Swisskarst Project – toward a sustainable management of karst water in Switzerland. Application to the Bernese Jura

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Abstract: Karst groundwater represents about 80 % of Swiss groundwater reserves and about 50 % of groundwater resources. Paradoxically these reserves/resources are badly documented which leads to a non-optimal management of karst systems. In the framework of the NRP61, supported by SNF, SISKA develops and applies a dedicated and systematic approach (named KARSYS) for documenting karst system in Switzerland. This approach is currently applied in the frame of the SWISSKARST project (started in 2010) to cover the Swiss territory.

We focus here on a recent application of KARSYS in the Bernese Jura, which represents around 540 km^2 of karst area and encloses more than 50 000 inhabitants. This region strictly depends on karst water for drinking supply and industrial purposes. Seventeen strategic karst springs emerging from the Malm aquifer are harvested by communities for drinking water. In addition, pumping wells have been recently drilled to reinforce this supply. In spite of many hydrogeological studies, delineation of the respective spring catchment areas remains unclear inducing difficulties in the implementation of protection rules.

Thanks to the additional funding provided by the AWA (Amt für Wasser und Abfall des Kantons Bern), SISKA applied KARSYS on the Malm aquifer and built a 3D geological model of the regional aquifer basement. Hydraulic features have been analyzed and added into the model to highlight the location and extension of groundwater bodies. Seven main karst groundwater bodies have been identified and their geometry was depicted in 3D: Saint-Imier, Tavannes, Moutier, Bellelay, Diesse, Orvin and Mont-Sujet. The total capacity of karst groundwater reserves reaches about 2.2 km^3 assuming an average porosity value of 2 %. This is twice the water volume of Lake Biel.

Results provide an understanding of flow mechanisms at regional scale as well as interactions occurring between adjacent or even between remote systems. It also reveals new questions and identifies places where investigation should be conducted in order to precise the proposed delineation of the karst systems and improve the protection of these water resources.

Key words: KARSYS, SWISSKARST; karst aquifer, karst groundwater body, Jura, Bern, Switzerland

Intoduction [1 2]

Many studies have been dedicated to the hydrogeology of the Bernese Jura, especially in connection with tunnel constructions (Grenchenberg: BUXTORF & BRAM, 1916, Pierre Pertuis: KELLERHALS, 1992, Twann: KELLERHALS, 1976 and further...), highway management (Transjurane: KELLERHALS, 1985, and others), water supply (deep boreholes and hydrogeological prospection: SCHINDLER, 1977, MFR GÉOLOGIE-GÉOTECHNIQUE SA, 1998, delineation of S zones: KELLERHALS & TRÖHLER, 1979…) or academic works (HÄFELI, 1964, AUFRANC, 1985). They provide good geological and hydrogeological materials to understand groundwater mechanisms. However there is no consensual work which gathers these data or interpreted information at the scale of the entire massif in order to give a systematic and pragmatic overview of karst groundwater reserves and flow. In the framework of the SWISSKARST project (NRP61), SISKA applied the KARSYS approach to the entire territory, and could therefore document these aquifers by the mean of a systematic process based on relevant literature and data, which were compiled and synthesized.

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The Bernese Jura – a complex karst area

The Bernese Jura belongs to the Northern part of the folded Jura (cf. Figure 1) jammed between the French boundary and Lake Biel and oriented along the ENE-WSW direction. Three main valleys expand within the massif according to the main regional thrusts and folding: St-Imier, Tavannes and Moutier. They include most of activities and residents. Surface stream networks show a multi-directional drainage. The most southern part (Diesse, Tüscherz-Alfermée) is drained towards Lake Biel while areas of Saint-Imier, Cortébert, la Heutte and Orvin are drained by the Suze river. North-eastern parts are drained through the Birse River (Tramelan, Tavannes, Court, Moutier) or the Sorne river (Souboz, Bellelay) towards Basel. Both belong to the catchment of the Rhine River and meet together in the Delémont region. The most North-western part of the Bernese Jura

(La Ferrière) is drained towards the Doubs River (Rhône catchment). These rivers are mainly fed by numerous perennial karst springs (Table 1) which contribute significantly to their discharge.

Despite a large number of studies and deep investigations (boreholes, tunnels…) catchment areas of these springs are still not well defined and several boundaries remain very unclear.

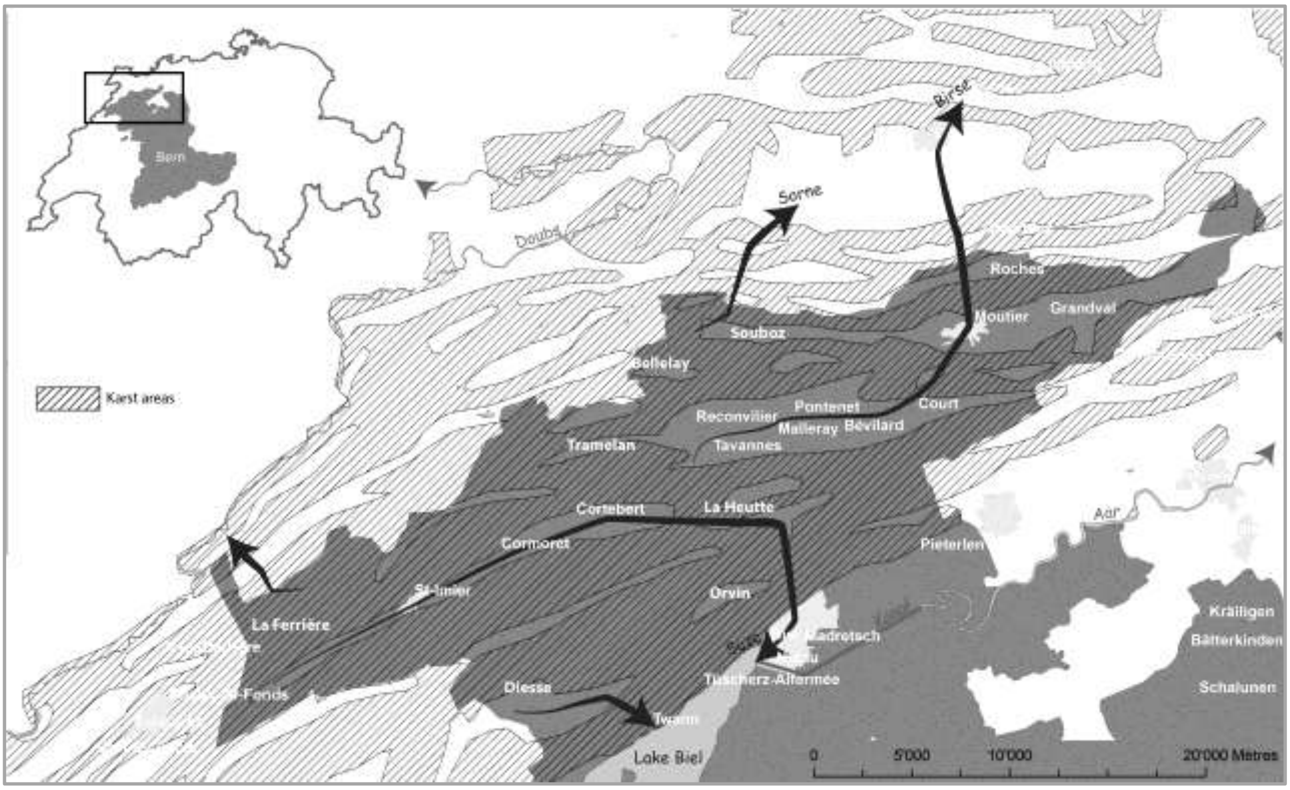

Fig. 1: Three main rivers drain the Bernese Jura: the Birse, the Suze and to some extends the Sorne. Locally flows are driven underground directly towards the lake Biel and the Doubs River.

Springs	Coord X (m)	Coord Y (m)	Elevation (m a.s.l)	Mean discharge rate (L/s)	Supplied rivers
Bez	576992	225585	710	200 to 500	Suze
Dou	569590	224215	746	More than 1000	
Merlin	585863	224381	530	200 to 500	
Romerquelle	585310	221325	455	50 to 200	
Torrent	570084	224153	719	50 to 200	
Cuchatte	580890	226551	636	50 to 200	
Raissette	570725	224845	725	200 to 500	
Foule	593538	235338	559	200 to 500	Birse
Birse	581555	229221	771	50 to 200	
Envers	591915	231193	733	50 to 200	
Gore	601389	237855	744	50 to 200	
La-Tu	602473	238057	744	50 to 200	
Etang	600430	236279	638	50 to 200	
Blanches-Fontaines	583663	237656	580	500 to 1000	Sorne

Table 1: Rivers of the Bernese Jura are mainly fed by various karst springs.

Identification of the main regional aquifer

Springs emerge from a limestone series limited at its bottom and possibly also at its top by aquiclude formations (usually marls). The first step is therefore to identify from which limestone series one particular spring emerges and, based on the geological literature to identify what impervious formation is expected to limit the bottom and the top of this aquifer. In the considered area springs of Blanches-Fontaines and Gore (sup) are the only ones emerging at the interface of the aquifer basement. Other springs overflow close to the top of the aquifer, where the overlaying Cretaceous or Molasse formations dam the limestone aquifer. This is the case for Brunnmühle, Moulin, Römer, Bez, Birse, Cuchatte-Tournedos, Dou-Torrent-Raissette, Envers, Etang, Foule, Grabenbach and Merlin. The spring of the Grenchen tunnel is an exception where water flows out of karst conduits intersected by the tunnel.

The Bernese Jura is composed of an alternation of limestone and marls from the lower Lias to the upper Jurassic with at least three limestone series being potential karst aquifers: Lias, Dogger and Malm. At some places (southern part) Cretaceous limestone series are also present (isolated from the Jurassic one by the Purbeckian marls). At the top of these formations Molasse deposits covered the entire Jura (overlaying the cretaceous formation in the South and the Jurassic ones in the North). These Tertiary deposits were deformed together with the Jura folding and faulting. They were protected from erosion in synclines where they are still present and sometimes overthrusted by upper limestone masses. The main karst aquifer of the Bernese Jura is composed by series of the Malm limestones: Portlandian, Kimmeridgian and Sequanian. The aquifer basement (or aquiclude) is constituted by the Argovian marls, here labeled as Effingen strata (cf. Figure 2), which isolates the Malm aquifer from the lower Dogger aquifer. This lower aquifer is less productive but obviously exchanges water at some locations with the Malm aquifer.

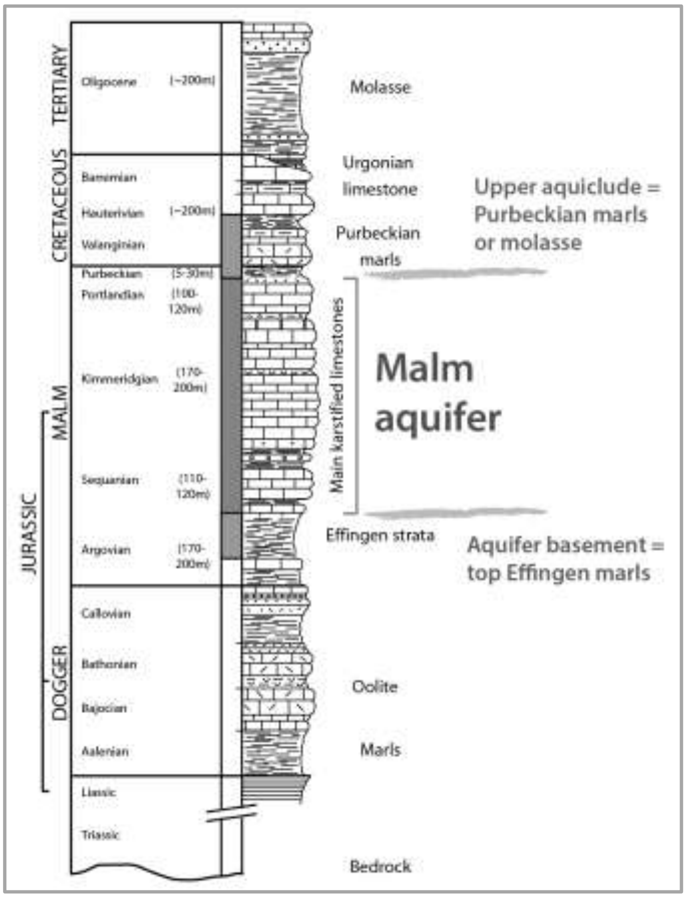

Fig. 2: In the Bernese Jura the main karst aquifer takes place in the Malm formations. The Effingen strata constitute the aquifer basement (adapted from DERIAZ et al. 2007).

Building up a 3D geological model to shape the aquifer basement

The Bernese Jura territory was divided into six square regions of 15 x 15 km. Each region was modeled with Geomodeller® software using 1/25 000 available geological map and 98 geological cross-sections collected among the literature. Seven geological formations have been considered. As their lithologies and thickness change from one region to another some of these formations are sometimes not distinguished and/or gathered under a same label (cf. Table 2). This implies that models show limitations in their geological details and could not be used for other purposes than karst-related questions.

Mol, C1-C2	Molasse and Cretaceous limestone – Purbekian marls on basis
i8	Portlandian limestone (Twannbach formation)
i7	Kimmeridgian limestone (Reuchenette and Balsthal formations)
i6	Sequanian limestone (Court Vellerat and Günsberg formations)
i5	Argovian marls (Effingen and Birmenstorf strata)
i4	Undifferentiated Dogger limestone
i3	Indicative Lias Formation

Table 2: Geological formations considered in modeling the Malm aquifer bottom (top of the Argovian marls) and top (bottom of overlaying Cretaceous and/or molassic formations).

The whole model construction is focused on approaching the geometry of the Malm aquifer basis (Argovian Marls) and top (Cretaceous and/or Molasse). In many places (mainly in valley) the top of the aquifer lies below the groundwater level, i.e. water is confined. Faults are included as long as they influence the geometry of the aquifer. When geological information of two nearby cross-sections is significantly different, preference is given to the author who contributed to the geological mapping of the area. Models are mainly constrained by surface data of the 1/25'000 geological maps. Data from the few existing boreholes and tunnels have been included for constraining the model at depth. However the density and the precision of the geological data decrease with depth.

Implementing hydrological features to assess the geometry of the groundwater bodies (GWB)

Some hydraulics principles are assumed in the KARSYS approach (JEANNIN et al. in print): (i) the aquifer volume below the main perennial springs is water saturated, (ii) the hydraulic gradient in the saturated zone is flat or inclined at most of 1 %. More than 70 karstic springs emerging from Malm aquifer and showing a significant discharge rate were implemented into the model. The elevation of each of them - as well as their relative discharge rate - were verified. Around 55 springs are considered as perennial, 15 as temporary or as estavelle. 21 deep boreholes reaching or passing through the aquifer and tagged with piezometric data (expected to give the level at low water stage) are also implemented. They are usually located in the core of the valleys, thus giving information on the thickness of the Molasse cover and the groundwater confinement.

From the perennial springs and water levels in boreholes horizontal plans are stretched through the karst media until they cross surface of the aquifer basement. They give the minimal extension of the saturated zone. In some cases the water table "overflows" over the top of the aquifer basis (e.g. over an anticline threshold or a pass) towards another karst system. Along one valley, if several springs are found at different elevation, and if there is no clear geological discontinuity which disconnects the groundwater body between them, the hydraulic gradient is adjusted to meet the elevation of each spring as far as the gradient remains lower than 1 %. The intersection between these water table plans and the top of the aquifer (non-karstic formations) gives the limit between unconfined and confined groundwater. The extension of the ground-water table is then controlled by emerging points (springs) on surface or subsurface (i.e. alluvial deposits) or by overflowing threshold over the aquifer basement.

Once groundwater bodies have been identified flows are determined. Two further characteristics of groundwater flow can be distinguished: (i) the catchment areas of surface runoff swallowing into the karst and vertical flow in the unsaturated zone, and (ii) main drainage axes at low (and high) water (solid lines in Figure 3) and drainage axes occurring only at high water stages. These flow lines are drawn according to the geometry of the aquifer basement in unsaturated areas and to the hydraulic gradient in the saturated zone. Most of them have been validated by results of dye tracer tests (226 connections or no-connections have been analyzed in the Bernese Jura). Organization of flows allows the delineation of catchment areas of all the main karst systems with well-defined boundaries when geological boundaries do exist and/or with diffluent areas where infiltrated water reaches a groundwater body (GWB) drained by two groups of springs or karst systems.

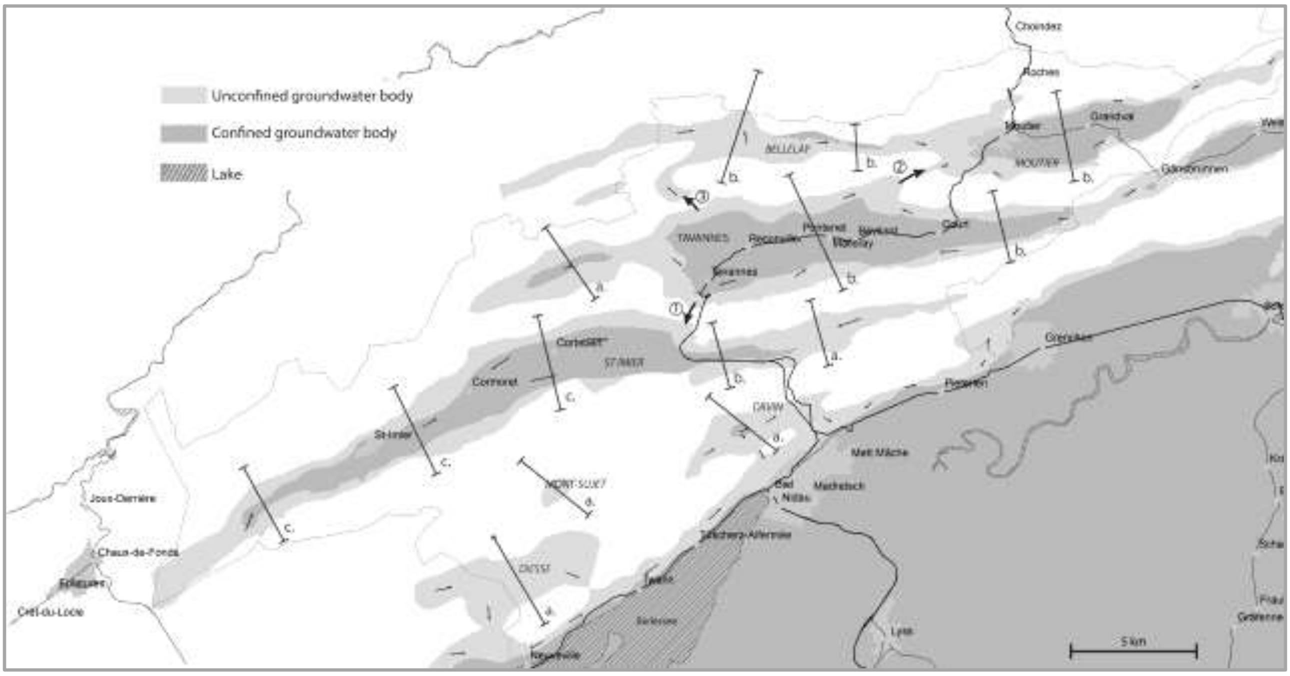

Fig 3: Location and extension of the main groundwater bodies identified in the Bernese Jura. Vertically three main profiles are distinguished (right): synform (a.) case of DIESSE, ORVIN, MONT-SUJET, west part of TAVANNES; simple faulted (b.) case of central TAVANNES, BELLELAY, MOUTIER; double faulted (c.) case of the west and central part of ST-IMIER. ①, ② and ③ represents overflow of the TAVANNES GWB over passes towards other GWB.

The application of the KARSYS approach allowed us to identify seven groundwater bodies in the Bernese Jura (without considering the one extending along the Jura foot). These are mapped on Figure 3. Three typical profiles are represented according to the structural geometry. The estimated water volume (reserve) strongly depends on the profile type. Table 3 summarizes characteristics of the seven groundwater bodies.

Flow lines show that MONT-SUJET and DIESSE GWB discharge toward Lake Biel while ST-IMIER and ORVIN GWB flow towards the Suze. The Northern BELLELAY and MOUTIER GWB discharge respectively towards the Sorne and the Birse rivers. Concerning the TAVANNES GWB, which is the upper one, flow arrows indicate overflow ① towards the ST-IMIER GWB over a threshold (or pass) in the Argovian marls at ~770 m a.s.l (back from the Birse spring) in the vicinity of the Pierre-Pertuis tunnel, Overflow ② leads water towards the MOUTIER GWB, over another pass in the Argovian marls under the village of Champoz at ~670 m a.s.l. Overflow ③ is a third threshold under the village of Le Fuet towards the Blanche-Fontaine GWB. The existence and elevation of this threshold is not confirmed and further investigations are suggested to understand hydrological mechanisms in this area. Therefore the TAVANNES GWB (the most elevated GWB) shows a multi-diffluent behavior in supplying both southern and northern valleys. These relations, except ③ have been confirmed by dye tracer tests (Pfirter et al. 1989, MFR Géologie-Géotechnique SA 2008). They bring new elements in the delineation of the Foule, Cuchatte-Tournedos and Blanches-Fontaines catchment areas, which are significantly enlarged, compared to previous studies which did suggest the ① and ② exchanges but did not predict the ③ one which may appear greatly significant for the groundwater management in the vicinity of Tavannes.

Conclusion

The application of the KARSYS approach to the entire Bernese Jura (540 km^2) documented and delineated 17 main karst systems draining the Malm aquifer, which are harvested by communities for supplying water. KARSYS made it possible to identify and delineate the extension of seven major groundwater bodies and precise their discharge outlets. The main underground flowpaths could be sketched for all systems, as well as interactions occurring between groundwater bodies. The TAVANNES GWB which is the central and most elevated GWB contributes to feed (i) towards the South the ST-IMIER GWB by overflowing over the Argovian marls threshold at the vicinity of the Birse spring (elevation ~770 m), (ii) towards the North-West to the MOUTIER GWB by overflowing the Argovian marls threshold under the town of Champoz and (iii) towards the North-East to the BELLELAY GWB by overflowing the Argovian marls threshold under the town of le Fuet. Further field investigations are encouraged to precise this third threshold and confirm this mechanism which may appear substantial to manage groundwater resources in the vicinity of Tavannes.

Results of this application to the Bernese Jura are available on the www.swisskarst.ch website.

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