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title: **Event based monitoring and early warning system for groundwater resources in alpine karst aquifers**

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BACKGROUND AND AIM OF RESEARCH

Water resources from alpine and other mountainous karst aquifers play an important role for water supply in many European countries. As regulated in the WFD (Water Framework Directive), karstic catchments require a sustainable protection. The increasing impact to such regions and the different utilization in the watersheds of karst springs are important reasons to establish early warning systems and quality assurance networks in water supplies. These systems rely heavily on in-situ measurements and online and near real-time availability of the data. With a satellite based networking of measuring and sampling stations it was possible to carry out precipitation triggered event monitoring campaigns at different karst springs (Stadler et al., 2010) combining on-line measurements of hydrological parameters with field-laboratory based analyses of microbial faecal indicators (Stadler et al., 2008).

The targets in the study were (1) to investigate the dynamic of chemical parameters, environmental isotopes and microbial faecal pollution indicators at a high resolution time scale during hydrological events, (2) to evaluate the in previous investigations established parameter SAC254 as an appropriate real-time pollution proxy for optimised spring water abstraction management within an early warning system and (3) to implement also automated sampling of event-causing precipitation in the catchment area to carry out isotopic analyses.

ORBCOMM SATELLITE SYSTEM

Based on extensive technical and cost comparisons and on validation measurements, e.g. (Skritek et al. 2001, Stadler & Skritek 2004), the ORBCOMM LEO Satellite system was chosen. ORBCOMM is a “Little-LEO” system, with 30 servicing satellites in 6 orbit planes of 800 km altitude. It provides bi-directional “short message” data-transfer at 2.4/4.8 kbps, with data blocks preferably less than some 100 Bytes. ORBCOMM operates at frequencies about 140 MHz, providing large satellite footprints, and requires only low-cost/low-power equipment, allowing, e.g., simple whip-antennas as well as small solar-panels for power supply and transmission even from forests. The ORBCOMM modem transmits its data to the satellite, from where downlink transmission is performed either directly to one of the Gateway Earth Stations (GES) or as “globalgrams” (data stored in the satellite and forwarded to earth when the satellite passes the desired GES). The GES emails the data to the receiver via internet or re-transmits it to any “nomadic” ORBCOMM modem again via satellite.

ASSEMBLING, CROSS-LINKED STATIONS AND DATA STREAMS

The precipitation station (PS) is located in the catchment area of the spring, where the event sampling will be carried out. It is equipped with a tipping bucket, a data logger and a LEO-Satellite modem. It can be supplemented with additional meteorological sensors and sampling devices. The monitoring and sampling site at the spring (spring sampling station, SSS) is equipped with an additional data logger, a pressure probe to register the changing of discharge, two automatic sampling units (one for the reference sample and one for the periodic samples) and a LEO-Satellite modem for real-time control and data transmission. It can be supplemented with additional hydrological or meteorological sensors.

Stream of data and information. As soon as the trigger-level is exceeded in the catchment area at the PS (predefined amount of precipitation in a definite period, both parameters are selectable) a trigger report is sent to the SMS via satellite. There the reference sample is taken automatically. In addition, the PS starts sending via LEO-Satellite continuously data about the rainfall to the CMS. The SMS is now ready to wait until the second trigger-level (increase of discharge, also programmable) is exceeded. If this happens, the periodic sampling within the event sampling starts automatically and the status information and measured values are continuously sent via satellite to the CMS and the local service team is informed.

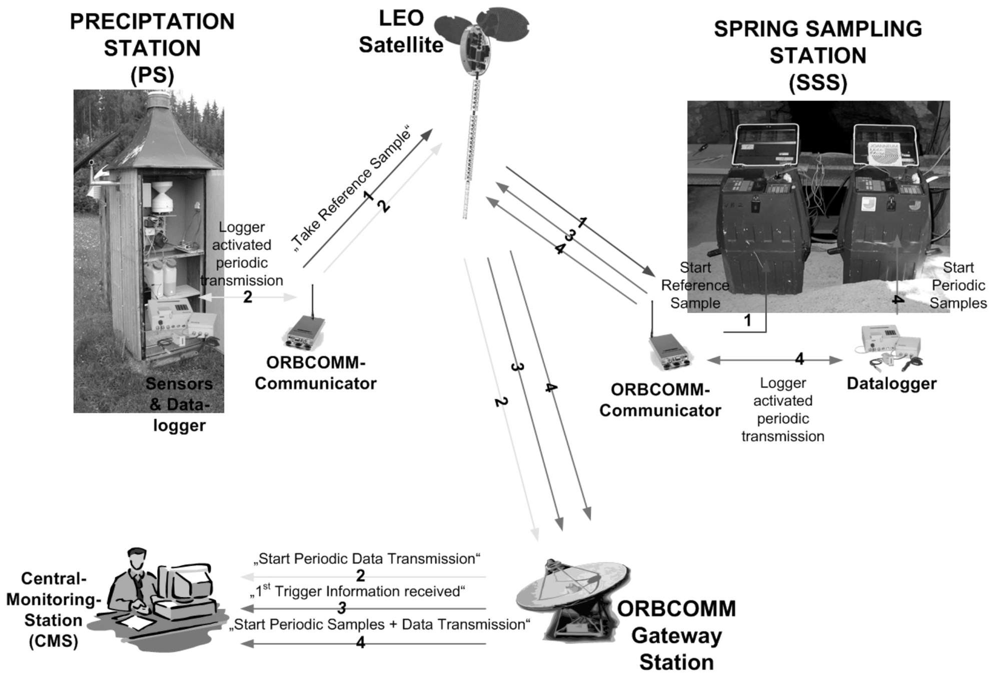

Figure 1. Block-Diagram of Assembling. Stream of data and information of an event-triggered LEO Satellite Hydrology Network.

Precipitation Station (PS). It records rainfall and other meteorological data. From the intensity and the recorded amount of precipitation a specific trigger criterion is derived. If this trigger-level is exceeded, the PS activates one or more SSS via satellite (Data Stream 1, Fig. 1) to take the reference sample. This happens before the event affects the discharge of the spring. The CMS is also informed via satellite by receiving periodic data sets from the PS to observe the further trend of precipitation (Data Stream 2, Fig. 1).

Spring Sampling Station (SSS). As soon as the activation data-set is received, the automatic sampling unit takes the reference sample. The status is sent to the CMS (Data Stream 3, Fig. 1).This procedure can be repeated several times, depending on the number of sampling bottles in the automatic sampling device. This is necessary because due to the hydrological boundary conditions the upcoming event at the spring is worth sampling.

Now the SSS is waiting during a specified period of time for the increase of the discharge, which is the second trigger event. The trigger level is derived from the increase of the gauge height within a period of time and is chosen according to the characteristics of the spring. This trigger criterion is activated from the data logger. If the predefined trigger level is exceeded, periodic sampling is started automatically. The information is sent via satellite to the CMS. The SSS starts also periodic data transmission to the CMS to trace this event (Data Stream 4, Fig. 1).

Central Monitoring Station (CMS) and Web-Interface. There the information from all stations is collected. Additionally the local service team is informed from the CMS automatically of important facts like starting of rainfall (1st trigger) and starting of the sampling procedure at the SSS (2nd trigger) via GSM cell phones. Depending on the sampling time increment and the number of bottles in the automatic samplers, they can plan their next visit at the SSS to maintain the station.

The CMS provides an online Internet-Portal for access to these environmental data. It is built around the server-based operating system Debian, which is a stable free software, providing perfect interaction and performance with the server. Among others, the server comprises a RAID-system for fault-tolerant operation.

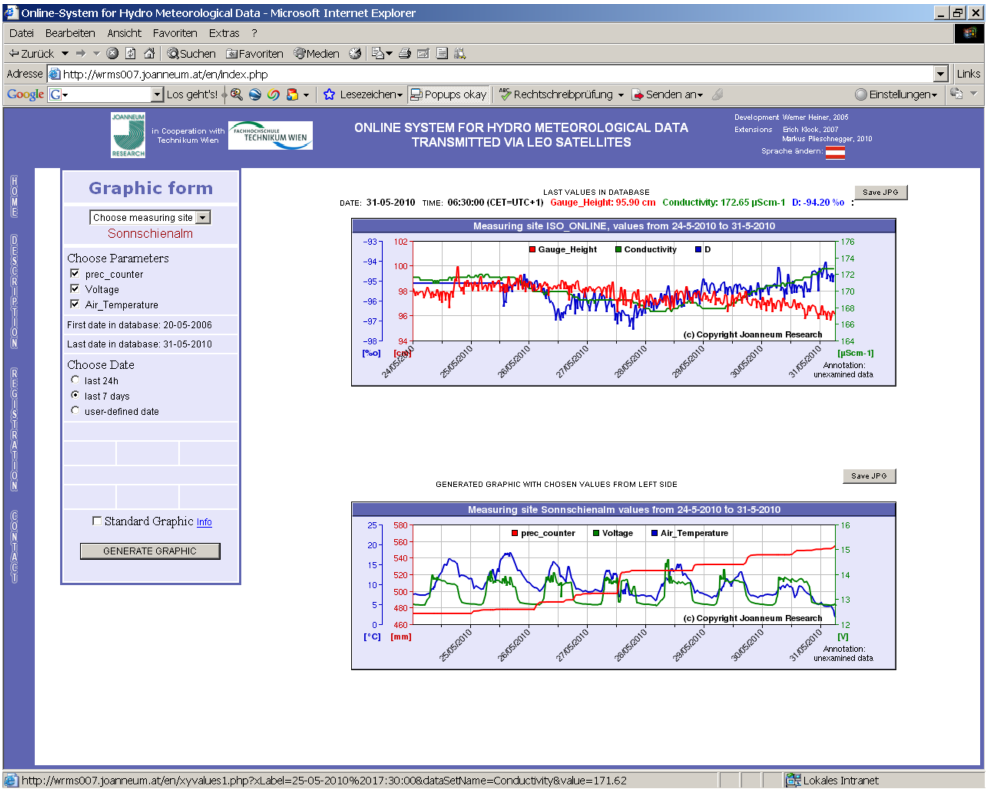

Figure 2. Dynamically generated Website for Online Data.

To provide on-line communication with access to the stored measurement data via the Internet, an ApacheWeb server was implemented on the Debian-Server. The dynamically generated online website can be viewed under http://wrms007.joanneum.at. The start-page is shown in Figure 2.

The freeware PHP was used for programming these interactions between the Internet users and the CMS. Furthermore, PHP can also interpret other interface languages, e.g., XML or JavaScript, using standardized modules, which makes the chosen implementation very flexible for on-line environmental communication.

Additional to the online graphical presentation, all co-workers and public access users may also download these graphics to their local machine. Using password-protection, several access levels to the data and visualization are feasible for different user groups, e.g., general public access to environmental information vs. individual access for specific in-depth data for research-project co-workers (Heiner, 2005).

STUDY AREA AND METHODS

The investigations were carried out in a karstic catchment area of the Northern Calcareous Alps. The event at the karst spring LKAS1 was caused by an aestival thunderstorm with 40.2 mm precipitation measured in the watershed at 1520 m a.s.l. The samples at the spring (n = 157) were taken with automatic sample devices from August 21 to August 31, 2009 at ambient spring water conditions and treated for the different analyses not later than 24 hours after sampling. The rain water was stored after automatic sampling in an air-tight container for 16 hours before treating. *E.coli* was analyzed by the colilert system (IDEXX) directly at a field laboratory as previously described (Stadler et al., 2008). Hydrological in situ measured on-line parameters were collected with an increment of 15 minutes. To study microbial faecal pollution *E.coli* was chosen as indicator organism. In contrast to other standard faecal indicators, detailed previous investigations highlighted its excellent applicability as a general faecal pollution indicator in alpine karstic environment (i.e. high prevalence and abundance in human, live stock and wildlife excreta, low or non prevalence in alpine soils, halve life time of *E.coli* in spring water in the range of the average event period length, Farnleitner et al., 2010).

RESULTS

The integration of on-line measured data, laboratory and field laboratory analyses, all of them recovered with high time resolution, allows a deep insight to these sensitive aquatic systems. Especially the combination with environmental isotopes (Fig. 4) generates new knowledge of the dynamics, mass transport conditions with different transfer behaviour of the particular substances being of fundamental importance for the sensible use of early warning systems. As an example the correlation between SAC254 (Spectral Absorption Coefficient at 254nm) and *E.coli* during the course of the event is shown in Figure 3. Very important for the use of SAC254 as an early warning proxi is the lead time of SAC254 to *E.coli*, which enables reactions times for water abstraction management.

The comparison of the Oxygen-18 as a proxy of the aquifer-dynamic and turbidity or the SAC254 as indicators of mass transport of substances with different transfer behaviour show the very different behaviours of these parameters.

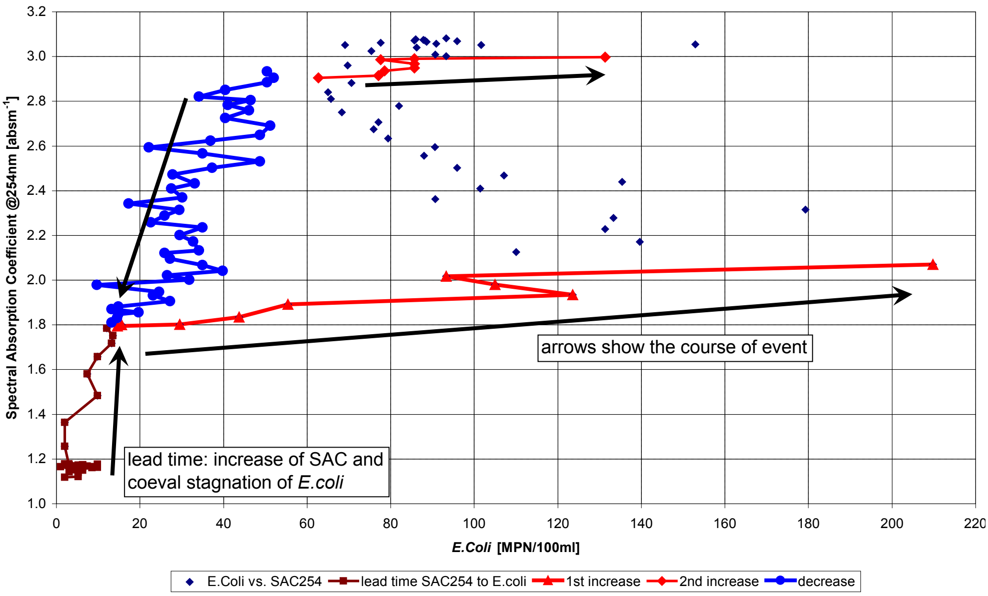

Figure 3. Correlation of SAC and E.coli during the observed event.

The difference of both of them to the hydraulic reaction, indicated by the course of discharge is also obvious. SAC254 and turbidity show in this karst system different behaviour. As SAC254 is more or less surface related and turbidity is mainly an indicator of particles, activated in the karst system by increasing pressure flow velocity, they show different reactions, as shown in Figure 4.

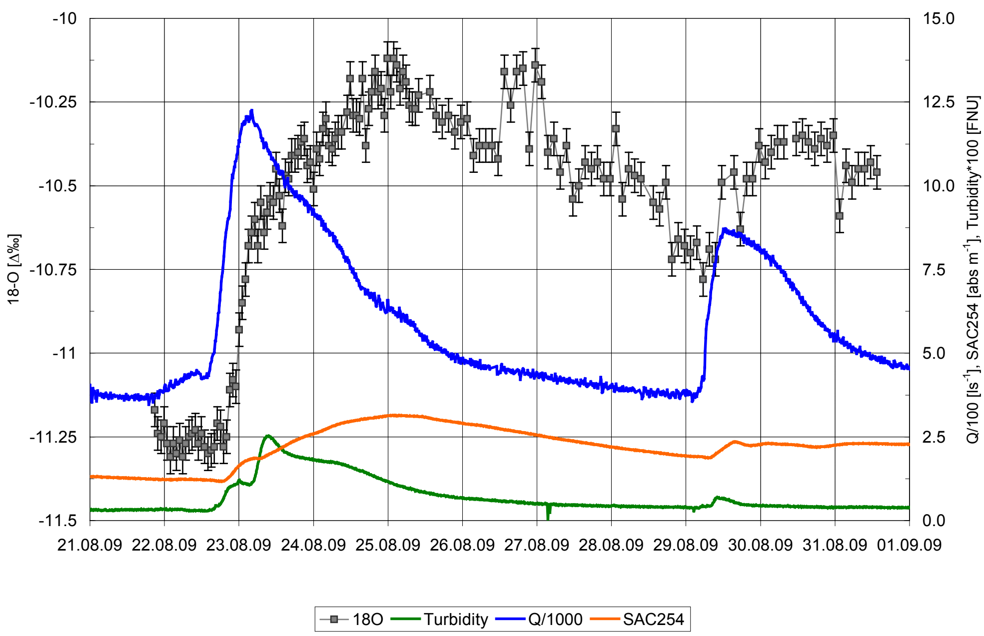

Figure 4. Course of in-situ measured parameters and Oxygen-18 from laboratory analyses during event.

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