Investigating artificial groundwater recharge to ensure the water supply to the city of Graz

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Abstract: Being Austria’s fourth largest water-supply company, the Grazer Stadtwerke AG., has ensured the successful water-supply of the Styrian capital with 250,000 inhabitants for many years. The average daily water demand of the area amounts to about 50,000 m³. Approximately 30 % of the total demand is covered by the bulk water supply from the Zentral Wasser Versorgung Hochschwab Süd. The waterworks Friesach and Andritz, which cover the additional 70 % of the water demand, operate by means of artificial groundwater recharge plants where horizontal filter wells serve as drawing shafts. The groundwater recharge systems serve to increase the productivity of the aquifer and to reduce the share of the infiltration from the Mur River. Protection areas have been identified to ensure that the water quality of the aquifer stay at optimal levels. The protection areas are divided into zones indicating various restrictions for usage and planning. Two respective streams serve as the source for the water recharge plants. Different infiltration systems are utilised. Each of the various artificial groundwater recharge systems displays specific advantages and disadvantages in terms of operation as well as maintenance.

In order to secure a sustainable drinking water supply the recharge capacity will be increased. Within an experimental setting different mixtures of top soils are investigated with respect to infiltration and retention rates and compared to the characteristics of the existing basins. It can be shown that the current operating sand basin with more than 90% grains in the range between 0.063 and 6.3 mm represents the best combination of infiltration and retention rates. In future experiments the performance of alternative grain size distributions as well as planting the top soil will be tested. Additionally, in order to optimize the additional groundwater recharge structures the composition of the subsurface water regarding its origin is statistically analyzed.

Keywords: Artificial groundwater recharge; groundwater management; retention capacity; topsoil

Introduction

The city of Graz, with approximately 250,000 inhabitants, is the second largest city in Austria. Recent statistics show that up to 70,000 people from the regions surrounding Graz commute into the city on a daily basis. The overall water demand totals approximately 50,000 m³ per day. In Graz artificial groundwater recharge systems have been successfully operating since the beginning of the last century. Because of a long drought period and an increased water consumption, groundwater recharge was introduced in Graz for the first time in 1921.

For the actual operation of the total water supply systems, the following three groundwater resources are used:

• The waterworks Friesach which is located 12 km north of the city of Graz. About 40 % of the total demand is drawn from the local aquifer. In Friesach several artificial groundwater recharge plants operate.
• The waterworks Andritz is located in the northern part of Graz. The aquifer system is managed by artificial groundwater recharge systems. The waterworks Andritz covers about 30 % of the total water demand.
• The bulk water supply from the Zentral Wasser Versorgung Hochschwab Süd covers approximately 30 % of the total demand.

Figure 1 shows a sketch of the municipality works Graz recharge site at Andritz. The Mur River is flowing in a Southeastern direction on the bottom left. The predominant groundwater flow direction is parallel to...
the Mur River with an average slope of about 0.5%. The groundwater level usually fluctuates between 4 – 6 m below the ground surface. The general aquifer is built of quaternary sand and gravel fluvial sediments of locally strong varying conductivity and thickness. The average annual precipitation in the area is 866 mm. Over the last ten years the two pumping wells (HFB 3 and HFB4 - marked as yellow dots) have withdrawn a daily average of about 14,500 m³. Two sand basins (red rectangles between observation wells 228 and 219) and one lawn basin (green rectangle at observation wells 227 and 223) have been recharging the aquifer with a cumulative daily average of about 12,300 m³ over the last ten years. The difference is covered by infiltrating surface water from the Mur River and inflowing groundwater from the upstream aquifer.

![Figure 1: Plan view of the location of the recharge structures (center top) and observation wells at the site Andritz. The Mur River can be viewed on the bottom left.](image)

The recharge system at Andritz functions as depicted in Figure 2.

![Figure 2: Scheme for artificial groundwater recharge in Graz](image)

Next to the raw water inlet a settlement tank, consisting of two chambers each with a capacity of 220 m³, has been installed. If the turbidity level exceeds 5 FNU, the inflow from the Andritzbach to the horizontal flow gravel filters is stopped by means of an automatic closing gate. The water flows through concrete pipes before entering the horizontal flow gravel filters with a granular size of 8/16 mm. The observed removal rate of suspended solids is between 50-70% (Nickl 1992). A certain reduction of organic biomass was also encountered. After an operation period of 2 to 3 years, the filter material has to be removed. Following the horizontal flow filter system passage, the water is distributed by several valves and cascades into the infiltration basins. The cascades serve to increase the oxygen content of the water. Different types of infiltration plants exist.
The lawn basin with an area of 2,000 m² boasts an infiltration capacity in the region of 1-2 m per day. The lower stratum, with a thickness of 20 cm consists of 8/16 mm gravel granules. The top layer consists of humus and was originally planted with grass. Due to the natural concurrence situation the grass has been displaced by local moss. The lawn basin operates intermittently for a period of 10 days. After an intermission of a further 20 days, the basin is flooded again. The lawn basin has to be mowed several times a year. The operational halt of 10 days is necessary to avoid the grass and moss dying, which would lead to blockage of the basin.

Additionally, two sand filter basins are used for the artificial groundwater recharge as well (area = 3,000 m²). The uppermost 50 cm sand layer has a granular size between 0.06-2 mm. The average infiltration capacity is approximately the same than that of the lawn basin. The sand basins are operated alternately. Each of the sand basins is flooded for 3 days. Especially during the warm summer months problems with the emergence of algae occur. The sand layer has therefore to be cleaned regularly. Both type of infiltration basins possess an overflow, which drains into the Mur River.

Furthermore, infiltration drains were installed which show a much higher infiltration rate than that of the sand and lawn basins. Regular maintenance work, to ensure the infiltration capacity of the drains, is necessary. In comparison, all three systems show specific advantages and disadvantages in terms of investment costs, infiltration rates, water quality and operation & maintenance.

The underground passage ensures the high quality of the drinking water. The groundwater level and quality is continuously monitored by means of a vast number of inspection wells. Horizontal filter wells (HFB 3 and HFB 4) serve as drawing shafts. The wells were constructed according to the Ranney system. Both wells have 2 vertical pumps and operate intermittently. To ensure the water quality, four types of protection areas have been identified and a comprehensive monitoring system is being carried out.

Although the Grazer Stadtwerke currently observes best water quality, some problems have been faced 20 years ago. The distance of the horizontal filter wells from the Mur River is only 200 m. This implies that the groundwater in the infiltration zones may be influenced by the river. The Mur River was a highly polluted river several years ago. Untreated waste water discarded by various paper mills located upstream, caused an extremely high organic pollution of the river. These organic substances were also found in the infiltration zones nearby the river causing the oxygen concentration to decrease to zero due to the activities of micro-organisms. Next the manganese and iron were mobilize in the aquifer by reduction processes. The concentrations of manganese and iron rose up to 1 mg/l, which created a problem in the water supply system in the years from 1965 to 1980 (see Figure 3)

![Figure 3: Manganese concentrations in the infiltration zones](https://iwaponline.com/wpt/article-pdf/3/3/wpt2008063/384007/63.pdf)

The high concentrations of manganese in drinking water produced precipitations of oxides in the pipes, in the reservoirs and in the filter systems of the consumers. In order to solve the problem, several methods of water treatment were discussed. It was decided to use artificial groundwater recharge to raise
the groundwater level near the wells and to force back the infiltration from the polluted receiving stream. Further overviews with respect to recent technological advances and water quality improvements are given by Pyne (2006) and Dillon et al. (2006), respectively.

Since the beginning of the artificial groundwater recharge in 1980, the organic pollution in the groundwater at Andritz site decreased rapidly. The manganese concentrations in the drinking water also decreased to values below 20 mg/l and so there were no more problems with precipitations in the water supply system. Because of the strict regulations on sewage drainage and waste water treatment, the water quality of the Mur River has improved during the past few years and therefore the demands on the reduction of the infiltration rate from the river were reduced.

Based on an extensive quantity of monitoring data options shall be explored to increase the amount of artificially recharged groundwater. In this context operational issues (e.g. maintenance costs and resting times) as well as infiltration and retention rates have to be considered. To explore the latter issues an experimental site at the waterwork Andritz was set up consisting of 3 concrete rings of 2.5 m diameter and 1.5 m depth with different fillings in the top 50 cm.

Method

Figure 4 depicts the three concrete rings at the Andritz research site. In the nearest concrete ring (ring 1) the grain size distribution of the existing sand basin (grain sizes between 0.01 and 8mm) is used for reference, in the central ring (ring 2) a mixture between middle sand (0.1-4 mm) and the local B-horizon is applied while the top 50 cm of the most distant ring (ring 3) consist of a mixture between sandy gravel (4-8 mm) and humus soil. The layer thickness of the fillings relates to the experiences with pilot plants of Hütter et al (2006). In order to consider the operational mode of the real sand basins, water is pumped to the three concrete rings for four days followed by a rest period of three days. The individual amount of water pumped to any ring is controlled by a floater so that neither one falls dry or overflows. The entire unit is equipped with just one pump and the surge before inflow in and after outflow out of the concrete rings are measured. The two vertical pipes per ring (see Figure 2) are intended for maintenance and vertical sampling purposes.

Surface water is taken from a local creek. The inflow and outflow concentration of coliform germs, Escherichia coli and Enterococci as well as the water discharge at the three rings are measured. Standard ion and anion parameter were also observed but didn’t show any significant changes between inflow and outflow of the concrete rings. Chemical parameters like Ammonium, Nitrite or TOC are mainly filtered in the horizontal gravel filter system before reaching the recharge structures.

Figure 4: The experimental plant at the Andritz recharge site

In order to analyse the hydraulic impact of the current recharge structures the composition of the groundwater with respect to its origin was computed in terms of frequency distributions at each well location. For this purpose observed chloride, sodium and sulphate concentrations at groundwater
monitoring wells, the two pumping wells, in the infiltrated water, the Mur River water and in the undis perturbed local groundwater were analysed. Based on monthly averages of the three conservative substances over the 18 months period between January 2005 and June 2006 the three fractions of potential water origin were determined.

As a complementary tool to evaluate the options of extending the artificial groundwater recharge facilities, a regional transient groundwater flow model will be set up. Depending on the dynamic hydrologic aquifer conditions and considering several artificial groundwater recharge scenarios (including the location of additional recharge facilities) the source of the pumped water can be predicted with the help of the numerical model. In any case, the pumping of water from the Mur River by bank filtration shall be avoided because of quality issues. Furthermore, current protection zones of the pumping wells can be controlled and the impact of the recharge facilities onto the local groundwater flow conditions (in particular the flow time between recharge structure and pumping well) can be predicted.

Results

Figure 5 shows the infiltration rates for the three concrete rings over 4 months. The results indicate that the existing sand basin (ring 1) and the sand mixture with humus (ring 3) have significant better retention rates than the sand mixture with the B-horizon (ring 2) for all three bacteriological characteristics. The general decrease in infiltration rates for rings 1 and 3 were related to plugging of the pipes rather than clogging of the top soil since the infiltration rates went back to their initial values after flushing the inflow pipes.

Figure 5: Infiltration rate at the three concrete rings

Figure 6 shows the behavior of the retention capacities for hygienic parameters within the three concrete rings. Retention capacities are computed by relating the difference between inflow and outflow bacteria counts to the inflow value. With exception of coliform germs the existing sand basin and the sand mixture with the B-horizon reveal similar retention capacities. In particular for Enterococci and Escherichia Coli the sand mixture with the B-horizon shows almost total retention whereas the value for coliform germs declines twice to 0.6. The retention values for the reference sand mixture (ring 1) show considerable higher variation, especially in the case of coliform germs retention, but with still high retention rates for the other two hygienic parameters. However, the sand mixture with the B-horizon is much less permeable making it a less attractive top layer for a recharge facility.

In contrast to the retention behavior of rings 1 and 2 the values for sand mixture with humus display strong erratic fluctuations for all three hygienic parameters. This may be due to the circumstances that the added humus still contained organic components so that only less germs could be withhold.
The high varying range of hygienic parameters for ring 3 may also be due to laboratory reasons. Figure 7 shows the relation between coliform germs retention rate and discharge, load and concentration of the water flowing into the infiltration rings. As expected, it can be seen that a negative correlation exists among the retention rate and load and concentration of the inflow, respectively, for the rings 1 and 2. Corresponding to the results depicted in Figure 6 the sand mixture with the B-horizon (ring 2) shows the highest retention rates and smallest spread of data pairs for any parameter. Results for the ring with the reference sand mixture (ring 1) display higher variance than ring 2 but are still interpretable. The retention rates of the sand mixture with humus (ring 3) have obviously no correlation to load and concentration for the reasons mentioned above. However, compared to the other two sand mixtures a weak negative correlation can be interpreted between discharge and the coliform germs retention rate.

Figure 6: Retention rates for Escherichia coli, Enterococci and coliform germs at the three concrete rings
In order to find the best solution for enlarging the artificial groundwater recharge facilities at the Andritz site not only the mixture of the top basin layer was investigated but also the current composition the pumped groundwater was analyzed for reference. The location of any new infiltration basin should increase the recovery rate of recharged water and decrease the amount of the Mur River water. For that purpose, yearly averages of chloride, sodium and sulphate concentrations at eight observation wells were statistically analyzed and related to the concentrations observed in water samples of the Mur River, groundwater upstream of the infiltration basins (representing inflowing groundwater conditions) and groundwater just downstream of the infiltration basins (representing the recharge influence).

Figure 7: Coliform germs elimination rate versus discharge, load and concentration at the three concrete rings
Table 1 shows the composition of the groundwater at 8 observation wells (KB’s; for location see Figure 1) and the 2 pumping wells (HFB 3 and HFB4). It can be clearly seen that on an average basis (AM in second column) the fraction of the Mur River water (monitoring station OG 18) withdrawn by either one of the two pumping wells is less than 10%. Yet, the high standard deviation (STD in second column) suggests that single larger values may occur indicating the need to adjust the amount of recharge water and the specific recharge structure to the Mur River water level and the recovery rate and pumping well used. The pumping well HFB 3 predominantly recovers recharged water (75% on average from monitoring station OG 7) whereas pumping well HFB 4 mainly draws inflowing local groundwater (65% on average from observation well KB 299). For the latter well artificial groundwater recharge equilibrates the regional groundwater balance.

Table 1: Composition of the groundwater at the respective observation wells

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<tr>
<th></th>
<th>KB 227</th>
<th>KB 228</th>
<th>KB 229</th>
<th>KB 225</th>
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Discussion

The above results have clearly demonstrated the trade-off between infiltration rate and retention capacity by designing the top layer of a new recharge basin. It can be shown that the current sand basin at the recharge site in Andritz performs quite well in this respect. To further explore the significance of the fraction of silt and clay grain sizes (relating to the good performance of the sand mixture with humus) two new sand mixtures are currently tested that combine specific compositions of the sand grain size distribution with the overall portion of clay and silt material. Additionally, the duration of the experimental series will be enlarged to get more reliable results and TOC data will be included into the general study. Later this year additional experiments with planted top layers representing lawn basins are scheduled and one ring will be used to address long term filter capacities.

The computation of the groundwater composition fractions will be used hereafter as a basis to distinguish between filtration, adsorption or decay processes and dilution by inflowing upstream groundwater. Thus, subsurface degradation rates can be more reliably inferred and flow distances of specific parameters can be estimated dependent on the infiltration rate. Moreover, the natural treatment of hydraulically induced surface water during the subsurface passage may be better taken into account.

Conclusions

Groundwater management and artificial groundwater recharge in Graz have been operated successfully for many years. Increased utilization conflicts and quality specifications demand a sustainable groundwater management for future generations taking into consideration the technology of artificial groundwater recharge in order to ensure sufficient water supply. Based on the existing know-how in the field of groundwater management as well the results of ongoing research activities, the groundwater plants will be revised. For a given and defined raw water quality several grain size distributions have been tested as top layer to find an optimal balance between retention capacity and infiltration rate. Initial results have shown that humus incorporations decrease the ability to withhold germs and that cumulative silt and clay fractions of more than 15% of the overall grain size distribution drastically reduce infiltration capacities. Additionally, planted top soil layers will be evaluated at the experimental site. In a further step fractions of the groundwater composition have been computed to discriminate between surface water, infiltration water and natural groundwater. Thus, subsurface biological and chemical processes can be more precisely identified and better accounted for in future management decisions of the entire recharge site. The conflict demands on the water quality and quantity have to be evaluated carefully.
Acknowledgements
A special word of thanks to Director DI Helmut Nickl, head of the Grazer Stadtwerke AG – Division Water, in supporting this effort and for his invaluable information. The research activities mentioned above was contracted by the Waterpool Competence Network which is mainly funded by the Austrian Federal Ministry of Economics and Labour.

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