Soustainable drinking water exploration and exploitation beneath cities

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Abstract: Hydro-chemical, hydraulic and isotope investigations of the recent decades showed that the groundwater systems are organized into an active recharge zone, that may readily be contaminated and reaches to some decametres below floor, followed by the passive recharge zone, which stretches to several hundred meters below ground and is well protected on a very long run of time against anthropogenic contaminants. This differentiation in recharge zones results from a significant decrease of immediate available groundwater recharge with depth, which is triggered by the existing sequences of aquifers and aquitards. As far as groundwater exploration disregards this geologic and hydraulic stratification, it provides short cut paths, which may favour the import of contaminants from the active into the passive recharge zone. The same gets true if groundwater exploitation from the passive recharge zone does not take care of the reduced immediate availability of groundwater; such non-adapted exploitation measures provide long-term transient conditions in the hydraulic behaviour of the subsurface system and may lead to undesired quality changes of the groundwater in deep exploitation well. - Field and numerical studies showed that groundwater exploitation from deep wells will not harm water quality if it is not excessive, deep enough and gets controlled by an early warning system, surveying primarily the hydraulic changes instead of any contaminant access to the exploitation floor. - Deep groundwater exploitation refers always to a much lower specific yield than shallow water exploitation, but may contribute to a sustainable drinking water supply if management is adapted to natural conditions, which differ significantly from conditions of shallow groundwater resources.

Key words: groundwater, exploitation, recharge, quality, water management

1 INTRODUCTION

In 1900 only 10 % of the world population lived in cities and after the year 2000 this number will exceed 50 % (UN 1991). As referred to 17,000,000 inhabitants - the average of the 10 biggest cities of the world - the water demand reaches 20 to 30 ml/s and on a long run of time can not be satisfied from the catchment area of the town without being faced with some overexploitation of the subsurface resources; as a consequence water is imported from neighbouring catchments.

In urban areas hydrologic problems concerning water quantities and water qualities often raise, because non-appropriate exploitation and management strategies are applied or basic hydrologic rules have been neglected.

- Cities areas enhance or reduce groundwater recharge.
- Leakages (5 to 50 %) from the drinking water distribution and waste water collector systems may affect groundwater quality beneath cities.
- City areas are often an agglomerate of punctual contaminant sources, which are difficult to control.
- According to the wastewater treatment big cities will affect the ecosystem functions of rivers, draining urban areas.
- Groundwater protection strategies are difficult to realize in city areas.

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Therefore, a drinking water supply from areas beneath cities is often considered as a invincible risk. Recent research, however, showed up that this risk can be limited using adapted exploration, exploitation and monitoring methods.

2 DYNAMICS OF GROUND WATERS

The majority of the groundwater (8,200,000 km^2) belongs to a long-term reserve (TOTH, 1963, FREEZE, WITHERSPOON, 1967, SEILER, LINDNER, 1995). On a long run of time, however, only the recharged portion of groundwater is available for water management and the conservation of the necessary ecological functions of landscapes. Any management of the long-term reserve (groundwater mining), starting in some areas of the world, presents an irretrievable groundwater consumption, which is often followed by water quality degradation.

To study the fate of groundwater recharge, numerical modelling and field investigations have been executed in temperate (SEILER, LINDNER, 1995), tropical (ALVARADO ET AL., 1996) and city areas (SEILER, ALVARADO, 2002) in terms of the determination of the depth related turnover of groundwater recharge. These modelling studies show that more than 85% of the groundwater recharge moves in near-surface aquifer system, less than 15% penetrates also to deep lying aquifers and these findings have been confirmed by field investigations. Related to this, groundwater in near-surface aquifers is always young (< 50 years) and in deep aquifers old (>100 years): Thus groundwater recharge may be attributed to an active or near-surface and a passive or deep groundwater recharge zone (see Figure below) and these two zones occur world-wide.

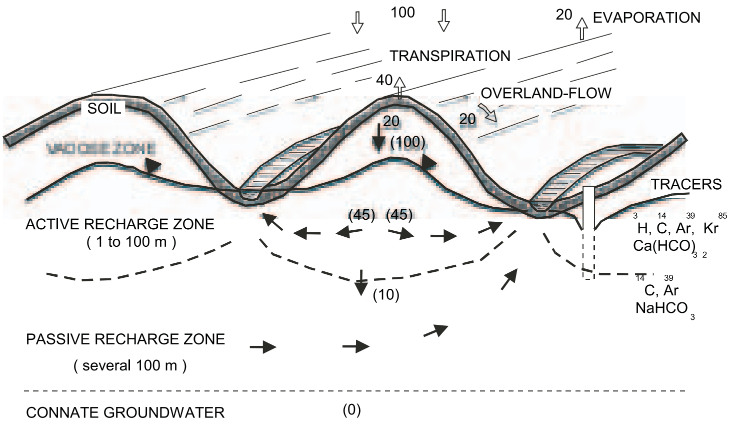

Figure Subdivision of the aquifer systems in active and passive groundwater recharge zones and connate groundwaters; not to scale. 100 = 100% of precipitation, (100) = 100% of groundwater recharge.

According to the hydraulic properties and the amount of groundwater recharge, the active recharge zone has a thickness of several 10 m (unconsolidated rocks) to 100 m (consolidated rocks). Contrary, the passive groundwater recharge zone can achieve a thickness of several 100 m and is underlain by the connate or formation water (v. ENGELHARDT, 1960); connate water did not return into the biosphere for millions of years

With respect to pollution, the active recharge zone offers easy access, whereas the deep aquifers dispose of a long-term dilution and reaction potential and therefore – by nature - is still untouched from anthropogenic influences of the industrial age. Since this is often disregarded in exploring and exploiting groundwater resources beneath cities, exploitation may lead to significant hydraulic short cuts between aquifers producing an undesired access of either polluted or high mineralised waters to deep groundwater systems.

The interface between the active and passive recharge zone can be identified by very sudden changes in the concentrations of ^{3}H, ^{14}C, ^{85}Kr and e.g. ion exchange waters (Ca, Na), all indicating an abrupt change in groundwater ages. If isochrones are incorporated in the numerical simulation of scenarios, it can be seen that water ages indeed change rapidly from near-surface, to deep aquifers.

The low flow velocities in the passive groundwater recharge zone also produce low leaching capacities. Therefore, chemical constituents of groundwater out of the passive recharge zone often show higher concentrations and comprise also more specific rare elements (e.g. As, I, F), missing as geogenic component in the active recharge zone because of a much stronger leaching.

As a consequence of these findings, drilling of wells should not only orient in hydraulic conductivities of aquifers and well yields, but should first investigate the interface between the active and passive recharge zone. Often, groundwater abstraction from the passive groundwater recharge zone does not relate to the low, yet available or effective groundwater recharge (< 15 %), instead, it uses the calculated groundwater recharge for the landscape. The consequence of such groundwater exploitation from deep aquifers (>50 m to > 100 m) was also calculated in scenarios. From many scenery simulations it appears that a quantitatively and qualitatively secure water supply from the passive zone was possible if applied in accordance with the aquifer specific recharge. Otherwise, it leads to a long-term contaminant input into a groundwater zone, that would have been naturally protected on a long term.

This process of short cut between the active and passive recharge zone can be monitored in a process-oriented way, using the natural stratification of environmental isotopes or chemicals in groundwater and its dislocation through groundwater exploitation. This monitoring becomes process oriented if the results fit mathematical models (Ghergut et al., 2001)

3 CONTROL OF DEEP GROUNDWATER EXPLOITATION

As can be seen from modeling, wells with deep screening are over flown by shallow groundwater and thus react like a Ranney well (Nemecek, 1961); according to the depth and quantity of groundwater abstraction, deep exploitation attracts groundwater from lateral, neighbouring areas and any protection zone close to the well head makes no sense for the well itself. This statement may even be a solution for sustainable drinking water exploitation in areas in which the active turn-over zone above the exploitation floor is significantly exposed to contaminants or can not efficiently be protected (e.g. urban and irrigation areas), but the bordering areas are free of pollution sources.

Forced hydrodynamic changes in deep groundwater experience to start transient changes over a long period of time; this can not be recognized monitoring contaminants in the exploitation well, however, it can be controlled by monitoring the changes in the chemical and isotope composition of the extracted water. Combining these analytic results with an appropriate mathematical model on the transport of non-reactive tracers (Ghergut et al., 2001) allows to validate and calibrate the model, to better predict the hydrodynamic changes within the system and to better assess the fate of contaminants than with traditional means. Accounting for the exploitation depth, isotope and chemical measuring accuracy, any mixing and the natural range of concentrations, ^{39}Ar proved in all model runs a quite sensitive early warning indicator. But also other isotope or chemical components may contribute.

Results of the numerical modeling on the behavior of a non-reactive contaminant, entering the subsurface system (400 m thick and 15 km long) at a constant and of isotopes with a real input function over a run of 30 years without groundwater abstraction, followed by a pertiod of 30 years of exploitation shows that in the passive turn-over zone abstraction rises in a very similar delayed way both contaminants and ^{3}H concentrations. Their intensities are relating to the abstraction quantities. It is to be noted that a delay is missing for ^{39}Ar. Therefore, ^{39} Ar is a more appropriate indicator than tritium; this relates to the differnt half lives of both environemntal isotopes. Mathematical modelling also showed that, once the contamination reached the deep groundwater, it remains even 30 years after a stop of exploitation unchanged and thus produces a quality deterioration over a long run of time.

4 CONCLUSIONS

Less than 15 % of the catchment recharge is available at depths exceeding maximum 50 m in unconsolidated and 100 m in fissured rocks; any precise determination of the depth related groundwater recharge is difficult to gain. Under natural conditions deep groundwater is well protected against pollutants, however, once contaminated, they create much longer problems than in near surface groundwater and are difficult to remediate.

Deep groundwater should only be explored and exploited in areas with a significant existing or expected pollution, like urban or irrigation areas and contribute to the water supply either as an emergency resource or for special purposes; it should not be used in any conventional way. Traditional management and protection strategies are hardly to apply for deep groundwater extraction and often the database is too limited for evaluation.

Deep groundwater abstraction, needs a special monitoring, because regional geologic and hydro-geologic data mostly are not detailed and precise enough to reliably assess the long-term transient behavior of the aquifer system. Therefore an early warning system has been developed which applies qualitatively very well with field observations. To apply it also quantitatively, long-term observations of appropriate environmental, non-reactive tracers are necessary, which are often still missing

Under the many indicators applicable as early warning indicators, ^{39}Ar and ^{14}C combined with ^{2}H and ^{18}O are very useful for water ages ranging from 100 to 1,000 years, respectively 1,000 to 20,000 years.

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