Raw water quality and pretreatment in managed aquifer recharge for drinking water production in Finland

Petri Jokela¹, Tapani Eskola², Timo Heinonen³, Unto Tanttu⁴, Jukka Tyrväinen⁵ and Aki Artimo⁶

¹Tavase Ltd., FINLAND; petri.jokela@tampere.fi
²Kymenlaakso Water Ltd., FINLAND
³ Tampere Region Central Wastewater Treatment Plant Ltd., FINLAND
⁴Tuusula Region Water Utility, FINLAND
⁵ Jyväskylä Energy Ltd., FINLAND
⁶ Turku Region Water Ltd., FINLAND
Water and Finland

- 56,000 lakes
- 10% of the surface area is covered by water
- Groundwater is favored in water supply, but aquifers are small
- Surface waters contain natural organic matter (NOM)

Humic substances increase the colour of water
Managed aquifer recharge (MAR) in Finland

- MAR is used for the production of drinking water
- Removal of natural organic matter
- Unconfined glaciofluvial esker aquifers
- Total number of MAR plants 26
- Most of the MAR plants have no pretreatment
The MAR plants (1)

- Ahvenisto MAR plant
  - Taken in use in 1976
  - Production 7,800 m³/d
  - Basin and sprinkling infiltration

- Vuontee MAR plant
  - Taken in use in 2000
  - Production 10,000 – 15,000 m³/d
  - Sprinkling infiltration
The MAR plants (2)

- Kuivala MAR plant
  - Taken in use in 1992
  - Production 22,000 m$^3$/d
  - Basin infiltration

- Vehoniemi MAR plant
  - Under permit process
  - Capacity 70,000 m$^3$/d
  - Well, sprinkling and basin infiltration
The MAR plants (3)

- **Rusutjärvi MAR plant**
  - Taken in use in 1997
  - Production 10,000 m$^3$/d
  - Well infiltration since 2007

- **Virttaankangas MAR plant**
  - Production 63,000 m$^3$/d
  - Capacity 105,000 m$^3$/d, the largest MAR plant in Finland
  - Basin infiltration
# Raw water characteristics of the MAR plants

(Infiltration: basin/sprinkl. sprinkl. well/sprinkl. /basin well basin)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>1.5 (0.3 - 5.6)</td>
<td>1.2 (0.4 - 2.4)</td>
<td>2.1 (0.54 - 3.4)</td>
<td>2.5 (1.0 - 6.1)</td>
<td>0.5 (&lt;0.3 - 0.7)</td>
<td>6.6 (0.9 - 17)</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
</tr>
<tr>
<td>pH</td>
<td>7.1 (6.7 - 7.7)</td>
<td>6.8 (6.0 - 8.4)</td>
<td>7.2 (6.9 - 7.5)</td>
<td>5.9 (5.7 - 6.1)</td>
<td>7.2 (6.8 - 7.7)</td>
<td>7.1 (6.8 - 7.5)</td>
</tr>
<tr>
<td>Colour</td>
<td>mgPt/l</td>
<td>mgPt/l</td>
<td>mgPt/l</td>
<td>mgPt/l</td>
<td>mgPt/l</td>
<td>mgPt/l</td>
</tr>
<tr>
<td>Electric conductivity mS/m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>µg/l</td>
<td>380 (76 - 660)</td>
<td>83 (1 - 470)</td>
<td>80 (23 - 140)</td>
<td>95 (39 - 150)</td>
<td>46 (25 - 79)</td>
</tr>
<tr>
<td>Manganese</td>
<td>µg/l</td>
<td>29.0 (5 - 54)</td>
<td>53 (2 - 490)</td>
<td>25 (6 - 54)</td>
<td>75 (19 - 330)</td>
<td>11 (&lt;10 - 18)</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>µg/l</td>
<td>590 (390 - 930)</td>
<td>380 (300 - 490)</td>
<td>360 (290 - 450)</td>
<td>380 (280 - 490)</td>
<td>500 (390 - 590)</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>µg/l</td>
<td>11 (6 - 22)</td>
<td>..</td>
<td>12 (8 - 15)</td>
<td>12 (9 - 17)</td>
<td>7.7 (5 - 11)</td>
</tr>
<tr>
<td>COD₅₆</td>
<td>mgO₂/l</td>
<td>12 (8.2 - 18)</td>
<td>5.6²</td>
<td>4.5 (3.6 - 5.6)</td>
<td>4.3 (3.7 - 5.0)</td>
<td>6.4 (5.4 - 8.4)</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/l</td>
<td>10.3</td>
<td>6.7</td>
<td>6.5³ (6.0 - 7.6)</td>
<td>6.0 (5.7 - 6.1)</td>
<td>6.7⁴ (6.2 - 7.0)</td>
</tr>
</tbody>
</table>

(Pretreatment: No No No/Maybe No Yes)
Case 1 – Vehoniemi MAR

Infiltration/pretreatment considerations

- Sporadic diatom occurrence in the raw water
- No problems for basin and sprinkling infiltration
- Well infiltration primary method reservation for mechanical drum sieve or/and parallel well and sprinkling infiltration
Case 2 – Virttaankangas MAR

Mechanical and chemical pretreatment

- Fluctuating raw water quality (river)
- Chemical pretreatment given as a condition during the permit process

River Kokemäenjoki

Water intake with bar screens
Pretreatment process:

- Bar screens at the water intake
- Drum sieves (3 lines, sieve opening size 300 µm)
- Chemical precipitation of NOM with polyaluminium choride (31 mg/l commercial PAX)
- Clarification by dissolved air flotation (8 lines, hydraulic loading 5 m/h)
- Rapid filtration in the same basins (dual media filters)
## Pretreatment results 2015:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Unit</th>
<th>Raw water quality (before pretreatment)</th>
<th>After pretreatment</th>
<th>Average reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>min.</td>
<td>max.</td>
<td>median</td>
</tr>
<tr>
<td>Turbidity</td>
<td>50</td>
<td>FNU</td>
<td>2.6</td>
<td>21</td>
<td>6.6</td>
</tr>
<tr>
<td>reduction</td>
<td></td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>43</td>
<td>mg/l</td>
<td>2.2</td>
<td>19</td>
<td>7.1</td>
</tr>
<tr>
<td>reduction</td>
<td></td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOC</td>
<td>48</td>
<td>mg/l</td>
<td>9.2</td>
<td>12</td>
<td>9.1</td>
</tr>
<tr>
<td>reduction</td>
<td></td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Water quality after the pretreatment and MAR processes:**
- TOC 1.9 mg/l
- Dissolved oxygen: 8 – 11 mgO₂/l
- Fe < 6 µgFe/l
Case 3 – Kuivala MAR

Chemical pretreatment for partial flow

- MAR plant taken in use in 1992 without any pretreatment
- No pretreatment requirements in the permit
- Gradual increase of TOC in the raw water
- Decrease of DO in the abstracted water
- Increased possibility for iron and manganese leaching from the soil

The development of organic matter content of Lake Haukkajärvi measured as COD$_{Mn}$
Case 3 – Kuivala MAR continued

- Pretreatment plant was constructed in 2006
- 60% of the raw water is pretreated and then mixed with the raw water (40%) before infiltration
- Chemical precipitation with ferric sulphate (110 mg/l)
- Clarification by dissolved air flotation followed by sand filtration

Abstracted water: 30 µgFe/l, 20 µgMn/l
Conclusions

• MAR in unconfined esker aquifers is used for NOM removal in Finland

• NOM is removed or decomposed by natural processes (biodegradation has a key role)

• There is no need for pretreatment at most of the MAR plants

• The need for pretreatment may arise if the raw water turbidity or NOM content is high
Conclusions

• Mechanical pretreatment can be used for clogging prevention in the case of well infiltration

• Chemical pretreatment can be used for lowering the NOM content prior infiltration to maintain high enough dissolved oxygen concentration in groundwater

• The decision for the construction of chemical pretreatment should be based on data of local conditions, including aquifer and soil properties (such as the share of the natural groundwater in the aquifer)