Water Practice & Technology

 Water Practice & Technology Vol 16 No 4, 1510 doi: 10.2166/wpt.2021.057

# Source water quality requirements for artificial groundwater recharge

K. Hägg[a,b,*], S. Chan[a], T. Persson[a] and K. M. Persson[a,c]
[a] Sydvatten AB, Hyllie Stationstorg 21, 215 32, Malmö, Sweden
[b] Sweden Water Research AB, Ideon Science Park, Scheelevägen 15, Lund 223 70, Sweden
[c] Division of Water Resources Engineering, Faculty of Engineering LTH, Lund University, 221 00 Lund, Sweden
*Corresponding author. E-mail: kristofer.hagg@sydvatten.se

KH, 0000-0002-5291-1258

## ABSTRACT

This study was an investigation of the need for pre-treatment of a new raw water source for artificial groundwater recharge. The study was done through a column test, well sampling and survey data relating to 11 artificial recharge plants in Sweden. The column test showed that only 30% of the natural organic matter (NOM) was removed from the new raw water source during infiltration. The survey revealed that the new water source's quality was within the range requiring pre-treatment prior to infiltration. The well sampling results showed a significant correlation between the NOM content in the raw and treated waters for WTPs without pre-treatment ($r = 0.78$ and $\rho = 0.04$), indicating one of the short-term limitations of artificial recharge. The study results indicate that the new raw water source is unsuitable for direct use in artificial recharge and that treatment is required prior to infiltration.

**Key words:** chemical flocculation, managed aquifer recharge (MAR), natural organic matter (NOM)

## HIGHLIGHTS

- This study shows the synergetic effect of chemical flocculation and managed aquifer recharge (MAR).
- NOM removal limitations during artificial recharge were observed.
- The investigation showed indications of different treatment efficiencies during MAR depending on NOM composition.
- Treatment efficiencies from Swedish water utilities are made available to an international readership.

## INTRODUCTION

Managed aquifer recharge is commonly used to store groundwater worldwide (Stefan & Ansems 2018). In Sweden, one quarter of all drinking water supplied comes from artificial recharge (ASR) and about half from surface water treatment plants (SWWA 2016). With the high natural organic matter (NOM) content recorded in surface waters in the Nordic countries (Löfgren & Andersen 2017) and the expected increase in surface water NOM (Eklund *et al.* 2015), a lot of work is needed to secure high quality drinking water. A common way to reduce NOM concentrations is chemical flocculation but little has been published about when the technique is needed.

Experience with ASR in Finland (Jokela *et al.* 2017) shows that 70–85% of the organic matter is removed from raw water with or without pre-treatment through chemical flocculation, and water treatment plants (WTPs) without pre-treatment prior to infiltration used raw waters containing up to 8 mg-COD/L. Similar results were presented in Tanttu & Jokela (2018), where treatment plants removed about 70% of the NOM content. Both studies reported that the water recovered comprised between 10 and 50% natural groundwater, depending on location. It is not known, however, whether NOM removal rates change if the source water is deteriorating or new sources are used for recharge.

In trying to secure the water supply for 16 municipalities in southern Sweden, Southern Sweden Water Supply (Sydvatten AB) plans to use water from Lake Bolmen as a new water source for Vomb WW, an ASR plant (Sydvatten AB 2018). However, it is not known whether the recharge field there can produce high quality drinking water from this new source. The capacity to remove NOM from the two raw water sources was studied using a column test and well-water samples from the Vomb WW recharge field. The results were compared with experience from other ASR plants using different pre-treatment methods. The study's objective was to investigate recharge field limitations and determine benchmark source water quality requirements for artificial recharge.

## MATERIALS AND METHODS

### Study sites and source waters

The study was conducted at Ringsjö WW surface water treatment plant and Vomb WW ASR plant in Southern Sweden. Ringsjö WW treats water from Lake Bolmen by chemical flocculation and lamella sedimentation as primary treatment. Water from Lake Vomb is treated at Vomb WW by micro-sieve filtration (40 μm) and basin infiltration. The recovered water after infiltration is aerated to remove iron and manganese, and softened to reduce the hardness. Fifty-four infiltration basins are excavated in the native glacifluvial deposits of the recharge field (Pott *et al.* 2009), where the deposits are sands with an effective grain size ($d_{10}$) of 0.10–0.87 mm (median 0.39 mm). In general, the deposits comprise finer material than those found in eskers, which are often used by other ASR-plants in Sweden (Hansson 2000; Hägg *et al.* 2018).

The two WTPs produce about 220,000 $m^3$/d and supply 16 municipalities in southern Sweden with potable water. Water from Lake Bolmen is transported 105 km to Ringsjö WW. Because of the low extraction limit and low water quality of Lake Vomb, a new pipeline is planned to transport water from Lake Bolmen to Vomb WW. Water from Lake Bolmen is rich in NOM and has high color content, as the catchment area is dominated by forests and iron-rich soils (Persson 2011; Eikebrokk *et al.* 2018; SMHI 2018). The organic matter's origin is confirmed by the high $UV_{254\,nm}$-absorbance and specific UV-absorbance (SUVA) values. Table 1 shows the water quality parameters for the raw water source at Ringsjö WW inlet and the treated water.

**Table 1** | Average source water quality before and after treatment at Ringsjö WW (Eikebrokk *et al.* 2018; Sydvatten AB 2020)

| Sampling point | Color [mg-Pt/L] | Turbidity [FNU] | $COD_{Mn}$ [mg/L] | TOC [mg/L] | DOC [mg/L] | SUVA [L/(m·mg)] |
|---|---|---|---|---|---|---|
| Raw water | 52.5 | 1.1 | 9.0 | 8.3 | 9.3 | 4.0 |
| Treated water | <5 | <0.10 | 1.3 | N/A | 2.2 | 1.8 |

### Data collection and well sampling

Data were collected from a survey of Swedish ASR plants (Hägg *et al.* 2018) and included the NOM content in the raw and infiltration waters, and water from the wells. The results from 11 ASR plants using basin infiltration were chosen, six of them with chemical flocculation prior to infiltration. Well samples were also taken from 35 wells distributed evenly across Vomb WW recharge field. Samples were collected in plastic bottles, stored refrigerated overnight and sent stored on ice to an accredited laboratory (Eurofins, Sweden) for TOC and COD analysis.

### Column test

A column test was conducted from 27 June 2019 to 15 May 2020 using a 3-meter-tall, 0.5-meter-wide column filled with soil from Vomb recharge field. It was fed with water from Lake Bolmen. The test was designed to achieve 14 days' retention by regulating the feed volume to 0.75 L/h. TOC samples were taken monthly before and after filtration throughout the test period.

## RESULTS AND DISCUSSION

The survey results show that the WTPs without chemical flocculation achieved COD and TOC removal ranging from 49 to 78% (Table 2). The same set of WTPs had on average the raw water sources with lower NOM content (3.6–13 mg-COD/L, 2.7–10.9 mg-TOC/L and 25–35 mg-Pt/L). They also showed a significant correlation between NOM-content ($COD_{Mn}$) in the source and finished waters ($r = 0.78$ and $\rho = 0.04$), which was not the case for the WTPs with pre-treatment. The raw water sources for WTPs with chemical flocculation had COD >9 mg/L, TOC >9 mg/L and color ≥50 mg-Pt/L, and total COD and TOC removal was between 87 and 93% (Table 3). After pre-treatment these WTPs still achieved about 62–78% COD removal, within the same removal range as those relying solely on infiltration, which shows the complementary effect of combining chemical flocculation and ASR. Contact filtration was used in the WTPs with pre-treatment and water output ≤16,000 $m^3$/d. WTPs with higher

**Table 2** | Results from ASR plants without pre-treatment

| | | Raw water | | | Finished water | | |
|---|---|---|---|---|---|---|---|
| **WPTs without pre-treatment** | **Production [m$^3$/d]** | **COD** | **TOC** | **Color** | **COD** | **TOC** | **Color** |
| Vomb WW | 86,400 | 6.7 | 6.8 | 17.5 | 2 | 2.7 | <5 |
| A | 25,000 | 8.1 | 10.3 | 35 | 3.3 | 5.3 | 10 |
| B | 20,600 | 5.2 | 5.1 | 25 | N/A | 1.8 | <5 |
| C | 6,000 | 13 | 10.9 | N/A | N/A | 3.4 | N/A |
| D | 19,000 | 3.6 | 2.7 | 33.6 | 0.8 | <2 | <5 |
| E | 15,000 | 9.3 | N/A | 25 | 3.4 | N/A | 10 |

Performance was measured in relation to COD, TOC and color (annual averages).

**Table 3** | Results from ASR plants with chemical flocculation pre-treatment

| | | Raw water | | | Infiltration water | | | Finished water | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **WPTs with pre-treatment** | **Production [m$^3$/d]** | **COD** | **TOC** | **Color** | **COD** | **TOC** | **Color** | **COD** | **TOC** | **Color** |
| F[a] | 16,000 | 17 | 18.7 | 139 | 4.7 | 6.4 | 10.4 | 1.3 | 2.4 | <5 |
| G[a] | 12,000 | 9.1 | 9 | 79.4 | 2.4 | 3.34 | 5.9 | N/A | <2 | <5 |
| H[a] | 12,200 | 28 | 23.7 | 250 | 5 | 6.25 | 9.7 | 1.1 | 2.4 | N/A |
| I[b] | 40,000 | 10 | N/A | 50 | N/A | N/A | N/A | 1.3 | N/A | <5 |
| J[b] | 33,700 | 20 | N/A | 150 | 4 | N/A | 7 | 1.4 | N/A | 5 |

Performance was measured in relation to COD, TOC and color (annual averages).
[a]Pre-treatment through contact filtration.
[b]Pre-treatment through flocculation and sedimentation.

outputs (about 30,000–40,000 m$^3$/d) used flocculation and sedimentation prior to infiltration. Contact filtration filters are designed as a compact, low footprint, continuous treatment option (Luque de Castro & Álvarez-Sánchez 2008; Nordic Water 2021). However, the production capacity of the units used by the surveyed WTPs is limited to about 500–1,700 m$^3$/d (6–20 L/s) depending on size (Byström 1988; Hägg *et al.* 2018; Li *et al.* 2019). This means that WTPs with higher outputs require a substantial number of filters, which indicates diminishing returns at higher production capacity demands.

The column test results show inadequate NOM removal during infiltration: after 14 days' retention, only 30%, on average, of the TOC is removed (Figure 1(c)). NOM removal from Lake Vomb water after infiltration at Vomb WW was about 60% (TOC) and 70% (COD), including minor dilution by mixing with native groundwater (<10%) (Table 2). In contrast to Lake Bolmen (Eikebrokk *et al.* 2018), a substantial amount of the organic matter in Lake Vomb originates from agricultural lands in the lake's catchment (Persson *et al.* 2010; Länsstyrelsen i Skåne Län 2012; Li 2020). Thus, the difference in NOM removal rates may be influenced by differences in NOM-composition. The biological treatment that occurs during artificial recharge seems to remove autochthonous material more effectively than allochthonous material from the source water. The NOM content range in Lake Bolmen water was similar to that of source waters (>9 mg-COD/L and color >50 mg-Pt/L) needing pre-treatment, indicating that this water needs treatment prior to infiltration. Figure 1 shows the performance of all WTPs, the column test and well sampling.

Vomb WW has utilized Lake Vomb as a raw water source since 1948 without any observed reductions in groundwater quality. On the other hand, water from Lake Bolmen is likely unsuitable for artificial recharge based on the high NOM content and composition, and its use would likely cause a loss in recovered water quality. Besides organic matter content, water chemistry is an important aspect when using new raw water sources. The soft water from Lake Bolmen will reduce the need for the softening reactors after infiltration. However, introducing a lower ionic strength water could cause increased deposit mobilization in the aquifer (Crittenden *et al.* 2012; Benamar 2013).

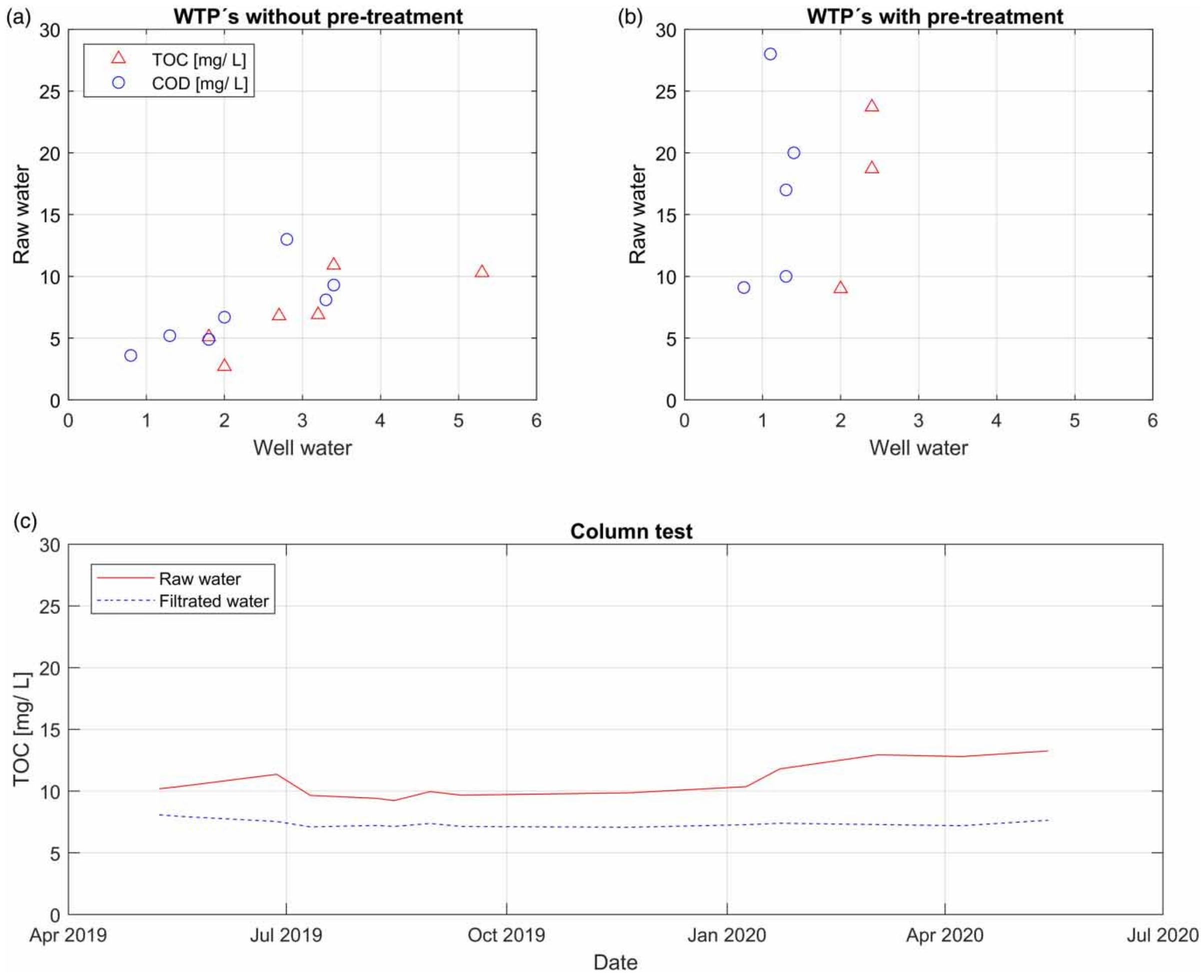


**Figure 1** | Results from the (a) survey, (b) well samples, and (c) column test. The figure shows the NOM content in the source and finished water.

## CONCLUSIONS

This study showed, within its scope, some of the synergetic effects of combining chemical flocculation and artificial recharge, in relation to ASR plants using raw waters with >9 mg-COD/L, >9 mg-TOC/L and color ≥50 mg-Pt/L, and chemical flocculation prior to infiltration. The water quality from Lake Bolmen, the new water source considered for infiltration, was within the NOM-rich range requiring treatment prior to infiltration. The column test results showed that infiltration removed about 30% NOM from Lake Bolmen water. The study's results suggest that the water from the new source is likely to need pre-treatment prior to infiltration.

## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## REFERENCES

Benamar, A. 2013 *Soil Clogging Phenomena in Vertical Flow. Clogging Issues Associated with Managed Aquifer Recharge Methods*. IAH Commission on Managing Aquifer Recharge, Australia, pp. 77–83.

Byström, M. 1988 *Contact Filtration of Surface Water – an Emerging Technology*. The Swedish Water & Wastewater Association, SWWA, Stockholm, Sweden, pp. 95–108.

Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J. & Tchobanoglous, G. 2012 *MWH's Water Treatment Principles and Design*, 3rd edn. John Wiley & Sons Inc., Hoboken, New Jersey.

Eikebrokk, B., Haaland, S., Jarvis, P., Riise, G., Vogt, R. D. & Zahlsen, K. 2018 *NOMiNOR: Natural Organic Matter in Drinking Waters Within the Nordic Region*. Norwegian Water BA, Oslo, Norway.

Eklund, A., Mårtensson, J. A., Bergström, S., Björck, E., Joel Dahné, L., Lindström, x., Nordborg, D., Olsson, J., Och, L. S. & Sjökvis, E. 2015 *Sweden's Future Climate – Groundwork for the Water Supply Investigation*. Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden. Available from: https://www.smhi.se/polopoly_fs/1.96078!/Menu/general/extGroup/attachmentColHold/mainCol1/file/klimatologi_14.pdf

Hägg, K., Persson, K. M., Persson, T. & Zhao, Q. 2018 *Artificial Recharge Plants for Drinking Water Supply – Groundwork for A Manual for Operation*. The Swedish Water & Wastewater Association, SWWA, pp. 2018–2011.

Hansson, G. 2000 *Artificial Groundwater Recharge – A Method Used in Swedish Drinking Water Supply*. The Swedish Water & Wastewater Association, SWWA, pp. 2005–2005.

Jokela, P., Eskola, T., Heinonen, T., Tanttu, U., Tyrväinen, J. & Artimo, A. 2017 Raw water quality and pretreatment in managed aquifer recharge for drinking water production in Finland. *Water* **9**(2), 138. VO - 9, 2, 138. https://doi.org/10.3390/w9020138.

Länsstyrelsen i Skåne Län 2012 Vombsjön. Report from the sea database. Available from: https://www.lansstyrelsen.se/download/18.6ae610001636c9c68e55840/1527064814580/Vombsjön.pdf

Li, J. 2020 *Managing Eutrophic Waters in Artificial Recharge Plants: Cyanotoxin Risks in Swedish Freshwaters*. Faculty of Engineering, Lund University, Lund, Sweden. Available from: http://ludwig.lub.lu.se/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=cat07147a&AN=lub.6423573&site=eds-live&scope=site

Li, J., Hägg, K. & Persson, K. M. 2019 The impact of lake water quality on the performance of mature artificial recharge ponds. *Water (Switzerland)* **11**(10). https://doi.org/10.3390/w11101991.

Löfgren, S. & Andersen, T. 2017 *The Color of Water – Climate Induced Water Color Increase in Nordic Lakes and Streams due to Humus*. Swedish University of Agricultural Sciences, Uppsala, Sweden. Available from: http://info1.ma.slu.se/IMA/Publikationer/brochure/The_color_of_water.pdf

Luque de Castro, M. D. & Álvarez-Sánchez, B. 2008 Chapter 9 - Membrane-based separation techniques: liquid–liquid extraction and filtration. In: *Advances in Flow Injection Analysis and Related Techniques*, Vol. 54 (Kolev, S. D. & Mckelvie, I. D. B. T.-C. A. C., eds). Elsevier, New York, NY, pp. 235–264. https://doi.org/10.1016/S0166-526X(08)00609-0.

Nordic Water 2021 Dynasand. Available from: https://www.nordicwater.com/product/dynasand/

Persson, K. M. 2011 *On Natural Organic Matter and Lake Hydrology in Lake Bolmen*. Lars Bengtsson – a water resource, pp. 127–140.

Persson, A. S., Olsson, O., Rundlöf, M. & Smith, H. G. 2010 Land use intensity and landscape complexity – analysis of landscape characteristics in an agricultural region in Southern Sweden. *Agriculture, Ecosystems & Environment* **136**(1), 169–176. https://doi.org/https://doi.org/10.1016/j.agee.2009.12.018.

Pott, B.-M., Cronberg, N., Annadotter, H., Johnsson, S. & Cronberg, G. 2009 *Effect of Nitrate Addition on Algae Bloom*. The Swedish Water & Wastewater Association, SWWA, pp. 2009–2014.

SMHI 2018 *Water Web*. Swedish Meteorological and Hydrological Institute (SMHI). Available from: https://vattenwebb.smhi.se/modelarea/

Stefan, C. & Ansems, N. 2018 Web-based global inventory of managed aquifer recharge applications. *Sustainable Water Resources Management* **4**(2), 153–162. https://doi.org/10.1007/s40899-017-0212-6.

SWWA 2016 The Swedish Water & Wastewater Association, SWWA. Available from: http://www.svensktvatten.se/Vattentjanster/Dricksvatten/Ravatten/

Sydvatten AB 2018 *Strategic Plan 2018-2022*. Sydvatten, Malmö, Sweden. Available from: https://sydvatten.se/wp-content/uploads/2019/02/Sydvatten_strategiskplan_2018_.pdf

Sydvatten AB 2020 *Productionsrapport 2019*. Available from: https://sydvatten.se/wp-content/uploads/2020/04/Produktionsrapport-2019.pdf

Tanttu, U. & Jokela, P. 2018 Sustainable drinking water quality improvement by managed aquifer recharge in Tuusula region, Finland. *Sustainable Water Resources Management* **4**(2), 225–235. https://doi.org/10.1007/s40899-017-0198-0.

First received 29 April 2021; accepted in revised form 14 June 2021. Available online 24 June 2021