Resiltherm
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Resilience of hydrothermal systems against natural and anthropogenic disturbances. Concept of the RESILTHERM project

Generally speaking, the term "resilience" is used for indicating a dynamic characteristic of a system, namely elasticity, physicists being the first ones to have adopted it. The first use of the resilience concept with reference to ecosystems was due to Holling (1973), who suggested that the ecological systems behaviour should be described by means of two distinct properties: resilience and stability. His concept is expressed as "Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes and still persist. In this definition resilience is the property of the system and persistence or probability of extinction is the result. Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is. In this definition stability is the property and the degree of fluctuation around a specific state the result."

The term "resilience" was further introduced in hydrology by Hashimoto *et al.* (1982), who for the water resources systems performance evaluation have adopted three distinct criteria. They are: *reliability* (the probability that the system will remain in a non-failure state), *resilience* (the ability of the system to return to non-failure state after a failure has occurred) and *vulnerability* (the likely damage of a failure event). Subsequently, the resilience concept started to be used in various fields, among which strategies for devising programs aimed at disaster risk mitigation (Bosher & Dainty, 2011; Manyena, 2006). Research centers, like the Stockholm Resilience Center for instance, as well as important scientific events (e.g., Hooper & Foufoula-Georgiou, 2008) and NSW IAH Symposium 2011 – Uncertainty in Hydrogeology are dedicated to this concept.

Research topics addressing the systems resilience are developing at the present time in three main directions: (1) ecological systems, among which a central place is occupied by resilience of microbial systems (e.g., Botton *et al.*, 2006); (2) social-ecological systems (e.g., Nelson *et al.*, 2007; Serrat-Capdevila *et al.*, 2009); (3) water resource systems. Within that latter research direction, concern is almost exclusively focused on the resilience of aquifers that undergo climate change stresses (e.g., Ajami *et al.*, 2008; Fowler *et al.*, 2003; Heimlich *et al.*, 2009; Jain & Bhunya, 2008; Kjeldsen & Rosbjerg, 2004; Peterson, 2009; Wagener *et al.*, 2010; Wang *et al.*, 2010).

Generally speaking, a system displays a series of specific characteristics and certain processes take place within it. If subject to certain disturbances, the system has the ability to undergo continuous changes and to adapt itself to the new circumstances in order to remain, as a result, within certain critical thresholds. Otherwise stated, the system exhibits resilience (Fig. 1.1). In order to remain within certain functionality limits, the system modifies its characteristics and the processes evolve in a certain sense. If a major external stress intervenes,

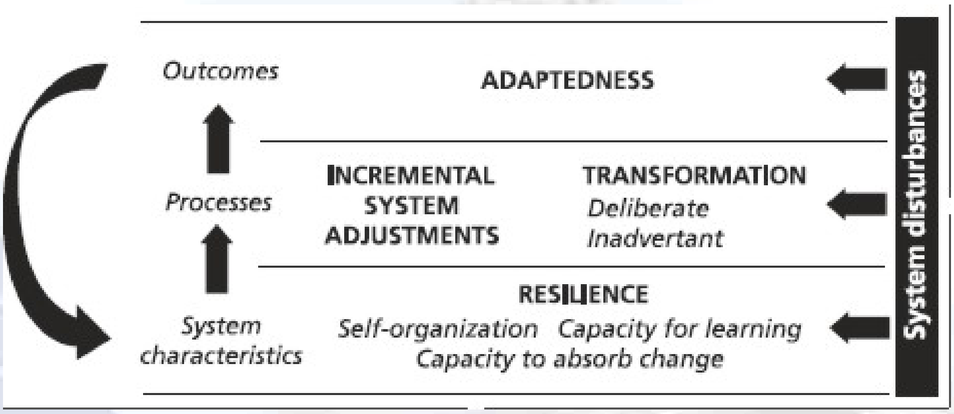

Fig. 1.1 – Characteristics, processes, and outcomes of resilience actions (after NELSON *et al.*, 2007).

the system self-organization capacity can be exceeded and as a result the system adapts to the new circumstances by correspondingly exhibiting characteristics which are different from the initial ones, then this cycle is resumed.

The present project aims to utilize the resilience concept for the characterization of the hydrothermal structures behaviour. Like any natural system, a hydrothermal structure exhibits specific hydrogeological, chemical and microbiological properties, and a series of characteristic geochemical and biogeochemical reactions are taking place in its framework. When subject to external perturbations, those reactions will obviously assume a certain direction of evolution and dynamics of propagation, and the hydrological, chemical and biological characteristics will be modified accordingly.

The aim of the present project is to acquire a fundamental understanding of the way by which hydrothermal systems behave when subject to natural and anthropogenic external disturbances, and to outline and quantify those hydrological, chemical and microbiological parameters which could be able to provide a general instrument for evaluating the resilience of those systems.

In order to achieve this goal, our intention is to perform an investigation, as extended as possible, of a very important and quite distinct hydrothermal structure in Romania, namely the thermo-mineral water accumulation at Băile Herculane, and to consequently acquire a background allowing us to devise concepts and conclusions whose applicability should be of general validity for any similar setting occurring worldwide.

The thermal aquifer in Băile Herculane area develops within reservoir rocks consisting of Late Jurassic limestone and of the underlying, highly fractured Cerna granite. Early–Late Cretaceous impervious deposits (Iuta layers and wildflysch) locally overlie the limestone. All those formations are included in two distinct, elongated (several kilometers long, for just a few hundreds meters wide), essentially N-S trending structures: the Cerna graben and the eastern limb of the Cerna syncline (NĂSTASEANU, 1982). Both structures plunge southward, with the syncline presumably further extending beneath an overthrust unit (the Presacina Nappe, that consists of crystalline schists), while the graben is still outcropping nearby.

A long sequence of sulfide-rich thermal water outlets (14 natural springs and 11 drilled wells) is distributed along the Cerna valley streambed, cumulatively discharging a minimum (98% confidence level) of 55 L/s. Water is of sodium chloride type (except for the northernmost well “Ghizela”, which is of calcium bicarbonate type), with outlet temperatures ranging between 38 °C and 60 °C (MARIN, 1984). So far, there is no information concerning the microbiological content of those water discharges. Tracer tests have indicated that small swallets/sinking streams high in the mountains recharge the thermal water reservoir in the Băile Herculane area (GAŞPAR & SIMION, 1985; POVARĂ, 1980; POVARĂ & LASCU, 1978).

The outflow of the largest natural discharge – Hercules spring – obviously involves a mixture between local, low TDS meteoric recharge conveyed via a shallow karst aquifer, and highly mineralized up-flows of deep origin: in response to meteoric water inputs (significant rainfall or snowmelt) the spring flow-rate increases, while its temperature and TDS content correspondingly decline. There has been inferred (BULGĂR & POVARĂ, 1978) that out of the two distinct supply sources of Hercules spring, only the shallow one was sensitive to meteoric recharge pulses,

Table 1.1 – **List of features, events and processes (FEPs) relevant with regard to resilience of a hydrothermal system.**

Structured FEPs classification
System understanding
– Hydrogeology of host rock and embedding formation
– Mineralogy of rocks
– Groundwater chemical and stable isotope composition
– Groundwater microbiology
– Water residence times in host formation
Reaction mechanisms
– Speciation of the elements in solution
– Sorption/adsorption to particulate phases
– Dissolution/precipitation
– Ion exchange/surface complexation
– Geomicrobiological processes
Transport mechanisms
– Advection/dispersion
– Diffusion
– Nanoparticles formation and transport

while the deep origin saline fluid was virtually insensitive to such external influences. Yet further investigations (POVARĂ & MARIN, 1984) suggested that the interplay between those two end-member components could be more complex.

A somehow analogous mixing process probably occurs also for other thermal discharges - although subject to much more stable mixing-ratios. Nevertheless, the phenomena possibly involved in shaping the physical-chemical "profile" of the deep-origin, saline parent-water are still a matter of debate (COSMA *et al.*, 2008; POVARĂ *et al.*, 2008; WYNN *et al.*, 2010).

For the present study, by considering the natural setting within which the thermo-mineral groundwater accumulation at Băile Herculane develops, we identify and we take into account the following disturbances as being potentially liable to influence its properties:

- **Natural perturbations**

– Geomechanical perturbations induced by seismo-tectonic processes;

– Hydrological perturbations due to the karst groundwater-flow of that area;

– Thermal perturbations related to the deep source of the local, thermally anomalous regime;

– Perturbations from coupled processes;

- **Anthropogenic perturbations**

– Perturbations resulting from the presence, in the region of the thermal water accumulation, of the "Prisaca" reservoir Lake and of its associated hydropower plant facilities;

– Perturbations generated by an inadequate exploitation of the thermal groundwater resources.

In order to evaluate the effects that a thermal hydrostructure in general, and the one at Băile Herculane in particular, may experience as a result of the various above-listed perturbations, we estimate that the features, events and processes (FEPs) indicated in Table 1.1 must be considered.

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