Application of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks

Part of D11.2: Demonstration of MAR effects on groundwater resources – development and application of different approaches for risk and impact assessment

The research leading to these results has received funding from the European Community's Seventh Framework Programme under Grant Agreement No.308339 (Project DEMEAU).

Title: Application of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks

Summary: The Australian Guidelines for Water Recycling – Managed Aquifer Recharge provide a ready-to -use and user-friendly compendium of knowledge. Practical instructions and checklists provide a step wise approach with a strong focus on implementation. The proposed models for water flow and substance transport allow a first tier estimation of present concentrations in ambient groundwater and the impacted zone in the aquifer. The use of stochastic models is not mandatory within the guidelines. A criticism which can be identified related to the use of models simply based on point estimates, is that especially in early stage risk assessments, where uncertainties are usually high, these models tend to pretend a level of certainty which often does not represent reality.

Risks associated to inorganic chemicals are required to be treated with more detail. Rigorous quantification of biodegradation kinetics (e.g. first-order rate constants) and adsorption parameters (e.g. linear distribution coefficients) for EOCs during subsurface passage determined on field scale are still scarce. It is clear that first-order rate constants and linear distribution coefficients provide only a simplified description of the removal mechanisms during subsurface passage, because they neglect spatial and temporal dynamics of physical and chemical conditions. Nevertheless, this approach often provides a good approximation and allows also for site independent comparison of removal processes.

Regarding the demonstration site in Berlin-Tegel the analysis showed that if the model of the Australian Guidelines is applied to the MAR system the travel time of 50d during subsurface passage cannot be guaranteed. In Germany, a residence time of 50d is usually considered to sufficiently reduce the risk of microbial hazards. Although risk calculations did not reveal immediate concern, it is recommended to develop and apply suitable verification monitoring techniques to quantify travel times and reduce present uncertainties. Moreover, this risk assessment and the study about the influence of the groundwater replenishment site on ambient groundwater (Sprenger and Grützmacher, 2015) clearly showed the need for protective measures against the input of undesired substances from shallow ambient groundwater.

Grant agreement no:	308339
Work Package:	11
Deliverable number:	D11.2 (section 5)
Partner responsible:	KWB
Deliverable authors:	Wolfgang Seis, Christoph Sprenger (KWB)
Quality assurance:	Sebastian Schimmelpfennig (Berliner Wasserbetriebe)
Planned delivery date:	31. August 2015
Actual delivery date:	31. August 2015
Dissemination level:	Pu

Table of contents

List of Figures

List of Tables

1 Application of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks

1.1 Introduction

During the last decade the Australian administration released a series of guideline documents in order to provide an authoritative reference that can be used to support beneficial and sustainable recycling of waters generated from sewage, grey water and storm water. The Phase 1 guideline is the overarching framework. The Phase 2 guideline refers to specific applications within the context of water recycling by Managed Aquifer Recharge (Figure 1-1).

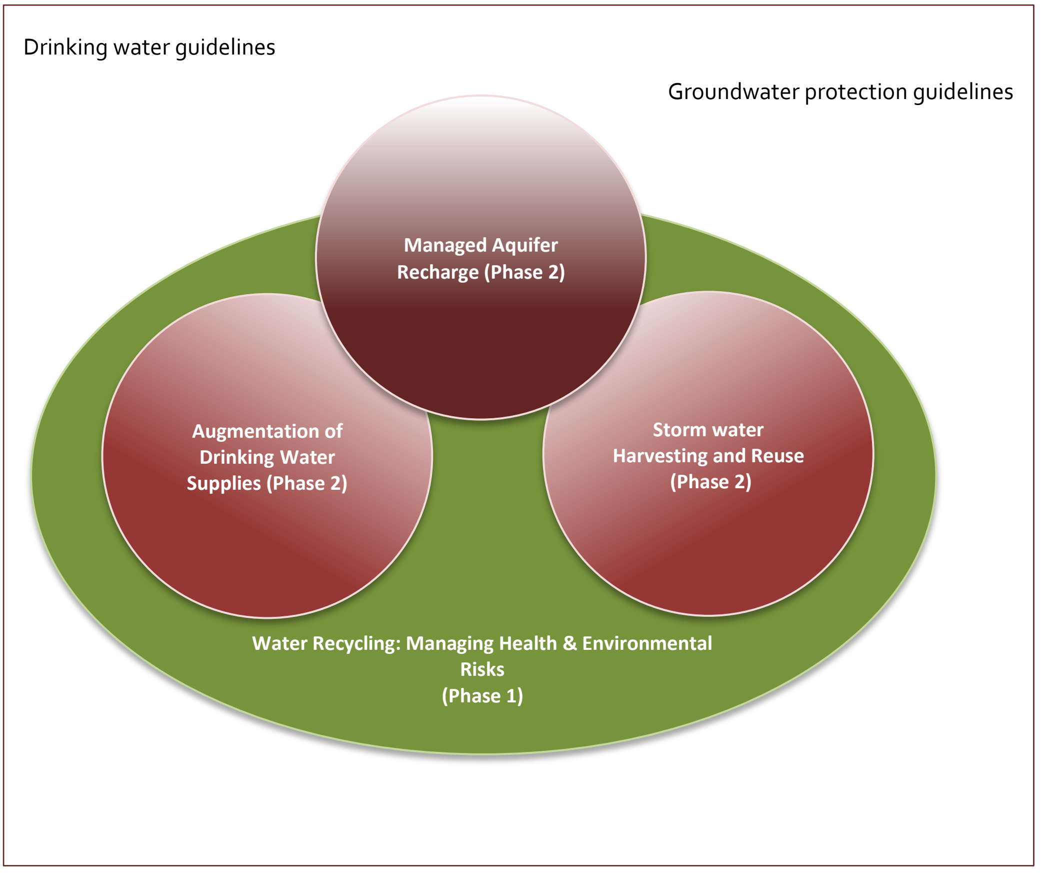

Figure 1-1: Overview of the series of guideline documents on water recycling released by Australian authorities (NRMMC-EPHC-NHMRC 2009).

Within this study these guidelines will be applied to the MAR site in Berlin-Tegel in order to demonstrate an additional methodological approach for impact assessment of MAR sites. In order to avoid redundancies, please see chapter 3 of this report for a detailed site description.

1.2 General approach

Within the Australian guidelines for water recycling a risk based and process oriented approach is promoted. The guidelines represent a practical guide to the planning and implementation of MAR projects, acknowledging that some developments cannot be predicted until full scale implementation. The assessment is based on a three level structure. Figure 1-2 shows the assessment levels and the objectives for the examined system.

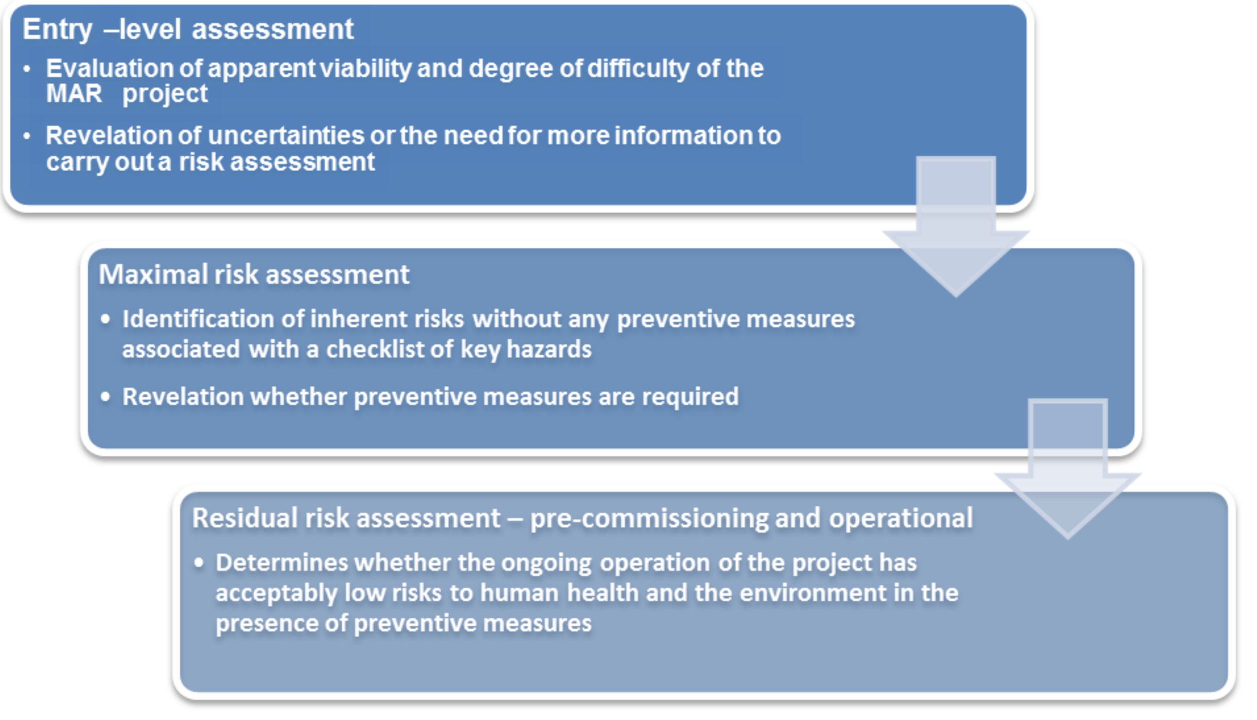

Figure 1-2: Overview and objectives of the general assessment stages (NRMMC-EPHC-NHMRC 2009).

Within this structure different assessment approaches are proposed in order to cover the full range of potentially important aspects when implementing a new MAR site. These include checklists, risk matrices, and simplified modelling approaches. During entry-level assessment a checklist approach is used to assess both viability and the degree of difficulty of the realisation of a new MAR project.

Moreover, a series of risk assessments that are designed to ensure protection of human health and the environment are foreseen. This includes an assessment of risks assuming the absence of any control measures (maximal risk assessment) and an assessment of the residual risk (both at a pre-commissioning and operational stage).

1.3 Application of Australian guidelines at Berlin-Tegel

This section demonstrates the application of the entry level assessment in Berlin-Tegel. Although Berlin-Tegel is an already running MAR project a periodic reassessment should be part of any proactive quality assurance. Entry level assessment may serve as a preliminary indicator of human health and environmental risks. Furthermore, it reveals existing knowledge gaps or the need for more information to carry out further risk assessment.

1.3.1 Entry level assessment of the MAR site in Berlin-Tegel

Entry-level assessment consists of a checklist approach for assessing viability the degree of difficulty of a MAR project (Table 1-1 and

Table 1-2).

Table 1-1: Entry level assessment for Berlin-Tegel.

Attribute	Answer and Explanation
1. Intended water use	
Is there an ongoing local demand or clearly defined environmental benefit for recovered water that is compatible with local water management plans?	YES - About 70% of recovered water for drinking water comes from bank filtration (BF) or aquifer recharge through infiltration ponds (IPs) (BWB 2013) to ensure the supply of drinking water for about 3.5 million inhabitants in Berlin
2. Source water availability and right of access	
Is adequate source water available, and is harvesting this volume compatible with catchment water management plans?	YES - Lake Tegel water is readily available and is recharge through the river Havel, Tegeler Fliess and Nordgraben
3. Hydrogeological assessment	
Is there at least one aquifer at the proposed managed aquifer recharge site capable of storing additional water? **Is the project compatible with groundwater management plans?**	YES - The unconfined aquifer of Quaternary age is in connection with lake Tegel (for Induced Bankfiltration) as well as with the infiltration ponds (IPs). Also it is the main aquifer for recovery of Berlin's drinking water supply. YES - AR through ponds has been used in Berlin-Tegel since 1943 (Paproth et al., 2011) as essential part of the drinking water management
4. Space for water capture and treatment	
Is there sufficient land available for capture and treatment of the water?	YES - IPs have already been built in the forest in Saatwinkel near the WW Tegel. There is existing water treatment and supply throughout wells located around the ponds.
5. Capability to design, construct and operate	

Is there a capability to design, construct and operate a MAR project?	YES - The Berlin water company (Berliner Wasserbetriebe, BWB) has experience to operate and maintain IPs and recovery wells
➡ *Go to* *Table* 1-2	

Table 1-2: Degree of difficulty assessment of Berlin-Tegel

Attribute	**Answers for Berlin-Tegel MAR site**
1. Source water quality with respect to groundwater environmental values	
Does source water meet the water quality requirements for the environmental value of ambient groundwater?	**No** - The environmental value of the aquifer is drinking water production. The aquifer is the source of water for the Berlin drinking water supply. Investigations are required to assess risk.
2. Source water quality with respect to recovered water end-use environmental values	
Does source water meet the water quality requirements for the environmental values of the intended end uses of the water on recovery?	**No** - Lake Tegel water does not meet the German drinking water standards (TrinwV 2001) for turbidity, microbiology, organic micro pollutants and copper. Investigations are required to evaluate hazard attenuation processes during infiltration.
3. Source-water quality with respect to clogging	
Does source water have low quality; for example: **total suspended solids (TSS) >10 mg/L** **total organic carbon (TOC) >10 mg/L** **total nitrogen >10 mg/L?** **and is the soil or aquifer free of macropores?**	**No** - Source water is of good quality and additionally the clogging layer in the infiltration ponds is removed and washed and cleaned of finer grained material and algae periodically. No further investigations needed.
11. Fractured rock, karstic or reactive aquifers	
Is the aquifer composed of fractured rock or karstic media, or known to contain reactive minerals?	**Yes** - The aquifer can contain ferrous or manganiferous sediment. Investigations are required to assess potential consequences of iron and manganese dissolution.
12. Similarity to successful projects	

Has another project in the same aquifer with similar source water been operating successfully for at least 12 months?	**Yes** - Sites all around Berlin (mostly riverbank filtration, but IPs as well) are in operation for decades. No further investigations needed.
4. Groundwater quality with respect to recovered water end-use environmental values	
Does ambient groundwater meet the water quality requirements for the environmental values of intended end uses of water on recovery?	**No** - Ambient groundwater (TEG342) has evidence of of elevatediron and manganese concentrations. SO4 concentration is also punctually elevated (up to 240 mg/L). Contaminated sites nearby (e.g. Tegel airport, abandoned industrial sites). MAR site at risk of contamination plume. Investigations are required to evaluate protective measures against contaminant input from shallow ambient groundwater.
5. Groundwater and drinking water quality	
Is either drinking water supply, or protection of aquatic ecosystems with high conservation or ecological values, an environmental value of the target aquifer?	**Yes** - The target aquifer is used for drinking water supply through wells. No groundwater dependant eco systems nearby. Investigations are required to assess the risk to groundwater quality and human health.
6. Groundwater salinity and recovery efficiency	
Does the salinity of native groundwater exceed either of the following: **(a) 10 000 mg/L** **(b) The salinity criterion for uses of recovered water?**	**No** - The mean value for TDS in TEG342 is 585 mg/L. This value is even lower in the source water. Also, sodium and chloride are below the guideline values. No further investigations needed.
7. Reactions between source water and aquifer	
Are redox status, pH, temperature, nutrient status and ionic strength of groundwater similar to that of source water?	**No** - Different water quality may lead to reactions. Investigations are required to evaluate geochemical reactions.
8. Proximity of nearest existing groundwater users, connected ecosystems and property boundaries	
Are there other groundwater users, groundwater-connected ecosystems or a property boundary within 100–1000 m of the MAR site?	**No** - The infiltration ponds are located within the catchment area of Tegel waterworks of the Berlin water company (BWB). Furthermore, the IPs are surrounded by recovery wells. No further investigations needed.
9. Aquifer capacity and groundwater levels	
Is the aquifer confined and not artesian? Or is it unconfined, with a water table deeper than 4 m in rural	**No** - The unconfined aquifer has a water table of 4 m within the rural area of the forest, but in urban areas it

areas or 8 m in urban areas?	may be higher than 8 m below ground. Investigations are required to assess risk of excessive groundwater mound height.
10. Protection of water quality in unconfined aquifers	
Is the aquifer unconfined, with an intended use of recovered water that includes drinking water supplies?	**Yes** - the aquifer is unconfined with recovered water for drinking water supply. Investigations are required to assess the protection of groundwater quality.
13. Management capability	
Does the proponent have experience with operating MAR sites with the same or higher degree of difficulty, or with water treatment or water supply operations involving a structured approach to water quality risk management?	**Yes** - The proponents have a history of operating drinking water supplies and groundwater exploitation and the MAR site is in operation for decades now. In Germany, a high level of standardization is reality. The Berlin Water Utilities are the largest water supplier in Germany and have the German standard for securing drinking water quality implemented.
14.Planning and related requirements	
Question is not relevant, because the project is already in operation for decades.	

Both checklists represent a well-structured and comprehensible foundation for a first desktop assessment of available information. Since in Berlin the later use of the source water (lake water) is drinking water the non-compliance with some of the water quality related questions was expected and additional investigation and reduction measures are necessary. In summary, the assessment of degree of difficulty identified investigations needed for a continuing risk assessment, such as:

- Source water quality investigations (questions 1 and 2)
- Evaluation of the recovered water quality against the German TrinkwV (2001) (questions 4 and 5)
- A geochemical evaluation (questions 7 and 11)
- An assessment of groundwater levels (question 9)
- An assessment of urban land users and risks to groundwater quality (question 10).

According to the Australian guidelines water quality requirements should be reached prior to infiltration. In contrast, the Berlin drinking water purification systems strongly rely on the cleaning capacity of the underground passage as a major barrier for microbial and chemical constituents.

1.3.2 Identification of key hazards

Within the guidelines for managed aquifer recharge potential hazards are grouped into 12 categories, so called key hazards (see Table 1-3). For a detailed description of the potential adverse effects, which might be caused by the respective hazard, it is referred to chapter 5 of the guideline document.

For each key hazard, a clear entry-level acceptance criteria is defined in the guideline (Table 1-3). These acceptance criteria will serve for preselecting relevant hazards for the recharge system of Berlin-Tegel.

Table 1-3: **Summary of key hazards in source water, groundwater and aquifer materials for MAR projects, with examples of specific hazards.**

Key hazard	Estimated risk after entry-level assessment	Selected for further risk assessment	Reasons
Pathogens	High	**Yes**	Acceptance criteria not met: end use includes drinking water supply. Source water has high risk of pathogen contamination due to influence of treated wastewater
Inorganic chemicals	Low	**No**	Some calcite (CaCO3) and rhodochrosite (Mn-CO_3) dissolves during subsurface passage leading to an increase of Ca and decrease of pH (Greskowiak et al., 2006) The predominant aerobic subsurface passage does not pose a high risk for geogenic mobilisation of metals, concentration of metals in source water is low
Salinity and sodicity	Low	**No**	Acceptance criteria met: TDS source water < 500 mg/L. Source water in respect to salinity and sodicity of almost equal quality to the ambient groundwater quality, even better.
Nutrients	Low	**No**	Acceptance criteria met: source water nitrogen species meet with the TrinkwV 2001
Organic chemicals	high	**Yes**	Acceptance criteria not met: Occurrence of various organic chemicals is known (e.g. pharmaceuticals). Even if the concentrations of the measured and selected pharmaceutical active compounds are below guideline values (NRMMC-EPHC-NHMRC 2009) they still may pose a significant risk. Other literature provide much lower concentrations as a safe drinking water level based on TDI or maximum residue level, e.g. Mons et al. 2014 90 ng/L for carbamazepine in comparison to NRMMC-EPHC-NHMRC 2008 with guideline value of 100 µg/L (=100.000 ng/L)
Turbidity and particulates	low	**No**	Acceptance criteria not met: estimated values for Lake Tegel (Ø 2,5 ± 1,4 NTU > 1 NTU acceptance criterion of the entry-level assessment as well as the TrinkwV 2001 (1.0 NTU) Long term experiences at the demo site and pre-treatment to non-selection.
Radionuclides	Low	**No**	Acceptance criteria met: low-risk lithology in storage zone (i.e. no granite or coal deposits) No radioactive isotopes in the source water

Pressure, flow rates, volumes and levels (unconfined aquifer)	Low	**No**	Even though, some criteria are not met risk is estimated as low. Prevention of water contamination by operation of infiltration ponds and operation of different extraction wells at a time. Control of water table is given by an alternating well operation. Also, there is no further investigation regarding this hazard because of already successful operation for so long.
Contaminant migration in fractured rock and karstic aquifers	Low	**No**	Not relevant since the aquifer is porous with sediments of Quaternary age that mainly contain glacio-fluvial sands with varying proportions of fine, medium and coarse grains.
Aquifer dissolution and aquitard and well stability	Low	**No**	Even though calcite dissolution occurs due to changing redox condition below the pond, at a larger scale influence of transient saturated or unsaturated conditions that lead to dissolution of calcite seemed not to be relevant (NUETZMANN ET AL. 2006)
Impacts on groundwater-dependent ecosystems	Low	**No**	There is no groundwater-dependent ecosystem within the area from infiltration pond to well 20.
Greenhouse gases	Low	**No**	The Berlin Water utilities fulfil entry-level assessment criteria with their environmental sustainability program (renewable energy use, energy efficient pumps, etc.)

1.3.3 Assessment of selected key hazards

The assessment of maximum and pre-commissioning risk provides information about the necessary treatment performance in the planning phase of an MAR project. In maximal risk assessment risk in the absence of any reduction measure is assessed. Crucial for the assessment risks of pathogens and chemicals in the aquifer is an estimation of travel times.

1.3.3.1 Estimating travel times during subsurface passage

Within the Australian MAR Guidelines for water recycling a simplified analytical modelling approach is proposed for predictions of the fate of organic and microbial hazards during MAR. The parameter values applied for the calculation of travel times are shown in Table 1-4.

Table 1-4: Parameters values used for the calculation of travel times.

Parameter	Value
Aquifer thickness (m)*	30-40
Porosity of the aquifer (%)	20-30
Distance between point of infiltration and recovery well (m)*	100

Average pumping rate of well 20 (m^3/d)	1920-2400
Minimum depth to the mounded water table beneath the infiltration basin or gallery (m)*	0-6
Saturated hydraulic conductivity (m/s)*	1.5×10^{-4}-1.1×10^{-3}

*from Greskowiak et al. (2005) and references therein

Within previous project and investigations at the site a travel time of 1-2 months (on average approx. 50d) was estimated. According to the methods proposed by the Australian Guidelines (NRMMC-EPHC-NHMRC (2009), Appendix 6) in combination with site specific parameter estimations (see Table 1-4) the modelled travel time lies between 28 and 59d with 50% of the values within an interval between 33 and 38d. Thus, although the results fall within the timeframe of 1-2 months the median or dominant travel time is 41d (Figure 1-3).

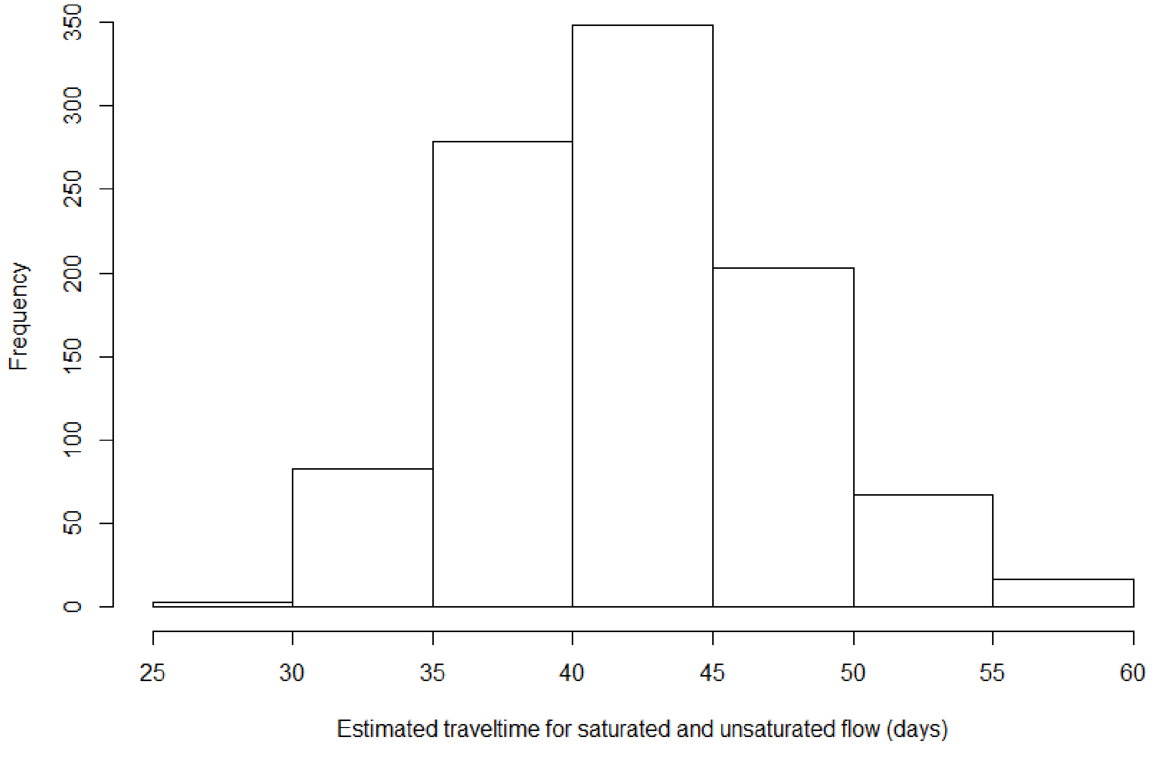

Figure 1-3: Histogram of calculated travel times during subsurface passage.

1.3.3.2 Organic chemicals

Organic substances are assessed at different stages of the overall assessment process. Table 1-5 gives an overview on the risk assessment and management approach regarding organic chemicals within the Australian guidelines.

Table 1-5: Assessment criteria for organic chemicals (NRMMC-EPHC-NHMRC 2009).

	Entry-level assessment and simplified assessment	Maximal and pre-commissioning residual risk assessment	Residual risk assessment (operational)
Acceptance criteria	Organic chemicals unlikely in source water at concentrations that would exceed acceptable concentrations for environmental values of aquifer or intended end uses Unlikely to be formed in the subsurface (no disinfection)	Any organic chemicals present in source water or formed in the subsurface are at or attenuate to concentrations that meet environmental values for aquifer beyond attenuation zone and in water recovered for use	As per pre-commissioning residual risk assessment
Preventive measures	na	Source control Pre-treatment, residence time in soil or aquifer or post-treatment	As per precommissioning residual risk assessment
Validation monitoring	na	na	- Determine organic chemical (hazard) and biodegradable organic carbon in: source water, attenuation zone, observation wells, recovered water - Analyze minimum period of aquifer storage using "natural" or introduced tracers - Evaluate physicochemical and redox conditions

The environmental values which would have to be applied at the case study in Berlin-Tegel would be the limit values of the German drinking regulation. Pharmaceuticals in Germany are addressed by the so-called health-oriented values (HoV), which apply a precautionary value of 0.1µg/L (0.01 µg/L for carcinogenic and endocrine disruptive chemicals) in case that no further information is available. HoV´s are recommended by the German Drinking Water Commission (Trinkwasserkommission) and are precautionary values for substances which either cannot or only partially assessed from a human toxicological endpoint. After testing several chemical properties and modes of action for the respective chemical less restrictive value may be applied.

In this study, measured data from source water (Lake Tegel) of five organic micro pollutants were used as an example. Measured substance concentration distribution was fitted to a gamma distribution for each data set using the "fitdistr" function in R for parameter estimation (www.r-project.org). Normal distribution was found to be not suitable as concentration will become negative. After fitting one thousand randomly distributed values were taken for further calculations.

The resulting concentrations in production well 20 were calculated using the equations outlined in the appendix 6 of the Australian guidelines (NRMMC-EPHC-NHMRC 2009) by:

1. Calculation of travel time of water from infiltration basin to production well (saturated and unsaturated)
2. Application of chemical specific retardation factors
3. Application of first order decay (dilution is not considered although the well 20 ab abstracts about 80-90 of infiltrate (Pekdeger et al., 2006))

Sorption processes during subsurface passage will retard the transport of chemical substances based on their physicochemical properties. The magnitude of the retardation factor is influenced by the partitioning coefficient (Kd) of the chemical substance and the fraction of organic carbon in the sediment. The soil organic carbon partition coefficients were determined by USEPA (1996) according to:

$$\log K_{OC} = 0.7919 \log K_{OW} + 0.0784$$

K_d is then calculated by multiplying K_{oc} by f_{oc} (the mass fraction of soil organic carbon content), according to:

$$K_d = f_{OC} \times K_{OC}$$

The log K_{OW} (Table 2) for the organic compounds can also be taken from the online database (www.chemicalize.org). Fraction of organic carbon in the sediments are f_{oc} = 0.02 – 0.08 wt % (Pekdeger et al., 2006). Table 1-6 gives an overview on the chemical properties used for transport calculation. The DT50 and log Kow values were previously determined by reactive modelling (Henzler et al., 2014) and represent the predominantly oxic to sub-oxic redox conditions at the site.

Table 1-6: Overview of chemical properties and drinking water benchmarks of different micro pollutants (from Henzler et al. (2014))

Substance	DT50 (days)*	Log Kow*
Carbamazepine	66	2.45
Diclophenac	36	4.01
Primidone	8022	1.12
Phenazone	57	1.22
EDTA	200563	-1.86

The retardation for each substance is calculated based on the following equation:

$$R_f = 1 + \rho_s \cdot K_d / ne$$

where

R_f	retardation factor [-]
n	porosity [-]
ρ_s	dry bulk density [g/cm³]
K_d	sorption isotherm [ml/g]

The effective porosity was assumed to vary between 0.2 -0.3. The dry bulk density varied between 1.450 - 1.900 g/cm^3, representing characteristic density for the porous aquifer. The retarded compound specific flow velocity is calculated by:

$$v_{compound} = \frac{v_{GW}}{R_f}$$

where

$v_{compound}$	flow velocity of compound [m/d]
R_f	retardation factor [-]
v_{GW}	flow velocity of groundwater [m/d]

The transport time for the compound for the distance between pond and abstraction well is calculated using the equation:

$$t_{compound} = \frac{x}{v_{compound}}$$

where

$t_{compound}$	compound specific transport time [d]
x	distance between recharge zone and abstraction well [m]
$v_{compound}$	flow velocity of compound [m/d]

The (biological) degradation for each compound during subsurface transport is calculated by first-order degradation term according to:

$$c = c_0 \cdot e^{-\lambda \cdot t_{compound}}$$

where

c	concentration in abstraction well [µg/L]

c_0	initial concentration in source water [µg/L], gamma distribution of measured concentration in source water
λ	decay constant [1/d]

with $\lambda = \frac{\ln 2}{DT_{50}}$

λ	decay constant [1/d]
DT_{50}	half-life time of the compound [d]

Dilution is not taken into account. Figure 1-4 shows the substance specific travel times.

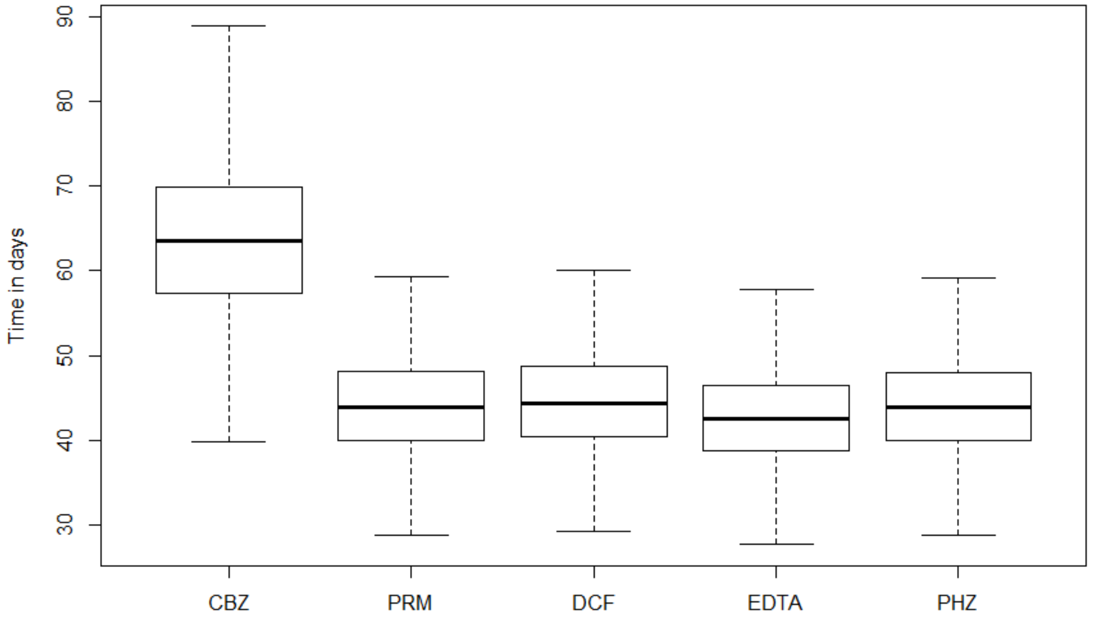

Figure 1-4: Substance specific travel time accounting for hydraulic and physico-chemical properties (Carbamazepine (CBZ), Primidone (PRM), Diclophenac (DCF), EDTA, and Phenazone (PHZ)).

Figure 1-5 shows the calculated and measured concentrations in production well 20. Upper and lower box shows the 75 and 25 percentile, maximum and minimum values are displayed by small horizontal lines at the end of the whiskers. Arithmetic average values are displayed by small rectangles and mean values are displayed by horizontal lines in the box.

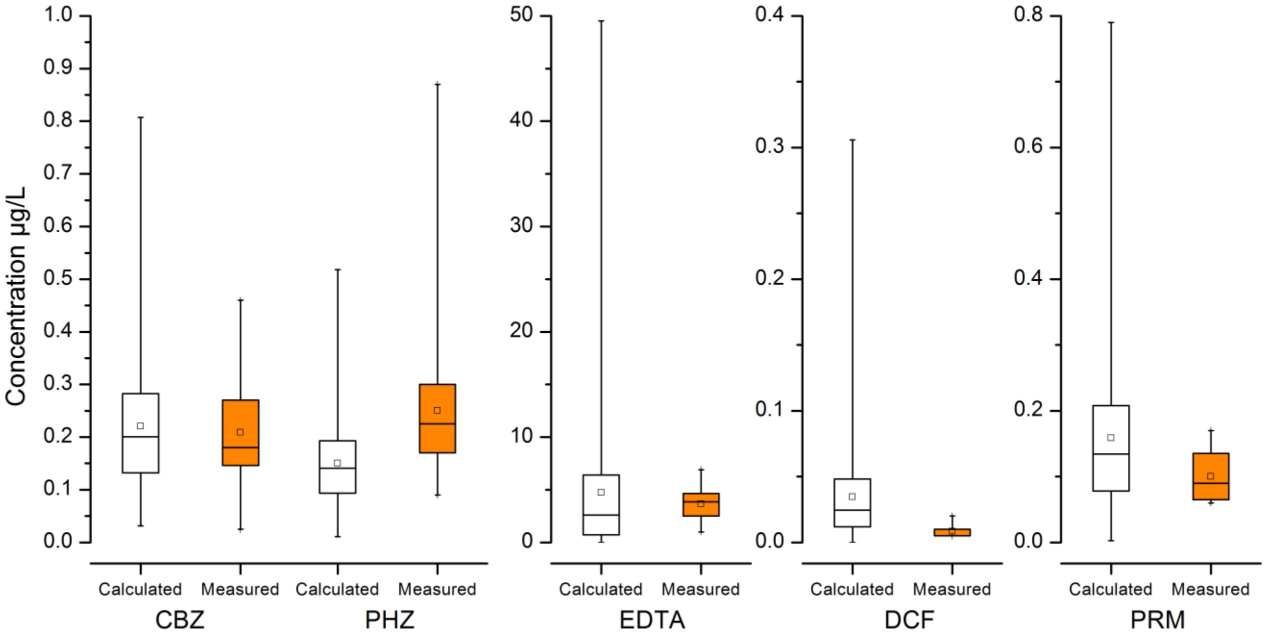

Figure 1-5: Calculated (blank) and measured (orange) concentrations of micro pollutants in production well 20 (Carbamazepine (CBZ), Primidone (PRM), Diclophenac (DCF), EDTA and Phenazone (PHZ)).

In general, the calculated concentrations show much larger concentration ranges compared to measured values. This is due to wide range of calculated travel times and the chosen distribution function of substance concentration. Calculated mean concentrations are higher compared to measured concentrations for CBZ, DCF and PRM, while PHZ and EDTA show lower calculated mean values, i.e. mean values do not represent a conservative value for risk assessment. However, considering the given input parameters and simple methodological approach the resulting concentrations are in a realistic range and represent a good approximation of attenuation processes in the subsurface.

Against the background of the used available information and assumptions the concentrations of DCF, PHZ, CBZ are not expected to exceed the benchmark of the HoV (0.1 µg/L and 0.3 µg/L). Although EDTA is expected to be present in the production well with a median value of approx. 2.4 µg/L the existing HoV threshold of 10 µg/L gives no reason for acute concern. However, this threshold is exceeded by calculated maximum concentrations by a factor of 5 approximately.

CBZ was measured at Berlin-Tegel with 0.47 µg/L in the source water and 0.21 µg/L in the abstraction well 20 (Heberer and Jekel 2006). The reduction of the concentration cannot be explained by dilution only (share of infiltrate 80-90%) and the measured concentration fits well with calculated values.

Calculated DCF values were mostly below limit of quantification (0.1 µg/L). As indicated by the high log Kow value (log Kow = 4.01) DCF shows a high affinity for sorption. Based on the assumed substance properties and the sake of risk assessment the resulting value adequately represents measured concentration. Measured PHZ concentrations are not adequately represented by this approximation and it is likely that native groundwater contribute to PHZ concentration.

1.3.3.3 Pathogens

For microbial hazards risk assessment via quantitative microbial risk assessment is proposed using the DALY (disability adjusted life years) indicator as a measure of risk. A health based target of 1 tolerable additional µDALY pppy is applied. This is in line with the current approach of WHO (WHO 2011). Risk is usually assessed for selected reference pathogens which cover bacterial, protozoan and viral pathogens. Here risk assessment is presented just for viruses, using Rotavirus as a reference pathogen.

For maximal risk assessment a rotavirus concentration of 1-10 virus particles per litre is assumed (WHO 2011). Assuming this concentration the risk resulting from Rotavirus without any reduction measures is calculated to be around 420 µDALYs per person per year (pppy) (see Figure 1-6). In order to be in compliance with the WHO standard of 1 µDALY pppy an additional reduction of 5-6 log units is necessary (Figure 1-7).

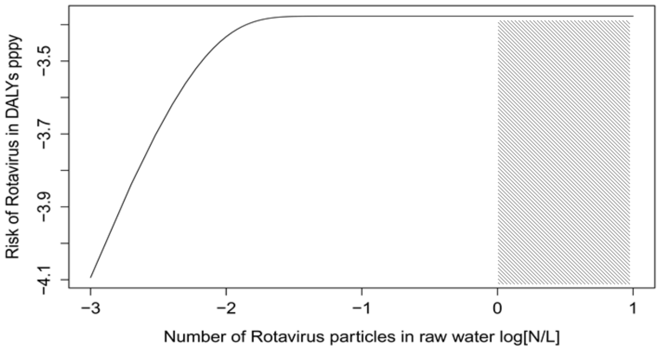

Figure 1-6: Disease burden in DALYs without any reduction measures in place. Assumptions (1L drinking water consumption per day, disease per infection ratio (0.5), susceptible fraction (6%), dose response parameters for Rotavirus from (Haas et al. 1999), severity factor ($1.4*10^{-2}$ DALYs/case of disease)).

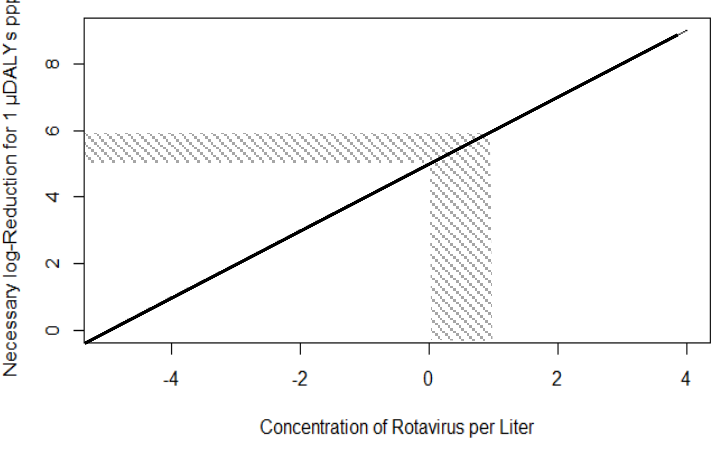

Figure 1-7: Number of log removal (LRV) required to be in compliance with a tolerable level of risk of 1 µDALY pppy. Assumptions: 1L drinking water consumption per day, disease per infection ratio (0.5), susceptible fraction (6%), dose response parameters for Rotavirus from ((Haas et al., 1999)).

1.3.3.4 Reduction measures in Berlin-Tegel and residual risk assessment

As described in chapter 3 of this report, drinking water treatment in Berlin-Tegel consists of an underground passage via bank filtration and groundwater recharge followed by aeration and rapid sand filtration before end-use. Regarding the effectiveness of the individual barriers with regard to virus removal the following values are given by WHO (WHO 2011) for bank filtration and rapid sand filtration (Table 1-7). It has to be mentioned that removal rates depend on the residence time, temperature, redox conditions and aquifer characteristics. Here, a stochastic approach is used to account for fluctuations and variation in pathogen removal.

Table 1-7: Barriers and assumptions of the effectiveness of virus reduction in Berlin-Tegel (WHO 2011)

Treatment	Log removal (LRV)	Remarks/assumption
Subsurface passage (assumption: effectiveness of comparable bank filtration for microbiological parameters)	2.1-8.3	Depending of the residence time in subsurface. Assumption used for calculation: 4-6 Log removal(LRV)
Rapid sand filtration	0-3.5	Depends on filter media and coagulation pre-treatment: Assumption used for calculation: 1-2 LRV

Following the assumptions made in the previous chapter an overall virus reduction potential of 5-8 LRV is assumed. In order to account for present uncertainties a Monte Carlo Simulation is conducted based on the made assumptions. The results are compared to the Australian and WHO standards of 1 additional µDALY per person per year (pppy). Results were grouped in five risk categories:

- A: risk exceeds tolerable WHO level by a factor of 10 or more
- B: risk exceeds tolerable WHO level by a factor of 10
- C: risk below tolerable WHO level by a factor of 10
- D: risk below tolerable WHO level by a factor of 100
- E: risk below tolerable WHO level by a factor of 1000

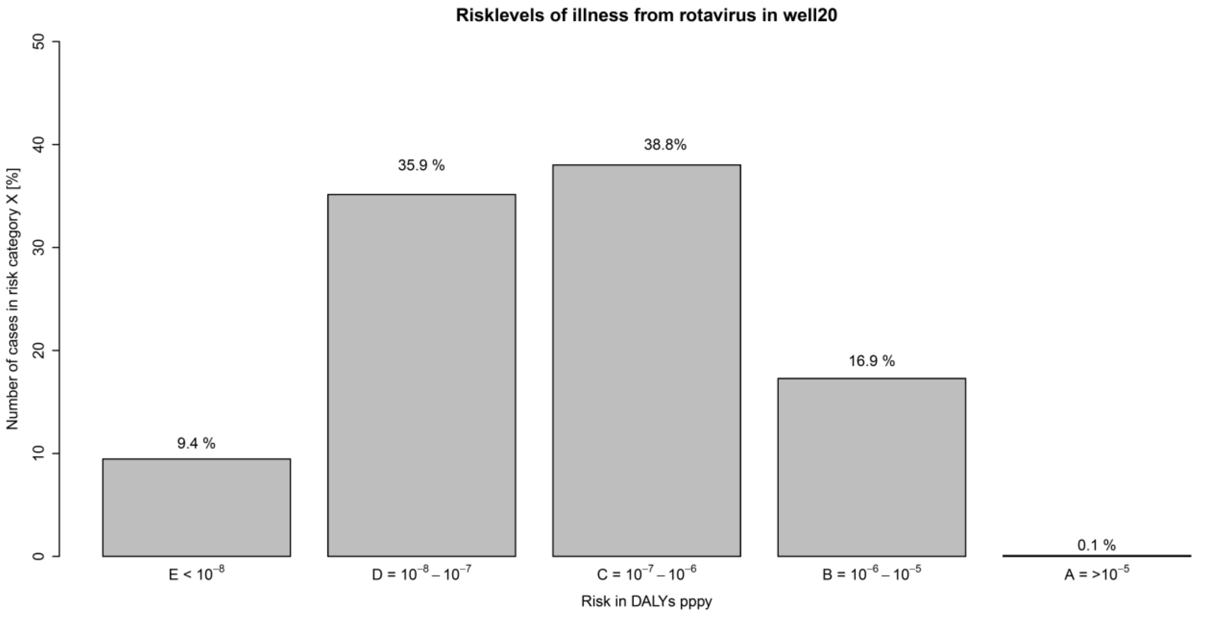

Figure 1-8: Results of risk calculation for drinking water production for well 20 at the MAR site in Berlin-Tegel.

The calculation reveals that against the background of the made assumptions the limit of 1 µDALY pppy is exceeded for about 17% of the calculated realizations. Both the mean and the median value are below this benchmark. An intolerable risk and an acute need for action can consequently not be postulated. However, as estimations of travel times in the aquifer indicate that a sufficiently safe residence time of 50 days cannot be guaranteed, it is recommended to further investigate the removal of viruses during subsurface passage and verify the residence time during MAR.

References

Greskowiak, J., Prommer, H., Massmann, G., and Nuetzmann, G., 2006, Modeling Seasonal Redox Dynamics and the Corresponding Fate of the Pharmaceutical Residue Phenazone During Artificial Recharge of Groundwater: Environmental Science & Technology, v. 40, no. 21, p. 6615-6621.

Greskowiak, J., Prommer, H., Massmann, G., Johnston, C. D., Nützmann, G., and Pekdeger, A., 2005, The impact of variably saturated conditions on hydrogeochemical changes during artificial recharge of groundwater: Applied Geochemistry, v. 20, no. 7, p. 1409-1426.

Haas, C. N., Rose, J. B., and Gerba, C. P., 1999, Quantitative Microbial Risk Assessment, John Wiley & Sons.

Heberer, T. and M. Jekel (2006). Occurrence and fate of drug residues and related polar contaminants during bank filtration and artificial recharge. NASRI - Final Project Report. Berlin, Technical University of Berlin, Dept. of Food Chemistry: 177

Henzler, A. F., Greskowiak, J., and Massmann, G., 2014, Modeling the fate of organic micropollutants during river bank filtration (Berlin, Germany): Journal of Contaminant Hydrology, v. 156, no. 0, p. 78-92.

Massmann, G., b, J. G., Dünnbier, U., Zuehlke, S., Knappe, A., and Pekdeger, A., 2006, The impact of variable temperatures on the redox conditions and the behaviour of pharmaceutical residues during artificial recharge: Journal of Hydrology, v. 328, p. 141-156.

Mons, M. N., Heringa, M. B., van Genderen, J., Puijker, L. M., Brand, W., van Leeuwen, C. J., Stoks, P., van der Hoek, J. P., and van der Kooij, D., 2013, Use of the Threshold of Toxicological Concern (TTC) approach for deriving target values for drinking water contaminants: Water Research, v. 47, no. 4, p. 1666-1678.

NRMMC-EPHC-AHMC 2006: Australian Guidelines for Water Recycling Phase 1, Managing health and environmental risks, ISBN 1 921173 06 8, Editing by Biotext Pty Ltd, Canberra

NRMMC-EPHC-NHMRC 2009: Australian Guidelines for Water Recycling Phase II, Managing health and environmental risks, Managed Aquifer Recharge ISBN 1 921173 47 5, Edited and produced by Biotext, Canberra

Paproth, F., Kade, N., Bayer, C., Havemeier, L., Pfahl, S., Fiebinger, S., and Vogel, L., 2011, Wasserwerk Tegel, Bewilligungsverfahren, Umweltverträglichkeitsstudie: UBB, Umweltvorhaben.

Pekdeger, A., Taute, T., Knappe, A., Massmann, G., and Greskowiak, J., 2006, Hydrogeological and hydrogeochemical processes during bank filtration and ground water recharge using a multi tracer approach.

TrinkwV, 2001, Verordnung über die Qualität von Wasser für den menschlichen Gebrauch, Trinkwasserverordnung in der Fassung der Bekanntmachung vom 2. August 2013 (BGBl. I S. 2977), die durch Artikel 4 Absatz 22 des Gesetzes vom 7. August 2013 (BGBl. I S. 3154) geändert worden ist.

Sprenger, C., and Grützmacher, G., 2015, Comparison of quantitative and qualitative data during MAR with aquifer baseline data – generic approach and site application.

USEPA, 1996, Soil Screening Guidance: Technical Background Document: EPA Document Number: EPA/540/R-95/128.

WHO (2011): Guidelines for drinking-water quality -4th edition, ISBN 978 92 4 154815 1