchment. The evaluation is semi-quantitative, by means of classification indices. The size of the surface unit depends on the accuracy required, which in turn depends on the local geological conditions. For each factor, a map showing the spatial distribution of the indices is established.

   The criteria for the semi-quantitative evolution of these factors are summarized below:

   Epikarst, E
   E1: epikarst connected to the karstic network
   E2: intermediate case
   E3: epikarst absent

   Protective cover, P
   P1: no protective cover
   P2: intermediate case
   P3: intermediate case
   P4: low-permeability cover

   Infiltration conditions, I
   I1**:** point infiltration
   I2: intermediate case
   I3: diffuse infiltration

   Karstic network, K
   K1: presence of a well-developed karstic network
   K2: presence of a poorly developed karstic network
   K3: spring located in a porous medium recharged by a karst aquifer

3. Evaluation of the protection factor ("F") for each surface unit of the catchment. F is calculated by adding up the values of the factors E, P, I and K and applying a specific constant coefficient ("weighting coefficient") for each of the indices mentioned above.
4. Vulnerability ranking for each unit surface of the catchment. Four vulnerability classes based on the values of F are carefully defined and plotted on a map showing the spatial distribution of vulnerability. Their mapped limits are used to assign the different protection zones, S1, S2 and S3, defined in the Swiss regulations, with the fourth class corresponding to low-vulnerability areas of the catchment.

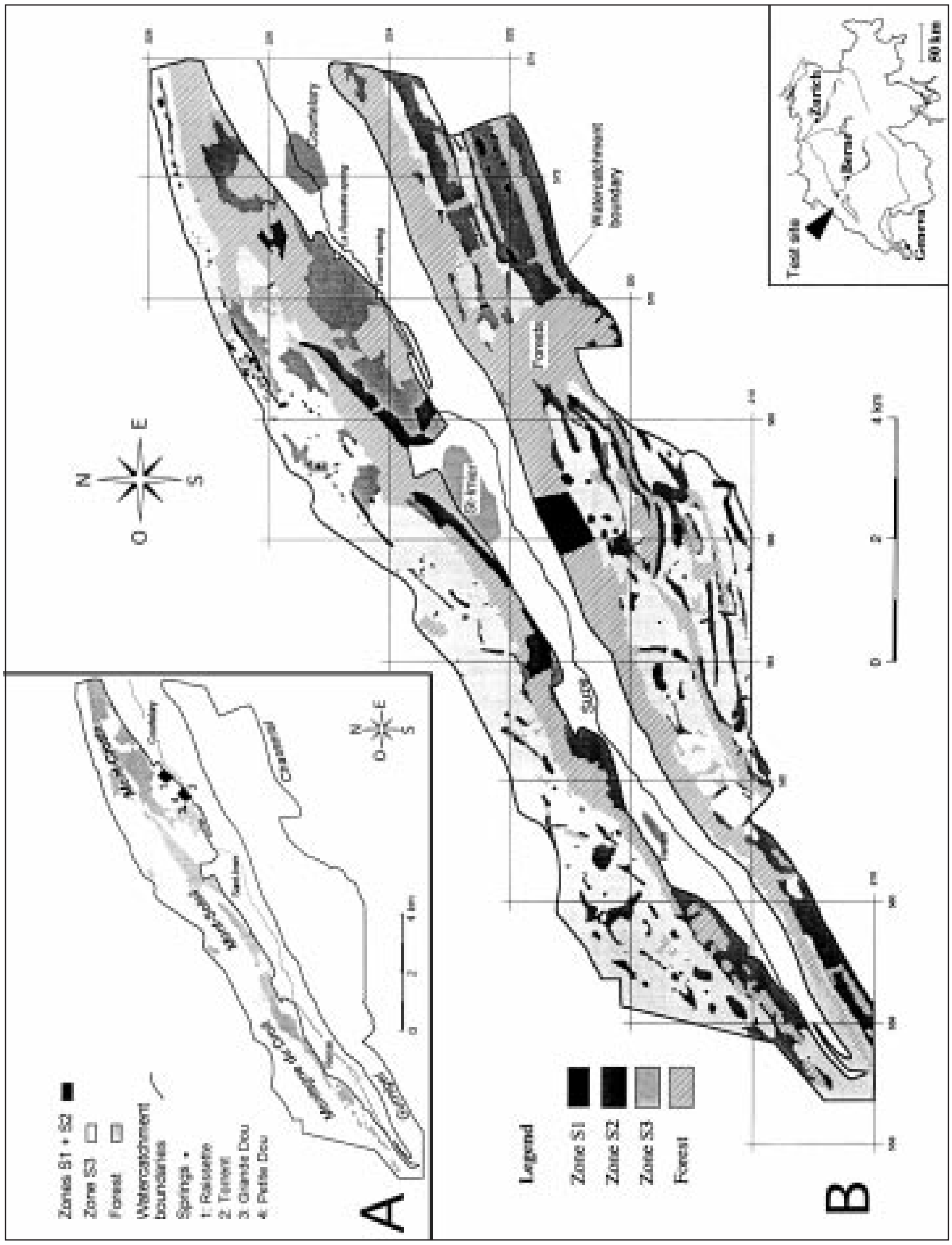

Fig. 2 : Saint-Imier pilot area : investigated catchment (DOERFLIGER & ZWAHLEN 1997)
Box A : Present protection zones, based on the existing guidelines.
Sl. 2: Pilotno področje Saint-Imier; raziskovano zbirno področje (Doelfinger & Zwahlen, 1997);
A - zaščitna cona po obstoječih smernicah.

FIELD APPLICATION: SAINT-IMIER PILOT AREA

Vulnerability mapping has been carried out within the catchment of a group of springs used for water supply in the folded Jura region (Commune of Saint-Imier, Canton Berne).

The EPIK method has been carried out in this catchment (Fig. 2) based on the following invetstigation methods:

Epikarst: analysis of aerial photographs, field surveying, analysis of geomorphological factors.

Protective cover (in the pilot area, the cover consists mainly of soil overlying karstic limestones): field surveying (emphasis on geological and geomorphological factors), analysis of topographic maps, drilling programme with hand auger.

Infiltration conditions: analysis of aerial photographs and of topographic maps at 1:10,000 scale, field surveying.

Karstic network: analysis of daily discharge of one spring (daily points measurements), brief rainfall-discharge correlation, analysis of the results of existing tracer tests.

For map processing, a Geographic Information System (GIS) was used, making it possible to significantly reduce the data analysis time; the testing of the method (adjustment of the weighting coefficients, sensitivity analyses) would have been extremely time consuming without the GIS.

The resultant groundwater-protection zones are shown in Figure 2 B. The pilot study has confirmed the suitability of the new approach and shown that the costs are similar to those for perviously used methods. The adjustment of the weighting coefficients and analysis of the equivalence between the vulnerability classes and protection zones is still being improved; for this, additional tracer tests are being carried out and quantitatively analysed.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The new EPIK approach for delineating groundwater-protection zones in karst areas based upon vulnerability mapping takes hydrogeological factors into account and a better source protection is expected as a result.

Groundwater pollution in karst regions is not inevitable, and for an improved protection of this resource, priority must be given to prevention; preventive measures are preferable to complex drinking-water treatment plants. It is the duty of hydrogeologists to convince the specialists concerned that improved protection of karst aquifers is not only a necessary objective, but also a feasible one; the new EPIK approach could contribute to the achievement of this objective.

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KARTIRANJE RANLJIVOSTI KRAŠKIH PODROČIJ IN NJEGOVA UPORABA V ŠVICI

Povzetek

Nova metoda za določanje varstvenih pasov za talno vodo na krasu, EPIK, ki temelji na kartiranju ranljivosti ob upoštevanju hidrogeoloških faktorjev, bo gotovo pripomogla k boljšemu varovanju kraških izvirov.

Onesnaževanje talne vode na kraških področjih ni neizogibno in za izboljšanje varovanja tega naravnega vira mora imeti prednost preprečevanje; veliko bolje je preprčevati onesnaženje, kot pa graditi kompleksne naprave za pripravljanje pitne vode. Dolžnost hidrogeologov je prepričati ustrezne strokovnjake, da izboljšanje varovanja kraških vodonosnikov ni le nujen ukrep, ampak je tudi izvedljivo. In nova metoda EPIK lahko pripomore k doseganju tega cilja.

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