

Ground Water – a Journey Through Time

New tracer methods show that ground water renewal rates can vary from days to millions of years. Even in Switzerland, the “water tower of Europe”, very “old” ground water is substrated from deeper aquifers. Dating back to the last Ice Age, this ground water is not renewable; therefore, the water resource is depleted in terms of mining.

Ground water not only moves through space, but it also evolves in time. The average ground water renewal time worldwide is 1500 years. Much more notable, however, is the fact that this renewal rate can vary over 5 orders magnitude. In zones with direct river infiltration, ground water renewal times are only a few days. In arid zones, on the other hand, ground water renewal may take hundreds of thousands of years, whereas stagnant ground water in porous strata may even be as old as the rock itself. Sustainable ground water utilization has to be ultimately based on the typical water renewal rate in the region concerned, which has to be determined individually for each ground water system. It has to be noted that in general, the ground water renewal time represents the center of age distribution being determined by all water flow lines that end up in a specific ground water well.

Inadequate Interpretation Due to Inadequate Data

In general the ground water residence time or the ground water age, e.g. the time elapsed between ground water re- and discharge, is determined by numerical models that calculate the ground flow field out of the hydraulic conditions. However, it turns out to be very difficult to identify and to determine the essential physical parameters that actually control ground water transport. Since the data available for model definition is always far less than that actually required, to physically constrain a ground transport model can principally never be precisely simulated. As a result, while ground water models may correctly reproduce the hydraulic data, the fundamental processes involved controlling ground water evolution might be completely misinterpreted. For example, due to this lack of conceptual

knowledge, neither the typical renewal times nor the mixing between young and old ground water may be adequately taken into account.

Complementing Spring Data with Tracer Methods

In contrast to numerical ground water models based on hydraulic data such as piezometer readings, transient tracer based methods enable the determining of ground water renewal (rates), the average ground water residence time and the mixing between different ground water components. Thanks to their complementary sensitivity, these tracer methods reveal the conceptual weakness of ground water models and help to adapt them accordingly.

In order to reduce the uncertainty of ground water models, innovative approaches combine numerical simulations with tracer based ground water dating which rely on the analysis of naturally occurring time sensitive trace substances in ground water. The substances normally used are inert both chemically and biologically, but their concentrations do change over time either due to radioactive decay/accumulation (tritium, rare gas isotopes) or due to time depended input functions (tritium, chloro-fluoro-hydrocarbons, CFC).

If the characteristic time scale on which the concentration of a transient tracer changes over time is comparable, this method is often suitable for accurately determining the average ground water age. Modern tracer methods can be used to date young ground waters with residence times between days and few decades as well as to date stagnant ground waters that recharge over millions of years if they renew at all.



EAWAG

Participants in the “Science et Cité” roundtable discussion comparing drinking water samples. One sample is young surface ground water, while the other comes from ground water 200 meters deep and 30 000 years old.

(Ground) Water and Riparian Forests in the Blenio Valley

The flood plains in Valle Blenio in Switzerland are of national importance. The sizes of these woods of the still active floodplains have been continuously decreasing over the last years, but the responsible processes remain unknown. Within the framework of an extensive EAWAG research project to investigate the ecological impact of storage power plant operations (Ökostrom project, cf. EAWAG news 47), hydraulic conditions in the riparian zone were investigated. The main point of interest here was whether ground water in this zone is fed and renewed by local infiltration from the main river (Brenno). To this end, the ground water age was measured every three months by

sinking several boreholes in the center of the zone; additional data was provided by chemical analysis (Fig. 1, left). It was found that ground water ages here vary both according to season and location. Seasonal fluctuation is common, with ages up to a few years in winter – even near the Brenno River – much younger ground water in spring and summer, and steadily increasing in age again in the autumn. Ground water age was also found to vary as function of depth and can be divided into two basic kinds. During the summer, the ground water near the surface is young, but the age and mean dwell time nine meters down correspond to the situation in winter. These seasonal fluctuations and age gradients according to depth are attributable to

the melting snow in spring and summer, which mixes fresh surface water into the upper ground water level which, in turn, forms a layer on top of the old ground water, which is not formed locally. Chemical analyses suggest the same chronological pattern (Fig. 1, right). In the spring and summer, the chemical composition of the ground water largely corresponds with that of the meltwater in the tributary streams. In the winter, the ground water in this zone has a much higher mineral content, similar to the highly gypsiferous old ground water emerging as springwater from the Brenno alluvial plain. Ground water in the riparian zone is thus a mixture of young, weakly mineralized meltwater from the valley slopes and old subterranean ground

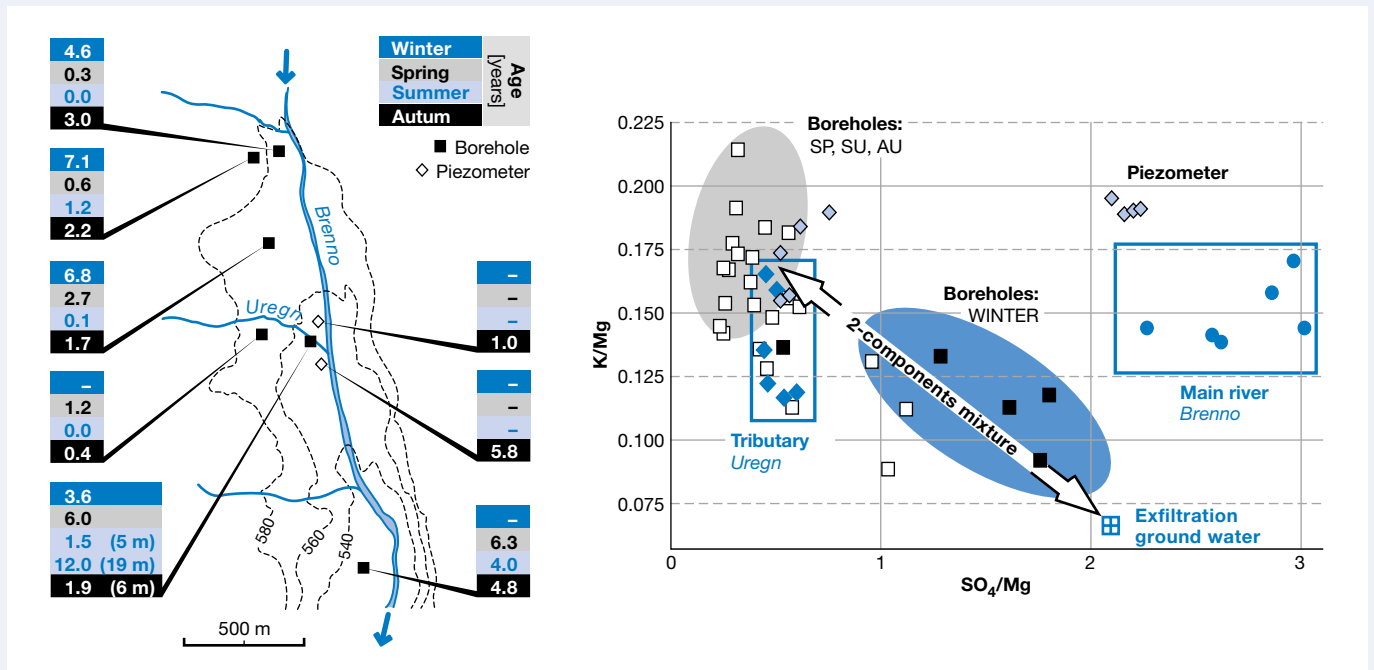


Fig. 1 Ground water in the central riparian zone of the Blenio valley is a mixture of two well-defined types. One of these components comprises ground water near the surface, which filters in as meltwater from the valley slopes. This locally formed ground water has a short dwell time (age ~"0") and is chemically similar to the tributary streams which are likewise fed by meltwater ("lateral inflow", "Boreholes: SP, SU, AU"). The freshly formed ground water forms a layer in the riparian forest zone on top of the heavily mineralized old ground water, which emerges as sulfurous springwater in the Brenno valley. The lower level ground water not formed locally ("exfiltration ground-

water") has a longer dwell time (several years) and much higher mineral concentrations. Accordingly, the boreholes deliver fresh, weakly mineralized ground water in spring and summer at high piezometer readings ("Boreholes: SP, SU, AU"). In winter ("Boreholes: Winter"), the levels are significantly lower and the ground water is much older, since it then comes mainly from a lower level ("exfiltration ground water"). Almost no river water from the Brenno ("main river") can be detected geochemically in the riparian zone. This indicates that the Brenno only influences ground water dynamics in this zone indirectly, as outfall for regulating the ground water level.



Armin Peter, EAWAG

River meadow along the middle Brenno River.

water with a high sulfate content (Fig. 1, bottom). The river itself appears to have only a very indirect though large-scale influence on the ground water in this zone, possibly for regulating the ground water level.

Ice Age water in the Upper Glatt Valley

In contrast to the unconfined ground water near the surface, the renewal rate of subterranean ground water is much slower. Important in this regard is the limited extent

of aquifer. Although extending only for some kilometers, the deep artesian ground water system in the upper Glatt valley contains water dating back to the last Ice Age (Fig. 2). Since the solubility of inert atmospheric gases depends, among other things, on the ground temperature at the time of ground water formation, tracer methods not only provide data on ground water age, but also on the climatic conditions during ground water infiltration. By this means, it has been found that the mean annual temperature in the upper Glatt valley during the last Ice Age was more than 5 °C lower than it is today (Beyerle et al., 1998).

It is notable that the ground water age increases by more than 10 000 years in less than one kilometer, although total age difference over the 10 km long aquifer is only 30 000 years. This age jump at the zenith of the last Ice Age is too great to be attributable to inadequate borings. The data show rather that glaciers and permafrost fundamentally changed the hydrological conditions during this last glacial maximum, thus greatly reducing ground water formation.

the ground water level in the subterranean aquifer has fallen sharply. Clearly the first ground water to be extracted was old and virtually nonrenewable, thus depleting the Ice Age resources. These hydraulic changes enabled young ground water near the surface to penetrate to the lower levels, where it now makes up most of the water that is extracted.

While the chemical composition of the ground water has changed due to extraction, there has been no change in drinking water quality. This example shows, however, that in Switzerland too there are ground water reserves that are not renewable on the human time-scale; they must, therefore, be considered non-renewal resources.

In the future, modern tracer methods, in combination with innovative ground water simulation models, will help to clarify the physical and temporal limitations of our water resources. This should lay the foundation for utilizing ground water resources on a truly sustainable basis.

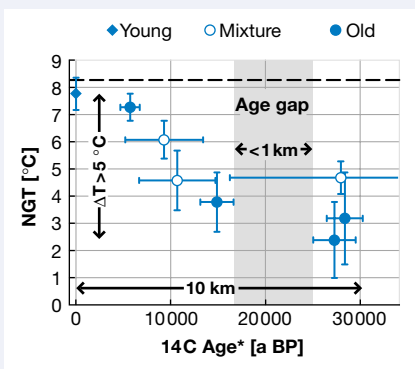


Fig. 2. The upper Glatt valley aquifer, only 10 km long and about 100 m deep, contains young ground water near the infiltration zone (young: ◆), but at the lower end, it contains water which infiltrated more than 30 000 years ago (old: ●, ○). Since the solubility of inert atmospheric gases depends very much on temperature, the high inert gas concentrations in the old ground water suggest that the mean annual temperature in the upper Glatt valley during the last Ice Age was more than 5 °C lower than it is today (8.3 °C, broken line). It is notable that between two borings only about 1 km apart, the ground water age abruptly increases from 15 000 to 25 000 years. This “age gap” is attributable to the fact that glaciers and permafrost during the last glaciation (18 000 years ago) fundamentally changed the hydrological conditions, thus greatly reducing ground water formation.

Nonsustainable Water Utilization

Although the upper part of the Glatt valley aquifer between Uster and Hegnau contains younger Ice Age water, the lower end of the same strata near Dübendorf now contains relatively new ground water. Since the beginning of the 1990s, when drinking water was first extracted from the subterranean Glatt valley aquifer, the chemical composition of the ground water has changed continuously. While the water was previously reductive and free of tritium, it now contains both oxygen and tritium. At the same time,



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Beyerle U., Purtschert R., Aeschbach-Hertig W., Imboden D. M., Loosli H. H., Wieler R., and Kipfer R. (1998): Climate and ground water recharge during the last glaciation in an ice-covered region. *Science* 282, 731–734.