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Groundwater balance of an urban area - the example of the city of Darmstadt

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The groundwater balance in urban areas is modified by anthropogenic impacts. While natural, direct recharge is reduced due to sealing of the surface, artificial and indirect recharge pathways are introduced, e.g. leakage from the water supply net and sewers. This additional recharge can compensate for the sealing reduction and even exceed it, but often introduces contaminants into the groundwater. Because of the many potential emission sources, recognition, quantification and remediation of contaminated sites in a city are difficult and need more integrative approaches. The aim of the project in Darmstadt (Germany, highly industrialized, 140.000 inhabitants) was to quantify the fluxes of chemical substances to water wells downstream of the city. The water flows had to be quantified and modelled, which was difficult because of heterogeneity of the geologic underground and due to urban influences. Darmstadt is located on the eastern border fault of the Oberrhein-Graben. The eastern part of the city area is made up of hard rocks (crystalline, sedimentary and basaltic). In the western part, quarternary sediments (sands, gravel with intercalated clay layers) form productive aquifers, though with highly variable thickness. The groundwater flow below the city is generally from east to southwest. The network of groundwater monitoring wells is rather dense, but erratically distributed in space, drilled for different purposes at different times and of varying depth and construction. Five wells have been drilled to fill up gaps in the monitoring network. Modelling of groundwater flow was restricted to the sediment area W of the Rhein-Graben border fault. This area is divided into a zone of low aquifer thickness and low depth to groundwater table in the NW and an area with high aquifer thickness and usually high depth to water table in the SW. Depth to water table is highest close to the fault (up to 40 m below surface) and decreases to the W, where the gradient of the surface is steeper than that of the groundwater table. The natural recharge around the city of Darmstadt is 180 mm/a on average,

with large interannual variations and local differences. From estimated freshwater and wastewater leakage data, the artificial recharge was calculated as 43 mm/a (about 25% of the natural recharge). The sealing effect was established directly by quantifying the spatial cover (buildings, roads, etc.) of the urban quarters (sealing ratio from zero to nearly 80% in the center). The results were confirmed by evaluating the annual groundwater level variations using different methods. Best agreement with the sealing ratio was obtained with the method of Ubell in areas with low depth to groundwater table. Thus, the natural recharge in the suburbs is reduced to 80 - 100 mm/a and in the center to 30 - 40 mm/a. In the area of high depth to water table, the hydrographs show no annual variations. Yet, short time infiltrations of storm water from sewer overfall basins can cause a sharp peak in the groundwater level. A breakthrough of degradable contaminants could not be verified. The most evident contaminations of groundwater are in the city center and the northwest area, where the depth to water table is low and also the most hazardous sources (industry as well as smaller sources) are located.