MAR in Germany

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According to the Federal Statistical Authority of Germany (FSA, 2013), public water supply in Germany relies on groundwater extraction (60,9 %), spring water (8,4 %), lake and dam water (12,2%) and river water (1,2 %). The remaining 17,4 % originate from MAR, whereby 8,6 % is bank filtrate and 8.8 % is defined as "recharged groundwater", consisting mainly of intentionally recharged surface water. In 2013, the public water supply produced ~5000*10^6 m³ of water out of which ~3500*10^6 m³ were domestic water provided for households and small businesses. According to these numbers approximately 870*10^6 m^3/year were abstracted via MAR. Surface water is the main source of MAR in Germany, recharged intentionally, for example via basins, or indirectly via induced bank filtration. MAR in Germany is generally done to achieve water quality improvements of the surface water used as a source, i.e. as a pre-treatment step, and to some extent also to preserve deeper groundwater resources. Since only a small fraction (~3 %) of the total amount of water available annually is required for the public water supply (Grischek et al., 2010), quantitative reasons for MAR are of lesser importance and strict legal regulations mostly impede the use of storm- or treated wastewater as well as the use of injection wells.

Table 1. Development of MAR in Germany and groundwater use

Annual MAR volume in the decade centred on date (Mm^3/y)						Groundwater Use (Mm^3/y)	MAR as % groundwater use	MAR as proportion of drinking water supply
1965	1975	1985	1995	2005	2010-15	2010	2010-15	2010-15
n.a.	867	766	875	765	872	3,077	28.2%	17.2%

The federal statistical agency in Germany collects the data only every 3 years. Data is based on public water supply only and was available from 1979 only for the years: 1979, 1983, 1987, 1991, 1995, 1998, 2001, 2004, 2007, 2010, and 2013.

Bank filtration has a long tradition in Germany. Amongst the sites exploited longest are those of the Düsseldorf-Flehe Waterworks on the River Rhine (Schubert, 2002), the Dresden-Saloppe Waterworks on the River Elbe (Grischek et al., 2010) and those of the Berlin Water Company along the lake-type extents of the rivers Spree and Havel in Berlin (Stadtentwicklung Berlin, 2016), all having provided drinking water since the 1870s. According to Lenk et al. (2006), decreasing river water qualities halved the amount of drinking water produced by bank filtration in former Western Germany between 1970 and 1990 and many sites were abandoned because of increasing chemical and organoleptic problems. Nowadays the water quality of major rivers has improved, possibilities for bank filtration are reviewed and new sites have been launched again (Lenk et al., 2006). Of the large river catchments in Germany, rivers within the Elbe (21 %) and Rhine (8,5%) catchments have the highest share of water originating from bank filtration in terms of % of total water production and also the largest total amount of water produced via bank filtration (Elbe: 189*10^6 m^3/year; Rhein: 140 *10^6 m^3/year; FSA, 2013). A literature review on bank filtration sites in Germany by Lenk et al. (2006) illustrates the clustering of sites identified as having >50 of bank filtrate in abstraction and observation wells in the Rhine and Elbe catchments (figure 1).

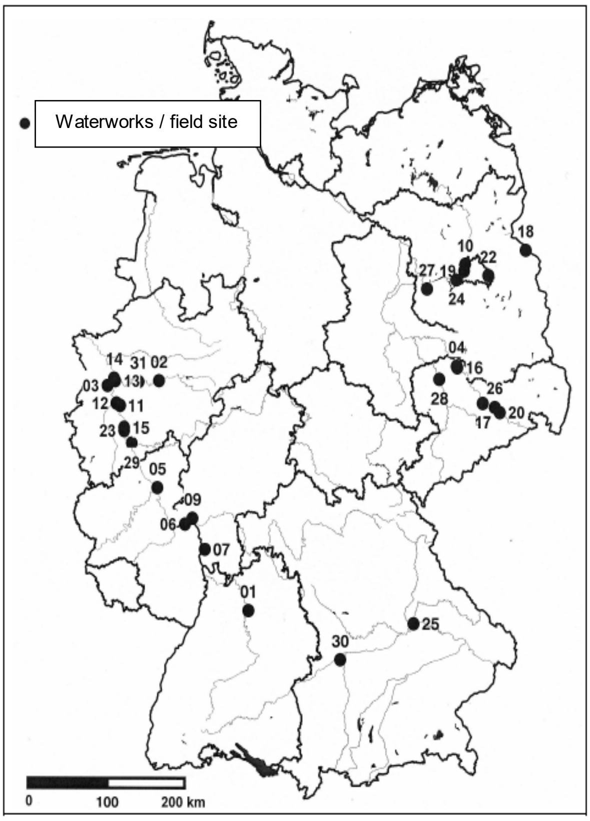

Figure 1: Water companies and field sites that were identified as having >50 of bank filtrate in abstraction and observation wells and studied in a large review on European bank filtration (Lenk et al., 2006).

In recent years, research on bank filtration in Germany has strongly focused on the behavior of organic trace pollutants during underground passage and a detailed report on the attenuation efficiency of the sub-surface for organic trace pollutants during bank filtration was presented by Schmidt & Lange (2006). Intensive research has, for example, been conducted regarding the semi-closed water cycle of Berlin, were 70% of the groundwater abstracted for drinking water purposes originates from bank filtration or infiltration via ponds and the fraction of treated sewage in the surface water courses is relatively high (e.g., Ziegler et al., 2002). Results from the NASRI and successive projects could show that most organic trace pollutants present in the surface water are readily removed, but a number of compounds behave persistent (e.g. Wiese et al., 2011). Overall, results also showed that the first meter of flow (i.e. the infiltration zone/river or lake base) is most efficient in removing trace pollutants and amongst other factors, redox conditions and temperatures strongly affect degradation (e.g. Burke et al. 2014). One of the largest challenges when assessing and quantifying organic trace pollutant attenuation during bank filtration and any other form of MAR is the transferability of attenuation parameters (such as first order degradation rate constants) between sites. This is mostly still impossible (e.g. Henzler et al., 2014; Nham et al., 2015; Hamann et al., 2016) and therefore prohibiting precise predictions on trace pollutant behavior at newly launched sites.

MAR with treated wastewater or stormwater is uncommon in Germany, the only exceptions being the cities of Braunschweig, where treated wastewater has been irrigated continuously for over 50 years onto agricultural fields (Ternes et al., 2007) and Wolfsburg, which irrigates ~$4*10^6$ m³/year of treated wastewater onto agricultural soils (WEB, 2014). In these two exceptional cases, MAR is practiced as soil-aquifer treatment and aims at stabilizing groundwater levels in addition to irrigation and fertilization of crops used for energy production.

Elsewhere in Germany the practice of treated or formerly even untreated sewage irrigation, which often lead to unintentional (and rather unmanaged) aquifer recharge, has been abandoned. A prominent historical example of "sewage farming" is the capital city Berlin, were untreated sewage was applied directly onto fields above unprotected aquifers from 1876 to the 1980s (Hass et al., 2012). Often, the remainders of this unintentional MAR practice continue to contaminate groundwater downstream of the former sewage farms (Scheytt et al., 2000; Richter et al., 2009; Hass et al., 2012).

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