Pollutant Prioritization Project for Water Reuse

Christopher Stacklin, P.E.*

1Orange County Sanitation District, 10844 Ellis Avenue, Fountain Valley, CA 92708-7018, USA
*Email: cstacklin@ocsd.com.

ABSTRACT

The goal of the Pollutant Prioritization Project for Water Reuse is to develop a prioritized list of pollutants of concern from an initial list of over 500 candidate constituents. The list will serve as the basis for OCSD’s Enhanced Source Control Program that is designed to protect the Groundwater Replenishment (GWR) System from potentially harmful pollutants that may impact one of Orange County California’s most reliable sources of drinking water supply.

The Pollutant Prioritization Project will determine unit process removal rates and action levels necessary to ascertain future Source Control restrictions in regards to the GWR System project and to satisfy the California Regional Water Quality Control Board Order. Pollutants identified will be used to implement various control strategies first, at an operational level and second at a source control level. Source control strategies may include voluntary reductions or local limits for point sources and public outreach or product substitution for non-point sources, etc. Methodology and results are presented herein.

KEYWORDS: Pollutant Prioritization, Water Reuse, Groundwater Replenishment System, Predictive Model, Fault Tree Analysis, Removal Rate, Action Level, Emerging Pollutants, Kalman Filter, Proactive

INTRODUCTION

The GWR System, which is a joint project of Orange County Water District and OCSD, is considered one of the largest water reuse project of its kind in the world. The project is designed to ultimately reuse approximately 45,620 million gallons per year of secondary treated wastewater provided by OCSD Reclamation Plant No. 1. The GWR System employs state-of-the-art technology including microfiltration, reverse osmosis, and advanced oxidation processes to produce purified water that will supply approximately 2.5 million people in Orange County for recharge, irrigation, domestic and industrial uses, and to protect Orange County Groundwater Basin from further degradation due to seawater intrusion.

Although the GWR System has many technology-based safeguards to reduce the risk of contamination of the water it produces, source control has been recognized by regulatory agencies as an additional enhancement to the technology-based safeguards. As a result, OCSD has been mandated by the California Regional Water Quality Control Board to expand its existing source control program to include emerging pollutants of concern specified by the California Department of Public Health as harmful to human health and drinking water supplies of Orange County.
With this magnitude of water reuse, the challenge is to execute a comprehensive methodology that involves evaluating and ranking approximately 500 constituents with about 75,000 water quality parameters, along with deriving unit level removal rates from each treatment process to ultimately establish a Priority Pollutant\textsuperscript{SC} list and implement an effective source control program.

A Priority Pollutant\textsuperscript{SC} is defined herein as a constituent that has the potential to adversely impact the GWR System product water quality, including those constituents which, while not presently known to contribute to use impairments or to show increasing loadings or concentrations, have characteristics that indicate a potential to impact physical or biological integrity. These characteristics include detectable presence in the product water or watershed, ability to bioaccumulate, persistence, and toxicity.

**Initial List of Priority Pollutant\textsuperscript{SC} Candidate Constituents**

The list of 500 constituents is composed of constituents with numerical limits or standards (regulated constituents) and constituents that do not have numerical limits or standards, but may have toxicity values (unregulated constituents). The basis for the list is shown in Figure 1.

For the GWR System, regulated constituents are derived from all applicable laws, ordinances,
regulations, and statutes. For example, Regional Water Quality Control Board (RWQCB) Order No. R8-2004-002 – Producer/User Water Recycling Requirements has recycled water quality specifications which include regulatory limits for about 101 pollutants.

A common attribute of regulated constituents is that toxicity information is highly developed. In contrast, unregulated constituents have moderate to no toxicity information and are referenced in a limitless variety of sources.

Unregulated constituents were selected based on their potential for future regulation. Therefore, the sources that identify constituents of this nature must have a formal screening process, whether based on peer review or preliminary toxicological data. Inherently, constituents which go through this process have a higher likelihood of being regulated. This being said, unregulated constituents are derived from the sources in Figure 2.

Figure 2. Referenced sources for unregulated constituents.

The initial list of candidate constituents is typically large. The initial list developed for the pollutant prioritization project contained 19 chemical classes of over 500 constituents.

Implementing a source control program at this stage would consume a tremendous amount of resources to sample, monitor and to establish source control of over 500 constituents for multiple point and non point sources including industrial, domestic, and commercial entities. Therefore, methodology for prioritization of this initial list of candidate constituents is the key.
Process Description
Wastewater from sources including industrial, commercial, domestic users, and urban runoff throughout Orange County is received by Reclamation Plant No. 1. The flow is diurnal and ranges from 110 MGD at the daytime peak to 40 MGD at night. The flow undergoes primary treatment through chemically enhanced primary treatment (CEPT), then secondary treatment through either trickling filter or air activated sludge systems.

The secondary effluent flows across Reclamation Plant No. 1 battery limits into the GWR System, through screening facilities where particles 2 millimeters and larger are separated and removed. The removal of particles reduces fouling of the microfiltration membrane system located downstream.

![Diagram of Reclamation Plant No. 1 and the GWR System.](image)

**Figure 3. Reclamation Plant No. 1 and the GWR System.**

The screened water flows across an 86 MGD microfiltration system. The membrane elements of the microfiltration system remove particles in the effluent of 0.2 microns or higher which includes bacteria, protozoa, and suspended solids. The purpose of the microfiltration system is to reducing fouling of the reverse osmosis system.

The filtered water from the microfiltration system is then pumped across a 70 MGD reverse osmosis (RO) system with an 85% recovery rate. Cleaned water that passes through the RO system is called, permeate. Wastes that cannot pass through the RO system are concentrated into an RO system reject stream.
The RO permeate flows across a 70 MGD two-step advanced oxidation process (AOP). First, hydrogen peroxide is added to the RO permeate upstream of an ultraviolet (UV) light treatment system. Second, UV irradiation is used for disinfection and reduction of light-sensitive organic contaminants.

The disinfected RO permeate has a high level of carbon dioxide and a low pH after treatment from the UV system. The disinfected RO permeate is routed through decarbonator towers which use blown air to strip off carbon dioxide and other dissolved gases in the water. Lime is added to both raise the pH and add salts back into the water. The added salts prevent the highly purified water from leaching minerals from the piping used to transport the water to settling basins. The degassed water is pumped across a dechlorination skid and becomes product water.

Nearly all of the product water from the GWR System will be placed in the Orange County groundwater basin in two ways. First, some of the product water will be injected into existing and/or new injection wells designed to prevent seawater intrusion in the Talbert Gap located in the Huntington Beach, Fountain Valley, and Costa Mesa areas. Second, most of the product water will be pumped to OCWD’s Santa Ana River water spreading basins in Anaheim and Orange. From there, the product water will percolate into the groundwater basin.

METHODOLOGY

The methodology for identifying Priority PollutantSC is developed with the intent of establishing a proactive Source Control program. Proactive means that constituents with the potential to cause non compliance with regulatory requirements or adverse human health affects will be ranked high. It also means that the methodology must be predictive. The predictive aspect of the methodology is achieved using probabilistic fault tree and constituent sensitivity analyses.

After establishing the initial list of Priority PollutantsSC candidate constituents, the constituents need to be strategically ranked using a risk analysis approach. There are two criteria that Priority PollutantsSC must satisfy to achieve high ranking. The constituent must: 1) be detected in the effluent of the treatment process or have the potential to break through the treatment process and 2) have a toxicological effect, regulatory limit, or regulatory standard. To begin, constituents are organized into two groups, those that are regulated with numerical limits or standards and those which are unregulated.

CASE 1: Prioritizing Regulated Constituents

Regulated constituents have existing, risk-based toxicity values. Figure-4 illustrates the method of what essential steps were utilized to prioritize the regulated constituents. Regulated constituents which are not detected in the secondary effluent of Reclamation Plant No. 1 or the GWR System product water are placed on a “watch list” where they are routinely monitored for detection.

Removal rates are calculated for regulated constituents that are detected in the secondary effluent of Reclamation Plant No. 1 or the GWR System product water. A removal rate is the fraction or percentage of the influent constituent mass loading that is removed from the waste stream across an entire wastewater treatment works or specific wastewater treatment unit within the works.
(U.S. EPA, 2004). Constituents with negative removal rates are grouped together for further study. Action levels for Source Control (action level^{SC}) are determined for constituents with positive removal rates. An action level^{SC} is a level above which triggers a Source Control action, such as source identification. An action level is calculated from a probabilistic model such as a fault tree or may be set intuitively. Constituents equal to or above the action level become Priority Pollutants^{SC}. Constituents that are below the action level are placed on a watch list.

CASE 2: Prioritizing Unregulated Constituents
Unregulated constituents typically have moderate to unknown toxicity information, making them difficult to prioritize. The key to prioritize these constituents is to perform a risk assessment using simplified or detailed risk-based approaches.

Several detailed risk-based evaluation approaches are available including: Thresholds of Toxicological Concern (Cramer, Ford, & Hall, 1978) (Kroes, et al., 2004), Calculated Margins of Exposure, FDA Pregnancy Categories, FDA Threshold of Regulation (U.S. FDA, 2005). The proper use, application, and refinements of these methods are still a topic of discussion among the research community (WateReuse Foundation, 2008). Implementation of these approaches can be a considerable effort both in time and resources and may require a domain expert or panel of experts.
While these detailed risk-based evaluation approaches are still being refined by the research community and regulators, a simplified approach is proposed in the meantime. It is important to note that this simplified approach is intended to be used only as an interim measure until researchers and regulators can determine toxicity using detailed risk-based evaluations.

The simplified approach is based on limiting toxicological queries to a small number of on-line sources, e.g., Integrated Risk Information System (U.S. EPA), Agency for Toxic Substances and Disease Registry (ATSDR) (U.S. DHHS), National Center for Toxicological Research (U.S. FDA), Maximum Recommended Therapeutic Dose (MRTD) Database (U.S. FDA) and Endocrine Disruptor Knowledge Base (EDKB) (U.S. FDA), per Figure 5.

**Figure 5. Partial listing of referenced sources for toxicity data.**

Some of these sources can be accessed through the Toxicology Data Network (TOXNET) (National Library of Medicine). TOXNET is a cluster of databases covering toxicology, hazardous chemicals, environmental health and related areas. It is managed by the Toxicology and Environmental Health Information Program (TEHIP) in the Division of Specialized Information Services (SIS) of the National Library of Medicine (NLM).

Toxicological concentrations which have human or biological effects are collected by querying the on-line sources for each constituent without regulatory limits or standards, based on oral consumption, e.g., drinking two liters of water per day for the average adult. In some cases, a high dose to low dose extrapolation may be required (U.S. EPA, 2005). Each concentration is
converted to a common unit basis and the minimum of these concentrations selected as the controlling case.

**Figure 6. Methodology for unregulated constituents.**

Unregulated constituents are dropped from the prioritization list if they are: 1) not detected in the effluent stream; 2) detected but are not toxic; 3) or have no available toxicity data.

Removal rates are calculated for unregulated constituents that are detected and have sufficient toxicity data. Constituents that have negative removal rates are listed for further study. Action levels\(^{SC}\) are calculated for constituents with positive removal rates.

Constituents that are below the action level\(^{SC}\) are added to the watch list. Constituents which are equal to or greater than the action level\(^{SC}\) become Priority Pollutants\(^{SC}\). This methodology is summarized in Figure 6.

**Water Side Mass Balance Model**

The mass balance model is shown in Figure 7 and encompasses only the water side. Note that sample points were established at the influent flow from the collection system to Reclamation Plant No. 1, the secondary effluent from Reclamation plant No. 1 to the GWR System, and the
Figure 7. Mass balance for back calculating action levels.
Definition of Equation Variables and Subscripts

- \( C \) : Constituent concentration in milligrams per liter
- \( F \) : Flow Rate in million gallons per day
- \( m \) : Mass flow rate in pounds per day
- \( \mu \) : Removal efficiency

Subscripts
- \( GWR,i \) : GWR System of constituent, \( i \)
- \( GWR-Inf \) : GWR System influent
- \( GWR-Inf,i \) : GWR System influent of constituent, \( i \)
- \( GWR-Eff \) : GWR System effluent
- \( GWR-Eff,i \) : GWR System effluent of constituent, \( i \)
- \( GWR-Rej \) : GWR System brine return to Treatment Plant No. 2 across \( j \) discrete sampling events
- \( GWR-Rej,i \) : GWR System brine return to Treatment Plant No. 2 across \( j \) discrete sampling events of constituent, \( i \)
- \( Ocean-SE \) : Ocean secondary effluent
- \( Ocean-SE,i \) : Ocean secondary effluent of constituent, \( i \)
- \( REG,i \) : Numerical limit or standard of constituent, \( i \)
- \( RP1-Eff \) : Reclamation Plant No. 1 secondary effluent
- \( RP1-Inf \) : Reclamation Plant No. 1 influent
- \( RP1-Inf,i \) : Reclamation Plant No. 1 influent of constituent, \( i \)
- \( RP1-Inf,i:calculated \) : Reclamation Plant No. 1 influent of constituent, \( i \), calculated
- \( RP1-Inf,i:measured \) : Reclamation Plant No. 1 influent of constituent, \( i \), measured

Figure 8. Equation variables and subscripts for the mass balance equations

The approach for the mass balance model uses the GWR System regulated contaminant levels or toxicity data to back calculate the allowable influent wastewater to Reclamation Plant No. 1. The allowable influent wastewater concentration to Reclamation Plant No. 1 is compared with the actual average influent wastewater concentration. This approach is formally called, “Back Calculating Action Levels”.

Start with a mass balance around the GWR System bounded by points 1, 2, and 3 in Figure 7. The design flow rating, water side removal rates, and regulated contaminant levels or toxicity data are known. Therefore, the allowable influent concentration to the GWR and brine return streams can be solved at points 3 and 2, respectively.

After closing the mass balance around the GWR System, a mass balance can be made around Reclamation Plant No. 1 which is illustrated by points 3, 4, and 5 in Figure 7.

Since the water side removal rate and mass flow rate across Reclamation Plant No. 1 are already known, the Reclamation Plant No. 1 allowable influent concentration can be determined.
The allowable influent wastewater concentration to Reclamation Plant No. 1 can be compared with the actual average influent wastewater concentration. If the actual average influent wastewater concentration is equal to or above the allowable influent wastewater concentration, the constituent will be placed on the prioritized list of emerging pollutants.

**Fault Tree Analysis**

Note that by varying the removal rate across the GWR System and comparing the change in removal rate with the change in constituents appearing above the action level that constituents can be assessed.

The removal rate across the GWR can also be adjusted relative to degraded operating states determined in a fault tree analysis. Fault tree analysis is a probabilistic failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events (Vesely, W.E., et al. 1981). An undesired state in this case would be contaminant breakthrough.

**DISCUSSION**

**Project Scope**

The scope of project involves the following sampling plan:

- Sample sites include Reclamation Plant No. 1 influent, influent and effluent from the primary treatment processes, and influent and effluent from the secondary treatment processes and the GWR System product water;
- Samples are initially collected over a two-year period from 2007 through 2009 and taken each day of the week, and repeated for three consecutive weeks.
- Although automated samplers collect most samples over a twenty-four hour period, volatile organics will be collected by hand at four-hour intervals over a twenty-four hour period.

Sample analysis is performed at an unprecedented scale. The sample analysis group will test for about 500 chemicals and physical properties of wastewater. This will include: 1) 3 classes of pesticides, 2) a large variety of industrial chemicals, 3) polychlorinated biphenyls, 4) the standard group of priority pollutants, 5) flame retardants, 6) several hormones and several pharmaceuticals, 7) NDMA and 8 other nitrosamines, 8) a suite of 19 metals, 9) mercury, 10) total suspended solids, 11) turbidity, 12) and total organic carbon. At the end of the project, the team will have approximately 75,000 separate measurements of water quality parameters. Sample results will be paired with mass balance flows to determine removal rates across each unit operation. Influent flow characterization and unit operation removal rates can be compared with both regulatory and operation –based constituent limits of the GWR System product water to identify constituent candidates for the prioritized list of pollutants.

In consideration of large scale of the pollutant prioritization project, strategic planning and method development are required for the success of the expanded Source Control program. Key
facets are: 1) develop an initial list of constituents to analyze; 2) establish a methodic approach to prioritize constituents; 3) apply the method to the GWR System; and 4) report the results.

Pollutant Prioritization Timeline
The pollutant prioritization project consists of three initial phases of sampling followed by a routine sampling program. The phases are based on the changing status of the GWR System from its construction to routine operation.

Figure 9. Pollutant prioritization project timeline sequence.

Note that the GWR System was under construction during the time of the Phase I sampling. Because of this, representative samples of the GWR System product water were not available to determine removal rates across the GWR System. However, because the methodology discussed in this paper uses a probabilistic approach, it was also used to predict Priority Pollutants<sup>SC</sup> during the construction phase of the GWR System. At the time of this paper that Phases I and II were completed and Phase III is in progress, per Figure 9.

RESULTS

Priority Pollutants<sup>SC</sup> List
In total, 502 constituents were analyzed in Phases I and II. The results show that there were no violations of numerical limits or standards and that the GWR System is in 100% compliance of Order No. R8-2004-002.
233 constituents were detected in either the secondary effluent of Reclamation Plant No. 1 or the GWR product water. 117 of the 233 constituents detected had numerical limits or standards. 32 had positive removal rates and 17 constituents were equal to or above action levels. Therefore, 17 regulated constituents are Priority Pollutants$^{SC}$.

**17 Regulated Constituents**

- 1,4-Dichlorobenzene
- 1,4-Dioxane
- Antimony
- bis(2-Ethylhexyl)phthalate
- Boron
- bromodichloromethane
- Formaldehyde
- Iron
- Manganese
- Nickel
- Nitrate
- Nitrite
- n-Nitrosodimethylamine
- Perchlorate
- Total Dissolved Solids
- tert-butyl alcohol
- Total Nitrogen

**Figure 10 - Priority Pollutants$^{SC}$ derived from regulated constituents.**

23 regulated constituents are on the watch list. 216 constituents had negative removal rates and are slated for further investigation. 164 constituents are of no concern. 179 unregulated constituents were detected. At the time of this paper, a toxicity assessment still needs to be applied to these constituents to prioritize them.
Figure 11 – Watch list derived from regulated constituents.

Note that the lists presented in Figures 10 and 11 still need to be finalized based on the Phase III results and the results of the toxicity assessment and are expected to change.

Evaluation of Quality of Results
The average molecular weight of constituents that were detected downstream of RO and AOP range from 10.8 to 390 Daltons (about 2 to 13 angstroms) which is consistent with the molecular weight cut-off of 300-500 Daltons for the RO membrane system. During this time, the RO permeate average transmittance was 98 percent and the average effluent turbidity was 0.04 NTU. The AOP UV dose averaged 585 mJ/cm², which exceeds the 50 mJ/cm² minimum regulatory requirement.

Phases I and II results are compared with outside data from similar treatment systems shown in Figure 12. Dataset 1 is from a plant which has microfiltration, reverse osmosis and ultraviolet light treatment processes. Datasets 2 and 3 are from plants which have microfiltration, reverse osmosis and advanced oxidation treatment processes. The comparison shows good agreement between Phases I and II and the three datasets with the exception of Aluminum, diethylphthalate, and fluorene.
<table>
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<tr>
<th>Compound</th>
<th>Phases I&amp;II Results</th>
<th>Dataset 1 MF, RO, UV</th>
<th>Dataset 2 MF, RO, AOP</th>
<th>Dataset 3 MF, RO, AOP</th>
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</thead>
<tbody>
<tr>
<td>1,4-Dichlorobenzene</td>
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<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>2,3,7,8-TCDD</td>
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<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Aluminum</td>
<td>CNA</td>
<td>CNA</td>
<td>CNA</td>
<td>CNA</td>
</tr>
<tr>
<td>bis(2-Ethylhexyl)adipate</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
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<tr>
<td>bis(2-Ethylhexyl)phthalate</td>
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<td>CNA</td>
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<tr>
<td>Boron</td>
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<td>Bromodichloromethane</td>
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<td>Bromoform</td>
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<td>CNA</td>
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<td>OK</td>
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<td>Chloral hydrate</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
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<td>CNA</td>
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</tr>
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<td>DEET</td>
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<td>CNA</td>
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<td>dibromomethane</td>
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<td>Diethylphthalate</td>
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<tr>
<td>Estrone</td>
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<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Fluorene</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Gemfibrozil</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Methylene chloride</td>
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<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Monochloroacetic acid</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>n-Nitrosodimethylamine</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Perchlorate</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Trichloroacetic acid</td>
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<td>CNA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Triclosan</td>
<td>OK</td>
<td>CNA</td>
<td>OK</td>
<td>OK</td>
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<tr>
<td>Trihalomethanes (total)</td>
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<td>CNA</td>
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</table>

Figure 12 – Phases I&II results compared with results from other POTW datasets.
Unit Process Removal Rates
Removal rates for eight constituents are shown in Figure 13. The data shows significant removals averaging 60 percent occur across the secondary treatment system with the exception of n-Nitrosodimethylamine (NDMA) in which about 70 percent is removed in the primary system. Significant removals in the secondary and especially the GWR System are to be expected.

![Figure 13: Removal rates of unit processes.](image)

1,4-dioxane, acetaminophen, and caffeine have slightly negative removals across the primary treatment system, but this appears to be error of measurement. Therefore, there is essentially no removal of these constituents across the primary treatment system. Perchlorate has a negative removal rate of 15 percent across the GWR, but this is attributed to an inconsistency in method detection limits as two different laboratories were used at the plant battery limits. Note that perchlorate is well below the regulatory limit as are the balance of constituents in the figure. Because the levels of detection are very low, secondary parameters such as removal rates become more sensitive to change. Also, please keep in mind that the data reflects only Phases I and II and statistical significance may yet have to be achieved.

Negative Removal Rates
It is important to note that constituents with negative removal rates may indicate that a byproduct is being formed within the treatment processes or an undesired constituent is being inadvertently added to the treatment processes via chemical addition. As an example, a polysorbate wetting agent may be used regularly by operations and maintenance on the RO membranes of the GWR.
System. The specifications of the solution based on a technical bulletin show that up to 0.5 mg/L of 1,4 dioxane may be present in the solution, per Figure 14.

<table>
<thead>
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<th>Specifications</th>
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<tbody>
<tr>
<td>Acid Value, mg KOH/g………………….. 2.0 Max.</td>
</tr>
<tr>
<td>Saponification Value, mg KOH/g………… 45.0 – 55.0</td>
</tr>
<tr>
<td>Hydroxyl Value, mg KOH/g…………… 65.0 – 80.0</td>
</tr>
<tr>
<td>Appearance @ 25 °C…………………. Oily Yellow Liquid</td>
</tr>
<tr>
<td>Water, %……………………………. 0.5 Max.</td>
</tr>
<tr>
<td>1,4 Dioxane, ppm…………………… 0.5 Max.</td>
</tr>
</tbody>
</table>

**Figure 14. Specifications for polysorbate wetting agent for membranes.**

Sample results from a treatment system using this chemical may show as non detected at the influent, but detected at the effluent. Therefore, constituents with negative removal rates need to be further investigated. If a constituent is being formed or added within the treatment processes, then it is up to Plant Operations and Maintenance to mitigate formation.

**Dispersion of Data for Emerging Pollutants**

Analytical data in Figure 15 shows that concentrations are more dispersed for emerging pollutants versus conventional pollutants. As an example, the average influent concentration of iron, a conventional pollutant is 110 micrograms per liter with a standard deviation of 14 micrograms per liter. Note that the standard deviation represents 13 percent of the average.

In contrast, salicylic acid, a pharmaceutical constituent, has an average of 50 micrograms per liter and a standard deviation of 54 micrograms per liter. In this case, the standard deviation is 108 percent of the average.

The dispersion of analytical results of this magnitude indicates that the domain space for pharmaceuticals and personal care products is a stochastic time series, akin to stock market data. The dilemma is: How does one develop a predictive Source Control program based on data of this nature?

In the stock market, analysts have applied Moving Average and Kalman filters to model their data. Both are of a family of techniques used to analyze time series data with the intent of smoothing out short term data and thereby revealing long term trends.

The benefit of these methods as applied to emerging pollutants is that they are recursive estimators, meaning that only the estimated state from the previous time step and current measurement are used to estimate the current state. For example, if a new pharmaceutical is introduced on the market and does not do well in its first few years, but does extremely well in subsequent years, the history of observations will be biased and incorrectly reflect lower influent concentrations.
Figure 15. Dispersion of results of select pharmaceuticals and personal care products.

A recursive estimator such as the Kalman filter will more accurately model the trend, allowing source control to predict whether to implement source control measures for the new pharmaceutical or other emerging pollutant. Details of the Moving Average and Kalman filter as applied to this pollutant prioritization effort will be discussed in another paper.

CONCLUSIONS

Overall, this technical risk assessment provided a prioritized list of 17 constituents for source control starting from an initial list of over 500 constituents in 19 groupings. From this, point and non point sources will be identified and classified. Next, a source control strategy will be selected such as targeted public outreach or voluntary reduction. Lastly, the source control strategy will be implemented and the effectiveness evaluated.

The pollutant prioritization project for water reuse provides a simple, but practical methodology for ranking constituents with and without numerical limits or standards using a probabilistic approach. While the methodology may not be ideal, improvements will be made on a continual basis. This methodology is presented for the benefit of others which may find themselves in similar situations.
ACKNOWLEDGMENTS

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REFERENCES


