Appendix 5 Health Recommendations

Introduction

Recycling water for the augmentation of drinking water supplies requires effective strategies to address potential public health risks from pathogenic micro-organisms, chemical contaminants and radioactive compounds. Contaminants analysed, in the secondary wastewater, in this Premiers Collaborative Research Program (PCRP) project comprised microbial pathogens and a range of chemicals with different physico-chemical properties, diverse toxic effects, and different frequencies of occurrence and concentration ranges (from pg/L to mg/L). The Department of Health (DoH) considers that the results of the PCRP project provide sufficient scientific information to design the validation and verification monitoring program of the Groundwater Replenishment Trial (GWRT), and provides recommendations on how this can be achieved below.

The DoH considers that the approach of a screening health risk assessment is appropriate and sufficiently conservative to ensure human health protection. Characterisation of the secondary wastewater from the three major wastewater treatment plants in Perth indicates that many of the analysed contaminants were above limits of detection and that some of them, in particular metals, disinfection by-products (DBPs) and polycyclic aromatic hydrocarbons, were above health values.

The advanced treatment, including microfiltration (MF) and reverse osmosis (RO), was able to effectively eliminate risks to human health, and reliably produced post-RO water in compliance with the Australian Drinking Water Guidelines (2004) (ADWG) and Australian Guidelines for Water Recycling - Phase 2: Augmentation of Drinking Water Supplies (2008) (AGWR phase 2) for all analysed contaminants, with one exception. N-nitrosodimethylamine (NDMA) was consistently detected in post-RO water, and occasionally above the guideline level of 10 ng/L set by the AGWR Phase 2. Moreover, when the potential toxicological contributions from all detected N-nitrosamines were added to produce a combined hazard quotient (HQ) where the imputed guideline value is 1, the calculated mean HQ was 0.69 and 1.5 in the post-RO water at BPP and KWRP respectively. N-nitrosamines were more commonly detected at KWRP, and therefore the HQ was higher at KWRP compared with BPP.

1 The Groundwater Replenishment Trial

The Groundwater Replenishment Trial will be undertaken by the Water Corporation. Water quality monitoring and management recommendations from the PCRP study will be incorporated into ongoing monitoring and management procedures.

Secondary wastewater from the Beenyup WWTP will be subject to advanced treatment using ultrafiltration, RO and ultraviolet disinfection, and up to 5 ML/day will be injected into the confined Leederville aquifer at a depth of
approximately 200 metres. The recycled water will be injected in a P3 drinking water source protection area (about 3 kilometres from drinking water abstraction bores) with the water quality being such that there will be negligible risk to the environment or human health.

The DoH is of the view that the GWRT will

- Assist in obtaining additional data on \(N\)-nitrosamines
- Validate the selected chemical and microbial indicators
- Highlight policy and regulatory areas requiring further development with a view to enabling a large GWR scheme to proceed in the future.

Therefore, the GWRT will be closely monitored to see whether it provides confirmation of the conclusions of this initial research, and in particular to observe the behaviour of NDMA and other disinfection by-products during the advanced treatment and in the aquifer.

The DoH supports the implementation of the three year GWRT proposed by the Water Corporation, subject to the following conditions and recommendations:

2 Recommendations

The Department of Health recommendations for this project are presented in the following sections:

- Water quality monitoring, covering the key technical findings and recommendations derived from the PCRP project.

- Management systems, covering operational and administrative recommendations for the GWRT, and for future projects considering augmentation of drinking water resources with recycled water.

2.1 Water Quality Monitoring Recommendations

A key outcome of the PCRP project is the understanding of what monitoring is required to validate and verify the process, and demonstrate adequate removal of chemicals and pathogens.

Recommendation

The DoH require an 8 week monitoring period to be conducted on the operating advanced treatment plant to assess water quality prior to approval to recharge to the aquifer. The parameters to be assessed during this Commissioning period are discussed and recommended below.

Chemicals
It has been demonstrated that certain chemical compounds can be used to represent larger groups of compounds that share similar physical and chemical properties relating to removal by treatment processes (Chang, Pan et al. 2002; Drewes, Heberer et al. 2003; Bellona, Drewes et al. 2004; Snyder, Adham et al. 2007; Drewes, Sedlak et al. 2008). Hence, it is not necessary to test for all potential contaminants in the recycled water.

Validation and verification for removal of chemicals by the treatment process is achieved by monitoring for a range of chemicals that can function in either or both of the following capacities:

- Treatment Performance Indicator chemicals, which demonstrate the **performance of the treatment process** as measured by the percentage removal of the indicator.
- Recycled Water Quality Indicator chemicals, which demonstrate **safety of the treated water with respect to a group of compounds** that share similar physical and chemical properties.

Adoption of this approach will allow monitoring of a small number of chemicals to provide verification that the treatment system is operating correctly and that hazardous chemicals are being consistently removed, thus, making it unnecessary to monitor for large numbers of chemicals.

### 2.1.1 Treatment Performance Indicator Chemicals

The Phase 2 Guidelines define an indicator as a chemical or microbial parameter that can be used to measure the **effectiveness of a process**

Suitable treatment performance indicator chemicals must:

- have characteristics that can be linked to a predominant removal mechanism (e.g. filtration, adsorption or oxidation), because different treatment processes target different properties
- be present in concentrations that are representative of the broader class of compounds and that are sufficiently high to determine a meaningful degree of reduction through a unit process or a sequence of processes
- be quantifiable using an established, and preferably accredited, analytical method.

The most sensitive indicator chemicals for assessing the performance of a specific treatment process will be those that are partially removed under normal operating conditions. If the level of removal of the indicator compound is significantly diminished, it will indicate reduced system performance. An indicator compound that is easily removed by the treatment would be less sensitive to partial failure, and an indicator compound that is poorly removed under normal operating conditions would provide little insight into system performance under any conditions.
The key physico-chemical properties that determine chemical rejection by MF/RO have been identified as size (molecular weight, width and length), hydrophobicity \( \log K_{ow} \), and acidic/basic character \( \log K_a \). \( \log K_{ow} \) also provides information on polarity (dipole moment) and solubility in water (associated with chemical charge). The selected chemical indicators listed in Table A.5.1 in small caps and bolded cover chemical groups with different:

- molecular weights (ranged from 10.8 to 296 g/mol),
- hydrophobicity properties (log \( K_{ow} \) ranged from -0.64 to 3.4) and
- acidic/basic characteristics \( (pK_a \) ranged from 2.13 to 10.4).

Rejection of chemical contaminants by MF/RO is related to interactions between membrane characteristics, filtration operating conditions and compound properties. While chemicals of low molecular weight and high polarity are expected to be poorly rejected by the membranes, the presence of any of the chemical indicators with high molecular weight in the post-RO water will indicate a failure of the treatment system.

The characteristics of a good Treatment Performance Indicator (see Conclusions Chapter 9) were taken into account to derive a group of chemicals appropriate for monitoring removal by MF/RO. The recommended Treatment Performance Indicators and the physico-chemical properties they represent are shown in Table 9.1. The physico-chemical properties of the individual Treatment Performance Indicators and the reason for selection are presented in Table A.5.1.

Recommended Treatment Performance Indicator chemicals were normally detected in secondary wastewater (most more than 90% of the time). They were usually detected at higher concentrations than other chemicals of the same group. If more than one compound was commonly detected in secondary wastewater at similar concentrations, the one with the lower percentage of rejection was selected as it is considered more sensitive to assess the performance of the treatment.

Further, many indicators were frequently detected after RO, with intermediate levels of removal. Thus, any reduction in removal levels will indicate a loss of performance in the treatment system, and a need for remedial action.

**Recommendation**

_Treatment Performance Indicator chemicals shown in small caps and bolded in Table A.5.1 be used in validation and verification monitoring to demonstrate process performance, and must be monitored at least 14 times during an 8 week commissioning period of the plant._
2.1.2 Recycled Water Quality Indicator Chemicals

Recycled Water Quality Indicator chemicals allow demonstration of the safety of the treated water with respect to specific chemical groups, and hence provide additional confidence beyond Treatment Performance indicator monitoring that all chemical hazards are being mitigated. This can be particularly important for sensitive chemical groups such as hormones and pesticides, for which there are no readily available Treatment Performance Indicators.

Recycled Water Quality Indicator chemicals differ from Treatment Performance Indicators in that they were not consistently found in the secondary wastewater during the three years of monitoring, making them unsuitable as Treatment Performance Indicators. In many cases these are very well removed by the advanced treatment process and have physico-chemical properties already covered by the Treatment Performance Indicators.

Recycled Water Quality Indicator chemicals identified during the project as best representing their respective chemical groups are listed (but not bolded) in Table A.5.1. These indicators were selected based on frequency of detection and concentration in secondary wastewater. It is intended that this list be reviewed and refined based on additional data from the GWRT and on future advances in toxicology.

**Recommendation**

*Recycled Water Quality Indicator chemicals shown in Table A.5.1 be used in validation and verification monitoring to provide additional confidence as to the safety of the treated water with respect to their respective chemical groups, and must be monitored during commissioning of the plant.*

2.1.3 Validation of Indicator Chemicals

As indicated above, the use of selected chemical indicators in Table A.5.1 for ongoing monitoring of the GWRT overcomes the need to monitor all potential chemicals. Nevertheless, it is recommended that a comprehensive list of chemicals be monitored during the commissioning and verification phase, and twice annually thereafter, to permit initial and periodic validation of the choice of indicator chemicals for ongoing monitoring.

**Recommendation**

*Comprehensive monitoring of chemicals be undertaken during validation and verification of the treatment process, and periodically thereafter, to confirm or refine selection of indicator chemicals*
2.1.4. Radioactive Material

Radioactive material is present in wastewater from both natural and man made sources. Although direct discharge of radioactive material into the sewerage system is regulated by the Department of Health, it is necessary to ensure that concentrations of radioactive material remain below the ADWG screening levels of gross alpha and beta radioactivity recommended for triggering analysis for radium or other isotopes.

Recommendation

Radioactive material shall be monitored during validation and verification monitoring for gross alpha and beta particle activities. If concentrations are above recommended screening levels, specific radioactive compounds shall be tested.

2.1.5 Chemicals Not Monitored During this Project

It is recommended that chemicals included in the initial (PCRP) list but not analysed during the project be evaluated for requirement to monitor (See Appendix 2). For example, glyphosate, salicylic acid, trichlocarban and the insect repellent N.N-diethyl-m-toluamide (DEET) have all be identified as requiring investigation, but were not able to be monitored during this study because of method development limitations.

Recommendation

Methods for assessment of chemicals listed in Appendix 3 that were not monitored during this project be developed, and monitoring undertaken during the GWRT to adequately characterise their occurrence and extent of removal.

2.1.6 Pathogen Indicators

MS2 coliphage has been selected as the key microbial indicator and will be used to measure the effectiveness of the AWTP to remove microorganisms (DoH WA 2009). MS2 coliphage, one of the smallest viral particles, is considered to have properties representative of faecally derived viruses, and is more resistant to UV irradiation than other viruses (Hijnen, 2006). However, MS2 coliphage does not occur in the source water in sufficient concentration to permit confirmation that the treatment process is capable of achieving the required level of virus removal (a 9.5 log reduction from raw wastewater to the final post-UV treated water, as recommended in the AGWR phase 2).

MS2 coliphage can be cultured in the laboratory to numbers sufficient to perform challenge tests of individual processes in the treatment train,
including ultrafiltration, RO and UV disinfection. It will therefore be required that during the trial period, virus removal by individual process units be validated by challenge testing, such that the entire treatment train can be demonstrated as capable of achieving a 9.5 log reduction in coliphage numbers. Where applicable, the US EPA Guidance Manuals for Membrane Filtration (2005) and UV disinfection (2006) will be used.

In addition, a guideline level of <1 pfu/L in the final treated water will apply for MS2 coliphage, and verification of compliance with this requirement is to be monitored at least 14 times during commissioning of the plant.

**Recommendation**

*The pathogen indicator MS2 coliphage is to be used for Commissioning validation and ongoing verification monitoring.*

**2.2 Management System Recommendations**

**2.2.1 Risk Management Framework**


This risk management framework forms the basis of the Water Corporation's Recycled Water Quality Management Plan (RWQMP), the satisfactory implementation of which is essential to ensure public health protection. Some of the key aspects of an effective and continuous operational management framework include: identification of the risks, application of clearly documented risk management plans to neutralise or minimise those risks, and rigorous management and monitoring protocols implemented by appropriately trained staff. The RWQMP shall include an incident and emergency response plan, documenting the procedures for any incident or emergency that may occur and affect the production or quality of the recycled water. Approval of the RWQMP by the DoH is required before recycled water can be used to supplement the Leederville aquifer.

A Hazard Analysis and Critical Control Points-based plan is required for the Beenyup Advanced Water Treatment Plant (AWTP) to ensure that the required corrective actions are identified and implemented prior to the recycled water being injected into the aquifer. Detection of unacceptable performance always requires an immediate response. Therefore, online monitoring of surrogate parameters is required at each critical control point, to initiate immediate action when abnormal conditions occur and to shut down or divert flow away from injection when a critical limit is reached (DNRW 2008).
Recommendation

*A comprehensive risk management framework, as used in drinking water management, needs to be properly documented and implemented to the satisfaction of the DoH, to ensure that only water meeting agreed specifications is able to enter the aquifer*

2.2.2 Online Monitoring of Operational Performance

A surrogate is a quantifiable parameter, for example, conductivity or total organic carbon (TOC), that can be measured online and serve as a continual performance measure of treatment processes in the removal of specific contaminants. Surrogates can provide an indication of acceptable or unacceptable treatment performance. They do not necessarily represent a hazard in themselves but they can indicate how successfully the treatment process has removed contaminants from the wastewater. Appropriate surrogates need to be measured around the actual “barriers” in order to detect failures of different system components (critical control points). They are therefore specific to a given treatment module, and thus must be derived and justified by the module’s proponent. Well established surrogates include particles or turbidity for MF, conductivity for RO, TOC measured in post-RO water and UV dose (based on flow rate) combined with water transmissivity for ultraviolet disinfection. Table A.5.2 presents the Water Corporation current assessment of required surrogate parameters for the GWRT plant based on the design and water quality requirements, and the critical control points at which they measure operational performance (Water Corporation 2009).

Recommendation

*Water Corporation derive appropriate surrogate parameters to the satisfaction of the DoH, to demonstrate continual performance of the GWRT treatment train, and undertake online monitoring of operational performance using those surrogates (presently shown in Table A.5.2) or improvements thereon.*

2.2.3 Operational and Critical Limits for Surrogate Chemicals to be established

For operational acceptability, control measures need to have defined limits that can be applied to the monitoring of operational parameters. To validate the chosen critical limits, the scheme should demonstrate that operating within those limits during the validation period achieves the intended results in the associated commissioning verification period. This validates that the critical limits have been set at an appropriate level.
Operational limits should be defined for parameters applying to each control measure. If monitoring shows that an operational limit has been exceeded, then predetermined corrective actions need to be applied. The detection of the deviation and implementation of corrective action(s) should be possible in a time frame adequate to maintain performance and water safety.

For some control measures, a second series of “critical limits” may also be defined, outside of which confidence in water safety would be lost. Deviations from critical limits will require urgent action, including immediate notification to the Department of Health.

**Recommendation**

*Operational and critical limits for the continually monitored surrogates be established and included in a hazard analysis and critical control points plan to prevent water that is out of specification from being injected into the aquifer.*

**2.2.4 Regular Review of Emerging Issues and Chemicals**

Scanning for developments and changes which have the potential to affect the risk profile of the project is vital. Aspects which may change include approval for use of new chemicals such as pesticides or pharmaceuticals, improved knowledge of hazards associated with known chemicals, and changes to the wastewater catchment (e.g. a large industry commences operation).

It is important that potential changes and developments are monitored, hazards assessed and appropriate actions taken, including where necessary modifications to monitoring programs.

**Recommendation**

*Regular environmental scans and risk reviews be undertaken, the health risks associated with identified issues assessed, and appropriate mitigations implemented. This may include revision to monitoring programs either in plant or within the catchment, management procedures for the source chemical, operating procedures within the plant, or no action (where the hazard is assessed as already managed with existing procedures)*

**2.2.5 Quality Assured Water Quality Analysis**

The DoH preference is that, where possible, all analysis be undertaken at a laboratory that is National Association of Testing Authorities (NATA) accredited or has NATA accredited methods. Where a NATA accredited
analysis is not used the Water Corporation should supply documentation of the methodology including the quality assurance (QA)/quality control (QC) procedures used to perform this analysis.

All operational and verification monitoring should be undertaken within a QA/QC framework. QC generally involves conducting the monitoring and calibration tasks, whereas QA involves checking the QC results, analysing and auditing them.

Recommendation

*All analysis be conducted by NATA accredited laboratories and in accordance with Australian Standards, unless otherwise approved by the DoH on the basis of satisfactory QA/QC data.*

2.2.6 Review, Revision and Reporting

Results from GWRT monitoring program will be reviewed regularly against the guidelines and health values.

Where necessary, the monitoring program will be revised based on knowledge gained from the previous monitoring. In addition, periodic review of the health values will be required to keep in step with future advances in toxicology.

Water quality reports will need to be submitted to Department of Health for demonstration of protection of human health.

Recommendation

*The outcomes from the GWRT monitoring program be reviewed, revised and reported on according to a schedule defined by the Department of Health taking account of the potential hazards.*

2.2.7 Communication and Consultation

Transparency in the management of groundwater replenishment is critical for public confidence. Community participation and confidence can be enhanced by effective community consultation. The consultation should include: the identification and engagement of stakeholders and communities that are directly involved in or affected by the project; preparation of a consultation strategy and the allocation of the necessary time and resources. Maintenance of communication throughout the process is critical for the implementation of the GWRT. All communication aspects stated in the *Draft*
Guidelines for the Use of Recycled Water in Western Australia (2009) need to be implemented during the GWRT.

The incident and emergency response plan shall include the protocols and people responsible for communication between the Water Corporation, the Department of Health and other stakeholders including the media.

Recommendation

The results of the PCRP research be used in the communication and consultation strategy

2.2.8 Department of Health Audit

Auditing is a form of verification of the performance of the scheme and is essential to ensure that compliance with the RWQMP is maintained. The Water Corporation must ensure that monitoring and audit results are communicated to all relevant stakeholders.

Recommendation

The DoH will undertake an annual audit of the GWRT.

3 Bioassays

The DoH acknowledges the applicability of bioassays to environmental and ecological assessment. With respect to public health, it is of the view that bioassays have the potential to complement the assessment of the recycled water, and have a role in communicating the safety of the recycled water. However, more research needs to be conducted to define their usefulness as a regulatory tool. Bioassays can evaluate the effects of multiple mixtures because they measure any observable toxic response to the water, thus taking account of the biological availability and interactions of any toxicants present. At this point in time, bioassays will not be required as part of this GWRT.

4 Future Direction
The scientific outcomes anticipated from the GWRT will provide essential data to:

- Better characterise the rejection efficiency of the selected indicators under standard operation conditions.
- Determine whether the selected Treatment Performance Indicator chemicals are adequate to demonstrate that processes are operating as required.
- Verify that the selected Recycled Water Quality Indicator chemicals adequately assure the safety of the treated water with respect to the chemicals that they represent.
- Understand treatment variability and the health implications of changes in the rejection efficiency of different contaminants.
- Predict rejections of emerging contaminants during advanced treatment based on membrane characteristics used in the Beenyup AWTP, filtration operating conditions and solute physico-chemical properties.
- Understand the effects of operational conditions including membrane flux, pH and temperature on chemical rejection, through the careful documentation of treatment conditions during the trial, so as to properly interpret the implications such changes may have on overall risk.
- Provide information about the behaviour of N-nitrosamines and other DBPs in the aquifer.
- Understand the hydrology of the receiving groundwaters in providing additional barriers, such as dilution, attenuation and biodegradation, before abstraction and drinking water treatment.

References


DNRW (2008). Recycled water management plan and validation guidelines. Brisbane, Queensland, Department of Natural Resources and Water.


Table A.5.1: Recommended Chemical Indicators for GWRT ordered by molecular weight. Treatment Performance Indicators used to monitor treatment performance are in small caps and bolded.

<table>
<thead>
<tr>
<th>Chemicals represented &lt;sup&gt;a&lt;/sup&gt;</th>
<th>Indicator (Chemical group)</th>
<th>Secondary Wastewater % Detection</th>
<th>Median Value</th>
<th>Removal Efficiency Median (Range)</th>
<th>Health Value</th>
<th>LOR&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Molecular Weight (g/mol)</th>
<th>logK&lt;sub&gt;ow&lt;/sub&gt; (logD at pH 7)&lt;sup&gt;c&lt;/sup&gt;</th>
<th>pK&lt;sub&gt;a&lt;/sub&gt;</th>
<th>Reason for selection and other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Charged (+ or -) Very Hydrophilic</td>
<td>BORON (Metals &amp; metalloids)</td>
<td>100% Med=160 µg/L n=31</td>
<td>89% Med=75 µg/L n=28</td>
<td>Moderate 62% (31–90%)</td>
<td>4 mg/L</td>
<td>20 µg/L</td>
<td>B</td>
<td>10.8</td>
<td>H₃BO₃, 61.8</td>
<td>B(OH)&lt;sub&gt;4&lt;/sub&gt;, 78.8</td>
</tr>
<tr>
<td>Small Charged (-) Very Hydrophilic</td>
<td>NITRATE (Inorganic anions)</td>
<td>100% Med=3.45mg/L n=18</td>
<td>100% Med=0.12 mg/L n=16</td>
<td>Moderate 88% (82–99%)</td>
<td>50 mg/L</td>
<td>0.01 mg/L</td>
<td>62.0</td>
<td>na</td>
<td>-0.64</td>
<td>10.44</td>
</tr>
<tr>
<td>Small Uncharged Very Hydrophilic</td>
<td>NDMA (N-Nitrosamines)</td>
<td>96% Med=16 ng/L n=25</td>
<td>92% Med=4.5ng/L n=26</td>
<td>Moderate 79% (30–95%)</td>
<td>10 ng/L</td>
<td>1 ng/L</td>
<td>74.1</td>
<td>na</td>
<td>-2.9</td>
<td>-</td>
</tr>
<tr>
<td>Small Charged (-) Very Hydrophilic</td>
<td>Chlorate (Inorganic Anions)</td>
<td>37% Med=12.8 n=30</td>
<td>46% Med=12.7 µg/L n=24</td>
<td>Moderate 75% (53–99%)</td>
<td>700 µg/L</td>
<td>10 µg/L</td>
<td>83.4</td>
<td>-0.27</td>
<td>na</td>
<td>Represents neutral water soluble compounds. Could be a good treatment performance indicator if a NATA accredited method becomes available.</td>
</tr>
<tr>
<td>Small Uncharged Very Hydrophilic</td>
<td>1,4 Dioxane (Miscellaneous)</td>
<td>100% Med=0.52µg/L n=22</td>
<td>28.5% Med=0.12 µg/L n=21</td>
<td>Moderate 89% (30–99%)</td>
<td>50 µg/L</td>
<td>0.08 µg/L</td>
<td>88.1</td>
<td>-0.27</td>
<td>na</td>
<td>Represents neutral water soluble compounds. Could be a good treatment performance indicator if a NATA accredited method becomes available.</td>
</tr>
<tr>
<td>Small Uncharged Slightly Hydrophilic</td>
<td>CHLOROFORM &lt;sup&gt;*&lt;/sup&gt; (Halogenated DBPs)</td>
<td>85% Med=0.4 µg/L n=33</td>
<td>56 % Med=0.14 µg/L n=27</td>
<td>Moderate 82% (-412–98%)</td>
<td>200 µg/L</td>
<td>0.06 µg/L</td>
<td>119.4</td>
<td>1.97</td>
<td>na</td>
<td>Less than 90% detection but commonly selected as an indicator in IPR schemes. May adsorb to RO membranes, enabling partitioning into the post-RO water. Both chloroform and bromochloromethane should be analysed to determine the best treatment performance indicator.</td>
</tr>
<tr>
<td>Chemicals represented(^a)</td>
<td>Indicator (Chemical group)</td>
<td>Secondary Wastewater % Detection Median (Med)</td>
<td>No samples (n)</td>
<td>Post-RO Water % Detection Median (Med)</td>
<td>No samples (n)</td>
<td>Removal Efficiency Median (Range)</td>
<td>Health Value</td>
<td>LOR(^b)</td>
<td>Molecular Weight (g/mol)</td>
<td>logK(_{ow}) (logD at pH 7)(^c)</td>
</tr>
<tr>
<td>-----------------------------</td>
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<tr>
<td>Small Uncharged Hydrophilic</td>
<td>BROMOCHLOROMETHANE(^e) (Halogenated DBPs)</td>
<td>94% Med=0.22 µg/L n=33</td>
<td>100% Med=0.11 µg/L n=27</td>
<td>Moderate 63% (-50–99%)</td>
<td>40 µg/L</td>
<td>0.03 µg/L</td>
<td>129.4</td>
<td>1.41</td>
<td>1.97</td>
<td>na</td>
</tr>
<tr>
<td>Small Uncharged Hydrophilic</td>
<td>1,4-DICHLOROBENZENE (VOCs)</td>
<td>95% Med=0.81 µg/L n=37</td>
<td>90 % Med=0.2 µg/L n=29</td>
<td>Moderate 84 % (-20–95%)</td>
<td>40 µg/L</td>
<td>0.03 µg/L</td>
<td>147.0</td>
<td>3.4</td>
<td>na</td>
<td>Highest median concentration and highest % detections in wastewater and post-RO water for VOCs</td>
</tr>
<tr>
<td>Medium Uncharged Hydrophobic</td>
<td>Fluorene (Polycyclic Aromatic Hydrocarbons)</td>
<td>64% Med=3 ng/L n=22</td>
<td>19% Med=3 ng/L n=21</td>
<td>Moderate 75% (50–93%)</td>
<td>140 µg/L</td>
<td>2 ng/L</td>
<td>166.2</td>
<td>4.18</td>
<td>4.15</td>
<td>23</td>
</tr>
<tr>
<td>Medium Charged (-) if pH &gt; 6.1 Hydrophobic</td>
<td>2,4,6-trichlorophenol (Phenols)</td>
<td>64% Med=44.5 ng/L n=22</td>
<td>0%</td>
<td>Moderate 82% (56–97%)</td>
<td>20000 ng/L</td>
<td>30 ng/L</td>
<td>197.5</td>
<td>3.69</td>
<td>6.1</td>
<td>Less than 80% detections in secondary wastewater and not appropriate as treatment indicator. May adsorb to RO membranes, enabling partitioning into the post-RO water. Indicator for moderately acidic, aromatic organic chemicals.</td>
</tr>
<tr>
<td>Medium Uncharged Slightly Hydrophobic</td>
<td>CARBAMAZEPINE (Neutral Pharmaceuticals)</td>
<td>97% Med=938 ng/L n=29</td>
<td>0 % Med=NA n=29</td>
<td>Good 99.8 % (98.8–99.9%)</td>
<td>100 µg/L</td>
<td>4 ng/L</td>
<td>236.3</td>
<td>2.67</td>
<td>7.3</td>
<td>Frequently detected in wastewater, and pharmaceutical with the highest median concentration. Known to persist through wastewater treatment. Represents large uncharged organic molecules with high removal efficiency.</td>
</tr>
<tr>
<td>Large Uncharged Hydrophobic</td>
<td>Estrone (Hormones)</td>
<td>48% Med=15 ng/L n=29</td>
<td>0%</td>
<td>Good 96.4% (72–98%)</td>
<td>30 ng/L</td>
<td>4 ng/L</td>
<td>270.4</td>
<td>3.69</td>
<td>10.34</td>
<td>Low % detections in secondary wastewater and not appropriate as treatment indicator. May adsorb to RO membranes, enabling partitioning into the post-RO water. Hormones are an important water quality indicator for public concern. Indicator for hydrophobic, aromatic organic chemicals, capable of hydrogen bonding.</td>
</tr>
<tr>
<td>Chemicals represented</td>
<td>Indicator (Chemical group)</td>
<td>Secondary Wastewater % Detection Median (Med) No samples (n)</td>
<td>Post-RO Water % Detection Median No samples (n)</td>
<td>Removal Efficiency Median (Range)</td>
<td>Health Value</td>
<td>LOR&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Molecular Weight (g/mol)</td>
<td>logK&lt;sub&gt;ow&lt;/sub&gt; (logD at pH 7)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>pK&lt;sub&gt;a&lt;/sub&gt;*&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Reason for selection and other comments</td>
</tr>
<tr>
<td>----------------------</td>
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<td>-------------------------------------</td>
</tr>
<tr>
<td>Large Charged (-) Very Hydrophilic</td>
<td>EDTA (Complexing Agents)</td>
<td>100% Med=2 µg/L n=27</td>
<td>48 % Med=0.5 µg/L n=27</td>
<td>Good 99.5 % (98–99.9%)</td>
<td>250 µg/L</td>
<td>0.8 µg/L</td>
<td>292.2</td>
<td>-0.43 (-0.84)</td>
<td>pK&lt;sub&gt;a&lt;/sub&gt;=0.0 pK&lt;sub&gt;a&lt;/sub&gt;=1.5 pK&lt;sub&gt;a&lt;/sub&gt;=2.00 pK&lt;sub&gt;a&lt;/sub&gt;=2.69 pK&lt;sub&gt;a&lt;/sub&gt;=6.13 pK&lt;sub&gt;a&lt;/sub&gt;=10.37</td>
<td>Always detected in wastewater, and complexing agent with the highest median concentration. Represents large, charged, hydrophilic organic molecules with high removal efficiency.</td>
</tr>
<tr>
<td>Large Charged (-) Hydrophobic</td>
<td>DICLOFENAC (Acidic Pharmaceuticals)</td>
<td>100% Med=362 ng/L n=26</td>
<td>0 % Med=NA n=26</td>
<td>Good 99.6% (76.7–99.8%)</td>
<td>1.8 µg/L</td>
<td>4 ng/L</td>
<td>296.2</td>
<td>3.28 (1.28)</td>
<td>4.15</td>
<td>Always detected in wastewater. Represent large, charged, slightly hydrophobic organic molecules with high removal efficiency</td>
</tr>
<tr>
<td>Large Charged (+) if pH &gt; 7.3 Very Hydrophobic</td>
<td>Trifluralin (Pesticides)</td>
<td>91% Med=0.48 µg/L n=32</td>
<td>0% Med=NA n=32</td>
<td>Good 97% (75–99.5%)</td>
<td>50 µg/L</td>
<td>20 µg/L</td>
<td>335.3</td>
<td>5.34</td>
<td>5.34</td>
<td>Most frequently detected pesticide and an important water quality indicator for public concern. Removal efficiency should be indicated by other large-molecule treatment performance indicators</td>
</tr>
<tr>
<td>Large Uncharged Very Hydrophobic</td>
<td>Octadioxin (Dioxins, Furans and Dioxin-like PCBs)</td>
<td>67% Med=16 pg/L n=14</td>
<td>18% Med=5 pg/L n=11</td>
<td>Moderate 72% (50–90%)</td>
<td>100 ng/L</td>
<td>10 pg/L</td>
<td>459.6</td>
<td>7-8</td>
<td>na</td>
<td>Less than 80% detections in wastewater and not appropriate as treatment indicator. An important water quality indicator for public concern. Removal efficiency should be indicated by other large-molecule treatment performance indicators</td>
</tr>
</tbody>
</table>

*Only one of the halomethanes would be required as an Indicator, which is most appropriate depends on the analytical method LOD.

<sup>a</sup>Molecular weight classification: Small <150 g/mol; Medium 150-250 g/mol; Large >250 g/mol

<sup>b</sup>LOR: average LOR in post-RO water

<sup>c</sup>logK<sub>ow</sub>: Octanol/Water Partition Coefficient. Hydrophilic molecules (logK<sub>ow</sub><1) Hydrophobic molecules (logK<sub>ow</sub>><3). logD at pH 7: distribution coefficient at pH 7, equal to the ratio of the equilibrium concentrations of all species (neutral and ionised) in octanol to the same species in the water phase. Only reported when significantly different to logK<sub>ow</sub>

<sup>d</sup>pK<sub>a</sub>: ionisation constant or acid dissociation constant is the negative logarithm of the equilibrium coefficient (-log K<sub>a</sub>) of the neutral and charged forms of a compound. pK<sub>a</sub> allows the definition of acidic or basic properties of the compound.
Table A.5.2: Surrogate parameters for AWTP monitoring and critical control points at which they measure operational performance.

<table>
<thead>
<tr>
<th>Critical Control Point</th>
<th>Surrogate Measured on-line in real time with</th>
<th>Hazard for which surrogate represents removal</th>
<th>Monitoring locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Water Acceptance Criteria</td>
<td>Dissolved Oxygen DO meters in WWTP aeration tanks</td>
<td>Organic chemicals, pathogens, particulates</td>
<td>WWTP aeration tanks</td>
</tr>
<tr>
<td>TOC</td>
<td>UV Absorbance</td>
<td>Dissolved organic chemicals</td>
<td>Raw (AWTP Feed)</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Turbidity meter</td>
<td>Particulates, pathogens, chemicals</td>
<td>Raw (AWTP Feed)</td>
</tr>
<tr>
<td>MF Operation</td>
<td>Turbidity</td>
<td>Turbidity meters</td>
<td>Particulates, pathogens</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Particle counter</td>
<td>Particulates, pathogens</td>
<td>Post-MF</td>
</tr>
<tr>
<td>Pressure Decay Test (Daily)</td>
<td>Daily test: Pressure pre and post membranes</td>
<td>Failure in seals, membrane degradation</td>
<td>Pre and Post-MF</td>
</tr>
<tr>
<td>RO Operation</td>
<td>Conductivity</td>
<td>Conductivity meter</td>
<td>Inorganic chemicals, organic chemicals, pathogens</td>
</tr>
<tr>
<td>TOC</td>
<td>TOC analyser</td>
<td>Organic chemicals</td>
<td>Post-MF, Post-RO</td>
</tr>
<tr>
<td>UV Operation</td>
<td>UV Transmittance</td>
<td>UV intensity</td>
<td>Microbial pathogens</td>
</tr>
<tr>
<td>UV dose (fluence)</td>
<td>UV dose &amp; flow</td>
<td>Microbial pathogens</td>
<td>UV unit</td>
</tr>
<tr>
<td>Injection Acceptance Criteria</td>
<td>Oxidation Reduction Potential ORP meter</td>
<td>Chemical stability (affecting aquifer risks)</td>
<td>Treated water</td>
</tr>
<tr>
<td>pH</td>
<td>pH meter</td>
<td>Chemical stability (affecting aquifer risks)</td>
<td>Treated water</td>
</tr>
</tbody>
</table>