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Quantification of typical urban contaminants in ground water of cities

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Groundwater in urban areas is often contaminated, and emission sources (housing and industrial areas, roads, sewers, gas stations, etc.) are usually located close to groundwater wells. The delineation of an existing contaminant plume is very difficult as well, because of the many potential emission sources. Moreover, the usually dense setup of buildings, roads, pipelines etc., makes it almost impossible to install a (good practice) sampling well network. Thus, recognition, quantification and remediation of contaminated sites in a city need more integrative approaches. To quantify the groundwater contamination in high-density areas, we chose the city of Darmstadt (Germany, highly industrialized, 140.000 inhabitants) as a test site to develop an integrative method based on a mass balance concept. A hydrogeological 3-D-model was established of the area of Darmstadt using the commercially available code Visual Modflow. Based on this model, the study area was divided into 3 control planes (upstream-, city-, downstream-plane) perpendicular to the main groundwater flow direction. 19 model budget zones, arranged in 6 budget strips, were defined between the city-plane and the downstream-plane. The water budget for each zone was calculated. Inorganic (cations, anions) and organic parameters (e.g. Polycyclic Aromatic Hydrocarbons PAH) were analyzed using standard methods. The concentrations of the contaminants and the water budget were used to calculate a mass balance (from upstream to downstream) for each contaminant. Due to specific geological conditions in the model area, the water budgets and mass balances could be calculated for a maximum depth of ca. 30 m below surface. The hydrogeological data showed that groundwater flow in the subsurface of the city is generally from east to southwest. Since there is no relevant contaminant source upstream, it was clear that all contamination to be found resulted from urban input. The groundwater monitoring wells (GMWs) in the upstream-plane showed natural, anthropogenically superposed background values for all naturally occurring

inorganic species. Organic compounds typical for urban environments, such as PAHs, were found in many samples. The contaminant concentrations increased in the city-plane (probably directly influenced by road traffic, gas stations, leaking sewers etc.). In the downstream-plane, concentrations usually decreased. For chloride, a positive budget could be calculated in several zones, which shows that chloride from urban sources is reaching the groundwater. Some zones show negative budgets, which can be mainly explained with dilution phenomena and diving plumes. Highest PAH fluxes correspond well with central urban and industrial areas and show higher values compared to the upstream fluxes. In many cases, a biological degradation of organic compounds in groundwater can be recognized with decreasing concentrations of potential electron acceptors, such as sulfate, nitrate, and the occurrence or increase of Fe^{2+} and Mn^{2+}. At the study area, it can be observed that with increasing contaminant concentrations, the concentration of nitrate is decreasing. In the GWM with the highest organic contamination, nitrate could not be detected. For all contaminated GMWs an increase of Mn^{2+} concentration was observed; Fe^{2+} shows increased concentrations if a higher concentration of an organic compound is detected. Particularly with regard to the results of the mass balances presented above, we conclude that this concentration pattern is due to natural attenuation processes, including biological degradation.