

Study: Dynamic of wastewater effluent contributions to surface waters and potential challenges for drinking water abstraction in Germany

Summary of the findings

1 Background & Motivation

In addition to the reliance on natural groundwater and springwater (around 70 % of Germany's public water supply), also surface water plays a significant role for Germany's drinking water supply. Usually surface water is used via bank filtration or artificial groundwater recharge (around 17 % of public water supply). Beside contributions from stormwater run-off, drainage from agricultural areas, or industrial dischargers, streams are also commonly receiving effluents from municipal wastewater treatment plants (WWTPs). With increasing contributions of wastewater effluents in streams, the relative portion of wastewater-derived compounds will also increase which are then becoming part of the natural water cycle. The situation might become more challenging due to climate change impacts with a potential increase of low flow conditions in streams.

In order to gain further insights the German Environment Agency assigned the Technical University Munich in cooperation with DHI WASY GmbH to the study "Dynamic of wastewater effluent contributions to surface waters and potential challenges for drinking water abstraction in Germany" that was prepared between September 2017 and July 2018. The resulting report allows to determine for the first time the relative contribution of wastewater effluents in all German surface water bodies during various flow conditions, and to assess their relevance for drinking water abstraction via bank filtration or artificial groundwater recharge.

2 Method

The flow conditions of streams are subject to seasonal dynamics. Considering impacts from climate change, these dynamics may become more extreme in the future. Thus, this study took into account long-term monitoring data of average flow and low-flow conditions for the most relevant watersheds in Germany. This data set was used to relate average and low-flow conditions to typical dry and wet years. For this nationwide stream network, the individual average discharge from 7,550 municipal wastewater treatment facilities across Germany was determined and the relative wastewater contribution calculated for both average and low-flow conditions for specific river basins. Results were presented in a geological information system (GIS) as well as watershed specific maps. Water protection zones were evaluated to identify waterworks close to rivers and streams practicing bank filtration or artificial recharge. For selected sites water quality monitoring data of conservative constituents of wastewater-origin (i.e., carbamazepine, oxypurinol, 4-methylbenzotriazole) were used to validate the degree of wastewater effluent impacts on the local drinking water supply. Building upon these findings and qualitative risk assessments, recommendations for establishing a precautionary groundwater and drinking water protection were derived.

3 Dynamics of wastewater effluent contributions to rivers

The presence of elevated wastewater effluent contributions in a receiving stream, which subsequently is used as a source for drinking via riverbank filtration or artificial groundwater recharge, does not exhibit *per se* an elevated risk to public health. Relevant for the assessment of a potentially elevated risk associated with the practice of a naturally-based drinking water abstraction are the site-specific hydrobiogeological boundary conditions of the underground passage and its capability to retain microbial and chemical contaminants. Important factors for the efficacy of subsurface treatment are the predominant hydrobiogeological parameters, the average hydraulic retention time, and the relative contribution and quality of landside groundwater. These factors will primarily impact the quality of the recharged groundwater or the abstracted raw water of a drinking water abstraction facility.

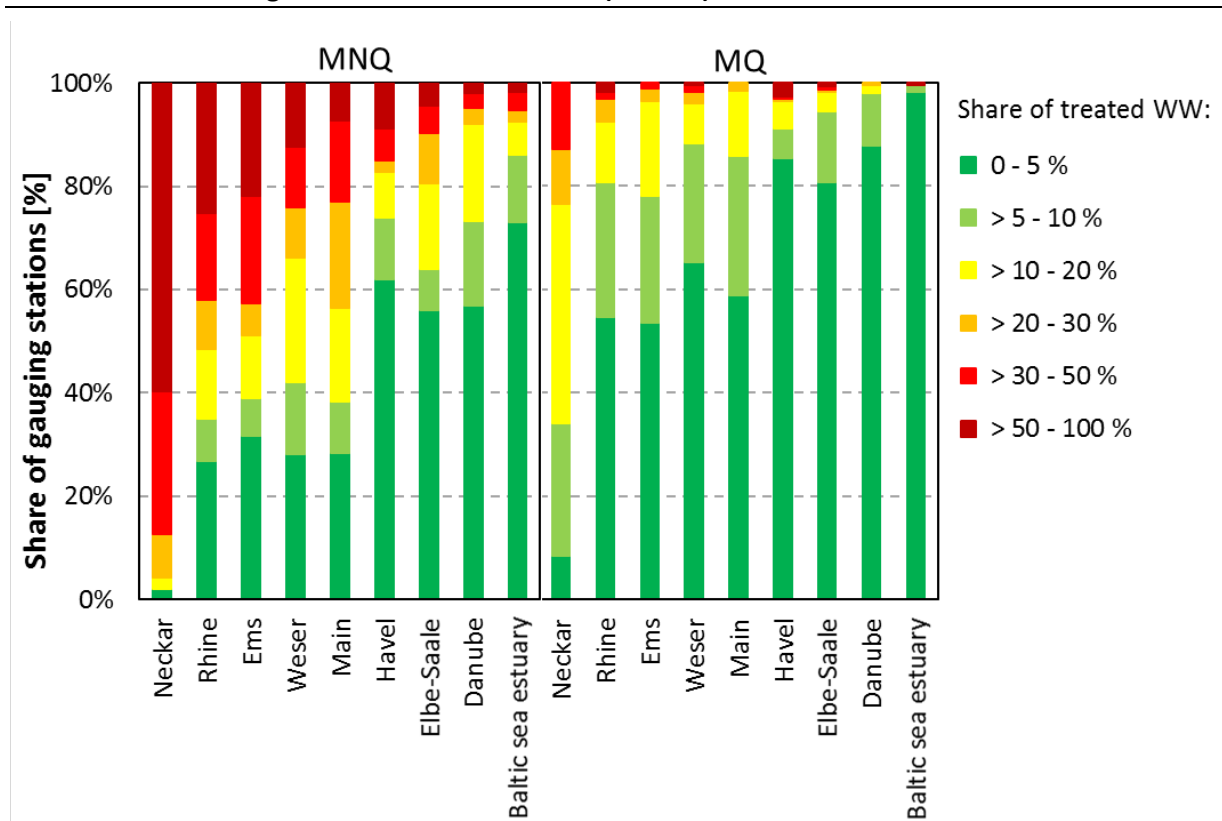
An adverse impact of the microbial quality after bank filtration or artificial groundwater recharge using surface water with elevated contributions from wastewater effluents can be neglected as long as a minimum travel time of 50 days in the subsurface is maintained even under fluctuating flow conditions in the stream. A large number of studies has demonstrated the efficacy of subsurface treatment like bank filtration or artificial recharge for the removal of pathogens even under low-flow conditions. There might reason for concern in situations where bank filtration is practiced without proper knowledge of the local hydrogeological conditions and where this practice is inadequately perceived as 'drinking water abstraction from native groundwater'.

For the occurrence of regulated chemical constituents in raw water for drinking water supplies, the requirements of the German Drinking Water Directive (Trinkwasserverordnung) apply. In addition, the German Environment Agency has published health related guide values for unregulated chemicals such as micropollutants or metabolites of pesticides in drinking-water. It is noteworthy that these health advisory values are not legally binding and due to limited data do represent values that are commonly lower than toxicologically-derived drinking water standards, which are based on a better scientific database. Thus, potential exceedances of health related guide values do not represent an immediate threat to public health. However, in case of exceedances of these health related guide values, the German Environment Agency recommends the establishment of counter measures that would result in an effective reduction of concentrations below these values to avoid any potential long-term adverse health effects. Very polar organic chemicals, which are not or only poorly degradable (like metabolites of some pesticides, some pharmaceuticals or household and industrial chemicals), carry a high potential to occur at elevated concentrations in bank filtrate.

Based on the results of this study, the contributions from wastewater effluents during average flow conditions vary in most upper river basins in Germany between 0 and 5 % (Figure 1). Contributions from >5-10 % and >10-20 % are dominant in river basins up- and downstream of urban centers (e.g. rivers Havel, Neckar, lower Rhine, Maas, middle Rhine) as well as river stretches characterized by generally low-flow conditions (i.e. rivers Main, Ems, Neckar).

During low-flow conditions this picture changes dramatically. Effluent contributions of >10-20 % are dominating under low-flow conditions nationwide in a large number of river basins. Several watersheds exhibit wastewater effluent contributions of >20-30 % (e.g. rivers Elbe/Saale, Weser, middle Rhine). Portions of the river Main, Ems, Weser and Havel as well as tributaries of the Rhine river are characterized by effluent contributions of >30-50 %. In portions of the river Neckar, Ems, the Baltic Sea estuary and the lower and middle Rhine watersheds effluent contributions are above 50 % during low-flow conditions.

Figure 1: Relative contribution of wastewater effluents for selected river basins under average and low-flow conditions (n=2344)

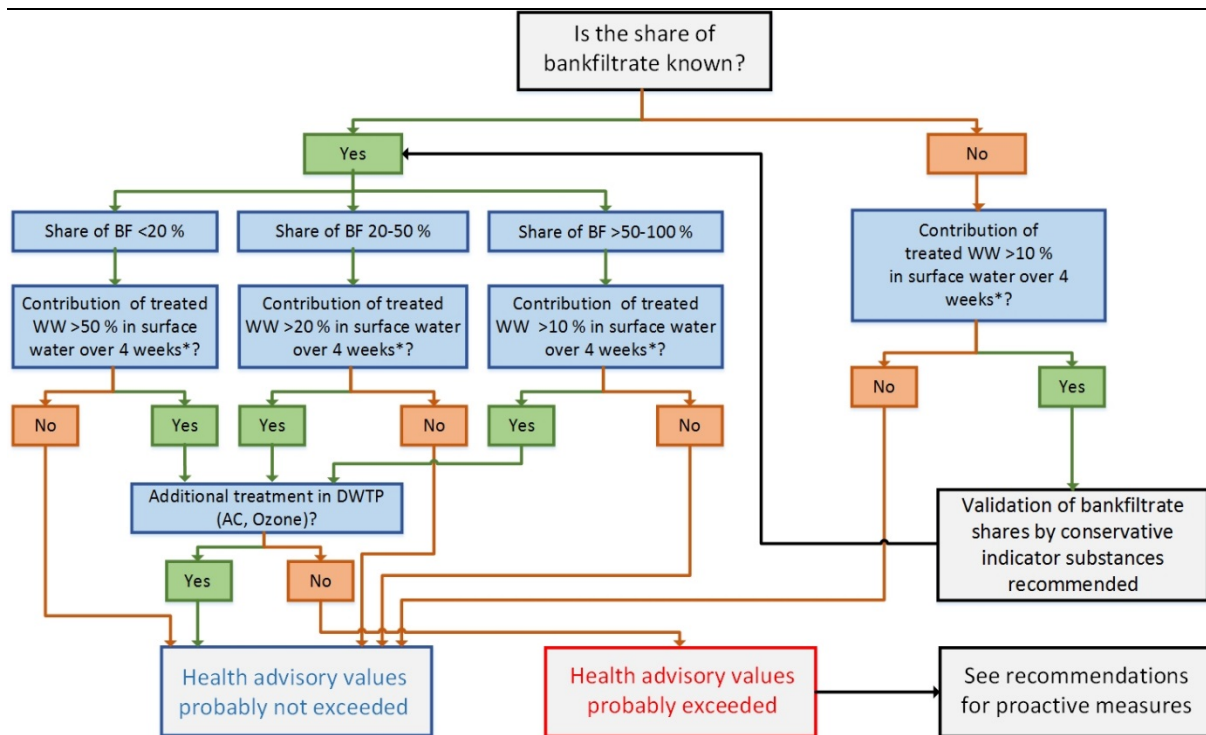


Source: Illustration by TU Munich, Chair of Urban Water Systems Engineering

4 Impacts on the drinking water supply

The relevance of elevated wastewater effluent in streams used for drinking water abstraction is determined by the relative share of bank filtrate in the raw water supply and the relative contribution of effluent. Calculations based on the ArcGIS model as well as trace organic chemical data from monitoring campaigns both confirm that at locations that exhibit bank filtrate shares of less than 20 % but effluent contributions of more than 50 % in the stream exceedances of health advisory values can be expected (Figure 2). This exceedance was also observed where the bank filtrate shares varied between 50-100 % but the effluent contribution in the stream was only 10 %. An important factor in these situations is the duration where these conditions prevail. Thus, where elevated effluent contributions dominate for more than 4 weeks, elevated concentration of conservative trace organic chemicals can be expected in abstraction wells, in particular where the travel time might be lower than the desired 50 days. For sites where the determined bank filtrate shares and relative effluent contributions would suggest potential exceedances of health related guide values, additional measures should be taken in particular where the downstream treatment train does not include any additional physical or chemical treatment barriers. These measures should be taken by the utility and overseeing regulatory bodies and should include a full risk assessment following principles of the WHO Water Safety Plan concept.

Figure 2: Decision framework to assess the relevance of elevated wastewater effluents in streams which are subject to drinking water abstraction via bank filtration.[†]



BF: bank filtrate

[†] In this study, we assumed a threshold value that represents a threefold exceedance of a health advisory value. A potential exceedance of a health advisory value following the proposed decision framework is illustrated using the metabolite oxipurinol (health advisory value of 0.3 µg/L). Based on the underlying assumptions, a bank filtrate with 30 % river water and an effluent contribution of 10% in the stream would already exceed the health advisory value. Considering 50 % of bank filtrate with an effluent contribution of 20 % would result in a threefold exceedance, which might trigger measures to minimize the discharge of chemicals to the receiving stream or targeted post-treatment strategies.

* A 4-week period is assumed since elevated concentrations of conservative trace organic chemicals over this time period will likely result in elevated concentrations in bank filtrate beside dispersion processes in the subsurface and dilution by landside groundwater.

Source: Illustration by TU Munich, Chair of Urban Water Systems Engineering

5 Recommendations for proactive measures

To address these issues, the following steps and recommendations are suggested:

- ▶ The calculated **relative wastewater contribution** to receiving streams (based on the ArcGIS model) should be validated by targeted monitoring campaigns in the field using selected wastewater indicators (e.g., carbamazepine, oxipurinol, 4-methylbenzotriazole, primidon, sucralose, EDTA). These campaigns should be repeated under average and low-flow conditions.
- ▶ For the selected site, the **relative share of bankfiltrate** of raw water supply should be determined through sampling campaigns of conservative wastewater indicators (see list above) with sampling locations along the stream and including the bankfiltrate under average and low-flow conditions.

- ▶ If not yet available, **hydrogeological investigations** and a site-specific model should be established to model and validate site-specific flow conditions. A hydrogeological calibrated model considering local boundary conditions can provide a more reliable assessment of travel time and an estimation whether the 50-day-travel time objective can also be met under various flow conditions in the stream.
- ▶ For the specific site, a **watershed assessment** should be conducted that considers all dischargers upstream. This should include the quantity and quality of dischargers like WWTPs, stormwater run-off, combined sewer overflows, industrial activities, and agricultural drainage. This evaluation might allow to pinpoint specific dischargers that might comprise the downstream drinking water abstraction and opportunities to minimize or reduce this point source contribution.
- ▶ If elevated contributions of wastewater effluents in a raw water supply are confirmed and are not avoidable on a short term, targeted measures at the point of discharge as well as **alternative abstraction and treatment strategies** should be considered.

The focus of this study has been on the assessment of wastewater effluents on stream quality, however, future studies should also consider relative impacts from stormwater run-off, combined sewer overflows, industrial dischargers, and agricultural drainages on receiving streams.

6 Outlook

Findings of the study underscore the importance of a comprehensive understanding of watershed dynamics on drinking water abstraction regarding discharges of wastewater effluents upstream, the variability of stream flow conditions, as well as site-specific hydrogeological conditions of bank filtration or artificial groundwater recharge operations.

So far not all responsible authorities and water providers have looked into these watershed related data and neither conducted a corresponding risk assessment. In places where high wastewater effluent contributions occur and bank filtration makes up a substantial share of the abstracted raw water, there is need for action.

The results of the study allow for a first assessment of local wastewater effluent contributions in the majority of German rivers under average and low-flow conditions. Federal state authority should follow-up on these results with further investigations to better evaluate the potential impacts for drinking water abstraction via bank filtration or groundwater recharge.

Considering impacts from climate change, the relative contribution of wastewater effluents in receiving streams is likely going to increase and thereby not only affecting the ecological and chemical status of surface water but also drinking water abstraction.