Investigating hydrodynamic and transport properties of karst aquifers using water level, turbidity, and electrical conductivity time series

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A signal analysis was performed on datasets from a karst spring in the lower Seine Valley for the 2000 and 2002 hydrologic cycles. The objective of this type of analysis is to investigate and compare the frequency content of different output (water level or discharge, turbidity, electrical conductivity) and input (rainfall) signals. Data were recorded at a 15-min time step. The 2000 cycle was characterized by high rainfall (cumulative rainfall of more than 1300 mm), and the 2002 cycle by more typical rainfall (700 mm) and a high water table resulting from high recharge during the two previous hydrologic cycles. For each signal, the results consist of a calculation of the autocorrelation function and the corresponding amplitude spectrum obtained by FFT.

The memory effect of the system is deduced from the autocorrelation functions and characterizes the duration of the influence of an event on the rest of the time series. It may be linked to a damping effect of the system and can be estimated for every type of time series. For the water-level time series it is usually related to the aquifer reserves. The results showed that the memory effect for the water level is short and its value (4 days) does not change from one hydrologic cycle to the next. It demonstrates rapid transport between the sinkhole and the spring via a main conduit system, with no significant reserves within the karst network. The memory effects for turbidity and electrical conductivity (EC) are always longer than for the water level. In addition they are greater for the 2002 than for 2000 (about 10 days greater than for the 2000 cycle, ranging from 20 to 30 days). The memory effects for EC and turbidity are quite similar for the 2002 cycle (about 30 days), but they are fairly different for the 2000 cycle (22 days for EC, 17.5 days for turbidity), indicating a change in the transport properties of the system as a function of hydrologic conditions. The increase in the memory effect for EC and turbidity in 2002 can be explained by a greater damping effect resulting from the high water table. The constant memory effect for water level suggests that the hydrodynamic functioning is not strongly influenced by the amount of water in storage: the system mostly behaves as a pulse-transfer system, consistent with the geomorphologic features of the site. The longer memory effects for EC and turbidity, as well as their variations between 2000 and 2002, suggest that transport properties are strongly influenced by the state of recharge of the aquifer (dilution effects, mass transport instead of pulse transfer). The differences observed between EC and turbidity during the 2000 cycle could be related to internal resuspension during this high rainfall cycle: the shorter memory effect for turbidity compared to EC imply that the particle transport signal is more complex, or random.

The frequency content of the water level spectrum shows that the signal is structured, even though rainfall is random, meaning that the hydrosystem organizes the flow. The turbidity and EC signals are structured as well. Some frequencies can be recovered on all spectra with a 10-day periodicity for the 2000 cycle and a 12-day periodicity for the 2002 cycle: these short periodicities reflect the short term effect of flood events, and demonstrate a strong link between turbidity, EC, and hydrodynamics. For each cycle, a tidal influence is clearly visible in the water level spectra, showing the strong influence of the Seine on the hydraulic gradient of the aquifer. The corresponding discharge can be reconstructed by inverse FFT. Finally, a 42.7-day periodicity with a high amplitude is identified on the water-level and EC signals for the 2000 cycle; a similar periodicity can be detected on the turbidity signal although the corresponding amplitude is attenuated. The same frequency is present in the water level spectrum of the 2002 cycle, but not the turbidity and EC spectra. This periodicity could be related to delayed infiltration, highlighting the role of surficial formations in the hydrologic behavior of the system.