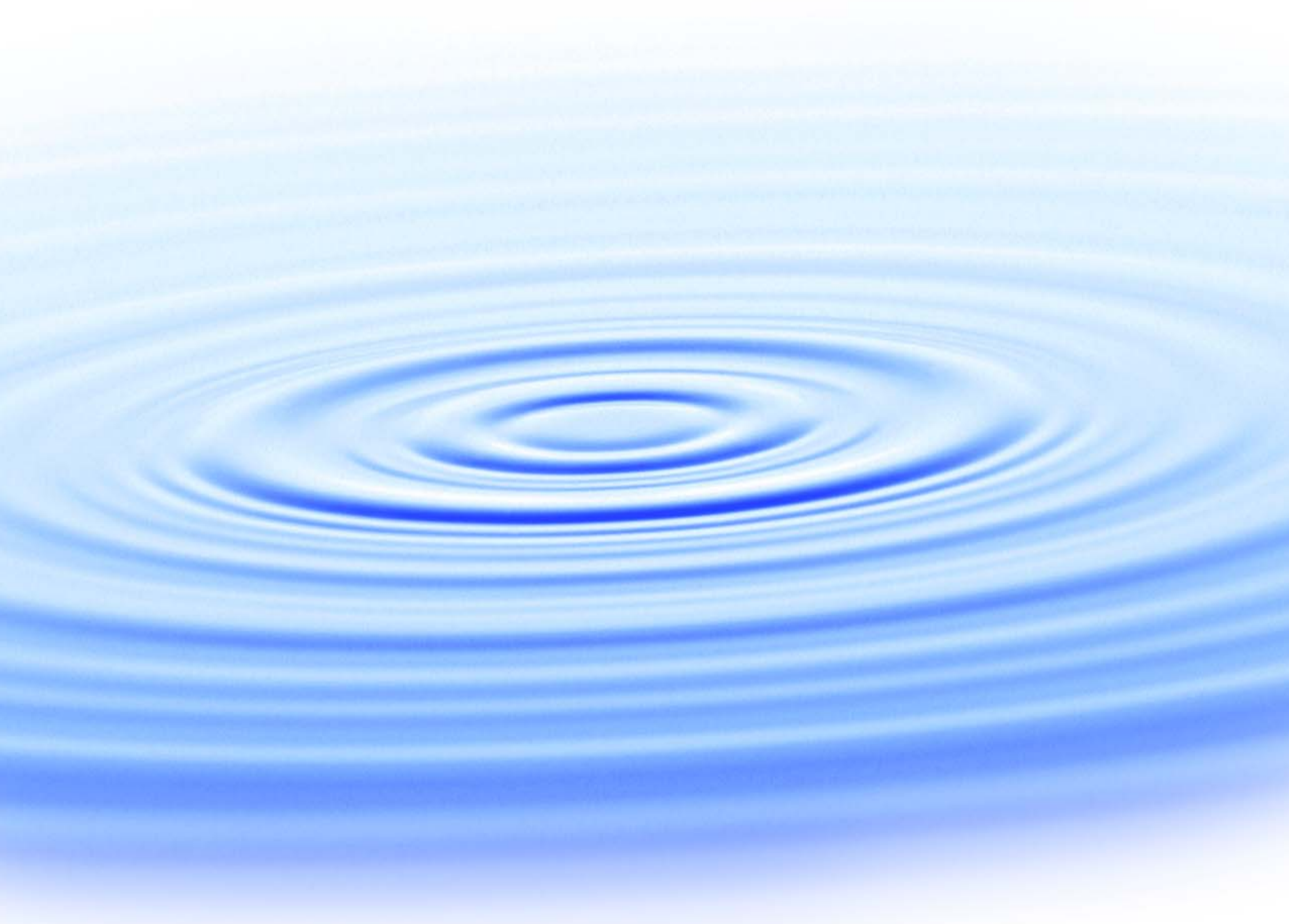
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

WATEREUSE

# Comparison of Chemical Composition of Reclaimed and Conventional Waters



WateReuse Research Foundation

# Comparison of Chemical Composition of Reclaimed and Conventional Waters

# About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high quality water for various uses through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, reduction of energy requirements, concentrate management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of providing a reliable, safe product for its intended use.

The Foundation's funding partners include the supporters of the California Direct Potable Reuse Initiative, Water Services Association of Australia, Pentair Foundation, and Bureau of Reclamation. Funding is also provided by the Foundation's Subscribers, water and wastewater agencies, and other interested organizations.

# Comparison of Chemical Composition of Reclaimed and Conventional Waters

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# Acronyms

| | |
|---|---|
| AVG | national drinking water average |
| BAA | bromoacetic acid |
| BHA | butylated hydroxyanisole |
| CAA | chloroacetic acid |
| CCL | Contaminant Candidate List |
| CDPH | California Department of Public Health |
| CECs | contaminants of emerging concern |
| DBAA | dibromoacetic acid |
| DBP | disinfection byproduct |
| DCAA | dichloroacetic acid |
| DEET | *N,N*-diethyl-*meta*-toluamide |
| df | detection frequency |
| DOC | dissolved organic carbon |
| DW | drinking water |
| EC | electrical conductivity |
| EDC | endocrine-disrupting compound |
| EEM | excitation–emission matrix |
| ESI | electrospray ionization |
| FI | fluorescence index |
| FP | formation potential |
| HAA | haloacetic acid |
| IPR | indirect potable reuse |
| LC-MS/MS | liquid chromatography tandem mass spectrometry |
| MCL | maximum contaminant limit |
| MDL | method detection limit |
| MF | microfiltration |
| MLE | modified Ludzack–Ettinger |
| MRL | method reporting limit |
| NDMA | nitrosodimethylamine |
| NOM | natural organic matter |
| NSAID | nonsteroidal anti-inflammatory |
| PAC | powdered activated carbon |
| PFCs | perfluorinated organic chemicals |
| PFOA | perfluorooctanoic acid |
| PFOS | perfluorooctanesulfonic acid |
| PRAM | polarity rapid assessment method |
| RO | reverse osmosis |
| SAT | soil-aquifer treatment |
| SEC | size-exclusion chromatography |

| | |
|---|---|
| SMP | soluble microbial product |
| SNWA | Southern Nevada Water Authority |
| SOC | synthetic organic chemical |
| SPE | solid-phase extraction |
| SSRI | selective serotonin reuptake inhibitor |
| SUVA | specific ultraviolet absorbance |
| TCAA | trichloroacetic acid |
| TCEP | tris(2-chloroethyl)phosphate |
| TCPP | tris(1-chloro-2-propyl)phosphate |
| TDS | total dissolved solids |
| THM | trihalomethane |
| TN | total nitrogen |
| TOBr | total organic bromine |
| TOC | total organic carbon |
| TOCl | total organic chlorine |
| TOI | total organic iodine |
| TON | total organic nitrogen |
| TOrC | trace organic compound |
| Tot. THM | total trihalomethanes |
| TOX | total organic halogen |
| UCMR | Unregulated Contaminant Monitoring Rule |
| UVA | ultraviolet absorbance |
| UV-AOP | ultraviolet irradiation with hydrogen peroxide addition |
| VOC | volatile organic chemical |
| WWTP | wastewater treatment plant |

# Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide sustainable sources of high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high-priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse and desalination research topics including:

- Defining and addressing emerging contaminants, including chemicals and pathogens
- Determining effective and efficient treatment technologies to create 'fit for purpose' water
- Understanding public perceptions and increasing acceptance of water reuse
- Enhancing management practices related to direct and indirect potable reuse
- Managing concentrate resulting from desalination and potable reuse operations
- Demonstrating the feasibility and safety of direct potable reuse

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project to provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

Many water agencies are currently using drinking water sources impacted by municipal wastewater discharge, whereas others are planning for and/or implementing potable reuse. The WateReuse Research Foundation provided funding to a team from the Southern Nevada Water Authority and the Colorado School of Mines to characterize and compare water quality from both planned and unplanned potable water reuse. The research designed a "roadmap," which is a process for selecting indicator constituents and surrogate bulk parameters, along with associated analytical methodology.

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The members of the project team also express sincere gratitude to the WateReuse Research Foundation staff, especially Anna Durden, Carolyn Sherony, Deana Bollaci, Julie Minton, and Joshua Dickenson, who helped manage and direct the project. We also thank Wade Miller for his tireless leadership and tenacity in finding and maintaining the funding to make projects such as this possible.

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# Executive Summary

## Project Background and Objectives

Many water agencies are currently using drinking water sources impacted by municipal wastewater discharge, whereas others are planning for and/or implementing potable reuse. The use of water sources impacted by wastewater has raised public and regulatory concerns because of uncertainties associated with the quality and composition of drinking water produced from these sources. Planned potable reuse projects often employ advanced water treatment processes and/or natural systems such as infiltration into groundwater and riverbank filtration. Often, trace organic compounds (TOrCs) are detectable in waters influenced by wastewater outfalls. Relatively poor toxicological data are available regarding many TOrCs, which is even worse when mixture toxicity and chronic life-time exposure scenarios are considered. Thus, a great deal of public and regulatory concern has been generated regarding the occurrence of these compounds in drinking water. Therefore, this project was designed to compare the occurrence of TOrCs in U.S. drinking waters produced from both unplanned (also known as de facto) and planned water reuse.

The WateReuse Research Foundation provided funding to the Southern Nevada Water Authority (Shane Snyder, PI)/Colorado School of Mines (Jörg Drewes, PI) team to characterize and compare water quality from planned and unplanned potable water reuse. The research designed a “roadmap,” which is a process for selecting indicator constituents and surrogate bulk parameters, along with associated analytical methodology. Thus, the roadmap provides for both inorganic and organic chemical analyses, including various indicator and surrogate species. Our research team, with the support and expertise of seven U.S. water agencies, was able to monitor five conventional drinking water treatment facilities and two indirect potable reuse (IPR) facilities for one year.

The objectives of this project were as follows:

1. Develop an analytical roadmap for characterizing water quality for organic and inorganic constituents.
2. Identify how the source water history and treatment processes affect the chemical composition of water.
3. Use statistical tools to compare the composition of water produced by planned potable reuse projects with that of drinking water produced from surface and groundwater sources under the impact of wastewater discharges.
4. Communicate project findings to water and environmental professionals as well as to the public.

To address the project objectives, the research was organized into six primary tasks:

1. Conduct a literature survey to summarize the current knowledge base regarding the quality and composition of water produced by planned potable reuse and conventional systems using source water impacted by wastewater discharge (de facto reuse).
2. Identification of full-scale water treatment facilities practicing planned potable reuse and conventional systems using source water impacted by wastewater discharge.

3. Development of an analytical roadmap for chemical characterization of different water types.
4. Determination of the treatment efficacy of the selected conventional and advanced treatment systems in attenuating, or forming, constituents from the roadmap.
5. Comparison of composition of water produced by planned potable reuse with that of “conventional” drinking water treatment systems.
6. Project reporting and outreach, including comparison of detected concentrations of TOrCs with health guideline values from the literature.

## Project Approach

In Task 1, the team reviewed the existing literature at the time the project was initiated to determine what tools were currently in use that define water quality and composition from planned indirect potable reuse and conventional drinking water systems. In addition, the team reviewed and considered modern analytical techniques that had not yet been widely utilized for characterization of water quality. The team also determined which water treatment processes should be represented within the sites to be selected for the investigation.

In Task 2, the team evaluated several water agencies in the United States and asked for information regarding their source waters, including the percent of wastewater influence known within their source waters. Although these values were subject to weather conditions and usage patterns, the drinking water sites selected self-reported 0 to 30% of their raw water originated from wastewater treatment plant (WWTP) discharge. The team also selected two IPR sites using two different treatment approaches. One IPR site utilized surface spreading and subsequent soil-aquifer treatment (SAT) for groundwater replenishment, whereas the other IPR location utilized direct injection into groundwater after advanced treatment including reverse osmosis (RO) and advanced oxidation using ultraviolet irradiation in the presence of hydrogen (UV-RO/AOP). These seven sites all produced more than 20 million gallons of water per day (MGD) and served populations in urbanized years. The selected sites served as representative locations for “ambient” conditions for de facto water reuse and for IPR.

Task 3 focused on the development of the analytical roadmap. Through the review of current literature, discussions with the Project Advisory Committee (PAC), and our team’s expertise, we developed an analytical roadmap that would encompass a wide breadth of organic and inorganic chemicals indicative of water qualities (see Table 2.9). The parameters within the analytical roadmap provide a comprehensive chemical characterization for each of the waters considered in this project.

During Task 4, water samples from the seven selected sites were collected quarterly for one year to monitor the parameters defined in the analytical roadmap. These water samples were collected from the source and post-treatment. Initially, the team intended to collect distribution system samples also; however, this became confounded by blending operations and distribution system management. Therefore, the team performed DBP formation potential tests for nitrosamines and TOX by incubating samples in the presence of chlorine (3-5 mg/L after 7 days contact time). In addition, 2 years of previous regulatory monitoring data were collected from each facility and evaluated in consideration of regulated contaminants, such as certain disinfection byproducts and metals, for which standardized U.S. EPA methods were applied. These historical data were compared with national averages when available. For each system, attenuation or formation of the roadmap constituents was evaluated and reported.

Analytical results were compared through summary statistics and through a nonparametric statistical test in Task 5. Individual constituents and water quality parameters from each site were plotted as box and whisker plots showing the data distribution with 25th and 75th quartiles, along with the median value. Also calculated for each constituent was the detection frequency, which is the percentage of samples where a given constituent was detected in a given number of measurements. Because of the frequency of nondetect results and the limited number of observations, the data sets were expected not to be normally distributed, and thus nonparametric statistics were applied. The Kruskal–Wallis univariate nonparametric multiple-comparison test was performed, which compares the medians of two or more samples to determine if the samples have come from different populations. This test is the nonparametric analogue of a one-way analysis of variance that would be applied to normally distributed data.

Last, Task 6 was accomplished through presentations at national and international conferences, presentations in regional public forums, and peer-reviewed journal publications. The team has found a great deal of public interest in this project. The public feel far more secure with the use of recycled water for drinking water augmentation when they can be assured that the water quality is at least equal to what they already consume. Thus, the primary question answered through this research was, “Is finished water quality produced by planned water reclamation projects of indistinguishable quality from finished water quality produced from conventional drinking water treatment using surface or ground water sources unimpacted or impacted by wastewater discharges?” In addressing this question through this research report, we provide some of the most compelling evidence to ensure the public that indeed planned potable water reuse can provide a water quality superior to what they already accept and consume. However, it also is clear that some TOrCs are detectable in all waters. Therefore, we compared the concentrations found in finished water in this study with health guideline values published in previous studies.

## Project Findings

Water can have vastly different chemical compositions, depending upon its source and treatment, yet all water can be evaluated with a common roadmap to define and compare chemical composition. Within this study, all waters provided for public consumption met or exceeded all regulatory parameters under the Federal Safe Drinking Water Act. Thus, regardless of source water quality, water treatment is capable of producing water that meets all regulatory requirements. Therefore, the analytical roadmap had to consider parameters beyond the regulatory framework for US drinking water. On the basis of the literature review completed in Task 1, the team selected a series of organic and inorganic constituents deemed to be most relevant in comparisons of chemical composition of conventional drinking water with that of IPR water. Beyond discrete chemical measurements, the team also chose a series of bulk parameters that can be used both to characterize water sources and to assess treatment performance, including on-line monitors for certain parameters.

The team selected five conventional drinking water systems and two IPR systems for evaluation in this study. The five drinking water systems self-reported their degree of wastewater influence in source water to range from 0 to 30%. Of these five systems, one served as a control (no influence), two as very-low influence (1–2%), one as low influence (5%), and one as moderate influence (30%). These systems are generally considered conventional water treatment facilities; however, one utilized ozone for disinfection and another used powdered activated carbon to reduce organic constituents. In the United States, IPR is generally accomplished either through infiltration of treated wastewater using SAT or by using advanced treatment processes and injecting the resulting water into an aquifer. We chose to evaluate one of each type of IPR system for this study. Both IPR systems utilized 100% wastewater effluent as their source water; thus for the sake of comparison we classify these systems as “high” influence. The IPR1 site, which uses surface spreading of tertiary treated wastewater followed by infiltration SAT, was monitored at the infiltration pond and at two wells located approximately 1.5 and 21 months of travel time downstream of the surface spreading operation. The second IPR2 system utilizes a secondary wastewater effluent that is subsequently treated using microfiltration (MF), reverse osmosis (RO), and ultraviolet irradiation with hydrogen peroxide addition (UV-AOP) before its injection into a potable aquifer. A single well located an estimated 24 months of travel time from the point of injection was monitored for this study. Generally, each of the seven systems was sampled quarterly for the roadmap analytical characterization. In addition, finished waters were evaluated for disinfection byproduct formation potential through chlorination with a contact time of 7 days. The team also requested the past 2 years of regulatory monitoring data from each utility; however, considering differences in compliance points and state regulations, not all data were directly comparable, nor was the volume of data received equivalent.

The analytical roadmap developed in Task 3 included total dissolved solids, nutrients, cations/anions, metals, perchlorate, chlorate, alkalinity, total nitrogen, disinfection byproducts, pharmaceuticals, potential endocrine disrupting compounds, steroid hormones, perfluorinated organic chemicals (PFCs), total and dissolved organic carbon, UV absorption, total organic halides (TOX), fluorescence excitation–emission matrix (EEM), polarity rapid assessment method (PRAM), size exclusion chromatography (SEC), color, conductivity, pH, and nitrosamines. Of these parameters, the greatest amount of public interest and concern generally is related to the unregulated contaminants of emerging concern (CECs). In order to select CECs, we included perchlorate and chlorate as unregulated inorganic contaminants, nitrosamines as unregulated DBPs, and a suite of TOrCs. The selection of TOrCs was based upon analytical capabilities, detection frequency from the literature review, biodegradability (both low and high), and consideration of the U.S. EPA’s Contaminant Candidate List (CCL) and the Unregulated Contaminant Monitoring Rule (UCMR). Using these criteria, the team eventually selected 33 TOrCs—specifically, two PFCs, 16 pharmaceuticals, four personal care/household products, two chlorinated flame retardants, five steroid hormones, and four additional compounds considered as “other” compounds.

The ability to attenuate various constituents and form certain byproducts was generally related more to the specific treatment processes employed than to type/quality of source water. For instance, although nitrate was well below the federal standard of 10 mg/L in the finished water of all seven facilities, nitrate was generally not attenuated in any of the drinking water systems (DW systems). However, nitrate was significantly reduced during the surface spreading/infiltration process used at IPR1 (SAT) and showed a minor increase in the production well from the advanced treatment system at IPR2 (RO-UV/AOP). The small increase (around 0.5 mg/L) in the production well of IPR2 was likely caused by blending with native ground water, because nitrate was not detected in the post-RO-UV/AOP water. As another example, four of the five DW systems did not exhibit attenuation of conductivity, whereas one DW utilizing softening showed a relatively small reduction in total dissolved solids (TDS). In comparison, IPR1 demonstrated a conductivity reduction of approximately 200 $\mu S/cm^2$, whereas IPR2 (using RO) reduced conductivity by approximately 1,300 $\mu S/cm^2$. The same trend for conductivity followed for sulfate and alkalinity. Total organic carbon (TOC) and $UV_{254}$ absorbance showed similar trends in all facilities, with negligible reductions in three of the DW systems and significant reductions in the DW systems with PAC/softening and enhanced coagulation/sedimentation. Both IPR sites exhibited significant

TOC and $UV_{254}$ absorbance reductions, with IPR2 (RO) having a greater magnitude of reduction than IPR1 (infiltration). The evaluation of TOrCs removal was somewhat limited, as frequency and magnitude of detection were far lower in the source water of the DW sites than for the IPR sites. At IPR1 and IPR2, 22 and 31 of the 33 TOrCs analyzed were detected, respectively, in the source water. The steroid hormones ethynylestradiol and testosterone were not detectable at any DW or IPR sites despite method reporting limits of 1 and 0.5 ng/L, respectively. The source waters for DW systems 1 to 5 contained 7, 8, 14, 20, and 14, respectively, of the TOrCs analyzed. This trend generally followed the degree of wastewater impact self-reported by the water agencies. As expected, DW3, with a self-reported 30% WWTP contribution to the source water, also had the greatest number and concentrations of detected TOrCs among the DW systems. This self-reported value seems reasonable when the IPR source waters are compared with DW3 source water and considering that IPR1 and IPR2 are not geographically similar.

Regarding TOrC attenuation, IPR2 using RO-UV/AOP exhibited the greatest amount of attenuation with removal efficiencies generally in excess of 98%, with only the synthetic fragrance musk ketone consistently showing a removal efficiency of less than 50%. In IPR1 (infiltration), TOrC attenuation rates were also good, with the exceptions of atrazine, carbamazepine, fluoxetine, PFOA, PFOS, primidone, and sulfamethoxazole, all of which were less than 50% attenuated. These compounds have been found previously to be relatively resistant to biodegradation; thus it is not surprising that these compounds were found to be somewhat persistent in infiltrated water. Conversely, the DW systems evaluated provided far less attenuation for those contaminants detected in the source water. The only consistent exception was the antibiotic sulfamethoxazole, which was better removed by the DW systems than IPR2. The reason is almost certainly the oxidation of sulfamethoxazole by chlorine and/or ozone at the DW systems versus biological degradation at IPR1. In general, DW5 performed best among the DW systems surveyed for TOrCs attenuation, which is likely due to the use of ozone at DW5. Among the remaining DW systems, DW4 performed better at TOrC attenuation than DW systems 1 to 3, likely because of the use of PAC for TOC reduction. TOrC removal often tracked the TOC reduction (ranging from approximately 25 to 50%) at DW4. The attenuation of TOrCs in DW systems 1 to 3 was meager, with the exception of sulfamethoxazole. However, DW systems 1 to 3 had very low WWTP impact and thus had lower occurrence and magnitude of detected TOrCs.

The final phase of this study was the comparison of chemical composition in finished “drinking” water among the seven locations. It is important to note that from the data collected in this study, there was no observed exceedance of any maximum contaminant limits (MCLs) from the Safe Drinking Water Act. In other words, all finished waters were compliant with federal regulations for contaminants evaluated. Concentrations of monitored constituents were generally lower at IPR sites than those DWs impacted by WWTPs (DW systems 2 to 5), but not always. For instance, nitrate levels were generally higher at IPR sites than in the DW systems; however, all detected values from both sites were less than the federal MCL of 10 mg/L. As mentioned previously, the potable water well chosen for IPR2 consistently had poorer water quality (i.e., total dissolved solids, conductivity, phosphate, sulfate, TOC, and PFOA) than the water produced directly from the IPR treatment facility. This is likely due to blending of the produced water prior to injection, mixing with other groundwater sources, and blending with recharged stormwater. However, it cannot be ruled out that the water quality assumedly 24 months prior was not the same at the production facility as it was when sampling took place. In other words, our sample of injected water versus harvested water was collected at essentially the same time and thus cannot account for the actual water quality of the produced water at the time of injection. Regardless, based on the data from this project, it appears that blending and/or injection into the subsurface deteriorates the quality of IPR water from the advanced treatment processes at IPR2.

Finished water quality varied significantly among the DW systems evaluated for most parameters. For instance, TDS ranged from approximately 100 mg/L in DW systems 1 and 4 to more than 600 mg/L for DW systems 2 and 5. Median TOC values were approximately 2 mg/L in DW systems 1 and 2; 3mg/L in DW systems 3 and 5; and 4 mg/L for DW system 4. Also quite noticeable was the variability among the seasons for the surface water systems (DW systems 1, 3, 4, and 5) compared to the highly stable values for the groundwater system (DW 2). Formation potential of NDMA was assessed at DW systems 2, 3, and 5 and resulted in values of 3, 14, and 7 ng/L, respectively. In comparison, IPRs 1 and 2 resulted in NDMA formation potentials of approximately 3 and 4 ng/L, respectively. For total organic halide (TOX) formation potential, all DW systems were higher than the two IPR systems, with DW3 reaching TOX levels >1000 µg/L, whereas the IPRs had a maximum TOX concentration less than 100 µg/L.

Concentrations of TOrCs were generally higher in DW systems than in the IPRs. However, carbamazepine, PFOS, primidone, and sulfamethoxazole are exceptions, where concentrations at IPR1 were higher than those from the DW systems. For instance, carbamazepine exhibited a median concentration of approximately 100 ng/L at IPR1, whereas the highest median concentration at the DW systems was approximately 40 ng/L at DW3. The median PFOS value at the IPR1 production well was approximately 60 ng/L, whereas the next highest median value was approximately 25 ng/L at DW3. For the pharmaceutical primidone, the median concentration at IPR1 was approximately 70 ng/L, whereas the next highest median value was at DW3 at approximately 20 ng/L. In the case of the antibiotic sulfamethoxazole, the median value from IPR1 was approximately 90 ng/L and the next closest median value was <10 ng/L at DW3. It is interesting to note that two wells were monitored for IPR1, with estimated travel times of 1.8 and 12.2 months, labeled IPR1a and IPR1b, respectively. All median concentrations for carbamazepine, PFOS, primidone, and sulfamethoxazole were higher in the IPR1b well as compared to IPR1a. This suggests that either the water quality was different at the time of infiltration or these chemicals are being contributed through blending with other waters in the subsurface.

With the exception of PFOA, all other TOrCs were near or below the method reporting limits at IPR2. However, considering the advanced treatment processes employed at IRP2 and considering that PFOA was nondetectable (MRL of 5 ng/L) in the produced water prior to blending/injection, it is quite likely that the observed PFOA concentrations originated from other water sources (i.e., raw surface water, stormwater) that blend with the produced water provided by the IPR2 facility.

The moderately impacted DW site (DW3) had consistently higher concentrations for nearly all TOrC than the other DW and IPR systems (noting the four exceptions for IPR1 discussed previously). For instance, the pharmaceutical meprobamate occurred at DW3 with a median value of approximately 120 ng/L, whereas DW5 and IPR1 had median values of approximately 10 ng/L. PFOA concentrations also were highest at DW3, with a median value of just over 30 ng/L. The concentrations of the flame retardants TCEP and TCPP at DW3 were remarkably high, with median values of approximately 300 and 900 ng/L, respectively. TOX and NDMA formation potential was also found to be highest at DW3, with a median TOX formation potential value of approximately 600 µg/L and an NDMA formation potential of 14 ng/L. A statistical evaluation of all waters is provided in Chapter 4 of this report.

## Project Conclusions

This project provides unique insight into chemical composition water produced through both planned potable reuse and through conventional U.S. drinking water facilities, of which some practice de facto potable reuse. The produced water quality in both scenarios is a function of source water quality and water treatment processes. Both IPRs and DW systems are able to produce water that consistently meets or exceeds all federal regulations. However, IPRs are generally able to provide a higher degree of TOrCs attenuation, especially when advanced water treatment processes are employed. The detection of trace levels of various constituents is inevitable in any source and produced water because of extraordinary analytical sensitivity. Even with advanced water treatment processes including RO and/or advanced oxidation, one should reasonably expect that some detection of TOrCs will be possible, depending on the analytical methods utilized and the performance of the treatment system.

This study demonstrates that a DW facility with even a moderate (30%) WWTP impact on its source waters can produce water that has higher concentrations, frequencies, and number of contaminants than an IPR scheme practicing groundwater recharge with either infiltration/SAT or direct injection after advanced treatment processes. Because conventional DW treatment processes are not highly effective for most TOrC removal, the degree of WWTP impact to the source water will affect the produced water quality. Whereas in IPR systems, the process performance for attenuation of TOrCs is far less susceptible to changes in source water quality. IPR systems that rely on infiltration/SAT as the primary barrier should expect that some biologically recalcitrant substances will not be well attenuated in the subsurface. Thus, if those compounds are deemed to be of concern/relevance, then the agency may have to employ additional treatment steps before or after the infiltration/SAT. However, considering that this study demonstrated the potential for dilution/blending water to negatively impact the quality of water produced by an IPR system, it may be prudent for infiltration/SAT systems to consider postharvest water treatment as opposed to preinfiltration treatment. For instance, the concentration of various monitored constituents was often higher in water production wells than in the water produced at the facility. In addition, utilities employing advanced water treatment processes, including RO and UV-AOP, may want to consider limiting or eliminating the use of an environmental buffer in favor of direct potable reuse in order to provide water of the best possible quality.

Concentrations of TOrCs detected in the finished waters from both DW and IPR sites were far too low for any known human health effects. Of the 33 targeted TOrCs, only 20 were detected in the finished waters from either IPRs or DW systems. The finished water at DW3 had the highest median concentrations for 10 of the 20 detectable TOrCs. DW4 and IPR2 had the second highest median concentrations for five of the TOrCs (five different ones at each location), whereas IPR2 had the highest median concentration only for bisphenol A, at 34 ng/L. However, the bisphenol A detection at IPR2 is not likely the result of recycled water because the RO-UV/AOP process is known to remove this contaminant well and because bisphenol A was below the MRL of 5 ng/L in two of the four sampling events of the finished water. When the concentrations of TOrCs detected in finished waters in this study are compared, it is evident that all TOrC concentrations are well below the human toxicity thresholds published in key reports and peer-reviewed journal articles. Ironically, the TOrC with a concentration nearest the toxicity level was the herbicide atrazine, which occurred with an average value of 300 ng/L in DW3. The U.S. EPA MCL for atrazine is 3000 ng/L. Thus the mean concentration of atrazine at DW3 is still 10× lower than the enforceable regulatory limit. Although not a regulatory limit/requirement, TOX and NDMA formation potentials (FPs) were significantly higher for DW3 than they were for IPRs 1 and 2. The median TOX

FP for DW3 was nearly 10× higher than the TOX FP for IPRs 1 and 2. Likewise, the NDMA FP for DW 3 was nearly 5× higher than that for IPR1 and nearly 3× higher than that for IPR2.

The findings presented in this report are significant to the water reuse community. The information in this report will help place potable water reuse in perspective in consideration of the chemical composition of water from existing and compliant drinking water treatment facilities. This study demonstrated that for nearly all parameters, properly designed and operated IPR systems can and will produce water that is of quality similar or superior to that of the ambient drinking water in many U.S. cities.

## *Chapter 1*

# Introduction

## 1.1 Background

The water cycle dictates that much of the water utilized by humans will eventually return to the environment. There is no doubt that water will be used and reused by humans over time; thus the debated issue is primarily one of proximity and time. Throughout the world, there are urban areas that are downstream of other urban areas. Thus, as one city withdraws from and subsequently discharges to a particular watershed, the upstream city's wastewater because a portion of the downstream city's drinking water. For instance, Richardson and Bowron stated in 1985 that "The River Lee is a source of potable water for North London and during summer months and dry weather conditions it can be composed of some 60% of STWs [sewage treatment works] effluent" (Richardson and Bowron, 1985). In 1962, the U.S. Public Health Service specified alkylbenzene sulfonate (ABS) an indicator species for "municipal sewage," stating that "waters containing ABS are likely to be at least 10 percent of sewage origin for each mg ABS/liter present." The Public Health Service went further, stating that "Concentrations of ABS above 0.5 mg/L are also indicative of questionably undesirable levels of other sewage pollution" and that "In one instance, a municipal water supply contained 5 mg/L [ABS] when a period of drought necessitated the use of an impounded, highly purified sewage treatment plant effluent as a raw water supply." The use of source waters impacted by wastewater outfalls and/or septic systems is not unique to these two cases, but rather, is the case for drinking water sources for millions of people worldwide. Thus, as the expansion of the intentional use of wastewater as a resource for potable water supply continues to grow, the looming question develops of how water produced through reuse of municipal wastewater compares with the ambient water quality of urban areas, particularly of those that are "downstream."

## 1.2 Project Motivation

With increasing water demand and the lack of alternative sources, water agencies are attracted to reusing treated municipal wastewater effluent to augment drinking water supplies. However, there is public and regulatory concern with the uncertainty of the quality of water produced by planned drinking water reclamation projects and with associated health risks. Concerns about chemical contaminants are not limited to planned indirect potable reuse projects. Although the traditional maxim for selecting drinking water supplies has been to use the highest-quality source available, many once-pristine river water sources have evolved over time into unintentional indirect potable reuse systems, as wastewater from upstream dischargers has increased to substantial portions of the stream flow. The presence of chemical contaminants in conventional supplies using source waters impacted by waste discharge is now a concern for water agencies, regulators, and the public.

Over the past decade, a plethora of reports have been published documenting the occurrence of trace organic substances of uniquely human origin in surface, ground, and drinking waters. It is widely understood that potable water reuse produces water that is compliant with all federal and state regulations; however, emerging contaminants, as yet unidentified contaminants, and potential health implications from complex mixtures can cause resistance to planned potable water reuse. As analytical methods become increasingly sensitive and selective, new contaminants are continually being identified at vanishingly minute concentrations. Consequently, many substances that are not detectable today will likely be detectable as analytical sensitivity continues to increase. Thus, attenuation of all possible water contaminants to nondetectable levels is largely futile, and reliance on assessment of health risks at the concentrations observed will be needed to set treatment goals that are meaningful to public health. Because risk assessment data for all potential contaminants and mixtures of contaminants are not available, or even feasible, one simple way to evaluate water quality is through comparison of chemical composition. The current project sought to compare the chemical composition of finished water from “conventional” drinking water treatment facilities with that of water produced by planned indirect potable reuse systems.

## 1.3 Project Approach

The team partnered with seven water agencies, which provided monitoring data, treatment process information, and water samples. The selected systems included five drinking water systems and two indirect potable reuse operations. To compare the chemical composition of various waters, the team developed an analytical roadmap for comprehensive chemical characterization. This roadmap was applied by analyzing historical monitoring data provided by participating water agencies as well as by collecting samples quarterly for analysis of a suite of unregulated constituents. Data from these systems were evaluated and statistically analyzed. Resulting concentrations of trace organic compounds in finished water were compared with published values relevant to public health. The project was arranged with the following six key tasks:

Task 1: Conduct a literature survey to summarize current knowledge
Task 2: Select IPR and DW systems for evaluation and monitoring
Task 3: Develop an analytical roadmap for chemical characterization
Task 4: Determine attenuation efficacy for roadmap constituents at selected sites
Task 5: Compare composition of water produced by IPR and DW systems
Task 6: Compare composition of finished water with human health data

## 1.4 Overview of Report

The project tasks provide the general framework for the organization of the report. Chapter 2 provides information on the sites selected for the study, including historical water quality data, treatment process train, and general operational information. Specific information regarding the location of each site is not provided, as this information is not pertinent to the findings of the study; therefore, the studied sites are simply identified as DW1-5 and IPR1 and 2.

Chapter 3 provides the analytical roadmap, along with information regarding the methods utilized for the constituents monitored. For the TOrCs evaluated in this study, molecular structure, general use, concentration ranges, and physical–chemical properties are provided. An additional text description of each TOrC is also provided. The statistical method applied to the resulting data also is described, along with example applications to total dissolved solids and nitrite.

Chapter 4 describes the change in chemical composition through the treatment process at each of the seven locations. Discrete chemicals, such as TOrC, were monitored in source and finished water at each location and the attenuation, if any, was calculated. Bulk parameters such as total organic carbon (TOC), total nitrogen, and conductivity were also monitored. Chapter 4 also discusses the changes in bulk organic matter as monitored by molecular weight distribution, fluorescence, UV absorbance, and polarity.

Chapter 5 presents a comparison of the chemical compositions of the finished waters from each of the sites. When available, the comparison also includes national average data from the American Water Works Association and U.S. EPA databases. This chapter also presents the results from NDMA and TOX formation potential tests conducted with finished water. Finally, the chapter ends with statistical analyses that compare the median values of various constituents among the seven sites.

Chapter 6 provides a summary of the project findings presented in Chapters 4 and 5. This chapter also compares the levels of TOrCs found at the seven sites investigated with published literature regarding the potential to impact public health. The chapter ends with recommendations for water professionals and future research needs.

Appendix A provides the entire collected historical data set received from each of the seven participating water agencies.

Appendix B provides the entire data set for constituents monitored in the current project.

Appendix C provides the entire statistical evaluation performed in this study.

Appendix D provides the complete data for the fluorescence excitation–emission matrix (EEM).

## *Chapter 2*

# Study Sites

## 2.1 Introduction

This chapter provides background information on methods employed for the comparison of finished drinking water quality from conventional drinking water facilities and planned indirect potable reuse systems. Five conventional drinking water facilities (DW1–DW5) located in various regions of the United States were selected for this study. One conventional drinking water facility (DW1) has no known inputs of municipal wastewater to its raw water supply, and four others are characterized by having various degrees of wastewater impact. For the purposes of this report, the sites DW2–DW5 were collectively named unplanned indirect potable reuse sites. Two planned indirect potable reuse systems (IPR1 and IPR2), both practicing groundwater recharge, were selected for this study. One of the IPR systems employs surface spreading of reclaimed water followed by soil-aquifer treatment and the other system injects reclaimed water directly into an aquifer after reverse osmosis and advanced oxidation (UV/$H_2O_2$) treatment. It is noteworthy that although these practices of indirect potable reuse are well established in the United States, other systems pursuing either groundwater recharge or surface water augmentation have chosen different treatment processes and overall treatment schematics, which will result in potentially different finished water quality.

## 2.2 Description of Field Sites

The seven facilities producing potable water selected for this study were monitored for one year during this project. The facilities varied in size and treatment processes, but all had a capacity of at least 20 MGD and served urbanized areas. Table 2.1 summarizes the treatment trains, source water and quality, and sampling frequencies. Samples were collected quarterly or semiannually from each facility and were analyzed for a wide range of water quality parameters. The raw data and analyses are presented in Appendix B. In addition, historic water quality parameters were requested for the 24 months leading up to the start of this project. These data were originally collected by each of the participating utilities and include traditionally monitored water quality parameters, such as TOC conductivity, ammonia, nitrate, alkalinity, phosphate, and disinfection byproduct (DBP) concentrations. The historical data are presented in their entirety in Appendix A. A discussion of these data and the quality of the water produced by planned or unplanned potable water reuse systems follows in Chapters 4 and 5.

**Table 2.1. Source Water Quality, Treatment Processes, and Number of Influent and Effluent Samples Collected as Part of this Project**

| Site | Source Water | Wastewater Impact | Treatment Process | # of Influent Samples | # of Effluent Samples |
|---|---|---|---|---|---|
| DW1 | Surface water | None (control) | CL, COA/FLOC, DBF, CAM | 2 | 2 |
| DW2 | Groundwater | Very low (1–3%) | DBF, UV, CL | 4 | 4 |
| DW3 | Surface water | Moderate (≈30%) | CL, COA/FLOC, DBF, UV | 4 | 4 |
| DW4 | Surface water | Low (≈5%) | PAC, SOFT, CAM, DBF, CAM | 4 | 4 |
| DW5 | Surface water | Very low (1–3%) | CAM, $O_3$, COA/FLOC, DBF, CL | 4 | 4 |
| IPR1 | Secondary-treated wastewater | High | CL, DL, SAT | 2 | 4 |
| IPR2 | Tertiary-treated wastewater | High | MF, RO, UV/$H_2O_2$, SAT | 4 | 4 |

*Notes:* CL = chlorination; COA/FLOC = coagulation/flocculation; DBF = deep bed filtration; CAM = chloramination; UV = ultraviolet; PAC = powdered activated carbon; SOFT = softening; $O_3$ = ozone; SAT = soil-aquifer treatment; MF = microfiltration; RO = reverse osmosis; UV/$H_2O_2$ = ultraviolet with peroxide (advanced oxidation).

### 2.2.1 DW1 (Nonimpacted Surface Water)—Control Site

The drinking water treatment plant DW1 provides drinking water to the local community through a conventional direct filtration treatment plant using a surface water source (Figure 2.1). Raw water enters the treatment facility, where chlorine, chlorine dioxide, aluminum sulfate, and cationic polymer are added. Co-application of chlorine and chlorine dioxide is practiced, in which chlorine targets virus inactivation and chlorine dioxide targets Giardia inactivation. Aluminum sulfate (3-8 mg/L) and cationic polymer (Polydyne 308P, 2-5 mg/L) were added immediately after the chlorine and chlorine dioxide addition at the inline flash mixer. The water was then evenly split into 12 dual-stage flocculation basins and was conveyed through a filter influent channel, where it was delivered to deep-bed filters. The filtration process consisted of 15 dual-media filters: 1.67 m of anthracite with an effective size of 1.25 mm over 0.30 m of sand with an effective size of 0.60 mm. Subsequently, the filter effluent passed over a weir where chlorine and ammonia (chloramination) were added. The targeted chloramine residual concentration was 1.75–2.00 mg/L and the chlorine dioxide residual concentration was less than 0.10 mg/L. Source water for DW1 originated from snowmelt run-off and contains no known inputs of municipal wastewater. Table 2.2 lists the average raw and finished water quality data for this plant for data collected in 2006.

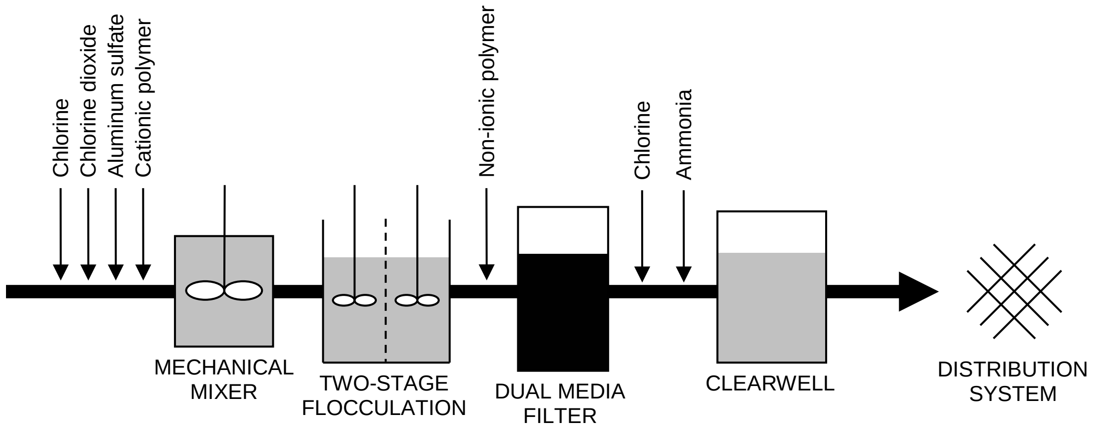


**Figure 2.1. Schematic of treatment processes employed at DW1.**

## Table 2.2. Historic Water Quality Data for DW1 (2006)

| | | Raw | | | | | Finished | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 67 | 14 | 12 | 44 | 94 | 68 | 14 | 12 | 50 | 99 |
| Aluminum (Al) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | 0.2 | na | 1 | 0.2 | 0.2 | 0.6 | 0.1 | 12 | 0.5 | 0.8 |
| Antimony (Sb) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Arsenic (As) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Barium (Ba) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Boron (B) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Calcium (Ca) | mg/L | 35 | 3 | 12 | 28 | 39 | 34 | 4 | 12 | 27 | 41 |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chloride (Cl) | mg/L | 15 | 4 | 11 | 8 | 22 | 18 | 3 | 11 | 13 | 24 |
| Chromium (Cr) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Color | PCU | — | — | — | — | — | — | — | — | — | — |
| Conductivity | µS/cm | 296 | 32 | 12 | 255 | 376 | 318 | 36 | 12 | 282 | 408 |
| Copper (Cu) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Fluoride (F) | mg/L | 0.85 | 0.15 | 11 | 0.58 | 1.00 | 0.85 | 0.14 | 11 | 0.59 | 1.00 |
| Hardness (Total) | mg/L | 117 | 7 | 12 | 108 | 130 | 115 | 8 | 12 | 104 | 136 |
| Iron (Fe) | mg/L | 58 | 25 | 12 | 24 | 98 | na | na | na | na | na |
| Langlier index | | — | — | — | — | — | — | — | — | — | — |
| Magnesium (Mg) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Manganese (Mn) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Mercury (Hg) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Nickel (Ni) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Nitrite ($NO_2^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | — | — | — | — | — | — | — | — | — | — |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — | — | — | — | — | — |
| pH | | — | — | — | — | — | — | — | — | — | — |
| Phosphate ($PO_4^{-3}$) | mg/L | 2.6 | 1.3 | 12 | 0.9 | 4.8 | na | na | na | na | na |
| Potassium (K) | mg/L | 2.4 | 0.1 | 4 | 2.3 | 2.6 | 2.3 | 0.1 | 4 | 2.2 | 2.4 |
| Selenium (Se) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Sodium (Na) | mg/L | 15 | 2 | 3 | 13 | 17 | 16 | 2 | 3 | 13 | 17 |
| Sulfate ($SO_4^{-2}$) | mg/L | 47 | 11 | 11 | 32 | 65 | 49 | 11 | 11 | 34 | 67 |
| Total dissolved solids (TDS) | mg/L | 202 | 34 | 12 | 170 | 286 | 212 | 24 | 12 | 188 | 272 |
| Total organic carbon (TOC) | mg/L | 2.21 | 0.55 | 12 | 1.58 | 3.54 | 1.80 | 0.34 | 12 | 1.38 | 2.66 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | na | na | na | na | na | 19.1 | 3.3 | 12 | 15.0 | 25.2 |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | na | na | na | na | na | 18.9 | 3.5 | 12 | 14.2 | 25.8 |
| Total trihalomethanes (THM)[a] | µg/L | na | na | na | na | na | 14.2 | 2.6 | 12 | 11.1 | 19.4 |
| Total trihalomethanes (THM)[b] | µg/L | na | na | na | na | na | 12.4 | 2.7 | 12 | 7.0 | 16.6 |
| UV 254 | $cm^{-1}$ | 0.054 | 0.009 | 12 | 0.042 | 0.073 | 0.038 | 0.004 | 11 | 0.032 | 0.045 |
| Vanadium (V) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — | — | — | — | — | — |

[a] Distribution system average, [b] Entry point

*Notes*: na=not applicable, — not measured.

### 2.2.2 DW2 (Very-Low-Impact Groundwater/Riverbank Filtration Treated Water)

The drinking water treatment plant DW2 treats groundwater under direct influence (GWUDI) from surface water (Figure 2.2). Wastewater-impacted surface water undergoes riverbank filtration (RBF) and raw water is extracted from an adjacent horizontal collector well. Infiltration of river water through the subsurface resulted in a change of redox conditions from oxic in the river water to anoxic in the RBF-treated water. As a consequence, manganese and arsenic were dissolved from the subsurface and concentrations are elevated in the reduced groundwater. Observed manganese concentrations of 0.38 mg/L are typical for RBF-treated water. The average arsenic concentration of 16 μg/L in the raw water is geologically derived and common for the soil type in this geographic region of the country. The drinking water treatment plant was designed to microbiologically and chemically remove manganese and arsenic from water. The treatment process consisted of an aeration tower and a mixing basin for blending with backwash water and coagulant chemicals. In addition, ferric chloride was added to the mixing basin to react with arsenic. A biologically active granular media filter removed microorganisms and manganese and arsenic precipitates from the water. Periodic backwashing was conducted and the backwash returned to the mixing basin. The water was subsequently directed through UV units and conveyed to chlorine contact basins prior to being pumped into the distribution system. The source water (surface water) for DW2 contains approximately 1 to 3% municipal wastewater, based on flow estimates. Table 2.3 lists the average raw and finished water quality data for this plant for data collected in 2006.

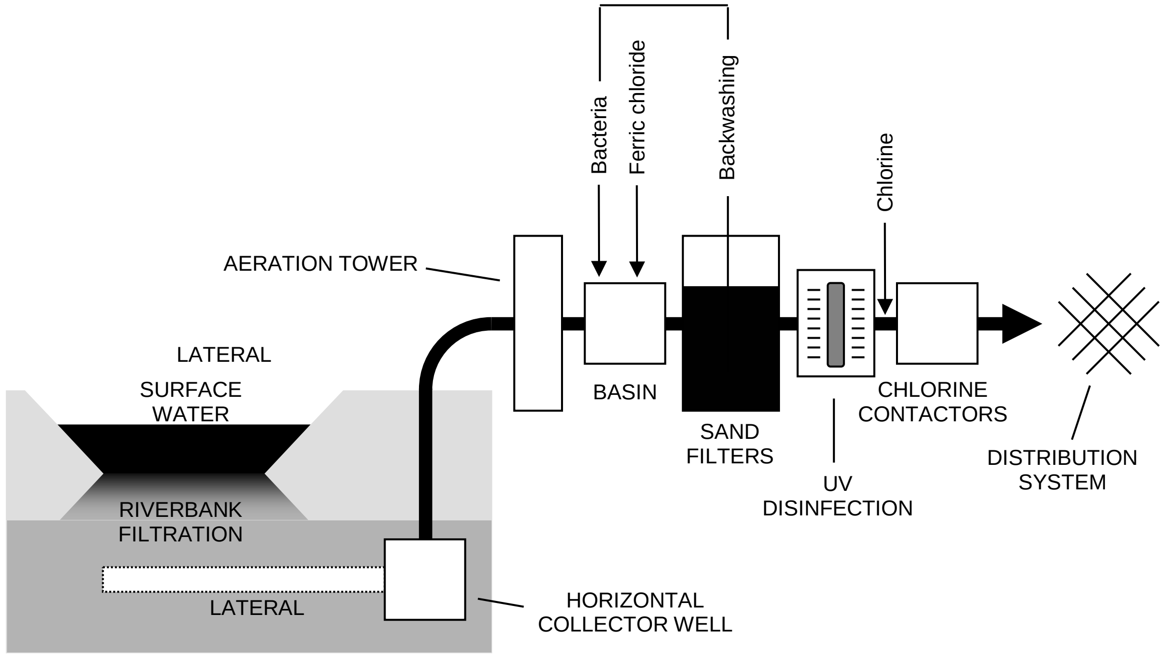


**Figure 2.2. Schematic of treatment processes employed at DW2.**

## Table 2.3. Historic Water Quality Data for DW2 (2006)

| | | Raw | | | | | Finished | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Units | Average | Standard Deviation | Number Above DL | Minimum | Maximum | Average | Standard Deviation | Number Above DL | Minimum | Maximum |
| Alkalinity | mg/L | 175 | 2 | 12 | 171 | 178 | 168 | 2 | 11 | 165 | 171 |
| Aluminum (Al) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | 0.34 | 0.06 | 12 | 0.25 | 0.45 | 0.11 | 0.01 | 12 | 0.10 | 0.12 |
| Antimony (Sb) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Arsenic (As) | ug/L | 0.016 | 0.002 | 23 | 0.014 | 0.022 | 0.005 | 0.001 | 21 | 0.003 | 0.008 |
| Barium (Ba) | mg/L | | | | | | 0.035 | na | 1 | 0.035 | 0.035 |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Boron (B) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Calcium (Ca) | mg/L | 133 | 2 | 12 | 131 | 136 | 133 | 2 | 12 | 130 | 136 |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chloride (Cl) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chromium (Cr) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Color | PCU | — | — | — | — | — | — | — | — | — | — |
| Conductivity | µS/cm | | | | | | 1200 | na | 1 | 1200 | 1200 |
| Copper (Cu) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | 8.2 | 0.4 | 12 | 7.7 | 8.8 | | | | | |
| Fluoride (F) | mg/L | | | | | | 0.63 | na | 1 | 0.63 | 0.63 |
| Hardness (Total) | mg/L | 333 | 6 | 12 | 319 | 340 | 332 | 6 | 12 | 317 | 340 |
| Iron (Fe) | mg/L | | | | | | 0.11 | 0.06 | 5 | 0.06 | 0.19 |
| Langlier index | | | | | | | 0.48 | na | 1 | 0.48 | 0.48 |
| Magnesium (Mg) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Manganese (Mn) | ug/L | 0.382 | 0.050 | 23 | 0.320 | 0.489 | <0.01 | na | 0 | na | na |
| Mercury (Hg) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Nickel (Ni) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Nitrite ($NO_2^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | — | — | — | — | — | — | — | — | — | — |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — | — | — | — | — | — |
| pH | | 8.02 | 0.05 | 12 | 7.95 | 8.08 | 7.79 | 0.03 | 12 | 7.75 | 7.83 |
| Phosphate ($PO_4^{-3}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Potassium (K) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Selenium (Se) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Sodium (Na) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 796 | 30 | 12 | 710 | 827 | 898 | 293 | 12 | 790 | 1827 |
| Total organic carbon (TOC) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — | 15 | 9 | 5 | 7 | 30 |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — | 72 | 17 | 5 | 54 | 94 |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — | 31 | 6 | 2 | 27 | 35 |
| UV 254 | $cm^{-1}$ | — | — | — | — | — | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — | — | — | — | — | — |

[a]Distribution system, [b]Water treatment plant

*Notes*: na=not applicable, — not measured.

### 2.2.3 DW3 (Moderate-Impact Surface Water)

The drinking water treatment plant DW3 treats water from a reservoir fed by a constructed wetland system. Feeding the constructed wetland is a 24 MGD wastewater treatment plant employing fine screening, grit removal, primary clarification, a modified Ludzack–Ettinger (MLE) sludge process including biological phosphorus and nitrogen removal, denitrification, secondary clarifiers, and disinfection with sodium hypochlorite. An average of 9.3 MGD of effluent is routed through a constructed wetland system with a hydraulic retention time of 5 days. Discharge from the wetlands is collected in a 1.14 billion gallon reservoir, which also receives natural input from a 10 square mile watershed. Thus, the drinking water treatment plant source water is highly influenced by wastewater discharge.

The drinking water treatment process consisted of chlorine dioxide preoxidation (at a dose of 0.5 mg/L), coagulation (using a 25 ppm alum dose), flocculation, upflow solids contact clarification, dual media filtration, UV disinfection (low-pressure, medium-intensity lamps at a dose of 25 mJ/cm$^2$), postchemical additions of chlorine (dose of 3.5 mg/L; 2.2 mg/L residual), lime, phosphoric acid, and fluoride (dose of 0.8 mg/L) (Figure 2.3). Finished water was provided to the distribution system, where it was blended with water from two other drinking water treatment plants. For the purposes of this study, source water is defined as water collected from the reservoir prior to drinking water treatment, and finished water is defined as water collected after drinking water treatment, but prior to blending with other water in the distribution system. The exact contribution of wastewater to the source water of DW3 is not known, though based on flow estimates it likely contains on the order of 30% wastewater, depending on the natural surface water flow that combines with the discharge from the constructed wetland. Table 2.4 lists the average raw and finished water quality data for this plant for data collected in 2006.

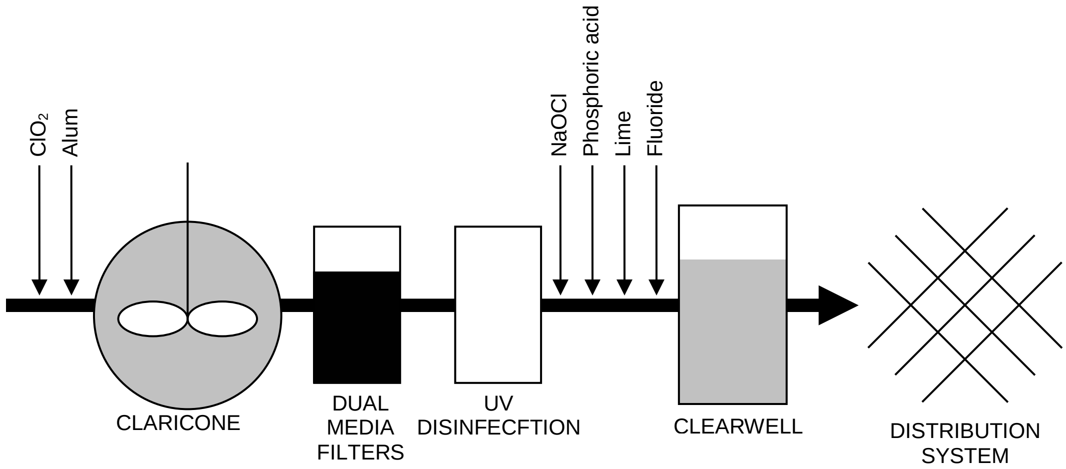


**Figure 2.3. Schematic of treatment processes employed at DW3.**

## Table 2.4. Historic Water Quality Data for DW3 (2006)

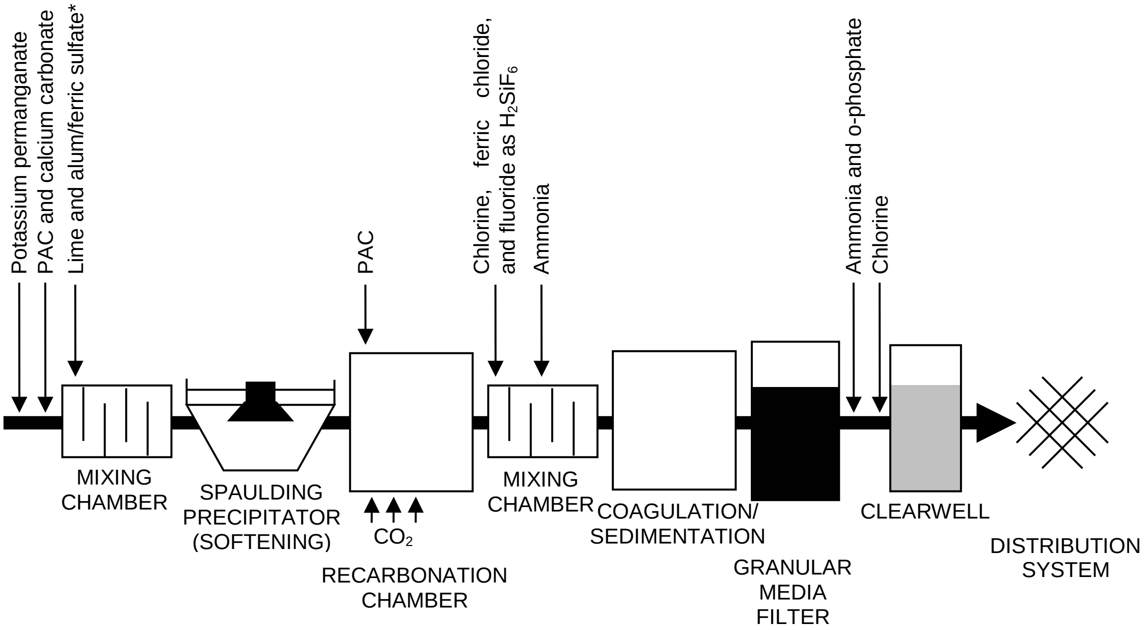
| | | Raw | | | | | Finished | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Units | Average | Standard Deviation | Number Above DL | Minimum | Maximum | Average | Standard Deviation | Number Above DL | Minimum | Maximum |
| Alkalinity | mg/L | 34 | 7 | 12 | 20 | 42 | 24 | 1 | 12 | 22 | 25 |
| Aluminum (Al) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | 0.13 | 0.15 | 12 | 0.00 | 0.40 | | | | | |
| Antimony (Sb) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Arsenic (As) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Barium (Ba) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Boron (B) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Calcium (Ca) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chloride (Cl) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chromium (Cr) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Color | PCU | — | — | — | — | — | — | — | — | — | — |
| Conductivity | µS/cm | 303 | 28 | 12 | 262 | 353 | | | | | |
| Copper (Cu) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Hardness (Total) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Iron (Fe) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Langlier index | | — | — | — | — | — | — | — | — | — | — |
| Magnesium (Mg) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Manganese (Mn) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Mercury (Hg) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Nickel (Ni) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | 2.0 | 3.8 | 12 | 0.2 | 13.8 | 0.4 | na | 1 | 0.4 | 0.4 |
| Nitrite ($NO_2^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | — | — | — | — | — | — | — | — | — | — |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — | — | — | — | — | — |
| pH | | — | — | — | — | — | — | — | — | — | — |
| Phosphate ($PO_4^{-3}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Potassium (K) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Selenium (Se) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Sodium (Na) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Total organic carbon (TOC) | mg/L | 4.0 | 1.0 | 12 | 1.3 | 5.0 | 2.2 | 0.3 | 12 | 1.8 | 2.7 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — | 29.6 | 4.4 | 3 | 24.6 | 33.1 |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — | 27.3 | 11.8 | 3 | 15.2 | 38.7 |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — | — | — | — | — | — |

[a] Distribution system, [b] Water treatment plant

*Notes*: na=not applicable, — not measured.

### 2.2.4 DW4 (Low-Impact Surface Water)

The drinking water treatment plant DW4 is processing surface water, which is known to be partially impacted by upstream wastewater discharges (Figure 2.4). At this facility, raw water entered the softening plant, where powdered activated carbon, calcium carbonate, lime, and alum were added (in 2008 the facility transitioned from alum to ferric sulfate). Potassium permanganate was also added during taste and odor episodes. Calcium carbonate (~2 ppm) was added in winter to control sludge freezing within softening cones. Lime (~140 ppm) and alum (20 ppm) or ferric sulfate (~15 ppm) were added within the mixing chambers. Powdered activated carbon was added throughout the year at the head of the recarbonation chambers (6–12 ppm). Water was then pumped to the filter plant, where gaseous chlorine (4 ppm dose), ferric chloride (~5 ppm), fluoride (1 ppm), and ammonia were added in mixing chambers. Water was then conveyed through the sedimentation basins and processed through granular media filters. Subsequently, ammonia, ortho-polyphosphate (0.4 ppm), and chlorine (to achieve 4 ppm dose total chlorine) were added to the filter effluent. In 2008, the facility also moved its point of fluoride addition from the mixing chambers to postfiltration. Based on flow estimates, the source water for DW4 contained approximately 5% wastewater. Table 2.5 lists the average raw and finished water quality data for this plant for data collected in 2006.



*between the first and second sampling regimes, alum was replaced with ferric sulfate

**Figure 2.4. Schematic of treatment processes employed at DW4.**

## Table 2.5. Historic Water Quality Data for DW4 (2006)

| | | Raw | | | | | Finished | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 170 | 22 | 12 | 131 | 199 | 39 | 4 | 12 | 31 | 45 |
| Aluminum (Al) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | 0.31 | 0.21 | 12 | 0.16 | 0.95 | 1.01 | 0.14 | 12 | 0.84 | 1.35 |
| Antimony (Sb) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Arsenic (As) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Barium (Ba) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Boron (B) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Calcium (Ca) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chloride (Cl) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Chromium (Cr) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Color | PCU | 35 | 14 | 12 | 19 | 66 | 4 | 2 | 12 | 1 | 8 |
| Conductivity | µS/cm | 218 | 17 | 12 | 189 | 244 | 378 | 44 | 12 | 299 | 442 |
| Copper (Cu) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Hardness (Total) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Iron (Fe) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Langlier index | | — | — | — | — | — | — | — | — | — | — |
| Magnesium (Mg) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Manganese (Mn) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Mercury (Hg) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Nickel (Ni) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | 0.17 | 0.10 | 12 | 0.01 | 0.28 | 0.17 | 0.10 | 12 | 0.01 | 0.27 |
| Nitrite ($NO_2^-$) | mg/L | 0.005 | 0.002 | 12 | 0.002 | 0.010 | 0.002 | 0.002 | 12 | 0.000 | 0.005 |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | — | — | — | — | — | — | — | — | — | — |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — | — | — | — | — | — |
| pH | | — | — | — | — | — | — | — | — | — | — |
| Phosphate ($PO_4^{-3}$) | mg/L | 0.05 | 0.02 | 12 | 0.02 | 0.08 | 0.50 | 0.10 | 9 | 0.31 | 0.72 |
| Potassium (K) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Selenium (Se) | ug/L | — | — | — | — | — | — | — | — | — | — |
| Sodium (Na) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 310 | 40 | 12 | 264 | 394 | 164 | 11 | 12 | 152 | 191 |
| Total organic carbon (TOC) | mg/L | 7.2 | 1.7 | 9 | 5.7 | 10.9 | 4.1 | 0.7 | 9 | 3.5 | 5.8 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — | 15.5 | 9.0 | 4 | 5.0 | 25.6 |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — | | | | | |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — | 15.5 | 9.0 | 4 | 5.0 | 25.6 |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — | 20.5 | 12.9 | 4 | 7.3 | 36.0 |
| UV 254 | cm$^{-1}$ | — | — | — | — | — | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — | — | — | — | — | — |

[s]Average of four locations, [b]Distribution system maximum

*Notes:* na=not applicable, — not measured.

### 2.2.5 DW5 (Very-Low-Impact Surface Water)

Drinking water facility DW5 is treating surface water with a low (3%) wastewater contribution based on flow contributions (Figure 2.5). The drinking water treatment processes comprised sequential chlorine, followed by ammonia addition (for bromate control), ozone disinfection (2-log *Cryptosporidium* inactivation), coagulation, flocculation, filtration, and secondary disinfection with free chlorine. Table 2.6 summarizes the average raw and finished water quality data for this plant for data collected in 2006.

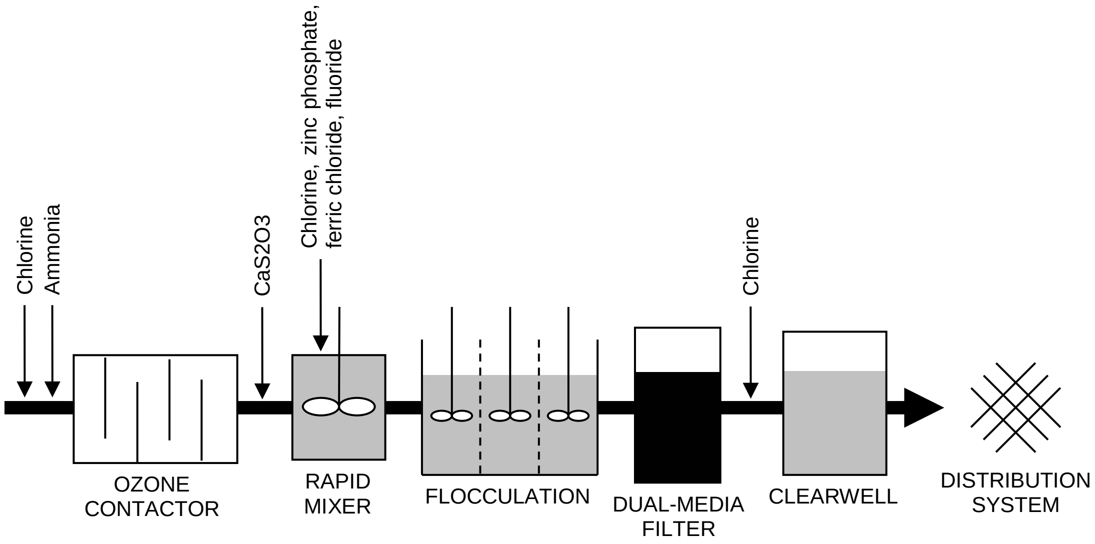


**Figure 2.5. Schematic of treatment processes employed at DW5.**

## Table 2.6. Historic Water Quality Data for DW5 (2006)

| | | **Raw** | | | | | **Finished** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 137 | 3 | 12 | 131 | 139 | 136 | 3 | 12 | 131 | 140 |
| Aluminum (Al) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Ammonia ($NH_3$) | mg/L | 0.033 | 0.006 | 3 | 0.026 | 0.038 | 0.032 | 0.009 | 4 | 0.022 | 0.042 |
| Antimony (Sb) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Arsenic (As) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Barium (Ba) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Bicarbonate ($HCO_3^-$) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Boron (B) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Calcium (Ca) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Carbonate ($CO_3^{2-}$) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Chemical Oxygen Demand (COD) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Chloride (Cl) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Chromium (Cr) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Color | PCU | 6.3 | 2.5 | 4 | 5.0 | 10.0 | 3.8 | 2.5 | 4 | 2.5 | 7.5 |
| Conductivity | µS/cm | 1054 | 18 | 4 | 1035 | 1074 | 1079 | 17 | 4 | 1058 | 1099 |
| Copper (Cu) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Dissolved Oxygen (DO) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Fluoride (F) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Hardness (Total) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Iron (Fe) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Langlier Index | | - | - | - | - | - | - | - | - | - | - |
| Magnesium (Mg) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Manganese (Mn) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Mercury (Hg) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Nickel (Ni) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Nitrate ($NO_3^-$) | mg/L | 0.56 | 0.09 | 4 | 0.47 | 0.69 | 0.57 | 0.07 | 4 | 0.50 | 0.66 |
| Nitrite ($NO_2^-$) | mg/L | - | - | - | - | - | - | - | - | - | - |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | - | - | - | - | - | - | - | - | - | - |
| Organic Nitrogen (Org-N) | mg/L | - | - | - | - | - | - | - | - | - | - |
| pH | | - | - | - | - | - | - | - | - | - | - |
| Phosphate ($PO_4^{-3}$) | mg/L | 0.003 | 0.000 | 11 | 0.002 | 0.003 | 0.062 | 0.004 | 12 | 0.056 | 0.070 |
| Potassium (K) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Selenium (Se) | ug/L | - | - | - | - | - | - | - | - | - | - |
| Sodium (Na) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Sulfate ($SO_4^{-2}$) | mg/L | - | - | - | - | - | - | - | - | - | - |
| Total Dissolved Solids (TDS) | mg/L | 665 | 12 | 12 | 648 | 689 | 675 | 12 | 12 | 660 | 702 |
| Total Organic Carbon (TOC) | mg/L | 2.6 | 0.1 | 12 | 2.3 | 2.7 | 2.4 | 0.1 | 12 | 2.1 | 2.5 |
| Total Reg. Haloacetic Acids (HAA5) | µg/L | - | - | - | - | - | 8.2 | 1.9 | 3 | 6.2 | 10.0 |
| Total Trihalomethanes (THM) | µg/L | - | - | - | - | - | 13.8 | 1.7 | 4 | 12.0 | 16.0 |
| UV 254 | µg/L | - | - | - | - | - | - | - | - | - | - |
| Vanadium (V) | µg/L | - | - | - | - | - | - | - | - | - | - |
| Zinc (Zn) | cm$^{-1}$ | - | - | - | - | - | - | - | - | - | - |

*Notes*: na=not applicable, - not measured

### 2.2.6 IPR1 (Groundwater Recharge via Soil Aquifer Treatment)

The indirect potable reuse facility IPR1 employs a surface spreading operation followed by soil aquifer treatment (SAT) using a tertiary treated wastewater (Figure 2.6). The water reclamation facility feeding the IPR system consisted of primary clarification (ferric chloride addition prior to inlet), activated sludge treatment with nitrification and denitrification, secondary clarification, alum addition for coagulation, prefilter disinfection (chloramination), tertiary dual-media filtration (anthracite, sand), and postfilter disinfection (chloramination). Sulfur dioxide was used to dechlorinate prior to discharge. The reclaimed water used for surface spreading represented one source of recharge, besides imported surface and/or storm water, which were applied to the surface spreading basins independently. The spreading facility was equipped with groundwater monitoring wells representing different retention times in the subsurface (weeks to months). The drinking water supply in the service area was a blend of surface and groundwater where roughly 20–30% of the drinking water was supplied by the local groundwater. There are 17 potable wells located near the spreading basins and most have travel times greater than 6 months, based on a tracer test. The source water for IPR1 contained 100% wastewater, which was blended after surface spreading with native groundwater and other recharge water sources (stormwater and imported surface water). Two monitoring wells were sampled at this site. One well represented rather short travel times of 1.5 months (IPR1A) and was characterized by reclaimed water quality after surface spreading and short-term SAT. An additional well represented water quality after travel times of 21 months that was also blended with native groundwater and recharged water from sources other than reclaimed water (IPR1B). Tables 2.7–2.9 list the average water quality data for the raw water, the observation well (IPR1A), and the finished water (IPR1B) from 2006.

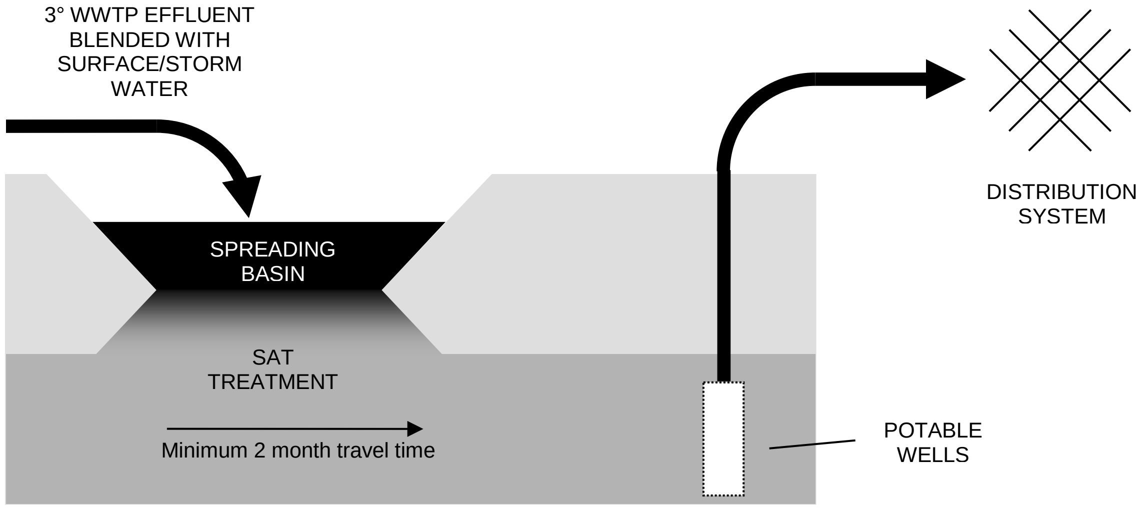


**Figure 2.6. Schematic of the surface spreading operation at IPR1.**

## Table 2.7. Historic Water Quality Data for IPR1 (2006)

| | | Raw | | | | |
|---|---|---|---|---|---|---|
| | Units | Average | Standard Deviation | Number above DL | Minimum | Maximum |
| Alkalinity | mg/L | 131 | 18 | 3 | 111 | 144 |
| Aluminum (Al) | ug/L | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | 0.41 | 0.41 | 3 | 0.13 | 0.88 |
| Antimony (Sb) | ug/L | — | — | — | — | — |
| Arsenic (As) | ug/L | — | — | — | — | — |
| Barium (Ba) | mg/L | — | — | — | — | — |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — |
| Boron (B) | mg/L | 160 | 26 | 3 | 130 | 180 |
| Calcium (Ca) | mg/L | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | 3.5 | na | 1 | 3.5 | 3.5 |
| Chemical oxygen demand (COD) | mg/L | 16 | 5 | 3 | 10 | 20 |
| Chloride (Cl) | mg/L | — | — | — | — | — |
| Chromium (Cr) | ug/L | — | — | — | — | — |
| Color | PCU | 22 | 3 | 3 | 20 | 25 |
| Conductivity | µS/cm | 925 | 128 | 3 | 777 | 1000 |
| Copper (Cu) | ug/L | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — |
| Hardness (Total) | mg/L | 217 | 15 | 3 | 200 | 230 |
| Iron (Fe) | mg/L | — | — | — | — | — |
| Langlier index | | — | — | — | — | — |
| Magnesium (Mg) | mg/L | — | — | — | — | — |
| Manganese (Mn) | ug/L | — | — | — | — | — |
| Mercury (Hg) | ug/L | — | — | — | — | — |
| Nickel (Ni) | ug/L | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | — | — | — | — | — |
| Nitrite ($NO_2^-$) | mg/L | — | — | — | — | — |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | — | — | — | — | — |
| Organic nitrogen (Org-N) | mg/L | 0.91 | 0.30 | 3 | 0.60 | 1.20 |
| pH | | 8.23 | 0.23 | 3 | 8.10 | 8.50 |
| Phosphate ($PO_4^{-3}$) | mg/L | — | — | — | — | — |
| Potassium (K) | mg/L | — | — | — | — | — |
| Selenium (Se) | ug/L | — | — | — | — | — |
| Sodium (Na) | mg/L | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 542 | 81 | 3 | 448 | 590 |
| Total organic carbon (TOC) | mg/L | 5.5 | 1.4 | 3 | 4.1 | 6.9 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — |

[a] Distribution system average; [b] Entry point

*Notes*: na=not applicable (samples were measured in either raw or finished water but not the other); — parameter was not measured in either water.

## Table 2.8. Historic Water Quality Data for IPR1-A (2006)

| | | IPR1-A (Observation Well) | | | | |
|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 118 | 13 | 5 | 104 | 133 |
| Aluminum (Al) | ug/L | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | — | — | — | — | — |
| Antimony (Sb) | ug/L | — | — | — | — | — |
| Arsenic (As) | ug/L | 6.6 | 1.2 | 5 | 5 | 7.9 |
| Barium (Ba) | mg/L | 0.12 | 0.02 | 5 | 0.078 | 0.14 |
| Bicarbonate ($HCO_3^-$) | mg/L | 143 | 14 | 5 | 127 | 160 |
| Boron (B) | mg/L | 0.23 | 0.05 | 5 | 0.16 | 0.29 |
| Calcium (Ca) | mg/L | 53 | 7 | 5 | 41 | 59 |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | 9.1 | na | 1 | 9.1 | 9.1 |
| Chloride (Cl) | mg/L | 103 | 19 | 5 | 74 | 120 |
| Chromium (Cr) | ug/L | 2.0 | 1.1 | 3 | 1.2 | 3.2 |
| Color | PCU | — | — | — | — | — |
| Conductivity | µS/cm | 838 | 120 | 5 | 636 | 923 |
| Copper (Cu) | ug/L | 2.9 | 0.7 | 5 | 2.1 | 3.8 |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — |
| Fluoride (F) | mg/L | 0.45 | 0.08 | 5 | 0.35 | 0.53 |
| Hardness (Total) | mg/L | 198 | 26 | 5 | 156 | 226 |
| Iron (Fe) | mg/L | — | — | — | — | — |
| Langlier index | | — | — | — | — | — |
| Magnesium (Mg) | mg/L | 16 | 2 | 5 | 13 | 19 |
| Manganese (Mn) | ug/L | — | — | — | — | — |
| Mercury (Hg) | ug/L | — | — | — | — | — |
| Nickel (Ni) | ug/L | 7.2 | na | 1 | 7.2 | 7.2 |
| Nitrate ($NO_3^-$) | mg/L | 1.8 | 0.7 | 5 | 1.3 | 3 |
| Nitrite ($NO_2^-$) | mg/L | — | — | — | — | — |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | 2 | na | 1 | 2 | 2 |
| Organic nitrogen (Org-N) | mg/L | 0.43 | 0.22 | 4 | 0.26 | 0.74 |
| pH | | 7.7 | 0.2 | 5 | 7.41 | 8 |
| Phosphate ($PO_4^{-3}$) | mg/L | — | — | — | — | — |
| Potassium (K) | mg/L | 8.5 | 1.6 | 5 | 6.1 | 9.8 |
| Selenium (Se) | ug/L | 220 | 28 | 5 | 184 | 260 |
| Sodium (Na) | mg/L | 11 | 2 | 5 | 10 | 14 |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 93 | 19 | 5 | 69 | 110 |
| Total organic carbon (TOC) | mg/L | 127 | 20 | 5 | 94 | 150 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | 510 | 62 | 5 | 400 | 546 |
| Total trihalomethanes (THM)[a] | µg/L | 1.5 | 0.3 | 5 | 1.2 | 1.8 |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — |

[a] Distribution system average; [b] Entry point

*Notes:* na=not applicable (samples were measured in either raw or finished water but not the other);—- parameter was not measured in either water.

## Table 2.9. Historic Water Quality Data for IPR1-B (2006)

| | | IPR1-B (Finished) | | | | |
|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 118 | 5 | 6 | 110 | 126 |
| Aluminum (Al) | ug/L | — | — | — | — | — |
| Ammonia ($NH_3$) | mg/L | — | — | — | — | — |
| Antimony (Sb) | ug/L | — | — | — | — | — |
| Arsenic (As) | ug/L | — | — | — | — | — |
| Barium (Ba) | mg/L | — | — | — | — | — |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — |
| Boron (B) | mg/L | 143 | 6 | 6 | 134 | 150 |
| Calcium (Ca) | mg/L | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | 5 | na | 1 | 5 | 5 |
| Chloride (Cl) | mg/L | — | — | — | — | — |
| Chromium (Cr) | ug/L | — | — | — | — | — |
| Color | PCU | 5 | 3 | 6 | 3 | 10 |
| Conductivity | µS/cm | 866 | 129 | 6 | 637 | 990 |
| Copper (Cu) | ug/L | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — |
| Hardness (Total) | mg/L | 207 | 28 | 6 | 160 | 230 |
| Iron (Fe) | mg/L | — | — | — | — | — |
| Langlier index | | — | — | — | — | — |
| Magnesium (Mg) | mg/L | — | — | — | — | — |
| Manganese (Mn) | ug/L | — | — | — | — | — |
| Mercury (Hg) | ug/L | — | — | — | — | — |
| Nickel (Ni) | ug/L | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | — | — | — | — | — |
| Nitrite ($NO_2^-$) | mg/L | — | — | — | — | — |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | — | — | — | — | — |
| Organic nitrogen (Org-N) | mg/L | 0.41 | 0.20 | 5 | 0.22 | 0.69 |
| pH | | 7.65 | 0.22 | 6 | 7.40 | 8.00 |
| Phosphate ($PO_4^{-3}$) | mg/L | — | — | — | — | — |
| Potassium (K) | mg/L | — | — | — | — | — |
| Selenium (Se) | ug/L | — | — | — | — | — |
| Sodium (Na) | mg/L | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 515 | 69 | 6 | 404 | 600 |
| Total organic carbon (TOC) | mg/L | 1.5 | 0.2 | 6 | 1.2 | 1.7 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — |

[a] Distribution system average; [b] Entry point

*Notes*: na=not applicable (samples were measured in either raw or finished water but not the other); — parameter was not measured in either water.

### 2.2.7 IPR2 (Groundwater Recharge via Direct Injection)

The indirect potable reuse site IPR2 practiced direct injection into a potable aquifer using highly treated wastewater. This reclamation facility utilized reclaimed water after primary and secondary treatment. Primary wastewater treatment consisted of coagulant addition and sedimentation. Following primary clarification, the primary effluent flow stream was split and oxidized using two secondary treatment processes, activated sludge and trickling filters. Secondary clarifiers at the activated sludge system and trickling filters produced fully oxidized and clarified secondary effluent. Subsequently, the effluent was treated with microfiltration, reverse osmosis (RO), and UV–peroxide (Figure 2.7). The secondary treated wastewater was first chloraminated prior to microfiltration. The water was then treated by microfiltration using Siemens/Memcor submerged hollow fiber membranes with a nominal pore size of 0.2 μm followed by reverse osmosis (ESPA2, Hydranautics). Upstream of the RO process, the flow was pretreated by adding sulfuric acid for pH adjustment and scaling inhibitor to prevent precipitation of sparingly soluble salts, and by 10-μm cartridge filtration. The system was designed to operate at an 85% recovery rate and a permeate flux of 12 gfd. Permeate from the RO system was subsequently treated by advanced oxidation using a 300–400 mJ/cm$^2$ dose with 3.0 mg/L $H_2O_2$. The advanced oxidation process consisted of two steps. Hydrogen peroxide exposed to UV irradiation produced hydroxyl radicals that resulted in advanced oxidation to destroy organic contaminants that were not rejected by RO. Following UV treatment, part of the water passed through decarbonators to release excess carbon dioxide. Lime was added to the final product water to adjust the pH and reduce the potential for minerals to be leached from the cement lining used in the transmission pipelines. The reclaimed water was blended with potable water before injection (75% recycled water and 25% potable water). The blended water was injected into the underlying aquifer, which is a source of municipal potable water supplies. Nineteen wells are used to monitor the aquifer. The retention time to the closest active potable extraction well is estimated at 24 months. The source water for IPR2 was 100% wastewater. Two sampling locations were selected at this facility. Finished water qualities after the RO/AOP processes (IPR2A) and after injection, blending, and 4 months retention time (IPR2B) were characterized. Tables 2.10–2.12 list the average water quality data for the raw water, the finished water after the RO/AOP processes (IPR2A), and the finished water (IPR1B) from 2008.

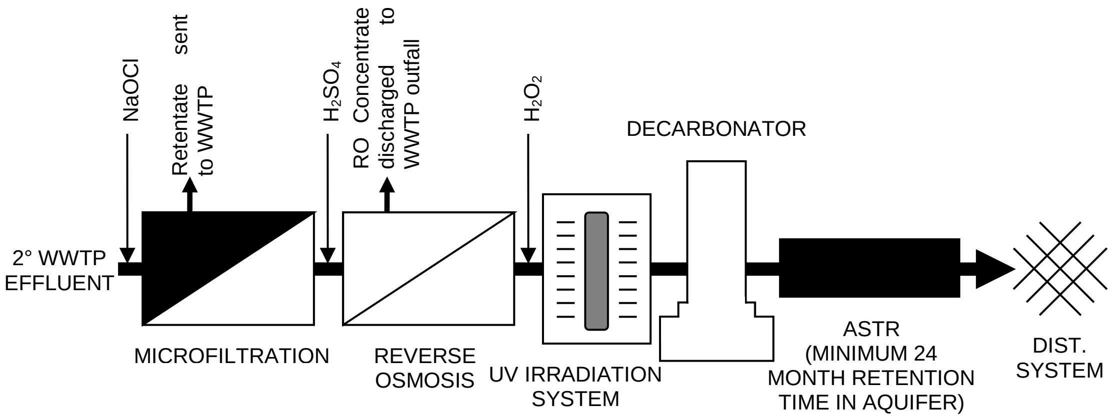


**Figure 2.7. Schematic of treatment processes employed at IPR2.**

## Table 2.10. Historic Water Quality Data for IPR2 (2008)

| | | Raw | | | | |
|---|---|---|---|---|---|---|
| | Units | Average | Standard Deviation | Number Above DL | Minimum | Maximum |
| Alkalinity | mg/L | 306 | 7 | 3 | 298 | 312 |
| Aluminum (Al) | ug/L | 16.2 | 1.7 | 3 | 14.7 | 18.1 |
| Ammonia ($NH_3$) | mg/L | 27.9 | 3.1 | 15 | 19.6 | 30.8 |
| Antimony (Sb) | ug/L | 0.8 | 0.2 | 3 | 0.7 | 1.0 |
| Arsenic (As) | ug/L | 1.2 | 0.1 | 3 | 1.1 | 1.3 |
| Barium (Ba) | mg/L | 21.9 | 1.3 | 3 | 20.8 | 23.3 |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — |
| Boron (B) | mg/L | 0.41 | 0.04 | 3 | 0.36 | 0.44 |
| Calcium (Ca) | mg/L | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — |
| Chloride (Cl) | mg/L | — | — | — | — | — |
| Chromium (Cr) | ug/L | 1.6 | na | 1 | 1.6 | 1.6 |
| Color | PCU | 42 | 3 | 3 | 40 | 45 |
| Conductivity | µS/cm | 1683 | 142 | 32 | 1430 | 1870 |
| Copper (Cu) | ug/L | 8.4 | 1.7 | 3 | 6.5 | 9.6 |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — |
| Hardness (Total) | mg/L | — | — | — | — | — |
| Iron (Fe) | mg/L | 189 | 13 | 3 | 179 | 204 |
| Langlier index | | — | — | — | — | — |
| Magnesium (Mg) | mg/L | 22.3 | 1.1 | 3 | 21.0 | 23.0 |
| Manganese (Mn) | ug/L | 43.8 | 2.5 | 3 | 42.3 | 46.7 |
| Mercury (Hg) | ug/L | 0.4 | 0.1 | 3 | 0.3 | 0.4 |
| Nickel (Ni) | ug/L | 9.7 | 0.9 | 3 | 8.9 | 10.7 |
| Nitrate ($NO_3^-$) | mg/L | <0.4 | — | — | — | — |
| Nitrite ($NO_2^-$) | mg/L | 0.5 | 0.2 | 2 | 0.3 | 0.6 |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | 26 | 16 | 19 | 7 | 62 |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — |
| pH | | — | — | — | — | — |
| Phosphate ($PO_4^{-3}$) | mg/L | 0.75 | 0.19 | 11 | 0.39 | 0.98 |
| Potassium (K) | mg/L | — | — | — | — | — |
| Selenium (Se) | ug/L | 2.8 | 0.2 | 3 | 2.6 | 3.0 |
| Sodium (Na) | mg/L | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 937 | 40 | 10 | 854 | 970 |
| Total organic carbon (TOC) | mg/L | 13.7 | 1.4 | 108 | 9.6 | 16.6 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — |
| Vanadium (V) | mg/L | 1.9 | 0.4 | 3 | 1.4 | 2.2 |
| Zinc (Zn) | mg/L | 29.8 | 7.1 | 3 | 21.6 | 34.4 |

[a] Distribution system average; [b] Entry point

*Notes*: na=not applicable (samples were measured in either raw or finished water but not the other); — parameter was not measured in either water.

## Table 2.11. Historic Water Quality Data for IPR2-A (2008)

| | | IPR2-A | | | | |
|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 32 | 4 | 5 | 28 | 38 |
| Aluminum (Al) | ug/L | 7.7 | 1.2 | 2 | 6.8 | 8.5 |
| Ammonia ($NH_3$) | mg/L | 1.2 | 0.3 | 5 | 0.8 | 1.6 |
| Antimony (Sb) | ug/L | — | — | — | — | — |
| Arsenic (As) | ug/L | — | — | — | — | — |
| Barium (Ba) | mg/L | — | — | — | — | — |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — |
| Boron (B) | mg/L | 0.3 | 0.0 | 4 | 0.24 | 0.28 |
| Calcium (Ca) | mg/L | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — |
| Chloride (Cl) | mg/L | — | — | — | — | — |
| Chromium (Cr) | ug/L | — | — | — | — | — |
| Color | PCU | — | — | — | — | — |
| Conductivity | µS/cm | 77.5 | 10.0 | 5 | 66.9 | 95.3 |
| Copper (Cu) | ug/L | — | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — |
| Hardness (Total) | mg/L | 20 | 7 | 2 | 16 | 28 |
| Iron (Fe) | mg/L | 13 | 17 | 3 | 1.9 | 33.1 |
| Langlier index | | — | — | — | — | — |
| Magnesium (Mg) | mg/L | — | — | — | — | — |
| Manganese (Mn) | ug/L | — | — | — | — | — |
| Mercury (Hg) | ug/L | — | — | — | — | — |
| Nickel (Ni) | ug/L | — | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | 0.5 | 0.3 | 5 | 0.22 | 0.9 |
| Nitrite ($NO_2^-$) | mg/L | 0.2 | 0.1 | 5 | 0.03 | 0.35 |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | 3.9 | na | 1 | 3.9 | 3.9 |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — |
| pH | | 7.9 | 0.7 | 2 | 7.4 | 8.7 |
| Phosphate ($PO_4^{-3}$) | mg/L | — | — | — | — | — |
| Potassium (K) | mg/L | — | — | — | — | — |
| Selenium (Se) | ug/L | — | — | — | — | — |
| Sodium (Na) | mg/L | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 35 | 11 | 5 | 20 | 53 |
| Total organic carbon (TOC) | mg/L | 0.2 | 0.1 | 5 | 0.12 | 0.27 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — |
| Vanadium (V) | mg/L | — | — | — | — | — |
| Zinc (Zn) | mg/L | — | — | — | — | — |

[a] Distribution system average; [b] Entry point

*Notes*: na=not applicable (samples were measured in either raw or finished water but not the other); — parameter was not measured in either water.

## Table 2.12. Historic Water Quality Data for IPR2-B (2008)

| | | IPR2-B (finished) | | | | |
|---|---|---|---|---|---|---|
| | **Units** | **Average** | **Standard Deviation** | **Number Above DL** | **Minimum** | **Maximum** |
| Alkalinity | mg/L | 50 | 9 | 2 | 44 | 56 |
| Aluminum (Al) | ug/L | 2.1 | 0.2 | 2 | 1.9 | 2.2 |
| Ammonia ($NH_3$) | mg/L | — | — | — | — | — |
| Antimony (Sb) | ug/L | <0.5 | — | — | — | — |
| Arsenic (As) | ug/L | 1.1 | na | 1 | 1.1 | 1.1 |
| Barium (Ba) | mg/L | 120.3 | 61.8 | 2 | 76.6 | 164.0 |
| Bicarbonate ($HCO_3^-$) | mg/L | — | — | — | — | — |
| Boron (B) | mg/L | 0.20 | 0.00 | 2 | 0.20 | 0.20 |
| Calcium (Ca) | mg/L | — | — | — | — | — |
| Carbonate ($CO_3^{2-}$) | mg/L | — | — | — | — | — |
| Chemical oxygen demand (COD) | mg/L | — | — | — | — | — |
| Chloride (Cl) | mg/L | — | — | — | — | — |
| Chromium (Cr) | ug/L | <1 | — | — | — | — |
| Color | PCU | <3 | — | — | — | — |
| Conductivity | µS/cm | 209 | 69 | 2 | 160 | 258 |
| Copper (Cu) | ug/L | <1 | — | — | — | — |
| Dissolved oxygen (DO) | mg/L | — | — | — | — | — |
| Fluoride (F) | mg/L | — | — | — | — | — |
| Hardness (Total) | mg/L | — | — | — | — | — |
| Iron (Fe) | mg/L | 4 | na | 1 | 4 | 4 |
| Langlier Index | | — | — | — | — | — |
| Magnesium (Mg) | mg/L | 1.3 | 0.4 | 2 | 1.0 | 1.5 |
| Manganese (Mn) | ug/L | 1.8 | 0.6 | 2 | 1.3 | 2.2 |
| Mercury (Hg) | ug/L | <0.1 | — | — | — | — |
| Nickel (Ni) | ug/L | <1 | — | — | — | — |
| Nitrate ($NO_3^-$) | mg/L | 6.55 | 0.64 | 2 | 6.10 | 7.00 |
| Nitrite ($NO_2^-$) | mg/L | 0.8 | 0.5 | 2 | 0.4 | 1.1 |
| *N*-Nitrosodimethylamine (NDMA) | ng/L | 2 | 0 | 2 | 2 | 3 |
| Organic nitrogen (Org-N) | mg/L | — | — | — | — | — |
| pH | | — | — | — | — | — |
| Phosphate ($PO_4^{-3}$) | mg/L | 0.02 | na | 1 | 0.02 | 0.02 |
| Potassium (K) | mg/L | — | — | — | — | — |
| Selenium (Se) | ug/L | 1.1 | na | 1 | 1.1 | 1.1 |
| Sodium (Na) | mg/L | — | — | — | — | — |
| Sulfate ($SO_4^{-2}$) | mg/L | — | — | — | — | — |
| Total dissolved solids (TDS) | mg/L | 140 | 17 | 2 | 128 | 152 |
| Total organic carbon (TOC) | mg/L | 0.3 | 0.0 | 2 | 0.3 | 0.4 |
| Total reg. haloacetic acids (HAA5)[a] | µg/L | — | — | — | — | — |
| Total reg. haloacetic acids (HAA5)[b] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[a] | µg/L | — | — | — | — | — |
| Total trihalomethanes (THM)[b] | µg/L | — | — | — | — | — |
| UV 254 | $cm^{-1}$ | — | — | — | — | — |
| Vanadium (V) | mg/L | 2.2 | 0.3 | 2 | 2.0 | 2.4 |
| Zinc (Zn) | mg/L | 2.5 | na | 1 | 2.5 | 2.5 |

[a] Distribution system average; [b] Entry point

*Notes*: na=not applicable (samples were measured in either raw or finished water but not the other); — parameter was not measured in either water

# *Chapter 3*

# Analytical Methods

## 3.1 Introduction

An analytical roadmap was developed for the project, in which the project team assembled a set of methodologies that allowed a comprehensive assessment of the water quality at each site. This approach provided the foundation for a material balance accounting for, and quantifying, as many of the organic and inorganic constituents of the water as possible. The team had access to numerous state-of-the-art instruments and analytical methods for the analysis of organic and inorganic contaminants in water.

The suite of analyses for general water quality parameters, inorganic contaminants, organic contaminants, and natural organic matter characterization included established methods and state-of-the-art approaches. The final analytical roadmap utilized for this project is presented in Table 3.1. Most analyses were applied to all water samples collected throughout this study (including field and laboratory blanks). The analytical approach is subdivided into inorganic and organic compounds targeting parameters representative of water quality or composition. The analysis of the inorganic components included measurements of total dissolved solids, nutrients, dissolved cations and metals, anions, perchlorate/chlorate, alkalinity, and total nitrogen.

Disinfection byproducts (DBPs) were also measured in each source and finished water from this project. The DBPs targeted in this study include some formed following chlorine disinfection: total organic halogen (TOX), trihalomethanes (THMs), and haloacetic acids (HAAs). (*Note:* TOX includes all halogenated organics formed during disinfection, including THMs and HAAs.) TOX data were subsequently speciated to obtain concentrations of the subcomponents, including TOCl, TOBr, and TOI, providing a more complete understanding of the distribution of halogenated compounds. In addition, benchtop TOX and nitrosamine formation potential tests were conducted for each site using water collected prior to secondary disinfection to assess the total amount of DBP precursors. Trace organic compounds (TOrC) were analyzed using three methods: pharmaceuticals and endocrine-disrupting compounds (EDCs); steroidal hormones; and perfluoroctanoic acid (PFOA)/perfluorooctanesulfonic acid (PFOS). It should be noted that the isotope dilution methods used for pharmaceuticals/EDCs and steroid hormones have proven to be very robust, allowing comparison of a variety of types of waters. The waters targeted in this work varied from relatively “clean” water with little NOM or wastewater influence to wastewater effluents. Utilization of this method provided an advantage over other methods that are more susceptible to artifacts of complex water matrices, such as signal suppression.

General organic carbon analyses included determination of total and dissolved organic carbon concentrations, as well as UV absorbance. Additional characterization of the organic fraction was subdivided into three important components: size, polarity, and composition. Size characterization was performed using size-exclusion chromatography coupled with UV and TOC detectors, allowing a multidimensional analysis of the organic fraction (Her et al., 2002a, 2002b; Rosario-Ortiz et al., 2007a). This multidimensional analysis allows the detection and identification of all components of the organic fraction, including humic and fulvic substances, polysaccharides, and low-molecular-weight acids and proteins, allowing a complete mass balance of the organic fraction.

The bulk polarity of the natural organic matter (NOM) was also determined. It has been established that organic matter from different origins (terrestrially derived versus microbially derived, including the microbially derived fraction from wastewater treatment) possesses different polarity signatures, allowing differentiation based on the overall polarity (Shon et al., 2006). A relatively new technique, the PRAM, was used for analysis of the polarity of NOM (Rosario-Ortiz et al., 2007a, 2007b).

For the study of the chemical composition of the organic matter, the team employed 1-dimensional and 3-dimensional fluorescence spectroscopy. Fluorescence has proven to be an extremely powerful technique for characterizing and identifying organic matter from different origins (Gerrity et al., 2010; Lee et al., 2006). For example, fluorescence distinguishes between organic matter from terrestrial and microbial origins, which is extremely useful in the characterization of the amount of organic matter stemming from soluble microbial products (SMPs) associated with activated sludge processes.

**Table 3.1. Analytical Roadmap for Chemical Characterization of Each of the Water Samples Targeted in this Project**

| Constituent/Parameter | Method |
|---|---|
| *Inorganic analyses conducted on all samples from each participating utility* | |
| Total dissolved solids (TDS) | SM 2210C |
| Nutrients ($NH_3$, $NO_2^-$, $NO_3^-$, $PO_4^{3-}$) | SM 4110 B |
| Dissolved cations and metals (Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Si, Sn, Sr, Ti, U, V, Zn) | SM 3125 B |
| Anions ($Cl^-$, $F^-$, $Br^-$, $NO_3^-$, $SO_4^{2-}$) | SM 4110B |
| Perchlorate/chlorate | (Snyder et al., 2005) |
| Alkalinity | SM 2320B |
| Total nitrogen (TN) | ASTM D 5176-91 |
| *Organic contaminant analyses conducted on all samples from each participating utility* | |
| Trihalomethanes (THMs; including bromodichloromethane, bromoform, chlorodibromomethane, chloroform, and total trihalomethanes | EPA Method 551.1 |
| Haloacetic acids (HAAs; including bromoacetic acid, chloroacetic acid, dibromoacetic acid, dichloroacetic acid, trichloroacetic acid, and total regulated haloacetic acids ) | EPA Method SM 6251 B |
| Pharmaceuticals and potential endocrine-disrupting compounds | (Vanderford and Snyder, 2006) |
| Steroid hormones | (Trenholm et al., 2006) |
| Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) | (Quiñones and Snyder, 2009) |
| *Organic carbon characterization conducted on all samples from each participating utility* | |
| Dissolved organic carbon (DOC) | SM 5310C |
| Total organic carbon (TOC) | SM 5310C |
| UV absorption ($UV_{254}$, $UV_{272}$, and $UV_{436}$) | SM 5910B |
| Total organic halogen (TOX; including TOF, TOCl, TOBr, and TOI) | Modified from SM 9020B |
| 3-D fluorescence excitation–emission matrix (EEM) | |
| Polarity rapid assessment method | (Rosario-Ortiz et al., 2007b) |
| Size-exclusion chromatography with UV, fluorescence, and TOC detection | |
| *Other analyses conducted on all samples from each participating utility* | |
| Color | SM 2120C |
| Conductivity | SM 2510B |
| pH | - |
| *Analyses conducted on one sample from each participating utility* | |
| Nitrosamines | EPA 1625M |

## 3.2. General Water Quality

Bulk water quality parameters, including conductivity, TOC, DOC, $UV_{254}$ (filtered), $UV_{272}$ (filtered), $UV_{436}$ (filtered), pH, alkalinity, ammonia, nitrate, and phosphate were measured using SM 5310C, 4110B, and SM 5910B (Standard Methods). The raw data for these parameters are presented in Appendix B.

### 3.2.1 Dissolved Cations and Metals

Dissolved cations and metals, including silver (Ag), aluminum (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), antimony (Sb), selenium (Se), silicon (Si), tin (Sn), strontium (Sr), titanium (Ti), uranium (U), vanadium (V), and zinc (Zn), were analyzed by ICP-MS following SM 3125B. The results of these measurements are presented in Appendix B.

### 3.2.2 Anions

Dissolved anions, including fluoride ($F^-$), chloride ($Cl^-$), bromide ($Br^-$), nitrate ($NO_3^-$), phosphate ($PO_4^{3-}$), and sulfate ($SO_4^{2-}$), were analyzed by ion chromatography following SM 4110B. The results of these measurements are presented in Appendix B.

### 3.2.3 Trihalomethanes and Haloacetic Acids

Trihalomethanes and haloacetic acids were analyzed by GC-MS following EPA Methods 524.2 and 552.2, respectively. These data are presented in Appendix B.

### 3.2.4 Nitrosamines

Nitrosamines, including *N*-nitrosodimethylamine, *N*-nitrosomethylethylamine, *N*-nitrosodiethylamine, *N*-nitrosodi-*N*-propylamine, *N*-nitrosomorpholine, *N*-nitrosopyrrolidine, *N*-nitrosopiperidine, and *N*-nitrosodi-*N*-butylamine, were analyzed following EPA method 1625M (Table 3.2). These data are presented in Appendix B.

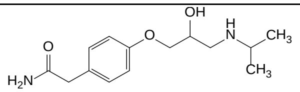
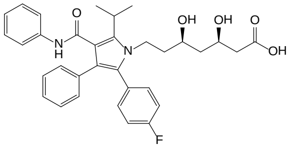
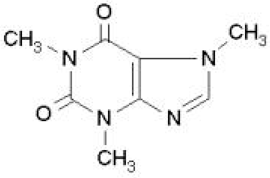
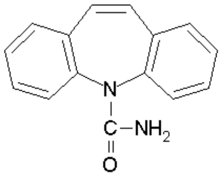
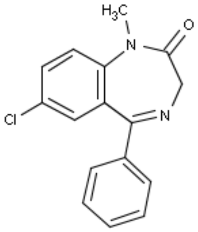
**Table 3.2. Nitrosamines Targeted in this Study**

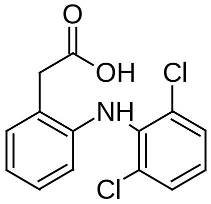
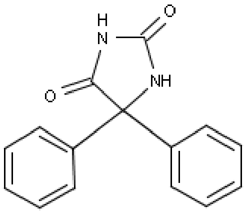
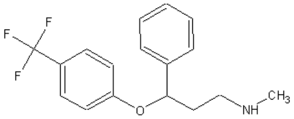
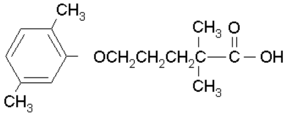
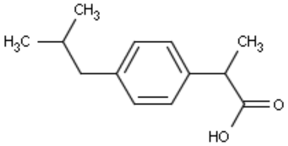
| **Compound** | **CAS #** |
|---|---|
| *N*-Nitrosodimethylamine | 62-75-9 |
| *N*-Nitrosomethylethylamine | 10595-95-6 |
| *N*-Nitrosodiethylamine | 55-18-5 |
| *N*-Nitrosodi-*N*-propylamine | 621-64-7 |
| *N*-Nitrosomorpholine | 59-89-2 |
| *N*-Nitrosopyrrolidine | 930-55-2 |
| *N*-Nitrosopiperidine | 100-75-4 |
| *N*-Nitrosodi-*N*-butylamine | 924-16-3 |

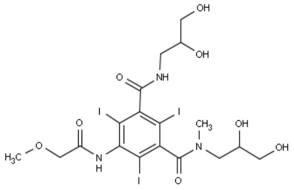
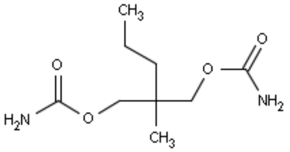
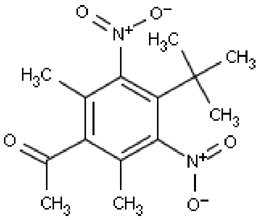
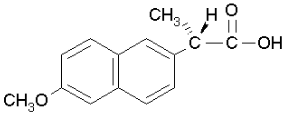
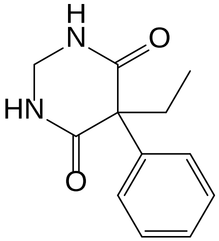
## 3.3 Trace Organic Compounds

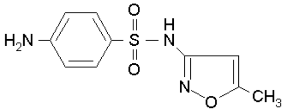
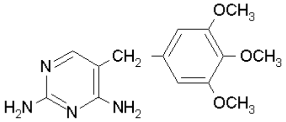
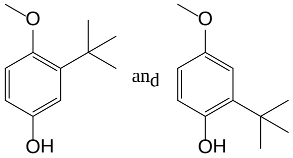
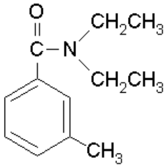
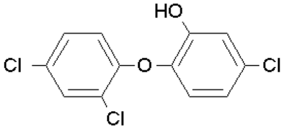
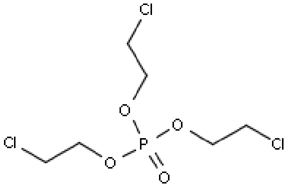
The TOrCs targeted in this study, their structures, CAS numbers, and physiochemical properties, and their uses are listed in Table 3.3. These TOrCs were selected because (1) they are largely wastewater-derived, (2) they exhibit relatively high occurrence in wastewater streams, and (3) their persistence through treatment and in the environment varies greatly, making some TOrCs good wastewater indicators. Analysis of TOrCs was accomplished using solid-phase extraction (SPE) and liquid chromatography tandem mass spectrometry (LC-MS/MS) following published methods (Quiñones and Snyder, 2009; Trenholm et al., 2006; Vanderford and Snyder, 2006). Briefly, 500 mL of sample was spiked with isotopically labeled standards and then extracted by AutoTrace automated SPE (Caliper Life Sciences, Hopkinton, MA) using Oasis SPE cartridges (Waters Corporation, Milford, MA). Cartridges were eluted with organic solvents and extracts were concentrated under nitrogen gas to 500 µL. LC-MS/MS analyses were accomplished using electrospray ionization (ESI) in both negative and positive modes. All analytes were monitored using multiple reaction monitoring with two transitions for each compound, one for quantitation and the other for confirmation. Method detection limits (MDLs) were determined by extracting 12 deionized water samples fortified with the analytes at levels near their expected detection limits and the isotopically labeled surrogate standards (10 ng/L). The standard deviation of the 12 measurements for each analyte was multiplied by the appropriate Student *T* value for *n*-1 degrees of freedom. The method reporting limit (MRL) was set above the MDL and was not greater than the lowest point on the analytical calibration curve. The data from these measurements are presented in Appendix B.

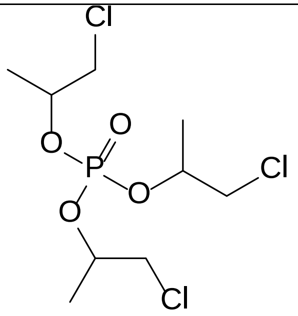
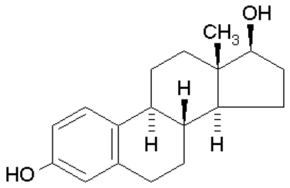
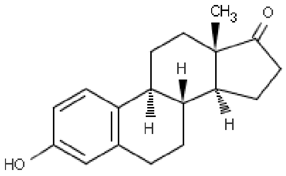
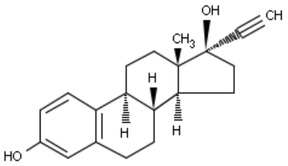
**Table 3.3. Trace Organic Compounds (TOrCs) Targeted in this Study**

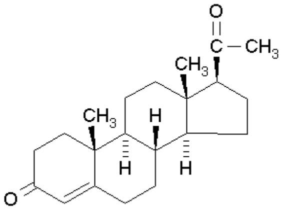
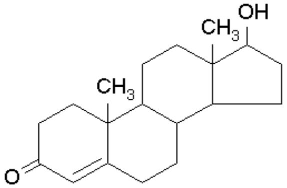
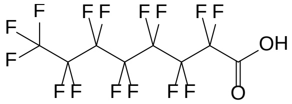
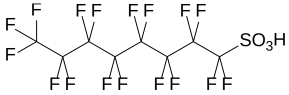
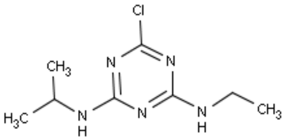
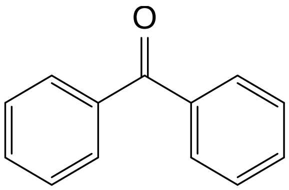
| Compound | CAS# | Structure | MW | p$K_a$ | Log $K_{ow}$ | Use | Range of Detected Conc. (ng/L)$^{e, f}$ |
|---|---|---|---|---|---|---|---|
| Atenolol | 29122-68-7 |  | 266.3 | 9.6 | 0.16 | Beta-blocker | SW: 3.44—241<br>DW: <0.25—18 |
| Atorvastatin | 134523-03-8 |  | 558.6 | 4.46$^a$ | 1.59$^b$ | Antilipidemic | DW: <0.25 |
| Caffeine | 58-08-2 |  | 194.2 | 10.4 | -0.07 | Stimulant | SW: <0.5—6,000<br>GW: <40, <5,000 |
| Carbamazepine | 298-46-4 |  | 236.3 | 13.4$^c$ | 2.45 | Anti-convulsant | SW: <8.7—7,100<br>GW: <32—900<br>DW: <0.5—18 |
| Diazepam | 439-14-5 |  | 284.8 | 3.4 | 2.82 | Anti-anxiety | SW: <10—33<br>DW: <1—19<br><0.25—0.33 |

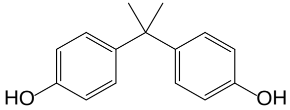
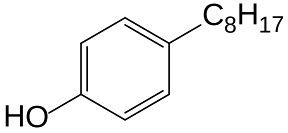
| Compound | CAS# | Structure | MW | p$K_a$ | Log $K_{ow}$ | Use | Range of Detected Conc. (ng/L)[e, f] |
|---|---|---|---|---|---|---|---|
| Diclofenac | 15307-86-5 |  | 296.2 | 4.15 | 4.51 | Nonsteroidal anti-inflammatory | SW: <1—1200<br>GW: <8.7—590<br>DW: <0.25 |
| Dilantin (Phenytoin) | 57-41-0 |  | 252.3 | 8.33 | 2.47 | Anticonvulsant | DW: <1—19 |
| Fluoxetine | 54910-89-3 |  | 309.3 | 10.1[d] | 1.22,[d] 4.05 | Antidepressant | SW: <0.50—3.0<br>DW: <0.50—0.82 |
| Gemfibrozil | 25812-30-0 |  | 250.4 | 4.42[e] | 4.77 | Antilipidemic | SW: <2—1,550<br>GW: <10<br>DW: 0.25—2.1 |
| Ibuprofen | 15687-27-1 |  | 206.3 | 4.91 | 3.97 | Nonsteroidal anti-inflammatory | SW: <0.2—5,850<br>GW: <10—200 |

| Compound | CAS# | Structure | MW | p$K_a$ | Log $K_{ow}$ | Use | Range of Detected Conc. (ng/L)$^{e, f}$ |
|---|---|---|---|---|---|---|---|
| Iopromide | 73334-07-3 |  | 791.1 | na | -2.05 | X-Ray contrast agent | SW: <20—1,600<br>GW: <50 |
| Meprobamate | 57-53-4 |  | 218.2 | na | 0.7 | Anti-anxiety | SW: 0.25—73<br>DW: 0.25—42 |
| Musk Ketone | 81-14-1 |  | 294.1 | na | 4.30 | Fragrance | DW: nd |
| Naproxen | 22204-53-1 |  | 230.1 | 4.15 | 3.18 | Nonsteroidal anti-inflammatory | SW: <1—2,000<br>GW: <10<br>DW: <0.5 |
| Primidone | 125-33-7 |  | 218.3 | na | 0.91 | Anticonvulsant | SW: nd—635 |

| Compound | CAS# | Structure | MW | p$K_a$ | Log $K_{ow}$ | Use | Range of Detected Conc. (ng/L)$^{e, f}$ |
|---|---|---|---|---|---|---|---|
| Sulfamethoxazole | 723-46-6 |  | 253.3 | 5.5 | 0.89 | Antibiotic | SW: <0.9—1,900<br>GW: <6.2—470<br>DW: <0.25—0.32 |
| Trimethoprim | 738-70-5 |  | 290.3 | 7.12 | 0.91 | Antibiotic | SW: <10—710<br>GW: <20<br>DW: <0.25 |
| Butylated hydroxyanisole (BHA) | 25013-16-5 |  | 360.5 | u | 3.5 | Food preservative | SW: <0.5—3,520<br>DW: nd |
| *N*,*N*-Diethyl-*meta*-toluamide (DEET) | 134-62-3 |  | 191.3 | na | 2.18 | Insect repellant | SW: <20—640<br>DW: <25—93 |
| Triclosan | 3380-34-5 |  | 289.6 | 7.9 | 4.76 | Antibacterial/ antimicrobial | SW: <0.5—2,300<br>DW: <1—1.2 |
| TCEP | 115-96-8 |  | 285.5 | na | 1.44 | Flame retardant | SW: <1—1,236<br>GW: <1—754<br>DW: <50—470 |

| **Compound** | **CAS#** | **Structure** | **MW** | **p$K_a$** | **Log $K_{ow}$** | **Use** | **Range of Detected Conc. (ng/L)$^{e, f}$** |
|---|---|---|---|---|---|---|---|
| TCPP | 13674-84-5 |  | 327.6 | na | 2.59 | Flame retardant | SW: <100—880<br>GW: <40, <5,000<br>DW: <50—510 |
| 17β-Estradiol | 50-28-2 |  | 272.2 | $10.4^{f}$ | 4.01 | Endogenous steroid hormone | SW: <0.02—93<br>DW: <0.5 |
| Estrone | 53-16-7 |  | 270.4 | $10.4^{f}$ | 3.13 | Endogenous steroid hormone | SW: <0.1—112<br>DW: <0.2 |
| 17α-Ethynylestradiol | 57-63-6 |  | 296.4 | $10.4^{f}$ | 3.67 | Synthetic steroid hormone | SW: <0.1—831<br>DW: <1 |

| **Compound** | **CAS#** | **Structure** | **MW** | **p$K_a$** | **Log $K_{ow}$** | **Use** | **Range of Detected Conc. (ng/L)$^{e, f}$** |
|---|---|---|---|---|---|---|---|
| Progesterone | 57-83-0 |  | 314.5 | na | 3.87 | Endogenous steroid hormone | SW: < 0.5—3.1<br>DW: <0.5—0.57 |
| Testosterone | 58-22-0 |  | 288.4 | na | 3.32 | Endogenous steroid hormone | SW: <5—214<br>DW: <0.5 |
| PFOA | 335-67-1 |  | 414.1 | 2.8 | 6.3 | Perfluorinated compound | No data |
| PFOS | 1763-23-1 |  | 500.1 | u | -2.64 | Perfluorinated compound | No data |
| Atrazine | 1912-24-9 |  | 215.7 | 1.7 | 2.61 | Herbicide | SW: <0.25—870<br>DW: <0.25—870 |
| Benzophenone | 119-61-9 |  | 182.2 | na | 3.18 | UV stabilizer | DW: nd |

| **Compound** | **CAS#** | **Structure** | **MW** | **p$K_a$** | **Log $K_{ow}$** | **Use** | **Range of Detected Conc. (ng/L)[e, f]** |
|---|---|---|---|---|---|---|---|
| Bisphenol A | 80-05-7 |  | 228.36 | 10.1 | 3.32 | Plasticizer | SW: <5—14<br>DW: <5—25 |
| Octylphenol | 27193-28-8 |  | 206.3 | u | 5.50 | Surfactant degradate | DW: nd |

[a](Wu, 2000 #600); [b](Kubota, 2004 #601); [c](Queiroza, 2008 #602); [d](Kwon, 2008 #409); [e]surface water (SW) and groundwater (GW) concentrations from (Snyder, 2008 #487) and (Benotti et al., 2009 #306); [f]drinking water (DW) concentrations from (Benotti et al., 2009 #306); nd = not detected.

### 3.3.1 Pharmaceuticals

*Atenolol.* Atenolol is a prescription pharmaceutical and belongs to the beta blocker class of drugs used primarily to treat cardiovascular disease.

*Atorvastatin.* Atorvastatin is a prescription pharmaceutical belonging to the drug class known as statins. It is primarily used for lowering cholesterol levels, but also stabilizes plaque and prevents strokes through a variety of mechanisms.

*Caffeine.* Caffeine is a naturally occurring alkaloid found in varying concentrations in the leaves, beans, and stems of certain plants. It is most commonly consumed via ingestion of coffee or tea, but is also included in some over-the-counter pain medications.

*Carbamazepine.* Carbamazepine is a prescription mood-stabilizing pharmaceutical used primarily to treat epilepsy, bipolar disorder, and trigeminal neuralgia.

*Diazepam.* Diazepam is a benzodiazepine derivative prescription pharmaceutical, first marketed as Valium, used for treating anxiety, insomnia, seizures, muscle spasms, and other conditions.

*Diclofenac.* Diclofenac is a nonsteroidal anti-inflammatory (NSAID) used as an analgesic for treatment of pain and to reduce inflammation.

*Dilantin (Phenytoin).* Dilantin (or phenytoin) is a prescription antiepileptic pharmaceutical.

*Fluoxetine.* Fluoxetine is a prescription antidepressant belonging to the selective serotonin reuptake inhibitor (SSRI) class of pharmaceuticals. It is primarily used to treat depression, obsessive-compulsive disorder, bulimia and anorexia nervosa, and other conditions.

*Gemfibrozil.* Gemfibrozil is a prescription pharmaceutical used to lower lipid levels and belonging to the group of drugs known as fibrates.

*Ibuprofen.* Ibuprofen is an NSAID used as an analgesic for treatment of pain and to reduce inflammation.

*Iopromide.* Iopromide is an X-ray contrast agent used primarily in the radiological diagnosis of soft-tissue conditions.

*Meprobamate.* Meprobamate is a prescription carbamate derivative pharmaceutical used to treat anxiety.

*Naproxen.* Naproxen is an NSAID used as an analgesic for treatment of pain and to reduce inflammation.

*Primidone.* Primidone is a prescription anticonvulsant belonging to the pyrimidinedione class of drugs. It is primarily used to treat seizures.

*Sulfamethoxazole.* Sulfamethoxazole is a prescription bacteriostatic antibiotic, most commonly administered with trimethoprim to treat infection. It belongs to the sulfonamide class of antibiotics. It is most commonly used to treat urinary tract infections, but is also used as an alternative to amoxicillin-type antibiotics.

*Trimethoprim.* Trimethoprim is a prescription bacteriostatic antibiotic belonging to the dihydrofolate reductase inhibitor class of chemotherapeutic agents.

### 3.3.2 Human Health/Personal Care Products

*Butylated Hydroxyanisole.* Butylated hydroxyanisole (BHA) is an antioxidant consisting of a mixture of two isomeric compounds, 2-*tert*-butyl-4-hydroxyanisole and 3-*tert*-butyl-4-hydroxyanisole, and is used as a food additive.

*Musk Ketone.* Musk ketone is a synthetic musk fragrance used in soaps, detergents, and cosmetics.

*N,N-Diethyl-meta-toluamide. N,N*-Diethyl-*meta*-toluamide (DEET) is the active ingredient in many insect repellants. It is applied to the skin or clothing and protects against mosquito and tick bites.

*Triclosan.* Triclosan is a wide-spectrum antibacterial and antifungal agent. It is the active ingredient in many antimicrobial soaps, sprays, and other cleaning agents. It is also an active ingredient in many toothpastes.

### 3.3.3 Flame Retardants

*Tris(2-chloroethyl)phosphate.* Tris(2-chloroethyl)phosphate (TCEP) is a phosphate-based flame retardant.

*Tris(1-chloro-2-propyl)phosphate.*. Tris(1-chloro-2-propyl)phosphate (TCPP) is a phosphate-based flame retardant.

### 3.3.4 Steroid Hormones

*17β-Estradiol.* 17β-estradiol is the major naturally occurring estrogen in humans. It is a steroid hormone primarily present in females, though it does occur in males at lower levels.

*Estrone.* Estrone is a naturally occurring steroid hormone present in humans at much lower levels than estradiol.

*17α-Ethynylestradiol.* 17α-Ethynylestradiol is a synthetic human estrogen. It is an active ingredient in birth-control medication.

*Progesterone.* Progesterone is a naturally occurring steroid hormone involved in the female menstrual cycle, pregnancy, and embryogenesis of humans and other species.

*Testosterone.* Testosterone is an androgenic naturally occurring steroid hormone. It is the principal male sex hormone and an anabolic steroid.

### 3.3.5 Perfluorochemicals

*Perfluorooctanoic acid.* Perfluorooctanoic acid (PFOA) is a synthetic perfluorinated carboxylic acid used in the production of fluorosurfactants. In addition to industrial production, PFOA can be formed by the degradation of precursors.

*Perfluorooctanesulfonic acid.* Perfluorooctanesulfonic acid (PFOS) is a synthetic fluorosurfactant. In addition to industrial production, PFOS can be formed by the degradation of precursors.

### 3.3.6 Other Compounds

*Atrazine.* Atrazine is an herbicide used in agriculture. It is banned in the European Union, but still commonly used in the United States. It is a suspected endocrine-disrupting compound, and is regulated by the Safe Drinking Water Act at a level of 3 µg/L in drinking water.

*Benzophenone.* Benzophenone is an organic chemical that is commonly used in chemical engineering for large-scale chemical production.

*Bisphenol A.* Bisphenol A is an organic chemical used in chemical engineering for large-scale chemical production. It is also used as a plasticizer in plastics manufacture.

*Octylphenol.* Octylphenol is a degradation product of octylphenol polyethoxylates, compounds that are used as surfactants and in industry.

## 3.4 Oxyhalides

The oxyhalides perchlorate and chlorate were analyzed by LC-MS/MS without extraction/concentration following a published method (Snyder et al., 2005). Results are presented in Appendix B.

## 3.5 Total Organic Halogen

Total organic halogen (TOX) was analyzed using carbon adsorption and microboulometric-titration detection following SM 9020B on a TOX analyzer (TOX-100, Mitsubishi, Japan). TOX samples were subsequently speciated for TOF, TOCl, TOBr, and TOI (Hua and Reckhow, 2005). The results of these measurements are presented in Appendix B.

## 3.6 Polarity Rapid Assessment Method

Polarity characterization of NOM was performed using the polarity rapid assessment method (PRAM). This method is based on the adsorption of specific components of the NOM relative to that of solid-phase sorbents (SPE) of different polarity. The experimental conditions of this method have been detailed previously (Rosario-Ortiz et al., 2007b). In brief, three SPE sorbents (Alltech Associates, Deerfield, IL) were cleaned by flushing with 10 mL of Milli-Q water. The sorbents used were C18, diol, and amino. After cleaning, samples were loaded onto each cartridge at 1.2 mL/min using a syringe pump (KD Scientific, Holliston, MA) and maximum breakthrough was measured by ultraviolet absorbance (UVA) at 254 nm (Lambda 45, Perkin Elmer, Boston, MA). The retention coefficient (*RC*) was defined as one minus the maximum breakthrough level achieved (Equation 3.1) and describes the capacity of each SPE cartridge for specific components of the organic matter:

$$RC = 1 - \frac{C_{\max}}{C_0} \tag{3.1}$$

In this expression, $C_0$ and $C_{\max}$ refer to the initial sample concentration and the maximum breakthrough concentration (between 4 and 8 min) as measured by UVA. The samples were characterized by their relative hydrophobic, hydrophilic neutral, and hydrophilic charged fractions based on the adsorption of NOM onto a C18, diol, and amino sorbent, respectively. Because the analysis is performed at ambient pH, the overall polarity will be dominated by deprotonated groups, giving the hydrophilic charged fraction the most importance.

## 3.7 Size-Exclusion Chromatography Coupled with UV, Fluorescence, and Total Organic Carbon Detection

The characterization of the molecular weight distribution of the NOM was performed using size-exclusion chromatography (SEC). Separation is based on the ability of fragments with different molecular weight distributions to elute from a column with a specific pore size distribution. An Agilent 1100 LC system (Palo Alto, CA) with a Toyopearl HW-50 S 250 × 20 mm column (Grom Chromatography, Rottenburg, Germany) was used. The injection volume into a mobile phase consisting of phosphate buffer (0.028 M) adjusted to pH 6.8 was 1.8 mL at a flow rate of 1.0 mL/min. Following separation, the LC flow was sent to three detectors in series: a UV detector (Agilent 1200 Series Diode Array Detector) monitoring at 254 nm, a fluorescence detector (Agilent 1200 Series fluorescence detector). and a TOC analyzer (800 Series Total Organic Carbon Analyzer, GE Analytical, Boulder, CO). Polyethylene glycol (PEG) was used for calibration.

## 3.8 Fluorescence Excitation–Emission Matrix

The fluorescence excitation–emission matrix (EEM) was recorded using a PTI fluorometer (Birmingham, NJ). Fluorescence EEM parameters were as follows: excitation from 220 to 460 nm in 5-nm steps, emission from 280 to 580 nm in 4-nm steps, 2 nm bandwidth and 0.1 s integration time. The intensity of all EEM spectra was normalized on a daily basis by dividing by the intensity of the Raman water line using 350-nm excitation and 397-nm emission wavelengths. Data processing was done using Matlab (version 7.4.0.287, R2007a, Natick, MA). The fluorescence index was obtained by calculating the ratio of the emission at 450 nm to the emission at 500 nm after excitation at 370 nm.

## 3.9 Disinfection Byproduct Formation Potential Studies

### 3.9.1 Total Organic Halogen Formation Potential

The TOX formation potential (TOX-FP) test was used to determine the maximum TOX formation by chlorination, which can be used as a surrogate to assess the amount of DBP precursors present, and thus compare DBP precursors in waters produced from conventional drinking waters and indirect potable reuse systems. Samples used for TOX-FP tests were collected prior to secondary disinfection. Bench-scale experimental parameters were as follows. Samples were analyzed for TOX before and after incubation with chlorine. TOX-FP tests with chlorine were conducted at pH 7 and 25 °C with a detectable chlorine residual after 7 days (SM 5710B). For the two facilities that have a chlorine residual present before secondary disinfection, the sample was not quenched and the DBP-FP test was performed on an unquenched sample. It was assumed that this procedure would not affect the maximum amount of DBPs formed at the end of the experiment. Chlorine demand tests were initially performed to determine the appropriate initial dose that allowed a detectable residual after 7 days of reaction. Table 3.12 summarizes the initial chlorine doses and the measured chlorine residual after 7 days for TOX-FP tests performed. The final chlorine residuals ranged from 0.2 to 11 mg/L after 7 days; with the exception of three tests the final residuals were between 2 and 7 mg/L.

**Table 3.4. Initial Calculated Chlorine Doses and Measured Chlorine Residual Concentrations After 7 Days**

| | | | TOC (mg/L) | Ammonia (mg-N/L) | Chlorine Dose (mg-$Cl_2$/L) | $Cl_2$:TOC (mg/mg) | Chlorine Residual after 7 Days (mg-$Cl_2$/L) |
|---|---|---|---|---|---|---|---|
| CO | DW1 | #1 | 1.73 | 0.42 | 9.35 | 5.4 | 3.57 |
| | | #2 | 2.27 | 0.56 | 9.34 | 4.1 | 7.10 |
| AZ | DW2 | #1 | 1.83 | 0.03 | 8.12 | 4.4 | 5.40 |
| | | #2 | 1.63 | <0.02 | 8.12 | 5.0 | 4.40 |
| | | #4 | 1.77 | 0.02 | 8.12 | 4.6 | NQ |
| GA | DW3 | #1 | 3.99 | <0.02 | 10.79 | 2.7 | 5.00 |
| | | #2 | 2.80 | <0.02 | 10.79 | 3.9 | 4.40 |
| | | #3 | 3.22 | <0.02 | 9.70 | 3.0 | 4.60 |
| | | #4 | 3.25 | <0.02 | 9.70 | 3.0 | 4.00 |
| MN | DW4 | #1 | 5.38 | 1.13 | 17.18 | 3.2 | 0.20 |
| | | #2 | 6.00 | 0.69 | 20.0 | 3.3 | 2.60 |
| | | #3 | 9.71 | 0.70 | 41.0 | 4.2 | 11.00 |
| | | #4 | 4.75 | 0.55 | 20.0 | 4.2 | 4.50 |
| NV | DW5 | #1 | 2.74 | 0.02 | 9.18 | 3.4 | 5.20 |
| | | #2 | 2.78 | 0.02 | 9.18 | 3.3 | 4.80 |
| | | #3 | 2.73 | 0.02 | 9.18 | 3.4 | 6.00 |
| | | #4 | 2.77 | 0.03 | 9.18 | 3.3 | 4.40 |
| SAT | IPR1B | #1 | 1.45 | <0.02 | 5.03 | 3.5 | 3.50 |
| | | #2 | 1.39 | 0.02 | 5.03 | 3.6 | 2.38 |
| | | #3 | 1.22 | 0.03 | 5.03 | 4.1 | NQ |
| | | #4 | 1.16 | 0.04 | 5.00 | 4.3 | 3.50 |
| RO | IPR2B | #1 | 1.15 | 0.20 | 5.00 | 4.3 | 2.90 |
| | | #3 | 0.45 | 0.47 | 5.10 | 11.3 | 0.65 |
| | | #4 | 1.26 | 0.43 | 7.20 | 5.7 | 2.00 |
| | Blank[a] | | 0.10 | <0.1 | 0.9 | 9.0 | 0.75 ± 0.17[b] |

*Notes:* [a]Chlorination of ultrapure water was performed in parallel for each set of tests.
[b]Mean and standard deviation. NQ = Detectable, but not quantifiable.

### 3.9.2 Nitrosamine Formation Potential

The nitrosamine formation potential test determined the maximum nitrosamine formation by chloramination, which can be used as a surrogate to assess the amount of nitrosamine precursors present, and thus compare nitrosamine precursors in waters produced from conventional drinking waters and indirect potable reuse systems. Samples used for nitrosamine-FP tests were collected prior to secondary disinfection. However, the test was not performed at the DW1 and DW4 sites, as a chlorine residual was present at this collection point because of prior disinfection (i.e., predisinfection). These samples could not have been quenched, as this would have quenched chloramines used during the bench-scale test. Also, not quenching the sample was not an option, as chlorine remaining after collection could react and consumes nitrosamine precursors during storage, which would otherwise react with chloramines during the nitrosamine-FP test. Thus, NDMA-FP tests were not conducted for waters from DW1 or DW4 treatment plants. Samples were analyzed for nitrosamines before and after incubation with chloramines. Chlorine was added based on the level of TOC (i.e., $Cl_2=3 \times$ TOC, weight basis), and a sufficient amount of ammonia was added to be at a $Cl_2$/N weight ratio of 3:1. The ammonia was added first and then the chlorine. The samples were held for 3 days at pH ~8 and 25 °C. Following incubation, the samples were analyzed for nitrosamines following the method outlined in Section 3.3.5. Table 3.13 reports the initial calculated chlorine and ammonia levels and the measured chlorine residual after 3 days. The blank was dosed at a higher $Cl_2$:TOC ratio of 100, which represents an extreme chlorine dosing condition and ensured a chlorine residual after 3 days. All samples exhibited a chlorine residual after 3 days.

**Table 3.5. Initial Calculated Chlorine and Ammonia Levels and the Measured Chlorine Residual After 3 Days**

| | TOC (mg/L) | Initial Chlorine[3] (mg-$Cl_2$/L) | $Cl_2$:TOC (mg/mg) | Initial Ammonia (mg-N/L)[a] | $Cl_2$:N (mg/mg) | Chlorine Residual after 3 Days (mg-$Cl_2$/L) |
|---|---|---|---|---|---|---|
| DW2 | 1.67 | 4.80 | 2.9 | 1.60 | 3.0 | NQ |
| DW3 | 3.30 | 9.66 | 2.9 | 3.22 | 3.0 | 7.9 |
| DW5 | 2.80 | 8.31 | 3.0 | 2.77 | 3.0 | 6.6 |
| IPR1B | 1.14 | 3.66 | 3.2 | 1.22 | 3.0 | 2.8 |
| IPR2B | 0.55 | 1.65 | 3.0 | 0.55 | 3.0 | 1.6 |
| Blank[b] | 0.10 | 10.0 | 100 | 3.30 | 3.0 | 9.45 ± 0.44[c] |

*Notes:* [a]Calculated levels. [b]Chloramination of ultrapure water was performed in parallel for each test. [c]Average and standard deviation of residual for five blank tests. NQ = Detectable, but not quantifiable.

## 3.10 Statistical Methods

Available historical water quality data from the seven water utilities were merged with the data from the four sampling campaigns. The water utilities generally provided monthly sampling data. For some analytes, data were provided from quarterly or semiannual sampling routines. Some of the general water quality parameters, such as ammonia and sulfate, were not available from all seven water utilities. The combined data sets were organized with results listed by month. At facility IPR2, the water utility collected samples more frequently, so monthly average results were used. For a few analytes, results were available from both the water utility and the project team in a single month. In these cases, only the results from the project team were used.

Matrices for statistical analysis were developed that include the numeric value of the detection limit for nondetect values. The data have also been preserved in a format where nondetect values are listed as "<0.05," for example.

Quality-assurance/quality-control measures were performed on the data to locate and correct data entry errors and to verify that units were consistent for each analyte. The data were screened for unusual results that might indicate a data analysis or reporting error. For example, where a string of nondetect values were reported for data that were expected to be detected, the data provider was contacted to verify the results. In another case, raw water sample results were reported with values lower than finished water sample results, so the data provider was contacted to determine whether there had been a data reporting error.

In addition to the data from the seven sites, finished water quality was obtained from the American Water Works Association 1996 survey of more than 900 water utilities in the United States (AWWA, 1996). Annual average values of 11 analytes were reported by the water utilities. The AWWA data for TDS were added to the box plot for a visual comparison between the seven sites and the national average (Figure 3.8). A more recent set of national average data was not available after consultation with both the U.S. EPA and the AWWA, as well as other sources.

### 3.10.1 Box-and-Whisker Plots

Box-and-whisker diagrams or box plots were developed for many of the general water quality parameters, as well as the 12 most frequently detected TOrCs. The box plot of TDS is presented as an example (Figure 3.8). Box plots are a useful screening tool, as they visually represent the differences in the means and distributions of data sets. The number above each of the box plots is the number of samples. The box plot centerline indicates the median value, and the box includes the upper 75% and lower 25% quartiles. The outer lines or “whiskers” end at an observed value that is at most 1.5 times the box width. Thus the whiskers include all values outside of the upper and lower quartiles that are within 1.5 times the box width. Values (+ signs) outside of the whiskers are generally considered outliers. As previously stated, the value of the detection limit is listed as the numeric value for nondetect results. Therefore, the lowest line on the box plot represents the detection limit for analytes with nondetect results. For analytes where only a single line is shown on the box plot for an analyte, this indicates that all results were below the detection limit.

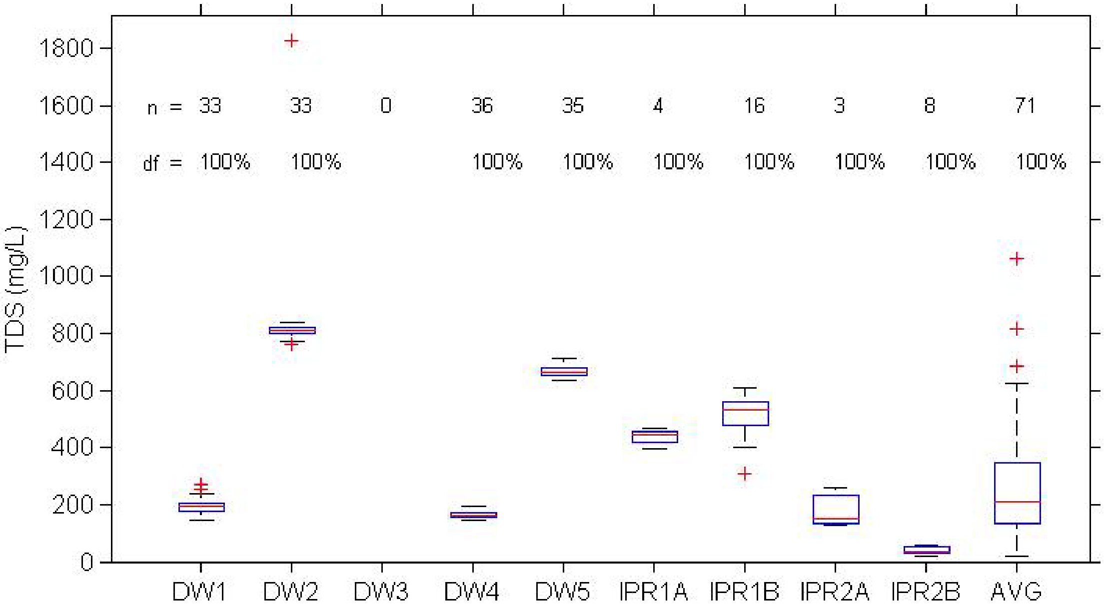


**Figure 3.1. Box plot for total dissolved solids.**

The box plots provide a qualitative assessment of whether measurements at each site are likely to be different or similar. In addition, the box plots indicate some analytes for which data are insufficient to draw any conclusions. For example, the nitrite box plot, Figure 3.9, indicates that the results from the only two sites that detected nitrite are lower than the detection limits at three of the other sites. Therefore, it is not possible to determine from this data set whether there is a difference in nitrite levels among the seven sites. As a further statistical screening tool, the detection frequency (df) of each analyte was determined at each site. Detection frequencies are listed within representative box plots, such as Figure 3.8.

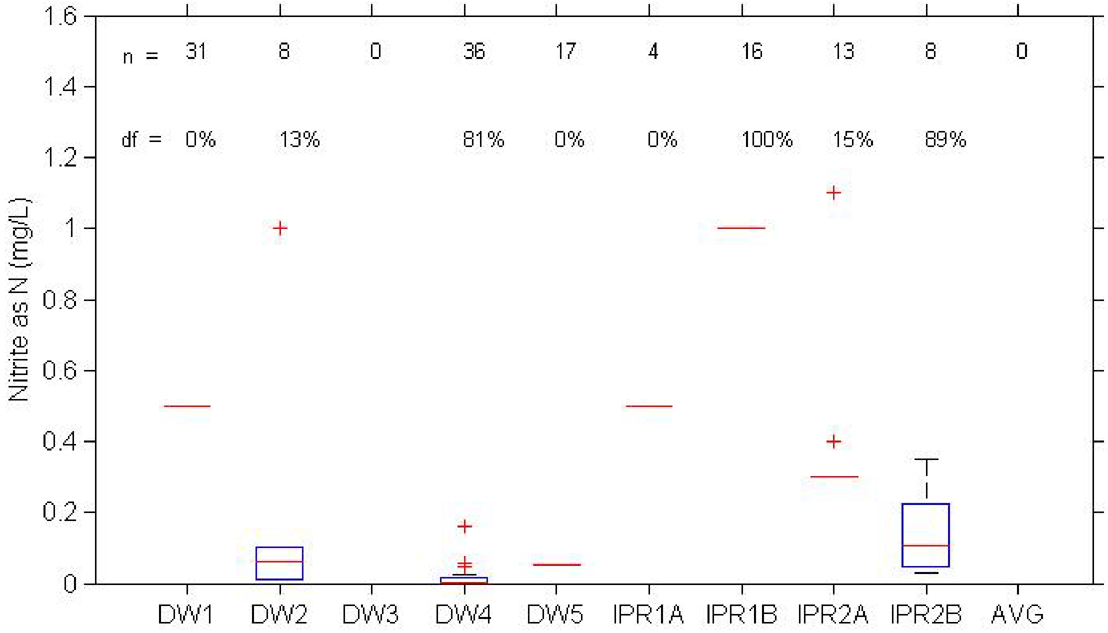


**Figure 3.2. Box plot for nitrite.**

### 3.10.2 Kruskal–Wallis Test

The univariate nonparametric multiple-comparison Kruskal–Wallis test was performed for a suite of analytes. Kruskal–Wallis compares the medians of two or more samples to determine if the samples have come from different populations. Because of the frequency of nondetect results and the limited number of observations for some analytes, most of the data sets are expected to have distributions that are not normal, so a nonparametric technique is used.

As an example, the Kruskal–Wallis test is used to compare TDS across multiple sites at the same time, where $\alpha$ was set to 0.05 as the level of significance for these comparisons. Table 3.14 includes the 95% confidence interval of the difference in the mean TDS value between sites. Where the confidence interval includes the value of “zero,” we cannot say with 95% confidence that the means are different. However, for comparisons such as DW2 versus IPR2A, the data indicate that the mean TDS value for the DW2 site is greater than the mean TDS value for the IPR2A site. Specifically, we are 95% confident that the mean TDS value for DW2 is 30—288 mg/L greater than the mean value for the IPR2A site.

Although the difference in means is not significant where the confidence interval includes the value “zero,” we also cannot say with certainty that the means are similar. For example, the confidence interval for the difference in mean values between DW5 and IPR2A is between -5 and 253 mg/L. It is possible that the means are the same, but given the mean difference of 124 mg/L, it is more likely that the mean value for DW5 is greater than the mean value for IPR2A.

**Table 3.6. Multiple Comparison Test for TDS**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1–Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$=0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | IPR1A | -170 | -57 | 57 | no | |
| DW2 | IPR1A | -38 | 76 | 189 | no | |
| DW4 | IPR1A | -202 | -89 | 24 | no | |
| DW5 | IPR1A | -73 | 40 | 154 | no | |
| DW1 | IPR1B | -132 | -67 | -1 | yes | IPR1B > DW1 |
| DW2 | IPR1B | 0.2 | 66 | 131 | yes | DW2 > IPR1B |
| DW4 | IPR1B | -164 | -99 | -35 | yes | IPR1B > DW4 |
| DW5 | IPR1B | -34 | 30 | 95 | no | |
| DW1 | IPR2A | -103 | 27 | 156 | no | |
| DW2 | IPR2A | 30 | 159 | 288 | yes | DW2 > IPR2A |
| DW4 | IPR2A | -135 | -6 | 123 | no | |
| DW5 | IPR2A | -5 | 124 | 253 | no | |
| DW1 | IPR2B | -3 | 82 | 166 | no | |
| DW2 | IPR2B | 130 | 214 | 299 | yes | DW2 > IPR2B |
| DW4 | IPR2B | -35 | 49 | 133 | no | |
| DW5 | IPR2B | 95 | 179 | 263 | yes | DW5 > IPR2B |
| IPR1A | AVG | -57 | 53 | 163 | no | |
| IPR1B | AVG | 4 | 63 | 123 | yes | IPR1B > AVG |
| IPR2A | AVG | -156 | -30 | 96 | no | |
| IPR2B | AVG | -165 | -85 | -5 | yes | AVG > IPR2B |
| IPR1A | IPR2B | 7 | 138 | 270 | yes | IPR1A > IPR2B |
| IPR1B | IPR2B | 56 | 149 | 241 | yes | IPR1B > IPR2B |
| IPR2A | IPR2B | -90 | 55 | 200 | no | |
| IPR1A | IPR1B | -130 | -10 | 110 | no | |
| IPR1A | IPR2A | -81 | 83 | 247 | no | |
| IPR1B | IPR2A | -42 | 93 | 228 | no | |
| DW1 | AVG | -49 | -3 | 42 | no | |
| DW2 | AVG | 84 | 129 | 174 | yes | DW2 > AVG |
| DW4 | AVG | -80 | -36 | 8 | no | |
| DW5 | AVG | 49 | 94 | 138 | yes | DW5> AVG |
| DW1 | DW2 | -185 | -132 | -79 | yes | DW2 > DW1 |
| DW1 | DW4 | -19 | 33 | 84 | no | |
| DW2 | DW4 | 113 | 165 | 217 | yes | DW2 > DW4 |
| DW1 | DW5 | -149 | -97 | -45 | yes | DW5 > DW1 |
| DW2 | DW5 | -17 | 35 | 87 | no | |
| DW4 | DW5 | -181 | -130 | -79 | yes | DW5 > DW4 |

## Chapter 4

# Characterization of Water Quality and Composition of Water Produced by Conventional Drinking Water and Planned Indirect Potable Reuse Treatment Systems

## 4.1 Introduction

This study selected five conventional drinking water sites and two IPR sites and compared source and finished water qualities among the different facilities. Although IPR can be accomplished via multiple combinations of engineered and natural treatment systems, in this study two IPR systems were selected that practiced surface spreading via soil-aquifer treatment (SAT) and direct injection (after reverse osmosis and UV/$H_2O_2$ treatment) leading to groundwater recharge. The drinking water facilities selected employed conventional and advanced treatment processes using surface and groundwater supplies with various degrees of impact from upstream wastewater discharge varying from pristine (DW1) to a range of 1% to more than 30% (DW2 to DW5).

This chapter presents water quality and treatment performance data that were compiled for these sites during the course of this study by comparing raw and finished water quality for a broad range of inorganic and organic water quality parameters. For the drinking water sites, finished water quality represents the water quality after treatment, but prior to entry into the distribution system. The final water quality of the two indirect potable reuse sites represents product quality after treatment and blending with other source waters (denoted as “IPR1B” and “IPR2B”). For most water quality parameters presented in this chapter, data are presented as averages, standard deviations, numbers of samples considered (*n*), and detection frequency (ratio between number of concentrations above detection limit and number of samples analyzed).

## 4.2 General Parameters of Source and Finished Water Quality

Source and finished water quality of all sites were further characterized by general water quality parameters. The results are presented as averages and standard deviations (shown as error bars) for levels of ammonia, nitrate, total nitrogen, conductivity, phosphate, sulfate, alkalinity, and regulated organic contaminants in raw and finished water samples (Figures 4.1 to 4.8). These figures represent data collected and measured during this study. The figures also list the detection frequency (df). The number of observations (*n*) for these parameters was 2 or 4 for each of these sample locations.

### 4.2.1 Ammonia

Ammonia concentrations in source raw and finished waters are reported in Figure 4.1 (note that the *y*-axis is on a log scale). The highest concentration of ammonia was observed in the source water of the indirect potable reuse site IPR2 (~20 mg-N/L), which represents a partly nitrified secondary wastewater effluent. The ammonia levels for the other source waters were less than 0.7 mg-N/L.

Ammonia levels increased during treatment at drinking water sites DW1 and DW4. This is due to addition of ammonia during water treatment to achieve chloramine disinfection. The ammonia level at DW2 decreased during treatment, which is likely due to a combination of aeration treatment and breakpoint chlorination. The ammonia levels at drinking water sites DW3 and DW5 also decreased during treatment, which is likely due to the application of breakpoint chlorination at these sites. A greater percentage of ammonia was removed at the IPR sites than at the conventional drinking water sites. The decrease of ammonia during soil-aquifer treatment (IPR1) is likely due to biotransformation occurring within the subsurface. A partial removal of ammonia was observed during advanced water treatment at IPR2 employing reverse osmosis followed by AOP treatment prior to direct injection. Reverse osmosis treatment can effectively remove ammonia, but it does allow some to pass into the permeate (Bellona et al., 2008).

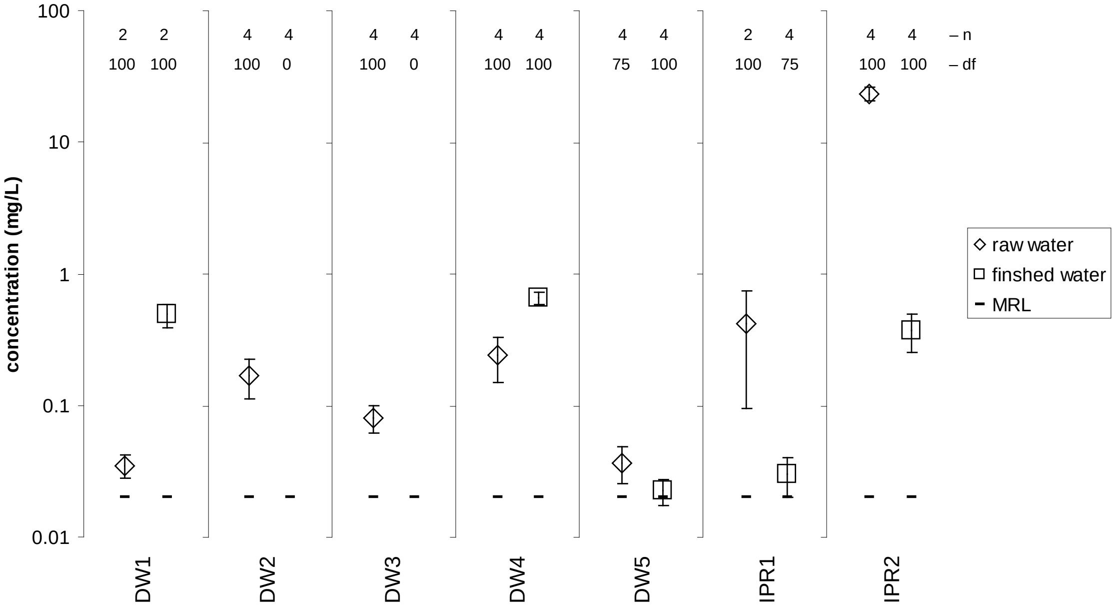


**Figure 4.1. Ammonia concentrations (average ± standard deviation) for raw and finished water.**

### 4.2.2 Nitrate

Nitrate concentrations in source raw and finished waters are reported in Figure 4.2. The highest concentration of nitrate was observed in the source water of IPR1 (~4.5 mg-N/L), which represents a typical range for nitrified/partly denitrified tertiary treated wastewater effluent qualities. The nitrate levels for the other source waters were less than 1.5 mg-N/L. Although no significant removal of nitrate was observed at the conventional drinking water sites, nitrate at IPR1 was further attenuated during soil-aquifer treatment, possibly by denitrification and dilution processes within the subsurface. Unexpectedly, the nitrate level during IPR2 increased after direct injection. This increase was not observed after RO/AOP treatment, in which nitrate is partially removed during RO treatment, and is likely due to blending with a local groundwater that has elevated nitrate concentrations.

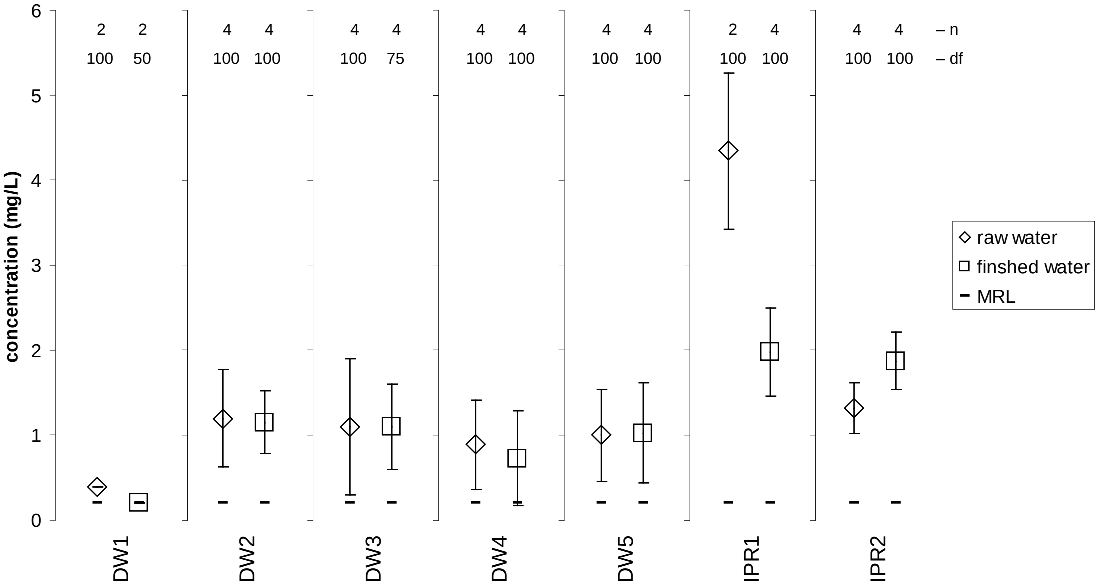


**Figure 4.2. Nitrate concentrations (average ± standard deviation) for raw and finished water.**

### 4.2.3 Total Nitrogen and Organic Nitrogen

Total nitrogen (TN) concentrations in source raw and finished waters are reported in Figure 4.3 (note that the *y*-axis is on a log scale). The total nitrogen comprises of the following species: ammonia, nitrite, nitrate, and organic nitrogen compounds, as well as chloramines at certain drinking water sites (i.e., DW1 and DW4 at finished water locations). The TN concentrations at drinking water sites DW1 and DW4 increased, which is attributable to increases of ammonia due to dosing and formation of chloramines in the finished waters. No significant removal of TN was observed during the treatment employed at drinking water sites DW2, DW3, and DW5. For these samples nitrate was the major fraction of TN.

The total organic nitrogen (TON) was calculated by subtracting out the inorganic nitrogen species from the total nitrogen. In general, the TON values for conventional drinking water source and finished waters were less than 0.1 mg-N/L. Absolute values could not be determined accurately, because TN was dominated by ammonia and/or nitrate species, so a large error was propagated when large values were subtracted from each other (TON=TN - N species). The TON levels for the IPR source waters (IPR1, IPR2) were 0.76 ± 0.35 and 3.77 ± 0.76 mg-N/L, respectively. These source waters are composed of 100% treated wastewaters (tertiary and secondary treatments for IPR1 and IPR2, respectively), which have higher organic nitrogen content than conventional drinking water sources. However, the TON was removed during IPR1 and IPR2 treatment, after which TON levels were less than 0.1 mg-N/L for IPR1 and IPR2 finished waters and similar to finished water quality of the drinking water sites.

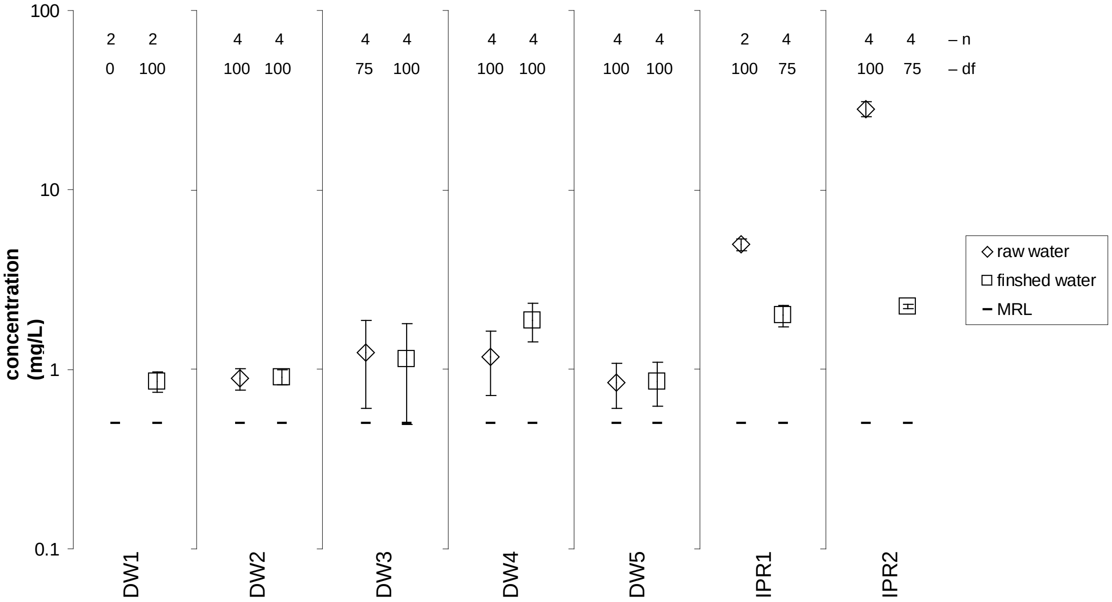


Figure 4.3. Total nitrogen concentrations (average ± standard deviation) for raw and finished water.

### 4.2.4 Phosphate

Phosphate concentrations in source raw and finished waters are reported in Figure 4.4. With the exception of IPR2, phosphate concentrations in raw water samples across all sites were less than 0.2 mg/L. Higher phosphate (~1.9 mg/L) was observed for the source water of IPR2, secondary-treated wastewater. Relatively elevated phosphate levels are typical for wastewaters. However, low phosphate is observed in the IPR1 source water, tertiary-treated wastewater. Phosphate was reduced during tertiary wastewater treatment via coagulation with alum and subsequent clarification. The phosphate concentrations in finished water at drinking water sites DW3, DW4, and DW5 increased, which is due to chemical addition of phosphoric acid, ortho-polyphosphate, and zinc phosphate, respectively, for corrosion control in distribution systems at these sites. Although IPR2 exhibited the highest levels of phosphate in the source water, the concentration was reduced following reverse osmosis treatment to less than 0.1 mg/L. In addition, phosphate levels decreased during soil-aquifer treatment, likely because of sorption to subsurface soil particles.

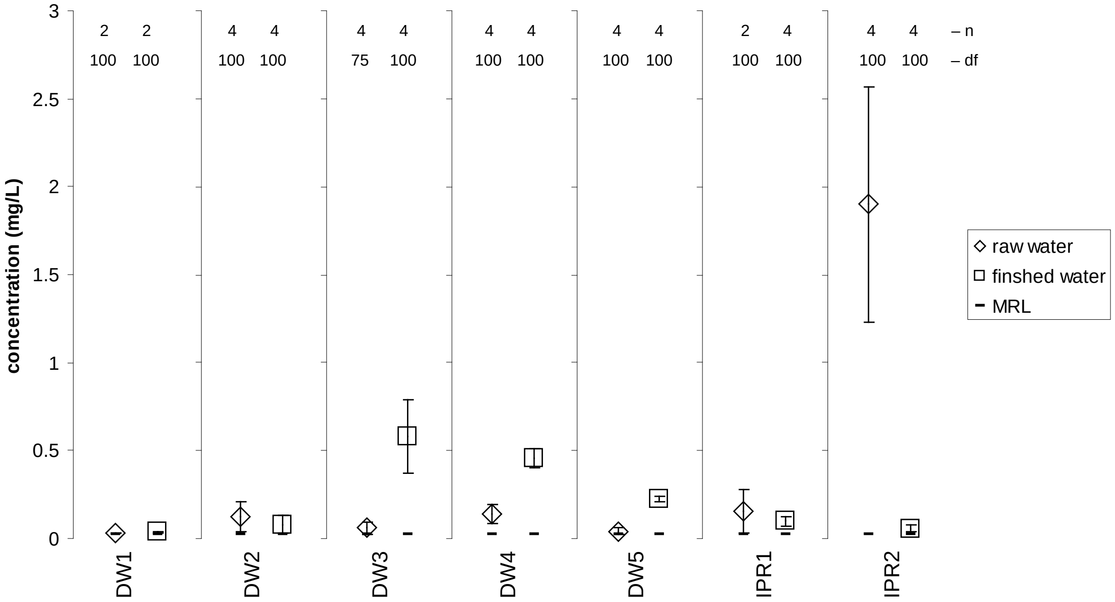


**Figure 4.4. Phosphate concentrations (average ± standard deviation) for raw and finished water.**

### 4.2.5 Conductivity

Conductivity measurements in source raw and finished waters are reported in Figure 4.5. Conductivity in raw and finished waters is determined by the origin of the source water in any particular watershed. Because sites DW2, DW5, and IPR1 share the same source water, which is characterized by naturally elevated TDS concentrations, conductivity levels appear to be similar for these three sites and relatively higher than for the other conventional drinking water sites. The source water of IPR2 had the highest conductivity level at ~1600 mg/L. Conductivity levels were, as expected, not attenuated during conventional treatment at DW1, DW2, DW3, and DW5. A slight removal was observed during treatment at site DW4, which could be due to the softening process employed at this site. The conductivity level was slightly lowered in the finished water at IPR1, which is likely a result of dilution with ambient groundwater. As expected for a desalination process, the RO treatment process was primarily responsible for the significant reduction of conductivity in the finished water of IPR2. However, conductivity after RO treatment increased again after blending of the product water with ambient groundwater and recharged surface water.

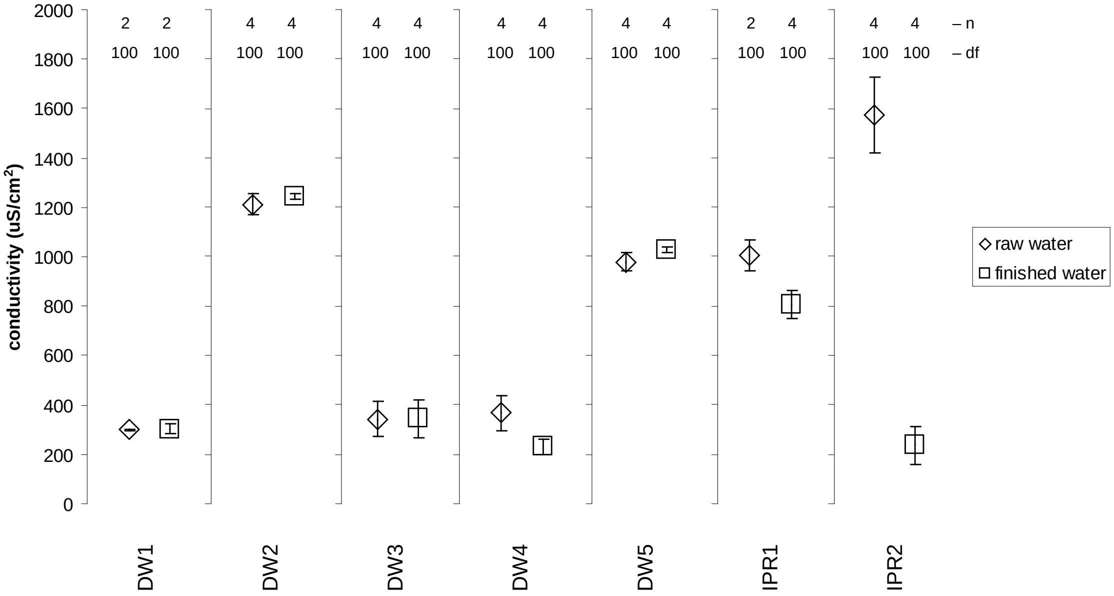


**Figure 4.5. Conductivity (average ± standard deviation) for raw and finished water.**

### 4.2.6 Sulfate

Similarly to conductivity levels, the sulfate concentrations are relatively high in raw water at DW2 and DW5 (Figure 4.6) than at other sites, which again is likely due to the fact that these systems share the same water source. Sulfate concentrations in raw and finished water from DW2 and DW5 remained unchanged during treatment at a concentration range of 260 to 280 mg/L. Sulfate concentration in finished water at DW1, DW3, and DW4 increased during treatment, which is due to the addition of aluminum sulfate in the coagulation process. Sulfate concentrations were reduced during IPR1 treatment to an average concentration of 130 mg/L, which likely is due to dilution with ambient groundwater that has lower sulfate concentration. RO treatment represents an efficient barrier responsible for the reduction of sulfate concentrations in the finished water of IPR2 (less than 40 mg/L).

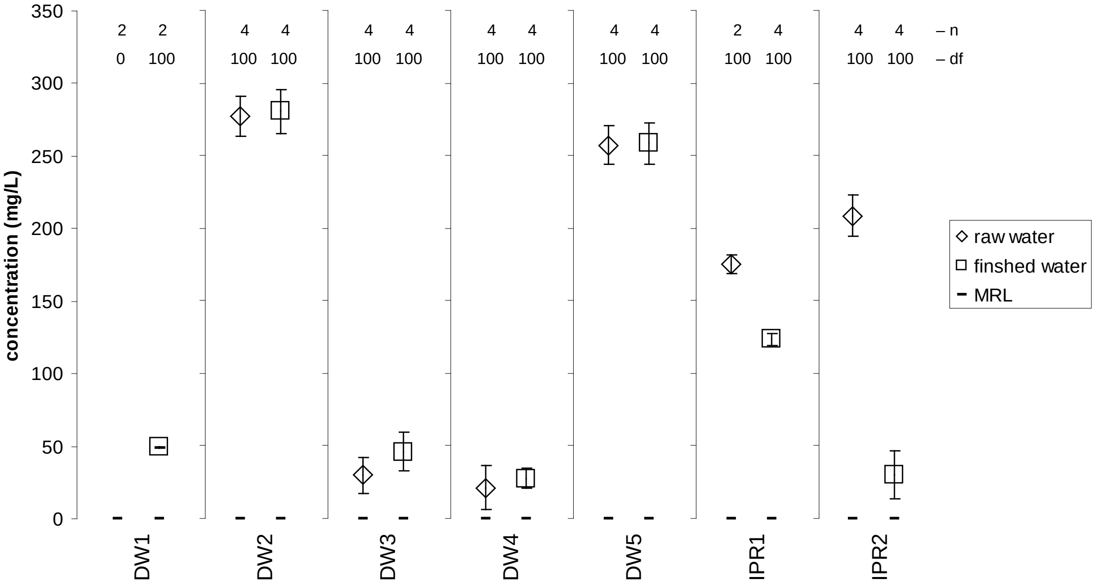


**Figure 4.6. Sulfate concentrations (average ± standard deviation) for raw and finished water.**

### 4.2.7 Alkalinity

Alkalinity concentrations in raw water are elevated (150–260 mg/L) at sites DW2, DW4, DW5, IPR1, and IPR2 (Figure 4.7). Alkalinity concentrations remained constant during conventional treatment at DW1, DW2, and DW5. Alkalinity also did not change significantly during soil-aquifer treatment (IPR1). Alkalinity was reduced during treatment at sites DW3 and DW4, which is likely a result of the higher concentrations of alkalinity-consuming coagulant chemicals applied at these sites. Alkalinity concentration changed significantly during RO treatment at site IPR2, resulting in less than 50 mg/L in the finished water.

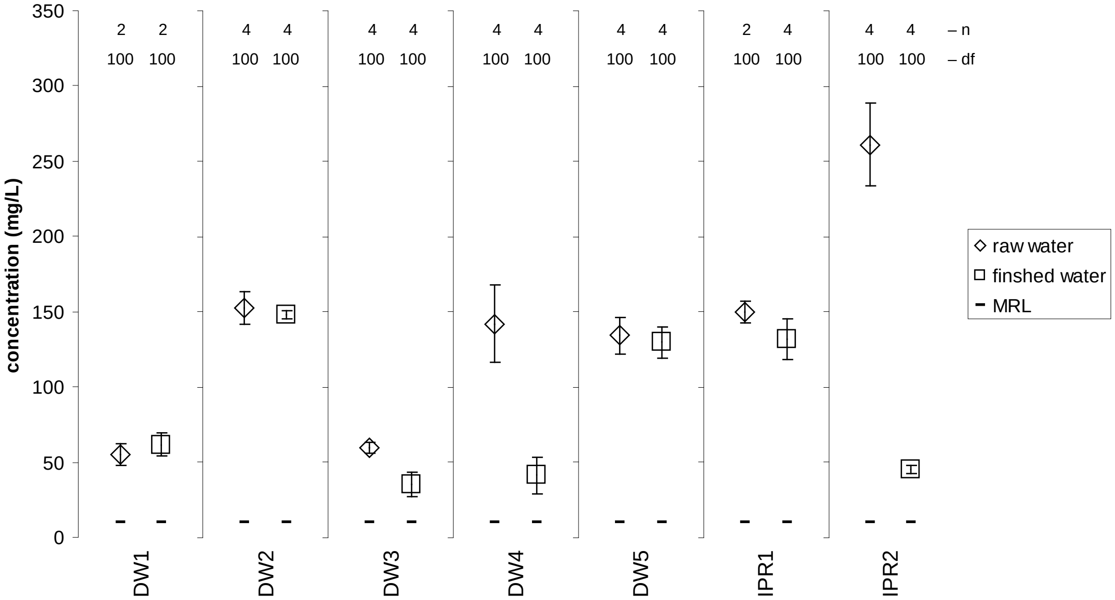


**Figure 4.7. Alkalinity (average ± standard deviation) for raw and finished water.**

### 4.2.8 Boron

Boron levels in source raw and finished waters are reported in Figure 4.8. The average boron levels are less than 0.33 mg/L for source and finished waters for conventional drinking water plants, where boron levels were lowest at the drinking water reference site DW1 (~0.05 mg/L). Average boron levels are higher in IPR1 (~0.55 mg/L) and IPR2 (~0.45 mg/L) source waters, representing 100% treated wastewater effluents. Boron concentrations remained unchanged during conventional drinking water treatment. Boron concentrations were reduced during IPR1 treatment to an average concentration of 0.37 mg/L, which is likely due to dilution with ambient groundwater. Reverse osmosis treatment is only partially effective at reducing boron concentrations in IPR2, where boron levels were reduced to 0.27 mg/L in the finished water.

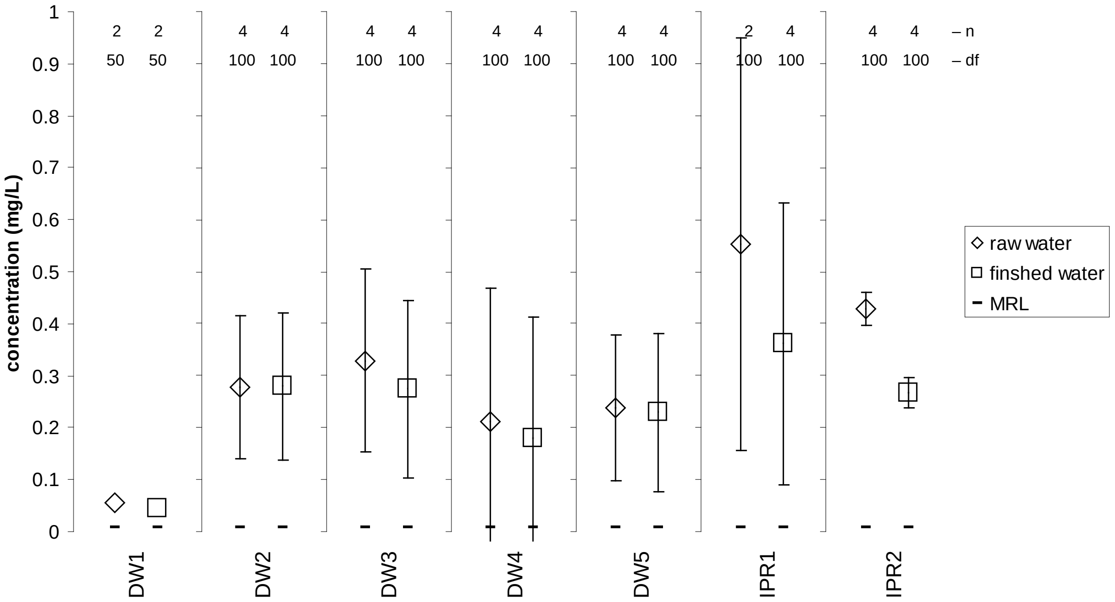


**Figure 4.8. Boron concentrations (average ± standard deviation) for raw and finished water.**

### 4.2.9 Regulated Organic Contaminants—Trihalomethanes/Haloacetic Acids

Regulated disinfection byproducts were analyzed at all sites, and average concentrations and standard deviations of total trihalomethanes (Tot. THM) and haloacetic acids (HAAs) in raw and finished waters are illustrated in Figures 4.9 and 4.10. For raw water quality of conventional drinking water sites, Tot. THM and HAA concentrations were nondetect or near the detection level (TTHM for DW4). Tot. THM and HAAs were formed after either chlorine or chloramine disinfection at the conventional drinking water treatment systems resulting in elevated concentrations in the finished water. The Tot. THM (Figure 4.9) and HAA (Figure 4.10) concentrations were lowest for the finished water of both IPR sites. The fate of Tot. THM and HAA concentrations present in the source or formed during the treatment process can be evaluated. For IPR1, the Tot. THM and HAA concentrations were reduced to nondetect levels after SAT treatment. For IPR2, the HAA levels were reduced to nondetect levels, because HAAs represent charged solutes that are efficiently removed during RO treatment (Drewes et al., 2005b). However, Tot. THM levels remained constant, and chloroform is known to be only partially rejected by RO treatment (Bellona et al., 2004).

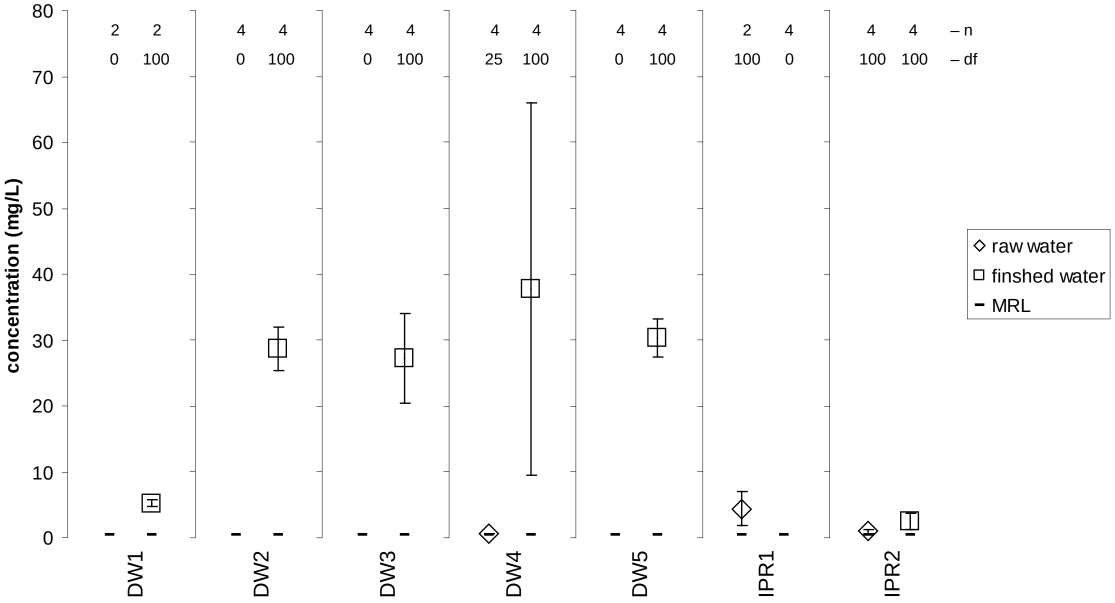


Figure 4.9. THM concentrations (average ± standard deviation) for raw and finished water.

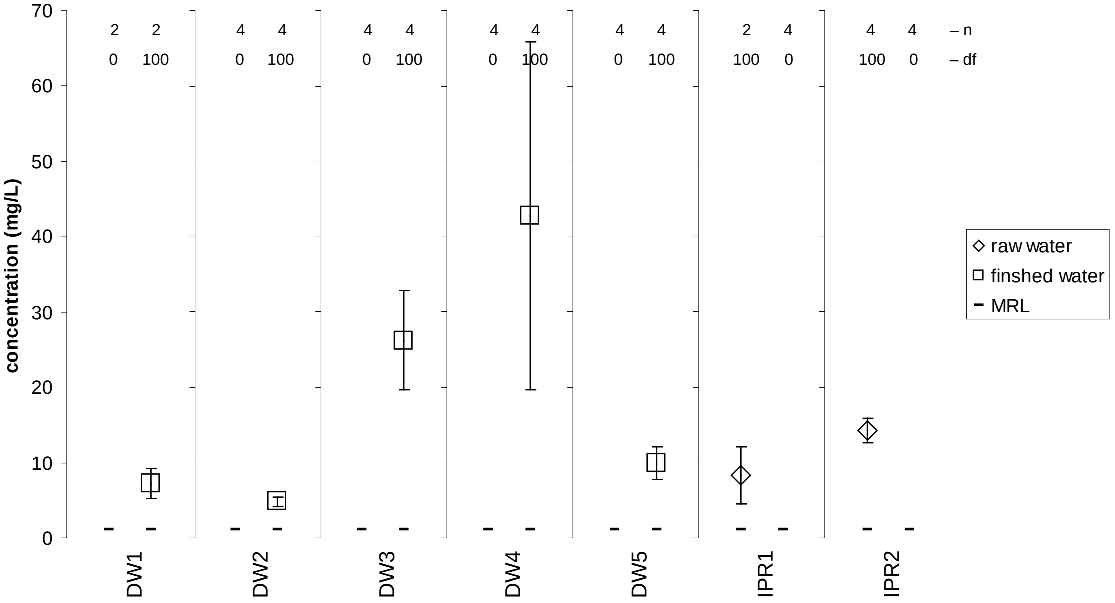


Figure 4.10. HAA5 concentrations (average ± standard deviation) for raw and finished water.

## 4.3 Bulk Organic Matter in Source and Finished Water

Bulk organic carbon can be quantified as total organic carbon (TOC) or dissolved organic carbon (DOC) and can be further characterized by specific UV absorbance (SUVA) and fluorescence spectroscopy. In addition, state-of-the-art characterization tools, such as polarity characterization (PRAM) and SEC with online DOC and UV absorbance detectors, were used to provide information regarding the nature and molecular weight distributions of major organic matter fractions, such as biopolymers, humic acids, and low-molecular-weight acids.

### 4.3.1 Total Organic Carbon and Specific UV Absorbance

TOC is a useful parameter, as it measures the total organic constituents present in a sample, and SUVA provides the degree of aromaticity of a sample, which is linked to the amount of aromatic humic substances that are present. The TOC, UV, and SUVA values for source raw and finished waters are reported in Figures 4.11, 4.12, and 4.13, respectively. The highest TOC concentrations in source waters were observed at site DW4 and the indirect potable reuse site practicing direct injection (IPR2; ~12 mg/L). Minimal TOC removal was observed at sites DW1, DW2, and DW5, facilities that all practice direct filtration with low coagulant doses. TOC levels at sites DW3 and DW4 are partially reduced by higher coagulant doses and application of upflow solids contact clarification and sedimentation processes, respectively. A significant amount of TOC was removed during SAT (IPR1) and RO/AOP/direct injection operations (IPR2), resulting in TOC concentrations that were lower than at the drinking water sites.

The highest SUVA value in source waters was observed for facility DW4 (~2.9 L/mg-m), which indicates this source water is impacted more by fresh terrestrial inputs, a major source of aromatic humic/fulvic acids (Figure 4.13). The other source waters had SUVA values less than 2.0 L/mg-m, suggesting that these source waters contain organic material of a more hydrophilic nature. During treatment, SUVA did not change at sites DW1 and DW2, representing direct filtration plants applying low coagulant doses. However, at DW5, also a direct filtration plant, the SUVA decreased during treatment, and this was likely due to the application of ozone at this plant, which is known to react effectively with aromatic structures, such as those within humic/fulvic acids. SUVA levels at sites DW3 and DW4 are also partially reduced during treatment by higher coagulant doses and application of clarification processes at these plants. Coagulation followed by sedimentation is effective at removing hydrophobic substances, such as aromatic humic/fulvic acids. Though the UVA did decrease during groundwater recharge at site IPR1 (Figure 4.12), the SUVA value did not change, indicating that the UV-absorbing and non-UV-absorbing compounds were equally reduced during this operation. However, at site IPR2, the SUVA value decreased after RO/AOP treatment. This decrease is due to the preferential removal of high-molecular-weight aromatic compounds, such as humic/fulvic acids, by RO rejection and AOP treatment.

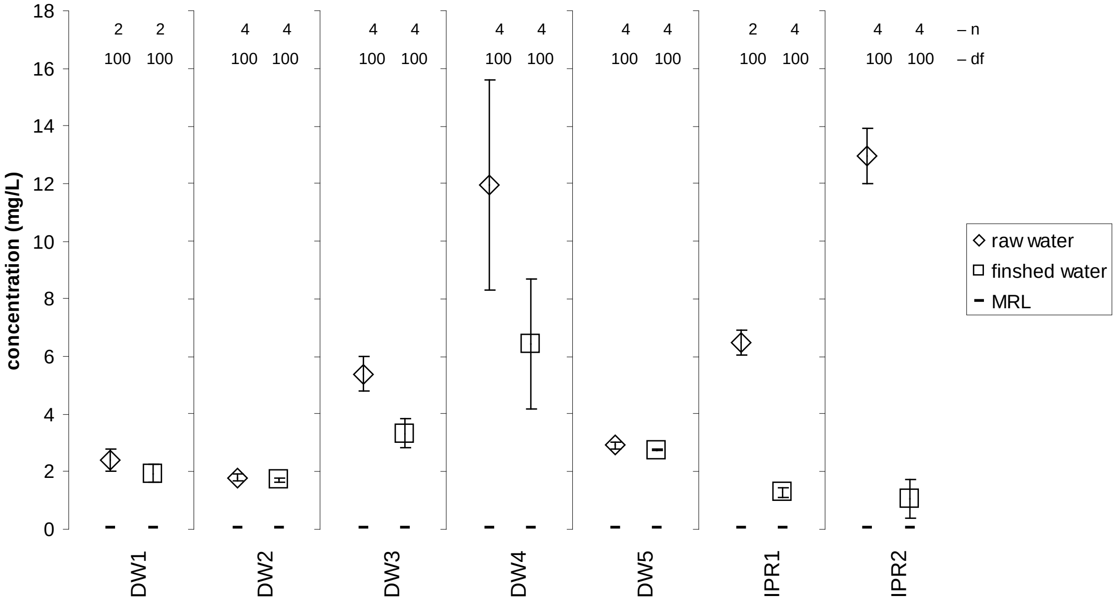


Figure 4.11. TOC concentrations (average ± standard deviation) in raw and finished water.

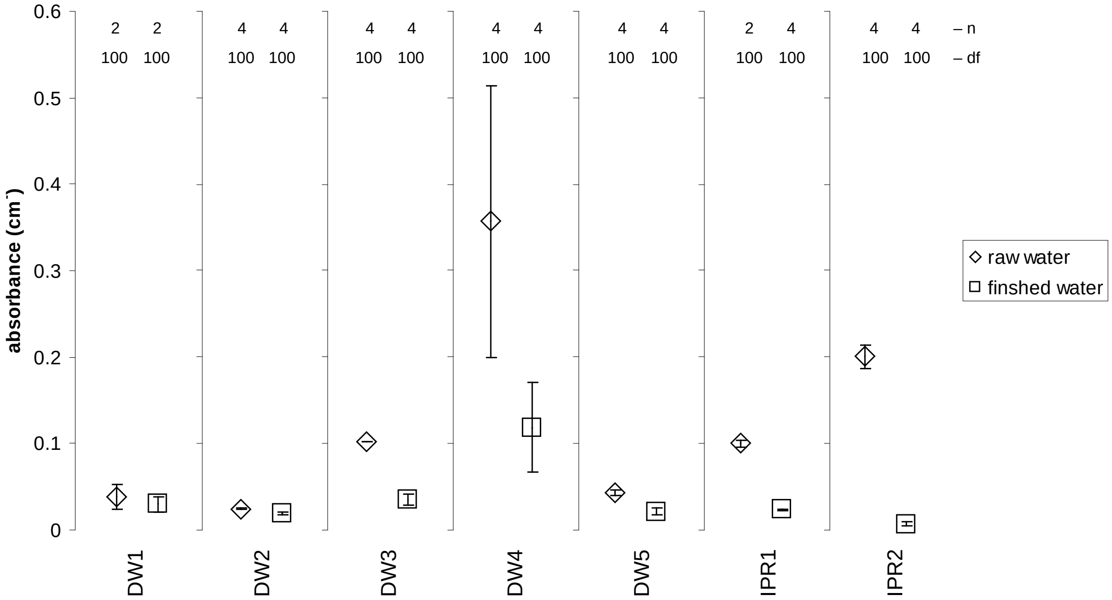


Figure 4.12. UV$_{254}$ absorbance (average ± standard deviation) in raw and finished water.

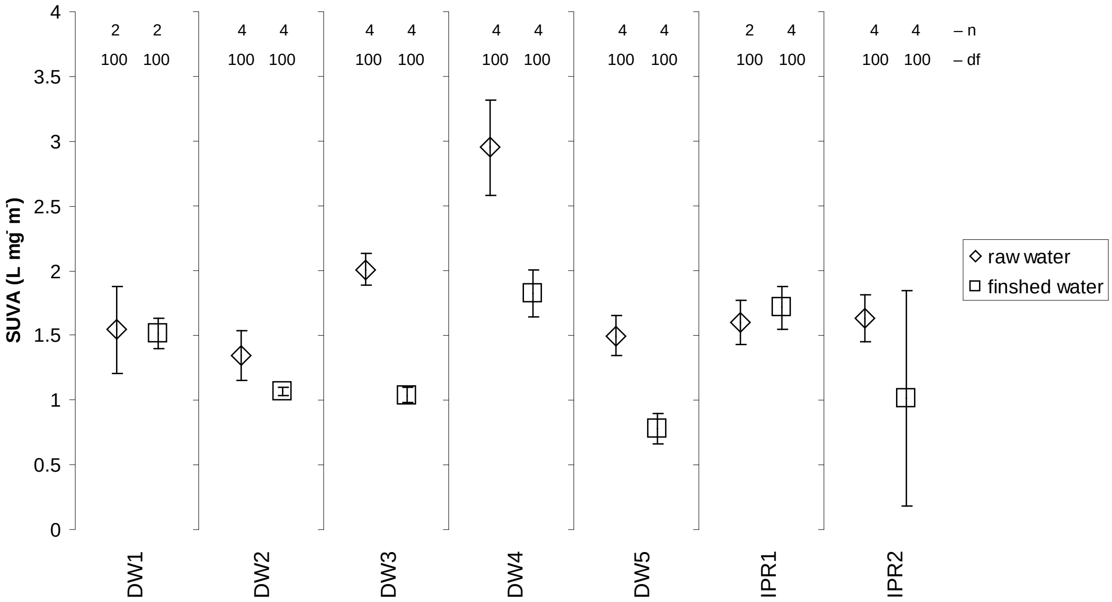


**Figure 4.13. SUVA (average ± standard deviation) in raw and finished water.**

### 4.3.2 Size-Exclusion Chromatography

Raw and finished water samples were analyzed using SEC with UVA and DOC online detection. The chromatograms typically exhibit three characteristic regions of organic matter fractions, as illustrated in Figure 4.14. Previous work by other groups is referenced and used in the identification of these regions. Region 1, which eluted at the high-molecular-weight exclusion limit, has been assigned to the high-molecular-weight components of DOM, including polysaccharides. Based on calibration of the SEC column with polyethylene glycol standards, Region 1 corresponds to molecular weights above 18,000 Da. Region 2, with elution times between 35 and 55 min, was attributed to humic substances, including building blocks and other components such as low-molecular-weight acids. Region 3 eluted at the low-molecular-weight exclusion limit for all samples. This region includes low-molecular-weight acids and amphiphiles (characterized by molecular weights below 100 Da, based on polyethylene glycol calibration).

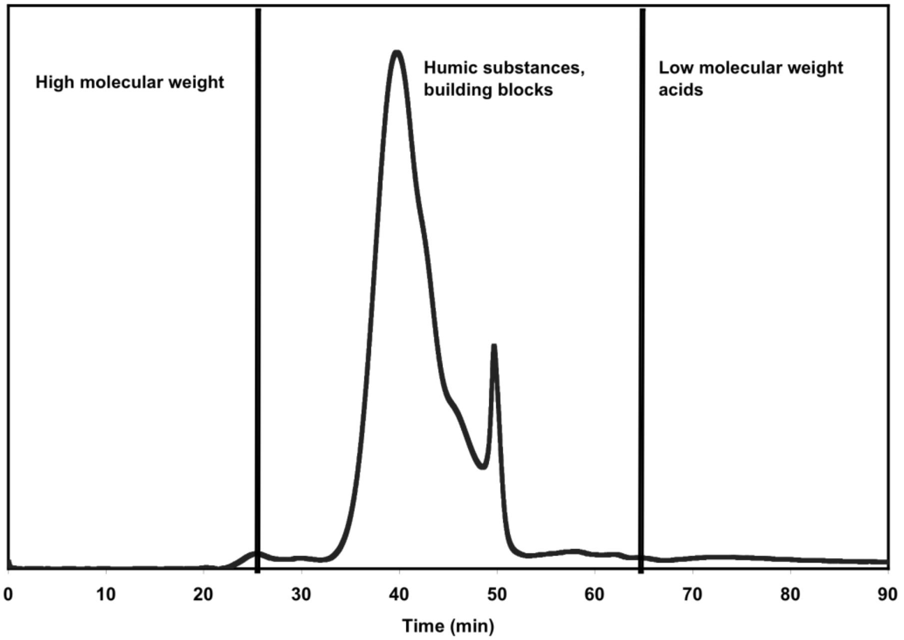


**Figure 4.14. Example SEC chromatogram illustrating the different regions of material and approximate elution times.**

Figures 4.15 and 4.16 present the SEC chromatograms for selected samples collected in this study (both raw and finished water samples). The differences between raw and finished water samples observed in the chromatograms are due to differences in treatment and also to the character and origin of the organic matter present in the source water. For example, organic matter with higher SUVA values is easier to remove via coagulation/flocculation treatment processes than organic matter with low SUVA values. Also, advanced processes, such as ozone or AOP (i.e., UV/$H_2O_2$), will be more effective at transforming the organic matter.

The chromatograms obtained for samples from the drinking water sites are presented in Figure 4.15. In this report, only one SEC chromatogram is presented for each site, as the results did not indicate significant temporal variability throughout the course of the study. The results for the control drinking water site (DW1) indicate that the NOM at this site is characterized by the presence of biopolymers and humic substances. For this site, limited reduction in TOC is observed, considering the DOC chromatogram, which is in agreement with the TOC results shown in Figure 4.11. The treatment using direct filtration reduced the $UV_{254}$ absorbance of the higher-molecular-weight humics, as shown by the UV reduction on the SEC chromatogram. As discussed previously, drinking water site DW3 exhibited a significant amount of high-molecular-weight material in the source water sample, which was easily removed during treatment. The TOC for the source water for the DW3 site was 4.4 mg/L, with a close to 50% reduction across the treatment train. The SEC results indicate that the treatment was efficient at removing the high-molecular-weight organic matter, as shown by the decreases observed with both UV and DOC chromatograms. The DOC chromatogram for drinking water site DW 4 exhibited relatively large amounts of biopolymers and humic substances. The average TOC for the raw water was 7.2 mg/L, which was reduced to 4.1 mg/L after treatment. The SEC chromatogram confirmed this trend for samples from drinking water site DW3, suggesting that the treatment was able to remove both the UV and the DOC components of the organic matter.

Sites DW2 and DW5 share the same source water, but the raw water at DW2 is pretreated by riverbank filtration. In contrast to DW5 and the other drinking water sites, the chromatogram of DW2 water samples exhibits no biopolymer peaks, whereas the humic substances and low-molecular-weight organics are similar. This is consistent with previous experiences regarding the effectiveness of riverbank filtration. Biopolymers are well degradable and removed during the short-term travel in the subsurface. The results for sites DW5 also exhibit high-molecular-weight material, which was more recalcitrant during treatment. As opposed to DW3 and DW4, the treatment processes removed less DOC at DW5. The SEC UV chromatograms that indicate the aromaticity of the sample is reduced during treatment. In the case of the DW5 site, ozonation is used, and this would explain the observed change in the UV profile, given that ozone reacts efficiently with electron-rich chromophores (Rosario-Ortiz et al., 2008).

The chromatograms for the IPR sites are presented in Figure 4.16. The source water sample of the IPR1 site was similar in character to the drinking water sites DW3, DW4, and DW5 in exhibiting a significant amount of high-molecular-weight in addition to lower-molecular-weight organics. Similarly to DW4 and DW3, significant bulk UVA and DOC removal was observed between raw and finished waters. In contrast to the DW sites, the final water quality of IPR1 exhibited a different character, with no presence of biopolymers, significantly reduced humic substances, and low-molecular-weight acids. In the case of -IPR2, the source water was dominated by the presence of biopolymers, building blocks of humic substances, and low-molecular-weight acids. The treatment train removed most of the DOC; therefore no quantifiable signal for a SEC DOC chromatogram was observed for the finished water.

In general, when the results for the source water chromatograms with DOC detection are compared, there appears to be similarities between the DW1, DW3, DW5, and IPR1 sites. The chromatograms for all of these sites indicate the presence of higher-molecular-weight organics. However, clear differences were observed when the overall change in the chromatograms after treatment was compared. In this case, the results indicate that the NOM at sites DW3, DW4, and IPR1 was more readily removed than that at sites DW2 and DW5.

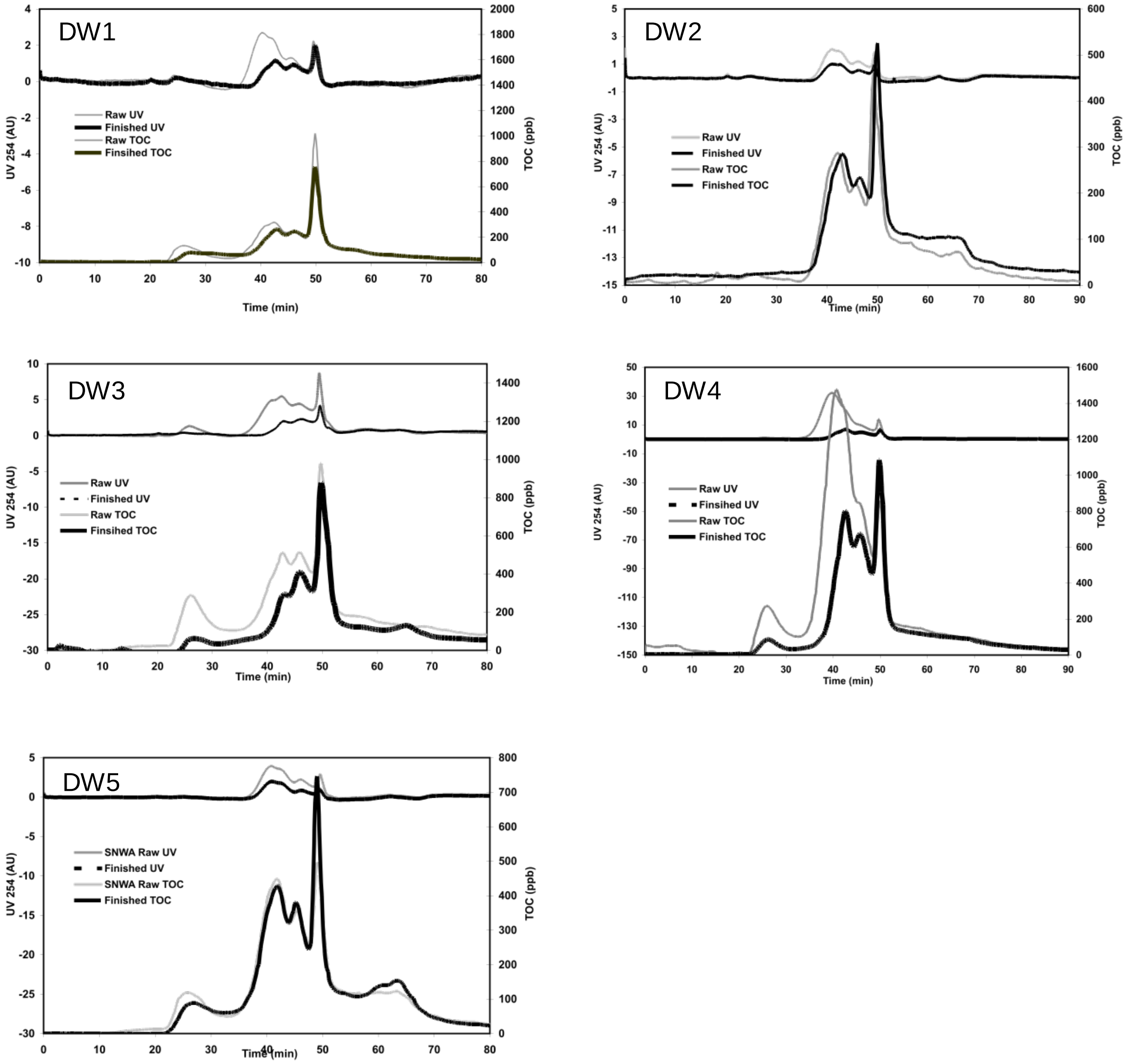


**Figure 4.15. SEC chromatograms for the DW sites.**

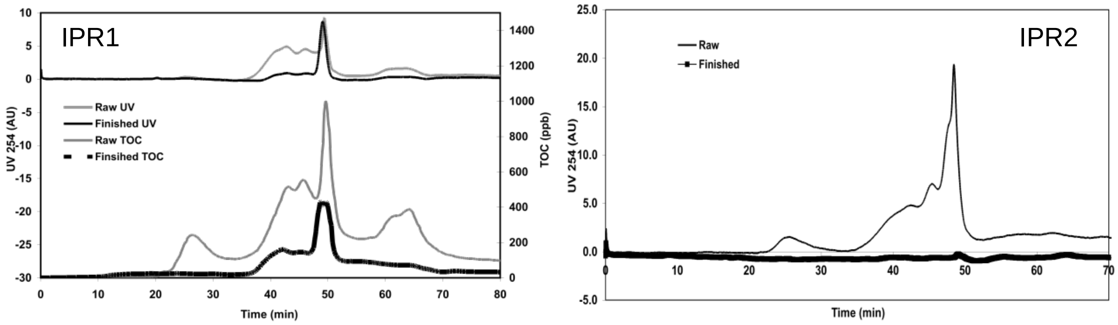


**Figure 4.16. SEC chromatograms for the IPR sites.**

### 4.3.3 Fluorescence Index

Fluorescence excitation–emission matrices (EEMs) were generated to derive a fluorescence index (FI) for each water sample. The FI is defined as the ratio of the intensities at 450 and 500 nm emission when the excitation wavelength is set at 370 nm. The range of values for the FI for the samples studied was between 1.15 and 1.45. Lower values are associated with NOM dominated by terrestrial inputs, whereas higher values are associated with microbially derived NOM. Distinctions between the FIs for different sites allow quick evaluation of the relative character of the NOM. The fluorescence characterization results, specifically the use of the FI for both the raw and finished waters, are presented in Figure 4.17. EEMs for each raw and finished water sample are presented in Appendix D.

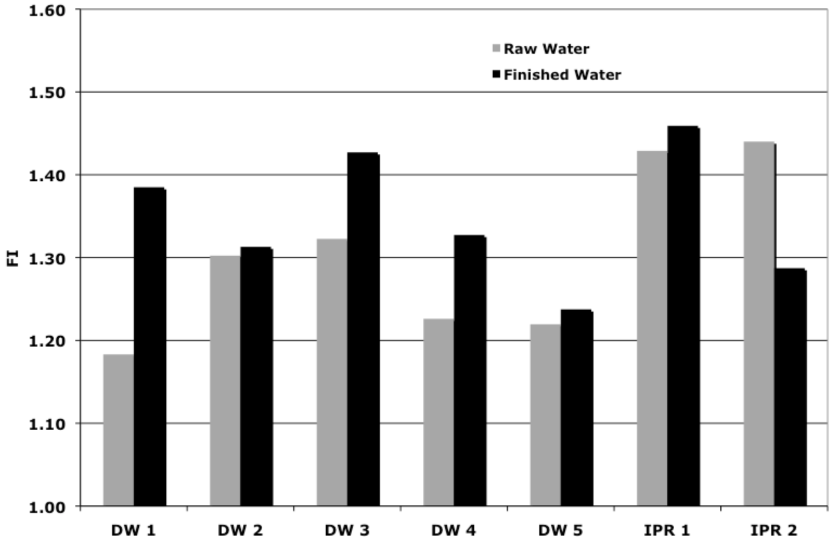


**Figure 4.17. Fluorescence indices for raw and finished water.**

The FI results indicate that the source water samples collected at both IPR sites (IPR1, IPR2) were of a slightly more microbial character than those collected at DW sites because of their higher FI values (approximately 1.42 as opposed to <1.32 for the DW sites). The two samples represent a mixture of natural organic matter and wastewater-derived effluent organic matter, likely explaining the observed FI.

Raw water samples from DW1 and DW4 exhibited lower FI values, indicating mostly terrestrial sources for the NOM, when compared with the other observed values. The SUVA for DW4 was the highest, which agrees with also having a low FI. However, for DW1, the low FI does not correspond to a relatively high SUVA. DW 5 also had a low FI value, indicating a higher proportion of terrestrially derived NOM. It is worth mentioning that the higher FI could also be associated with sites impacted by high aquatic-derived NOM.

For the finished waters, the highest FI was observed for the IPR1 site, followed by the DW3 and DW1 sites. The microbial signature had been decreased for the IPR2, as a function of advanced water treatment processes, such as RO. Previous results indicated an increase in FI during water treatment, as terrestrially derived NOM is removed by coagulation and filtration. This would explain the increase observed for some of the sites, such as DW1, DW3, and DW4.

### 4.3.4 Polarity Rapid Assessment Method

Additional polarity characterization of the organic matter was conducted for raw and finished water samples from each site, using the PRAM. Results are presented in Figure 4.18. The data for the polarity characterization are presented in terms of percentages for each of the properties characterized (i.e., nonpolar or hydrophobic, polar or hydrophilic neutral, and anionic or hydrophilic charged). The nonpolar hydrophobic component is measured by the retention on the C18 hydrophobic resin. The hydrophilic neutral is quantified by retention onto a diol functionality, and the hydrophilic charge is measured using a weak anion-exchange resin ($NH_2$). All analyses are conducted under ambient conditions; therefore the majority of the NOM is expected to be characterized as hydrophilic charged as a function of the carboxylic acid, and a portion of the phenolic moieties would be deprotonated. The fact that the analysis is done under ambient conditions indicates that the results will be different from those done with the more traditional XAD fractionation technique. Furthermore, because analysis is based on UV detection, only the fraction of the NOM that absorbs light at 254 nm is characterized.

The results for the source waters reveal that IPR1 had the highest hydrophobic character, followed by source water samples from DW3 and DW2. The lowest hydrophobic character of all samples was observed for DW1, DW4, and DW5. This order seems to follow the same order as the FI for the raw waters, as the highest and lowest FIs for raw water were observed for IPR1 and DW1, respectively. The hydrophilic charged organics represent the fraction of the NOM that has a negative charge because of deprotonated acidic and some phenolic groups. The overall hydrophilic charged fraction was lowest for the IPR1 site and highest for the DW1 site, opposite to the pattern observed for the hydrophobic character. The DW1 site is the reference site, so the polarity results clearly indicate differences between control and impacted sites. For the finished water samples, the strongest hydrophobic character was observed for the DW3 site, followed by the IPR1, DW4, DW2, DW3, and DW1 sites. No data were available for IPR2 because of low levels of organic carbon.

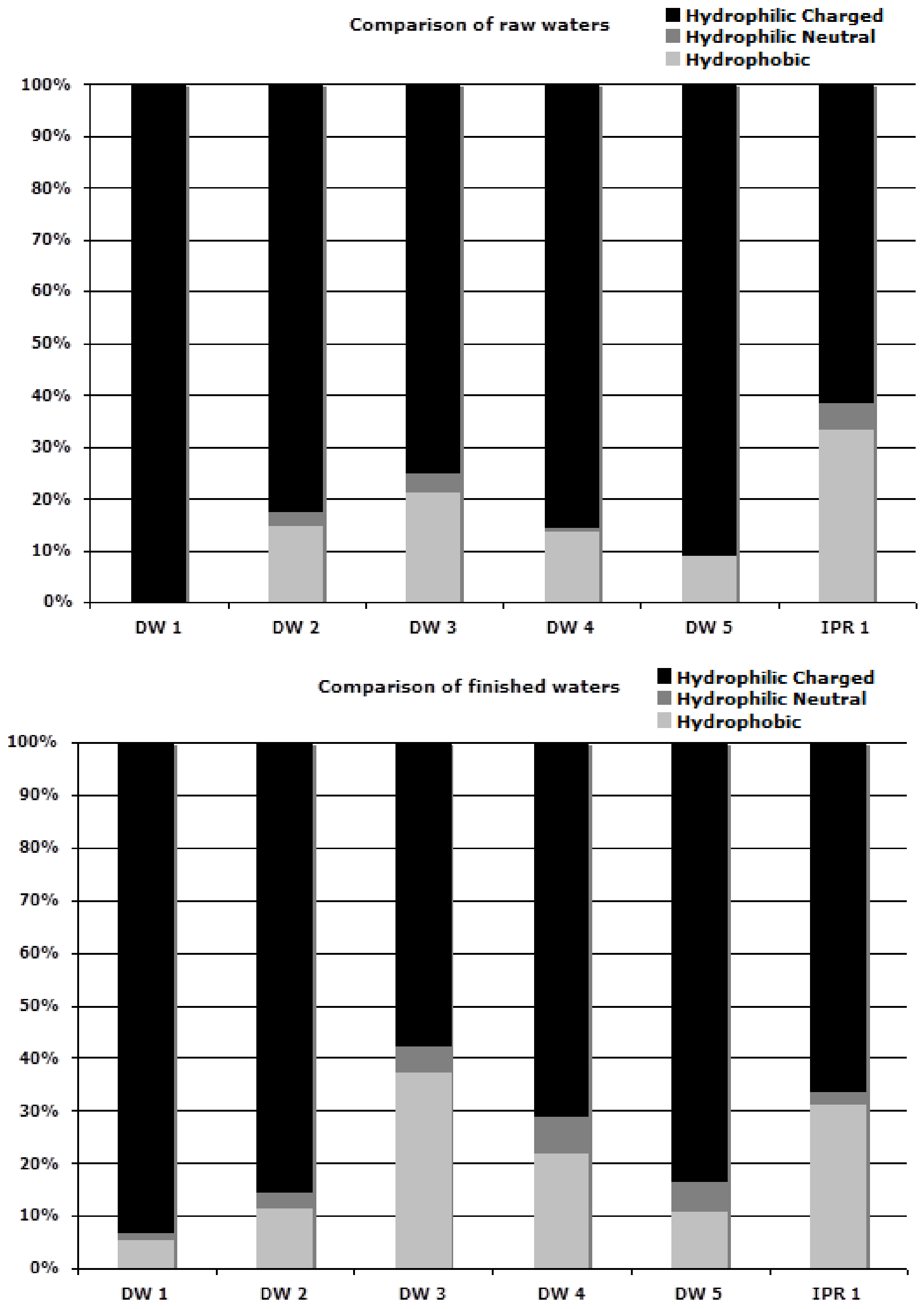


**Figure 4.18. Polarity results for raw and finished samples.**

## 4.4 Trace Organic Compounds

During this study, several emerging TOrCs were monitored in raw and finished water samples, and absolute concentrations are reported in Appendix B. Many of the targeted compounds have been proposed as indicator compounds that can be used to assess the efficacy of treatment or the potential for contamination (Dickenson et al., 2009). The presence of TOrCs in finished drinking waters is a function of source water quality and the type of treatment employed by the utility. Conventional water treatment processes, such as coagulation, flocculation, sedimentation, and filtration, are not effective in significantly reducing concentrations of TOrCs, and it is the chemical disinfection process that is largely responsible for any contaminant removal (Snyder et al, 2006a, 2006b, 2010; Westerhoff et al., 2005). Advanced water treatment processes, such as ozone, AOPs, and NF/RO membranes, have been shown to be very effective forms of treatment for removing TOrCs from water. Also, natural processes, such as SAT, have been shown to be effective at TorC removal (Drewes et al., 2003, 2006; Mansell et al., 2004; Snyder et al., 2007). Natural processes are particularly appealing, as they are very inexpensive, require low energy input, are residual-free, and use natural biophysiochemical processes, such as adsorption, microbial degradation, dispersion, and dilution, to reduce concentrations of contaminants in water. Occurrence concentrations for select TOrCs are summarized in Figures 4.19–4.30 and a discussion of their occurrence pattern and treatment efficacy is presented in the following sections. Also, a summary of removal efficiencies for all TOrCs examined is provided in Table 4.2.

**Table 4.1. Mean (± Standard Deviation) Removal Efficiencies in Percentage Observed for TOrCs at DW and IPR Sites Studied in this Project**

| | DW1 | DW2 | DW3 | DW4 | DW5 | IPR1 | IPR1 |
|---|---|---|---|---|---|---|---|
| Atenolol | | | 40.4 (7.3) | 60.7 (17.4) | 73.6 (19.6) | 99.8 (0.0) | 99.9 (0.0) |
| Atorvastatin | | | | 25.4 (NA) | | | 99.3 (0.1) |
| Atrazine | 9.6 (13.6) | 5.0 (10.0) | 24.9 (13.8) | 18.0 (18.1) | 59.0 (1.4) | 2.7 (3.8) | 92.0 (2.1) |
| Benzophenone | | | | 42.9 (0.5) | | 64.4 (3.6) | 87.5 (3.6) |
| BHA | | | | | | | 99.3 (0.2) |
| Bisphenol A | | | 21.9 (20.4) | | | | 49.2 (56.8) |
| Caffeine | 0.4 (0.5) | | 0.0 (0.0) | 33.1 (18.1) | 17.4 (NA) | 94.8 (5.0) | 98.5 (0.5) |
| Carbamazepine | 0.0 (0.0) | 26.3 (14.0) | 29.6 (19.9) | 34.4 (26.4) | 89.9 (4.1) | 39.7 (11.5) | 99.7 (0.0) |
| DEET | 4.5 (6.4) | | 9.1 (11.1) | 32.7 (6.9) | 48.0 (33.0) | 99.2 (0.4) | 99.9 (0.1) |
| Diazepam | | | | | | 63.9 (11.6) | 87.1 (4.5) |
| Diclofenac | | | | | | | 99.7 (0.1) |
| Dilantin | | 5.3 (10.5) | 32.6 (10.7) | 8.2 (11.1) | 69.7 (7.5) | 82.8 (3.5) | 99.1 (0.2) |
| Estradiol | | | | | | | 85.3 (12.6) |
| Estrone | | | | 44.7 (7.5) | | | 99.7 (0.1) |
| Ethynylestradiol | | | | | | | |
| Fluoxetine | | | | | | 37.9 (23.6) | 98.1 (0.3) |
| Gemfibrozil | 2.0 (2.8) | | 71.4 (7.2) | 11.8 (7.7) | 61.4 (28.4) | 100.0 (0.0) | 100.0 (0.0) |
| Ibuprofen | | | 36.0 (NA) | 0.0 (0.0) | | 83.8 (20.0) | 99.8 (0.0) |
| Iopromide | | | | | | 98.7 (0.2) | 52.7 (38.1) |
| Meprobamate | 0.7 (1.0) | 32.9 (8.9) | 32.9 (8.9) | 13.6 (10.8) | 49.9 (3.9) | 97.5 (0.2) | 99.5 (0.2) |
| Musk Ketone | | | | | | | 38.3 (6.7) |
| Naproxen | | | | 53.7 (9.5) | 54.5 (NA) | 97.5 (0.6) | 99.9 (0.1) |
| Octylphenol | | | | | | | 87.8 (0.4) |
| PFOA | | 1.0 (1.9) | 1.0 (1.9) | 67.8 (NA) | | 27.6 (16.5) | 69.7 (25.1) |
| PFOS | | 5.5 (4.4) | 5.5 (4.4) | 20.6 (29.1) | 4.0 (6.9) | | 98.2 (1.8) |
| Primidone | | 2.4 (2.9) | 2.4 (2.9) | 4.2 (7.2) | 76.1 (4.3) | 42.7 (7.1) | 99.3 (0.1) |
| Progesterone | | | | | | | 96.8 (NA) |
| Sulfamethoxazole | 94.3 (0.6) | 98.8 (0.2) | 98.8 (0.2) | 72.5 (17.6) | 98.8 (0.4) | 56.5 (1.3) | 100 (0.0) |
| TCEP | | | | | 35.5 (NA) | 97.2 (1.1) | 97.9 (0.3) |
| TCPP | | | | 9.1 (0.0) | | 91.7 (0.0) | 95.2 (2.2) |
| Testosterone | | | | | | | |
| Triclosan | | | | 32.5 (45.9) | | 80.8 (7.3) | 99.7 (0.1) |
| Trimethoprim | | | | 74.3 (6.3) | 61.4 (23.5) | 99.7 (0.0) | 100 (0.0) |

*Note:* NA = not applicable: only a single removal efficiency was calculated.

### 4.4.1 Atrazine

Average atrazine concentrations and standard deviations in raw and finished water samples for all sites are presented in Figure 4.19. The herbicide atrazine was one of the most ubiquitously detected TOrCs across all sites investigated. It was detected in all raw and finished drinking water samples, in all samples from IPR1, and in all but two IPR2 finished water samples. As an herbicide, the highest atrazine concentrations are usually observed where watersheds are under the impact of agricultural activities, making it a poor wastewater indicator as compared with other TOrCs. The watershed of study sites DW1, DW2, DW5, IPR1, and IPR2 are not located in agricultural areas of the United States, and concentrations of atrazine in samples from these sites were almost always less than 10 ng/L. Sites DW3 and DW4 are located in agricultural areas of the United States where atrazine is applied, and atrazine concentrations at these sites were higher than at the other drinking water sites, ranging from 150 to 560 and from 11 to 200 ng/L in DW3 and DW4 raw waters, respectively. Concentrations of atrazine in the raw water at DW3 were biased by one sampling event with anomalously high concentrations. These elevated concentrations were measured in late spring and are likely the result of springtime application of atrazine. This is the only TOrC that exhibited any seasonal occurrence variability. Little atrazine removal was observed during treatment at sites DW1, DW2, DW3, DW4, DW5, and IPR1 (Table 4.2). However, 92% removal was observed during IPR2 treatment, where most of the removal occurred during RO treatment.

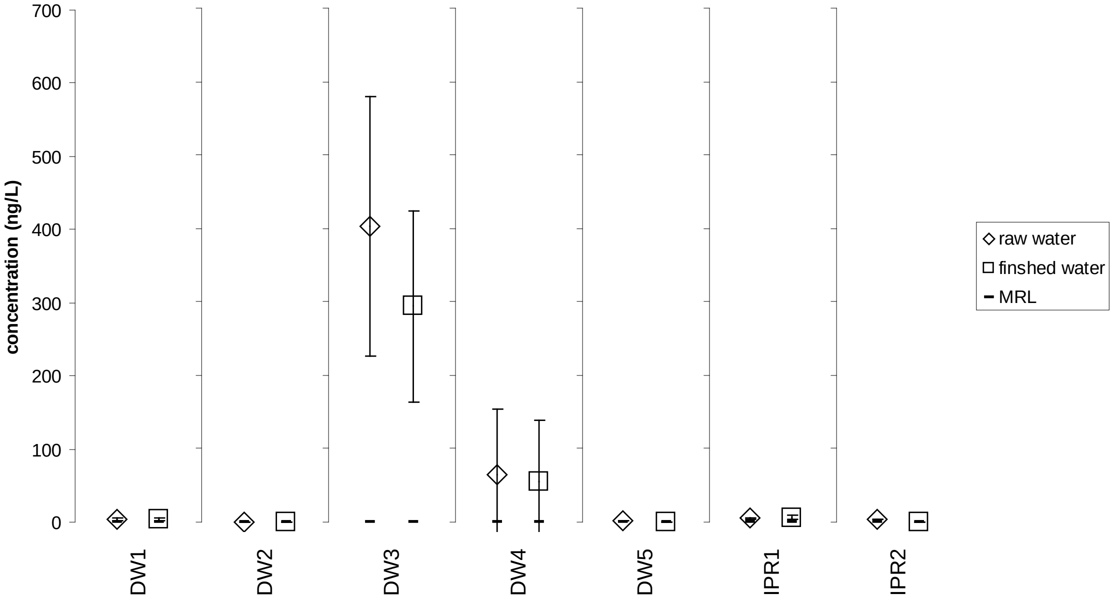


**Figure 4.19. Atrazine concentrations (average ± standard deviation) for raw and finished water.**

## 4.4.2 Caffeine

Caffeine was detected in all raw and finished water samples at DW1, DW2, DW3, and DW4, as well as in all source water samples at both IPR1 and IPR2 (Figure 4.20). However, at DW5 it was detected in only one raw water sample and was not detected in any finished water samples. The reason for the lack of detects in the DW5 source water is not known, but caffeine has been reported to have variable persistence in surface waters (Buerge et al., 2003; Kolpin et al., 2004; Seiler et al., 1999), and caffeine may not persist well in the source water of DW5. Measured caffeine concentrations at the drinking water sites were low and ranged from 5.9 to 59 ng/L. The lack of detected caffeine concentrations at DW5 is influenced by both the lack of detects in source water at this site, as well as the fact that ozone readily removes trace levels of caffeine to below detection limits (Snyder et al., 2006a). Of these locations, DW4 had the highest caffeine concentrations, which might indicate a higher degree of wastewater discharge in its watershed. Besides DW5, caffeine was not attenuated at DW1, DW2, DW3, and DW4 sites (Table 4.2). Measured concentrations in the source water of the indirect potable reuse sites were relatively high and ranged from 57 to 290 ng/L at IPR1 and from 290 to 540 ng/L at IPR2, respectively. However, it was not measured in any final water samples at either IPR site. This is consistent with the fact that caffeine has been shown to be readily removed by SAT as well as RO treatment (Drewes et al., 2003).

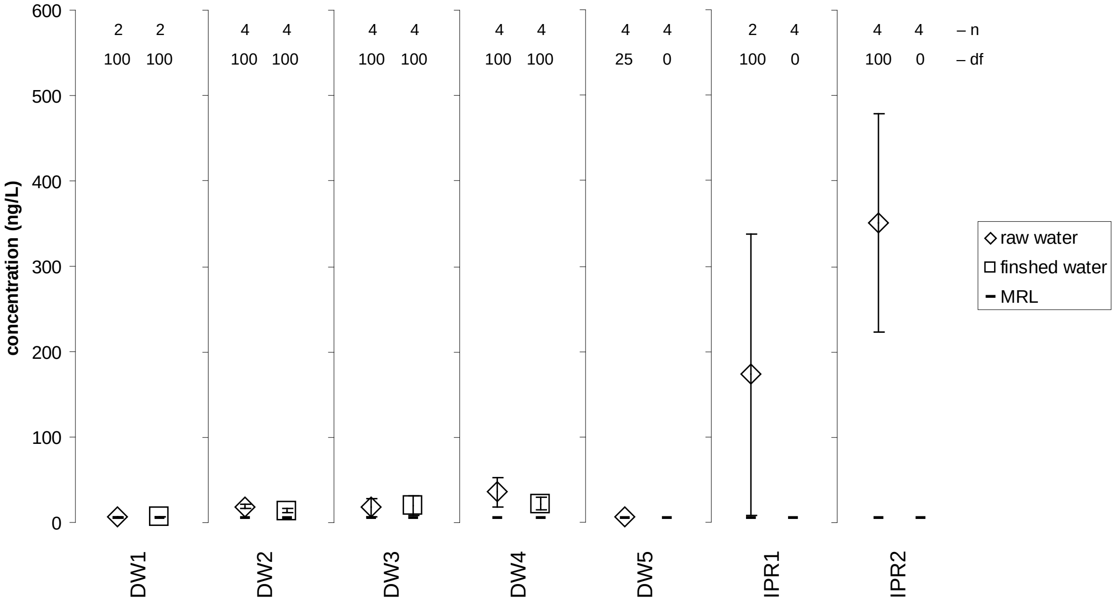


**Figure 4.20. Caffeine concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.3 Carbamazepine

Carbamazepine is an anticonvulsant and it was detected in all raw and finished water samples at DW1, DW2, DW3, and DW4, as well as in all raw water samples at DW5 at concentrations from 0.74 to 110 ng/L (Figure 4.21). The reason for the presence of low concentrations of carbamazepine in the source water at the control site (DW1) is not known, but likely indicates some unknown wastewater source influencing this site. Carbamazepine was also detected in all raw water samples and all but one finished water sample at PR1 and IPR2. It was not detected in any finished water samples at drinking water site DW5, which is consistent with the fact that it is easily removed by ozone. Measured carbamazepine concentrations at DW1, DW2, DW4, and DW5 were low and ranged from 1.1 to 21 ng/L. Measured concentrations at DW3 were slightly higher and ranged from 52 to 110 ng/L in raw waters. This is consistent with the fact that DW3’s watershed is impacted by a higher level of wastewater discharge. Carbamazepine concentrations at IPR1 were comparable to concentrations observed at DW3, ranging from 190 to 230 ng/L in the source water. Measured source water concentrations at IPR2 were also relatively high and ranged from 175 to 240 ng/L. Carbamazepine was not well removed at sites DW1–DW4 (Table 4.2). However, 90% of it was reduced at site DW5 because this compound was amenable to oxidation during the ozonation employed at this site. Carbamazepine was poorly removed during subsurface transport, where the decrease (40%) in concentration between raw and finished water at IPR1 is likely due to dilution with native groundwater. At IPR2, 99.7% removal of carbamazepine was achieved during RO treatment.

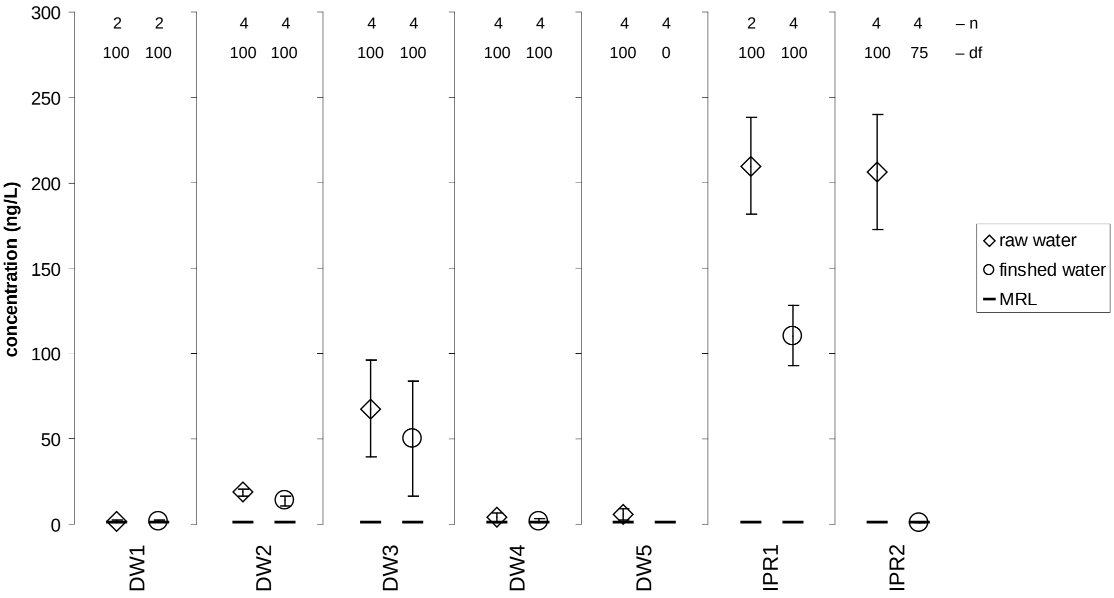


**Figure 4.21. Carbamazepine concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.4 Dilantin

Like carbamazepine, dilantin is an anti-epileptic pharmaceutical. During all sampling campaigns, it was detected in all raw and finished water samples at DW2, DW3, and DW4 (Figure 4.22). It was also detected in all raw water and two finished water samples at DW5. It was not detected in DW1 source water samples, although it was detected in one DW1 finished water sample just above the detection limit. Dilantin was also detected in all source water samples at IPR1 and IPR2. It was detected in two finished water samples at IPR2 but was not detected in any finished water samples at IPR1. Measured dilantin concentrations at DW2, DW4, and DW5 were low and ranged from less than 1.0 to 9.9 ng/L. Dilantin was not well removed at DW2 and DW4 sites (Table 3.2). Concentrations measured at DW3 were slightly higher and ranged from 75 to 150 ng/L in the raw water; some removal (30%) was observed after treatment, which might have been due to photolytic decay during UV disinfection. Measured dilantin concentrations in the source water samples of both indirect potable reuse sites were slightly higher than for the drinking water sites. Dilantin concentrations at these sites ranged from 150 to 190 ng/L for IPR1 and 85 to 160 ng/L for IPR2 source water samples, respectively. Dilantin was partially reduced (82%) during IPR1 treatment. The decrease in concentration at IPR1 suggests that dilantin is at least partially removed during SAT, though dilution may also contribute to lower finished water concentrations. Dilantin was more than 99% removed during IPR2 treatment, where RO treatment was primarily responsible for this reduction.

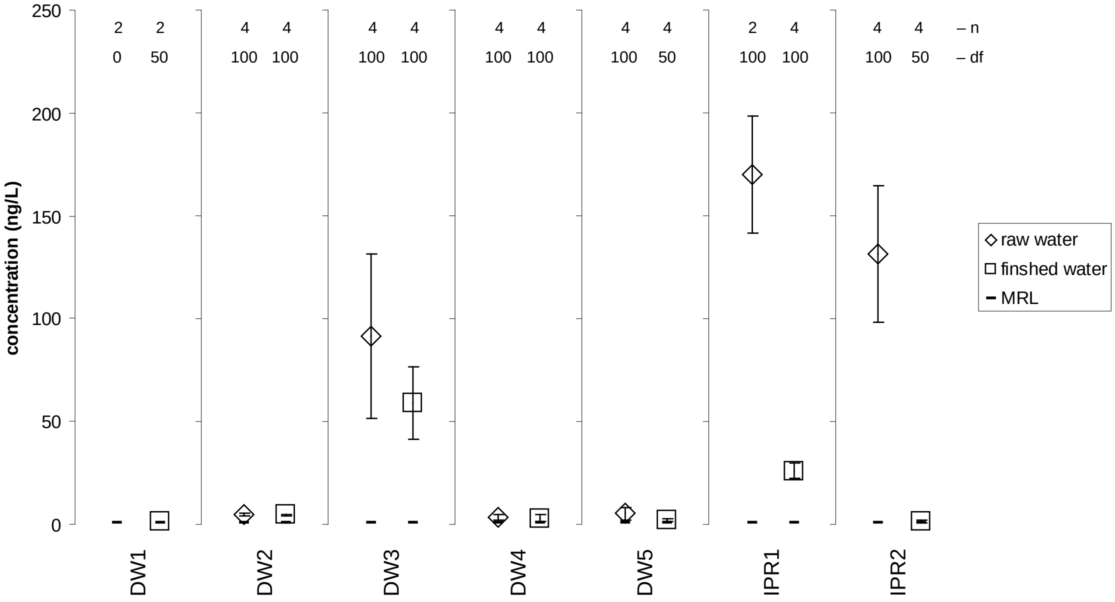


**Figure 4.22. Dilantin concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.5 DEET

DEET is a mosquito repellent and was detected in all raw and finished water samples at DW1, DW3, DW4, and DW5 (Figure 4.23). DEET was not detected in any raw or finished water samples at site DW2. The lack of detection in the raw water could be due to removal of this compound during riverbank filtration. It was also detected in all source water samples at both IPR1 and IPR2. It was not detected in any samples representing final water quality at IPR1 and IPR2. Measured DEET concentrations at DW1, DW3, DW4, and DW5 ranged from 1.5 to 71 ng/L. Among the drinking water sites, the highest DEET concentrations were observed at DW3 and DW1. The elevated concentrations at DW1 were somewhat surprising, because this was the reference site, with no known sources of wastewater affecting the raw water. Because DEET is an insect repellant, it is possible that its source stems from outdoor human recreation, which does occur upstream of DW1. Measured DEET concentrations at both indirect potable reuse sites (IPR1 and IPR2) were higher than at the drinking water sites, and ranged from 95 to 180 ng/L for IPR1 and 550 to1700 ng/L for IPR2 source water samples, respectively. DEET was not well removed at DW1, DW3, and DW4 sites (Table 4.2). DEET was partially removed at DW5 (48%), where ozonation was primarily responsible for this reduction (Dickenson et al., 2009). DEET was efficiently removed by the IPR1 (99.2%) and IPR2 (99.9%) treatment systems, where SAT and RO treatment, respectively, were primarily responsible for these reductions.

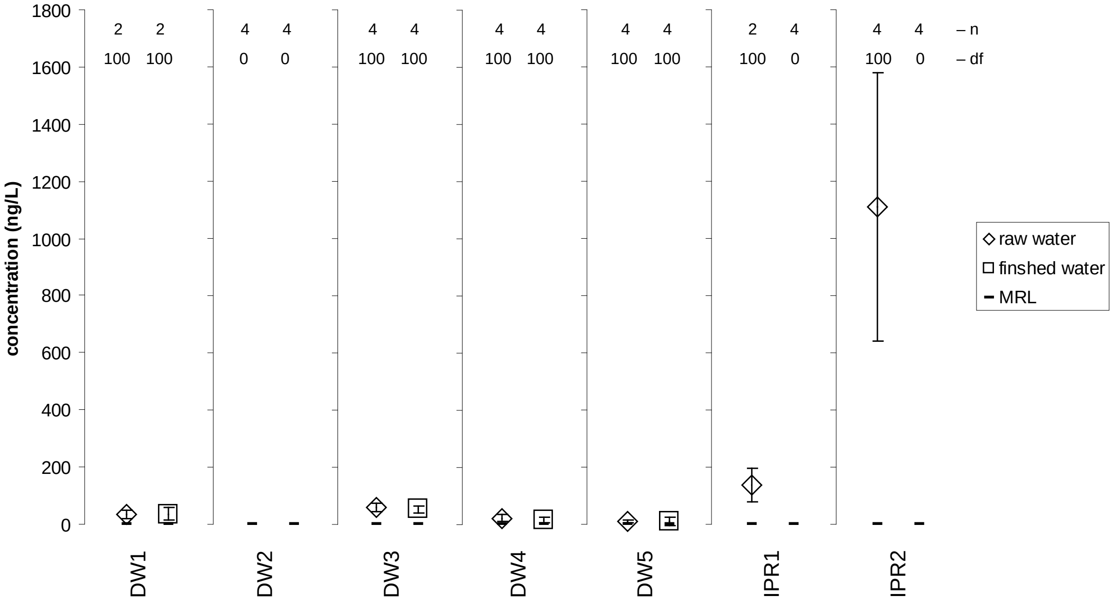


**Figure 4.23. DEET concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.6 Meprobamate

Meprobamate was detected in all raw and finished water samples at all conventional drinking water sites (Figure 4.24). The reason for the presence of low concentrations of meprobamate in the source water at the control site (DW1) is not known, but it could indicate some unknown wastewater source influencing this site. Meprobamate was also detected in all source and finished water samples from both IPR sites (IPR1 and IPR2). Measured concentrations at DW1, DW2, DW4, and DW5 were low and ranged from 0.68 to 37 ng/L. Concentrations measured at DW3 were slightly higher and ranged from 100 to 180 ng/L in raw water and 77 to 160 ng/L in finished water. The elevated concentrations of meprobamate at DW3 are consistent with the fact that DW3’s watershed had the strongest influence of wastewater. Measured meprobamate concentrations in the IPR1 and IPR2 source water samples were higher than those at the drinking water sites. Concentrations ranged from 310 to 380 ng/L for IPR1 source water samples and from 310 to 340 ng/L for IPR2 source water samples, respectively. Meprobamate was not well removed at DW1, DW2, DW3, and DW4 sites (Table 3.2). Meprobamate was partially removed at DW5 (50%), where ozonation was primarily responsible for this reduction (Dickenson et al., 2009). Meprobamate was efficiently removed by IPR1 (97.5%) and IPR2 (99.5%) treatment systems, in which SAT and RO treatment, respectively, were primarily responsible for these reductions.

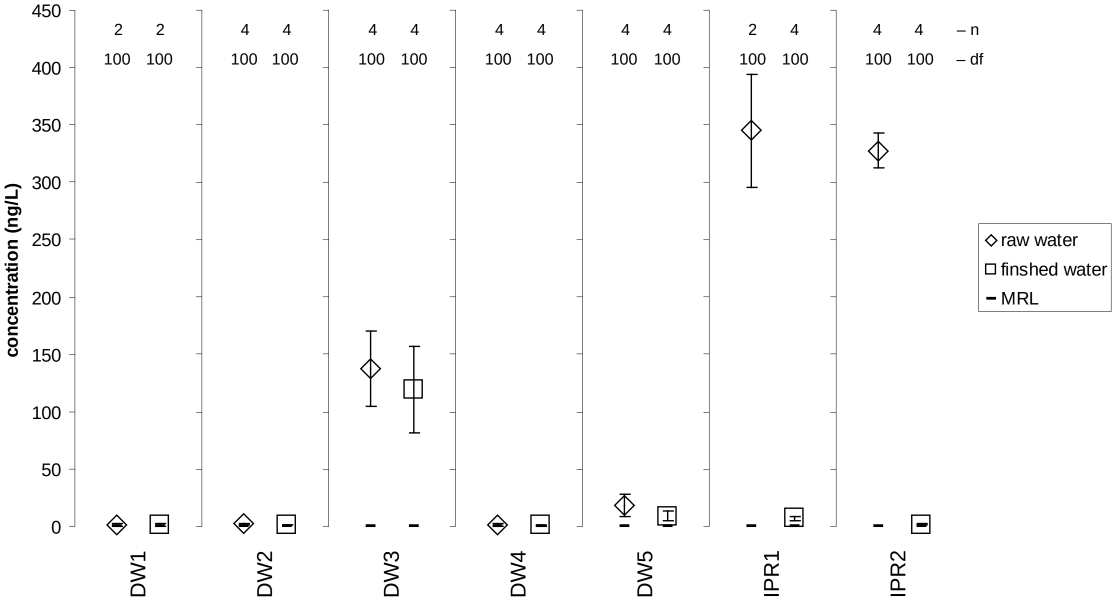


**Figure 4.24. Meprobamate concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.7 Perfluorooctanoic Acid

PFOA was detected in all raw and finished water samples at DW2 and DW3 (Figure 4.25). PFOA was detected in only one raw water sample at DW4, and was not detected in any raw or finished water samples at DW1 and DW5. PFOA was detected in all raw and finished water samples at IPR1. It was also detected in all raw water samples, but was only detected in one finished water sample at IPR2. Measured concentrations at DW2 were low and ranged from 9.1 to 13 ng/L in the raw water samples. Concentrations measured at site DW3 were slightly higher and ranged from 27 to 36 ng/L in the raw water. Measured PFOA concentrations in samples collected from IPR1 were similar to those measured at DW3. Concentrations ranged from 25 to 28 ng/L for IPR1 source water samples. Measured concentrations ranged from 15 to 28 ng/L for IPR2 source water samples. PFOA is not amenable to coagulation, UV, chlorine, ozone, or AOP oxidation processes (Quiñones and Snyder, 2009). This is in agreement with DW2 and DW3 results where PFOA was not removed (Table 4.2), indicating that it is resistant to conventional drinking water treatment that includes chlorine and disinfection processes. In addition, its persistence through IPR1 (27% reduced) suggests that it persists during subsurface transport. It was only detected in one of four IPR2 finished waters, which may suggest that it is effectively removed by RO treatment.

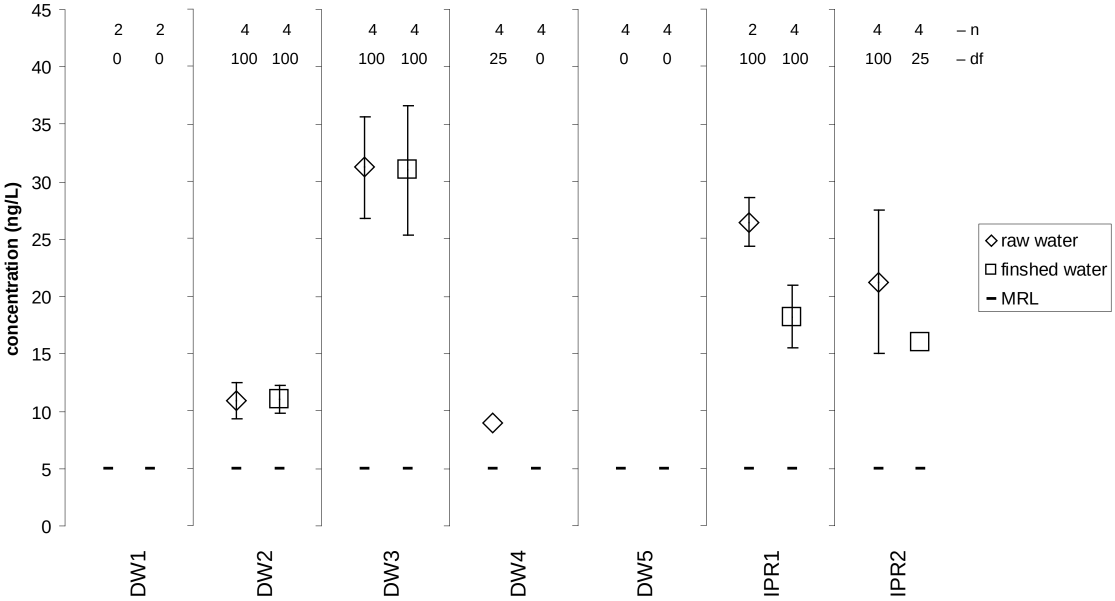


**Figure 4.25. PFOA concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.8 Perfluoroctanesulfonic Acid

PFOS was detected in all raw and finished water samples at DW2 and DW3 (Figure 4.26). PFOS was detected in three raw water samples and three finished water samples at DW5, and in two raw water samples and two finished water samples at DW4. It was not detected in any samples from DW1. PFOS was detected in all raw and finished water samples at IPR1. It was also detected in all raw water samples, but was not detected in any finished water samples at IPR2. Measured concentrations at sites DW4 and DW5 were low and ranged from 1.0 to 12 ng/L in raw and finished water samples. Concentrations measured at site DW2 were slightly higher and ranged from 7.7 to 12 ng/L in raw water samples. Concentrations measured at site DW3 were the highest of all drinking water sites, and ranged from 19 to 23 ng/L in raw water samples. Similarly to PFOA, PFOS concentrations did not change during treatment at sites DW2, DW3, DW4, and DW5 (Table 3.2), suggesting that it is poorly removed by chlorine or ozone oxidation. Measured PFOS concentrations at the IPR1 site ranged from 11 to 13 ng/L and from 43 to 73 ng/L in the source and finished water samples, respectively. The reason for the apparent increase in PFOS concentration is not known, but may be dilution with infiltrated stormwater that is elevated in PFOS. Regardless, its presence in finished water suggests that it is persistent during subsurface transport. PFOS is well removed during IPR2 treatment (98% removed), where it is well removed during RO treatment.

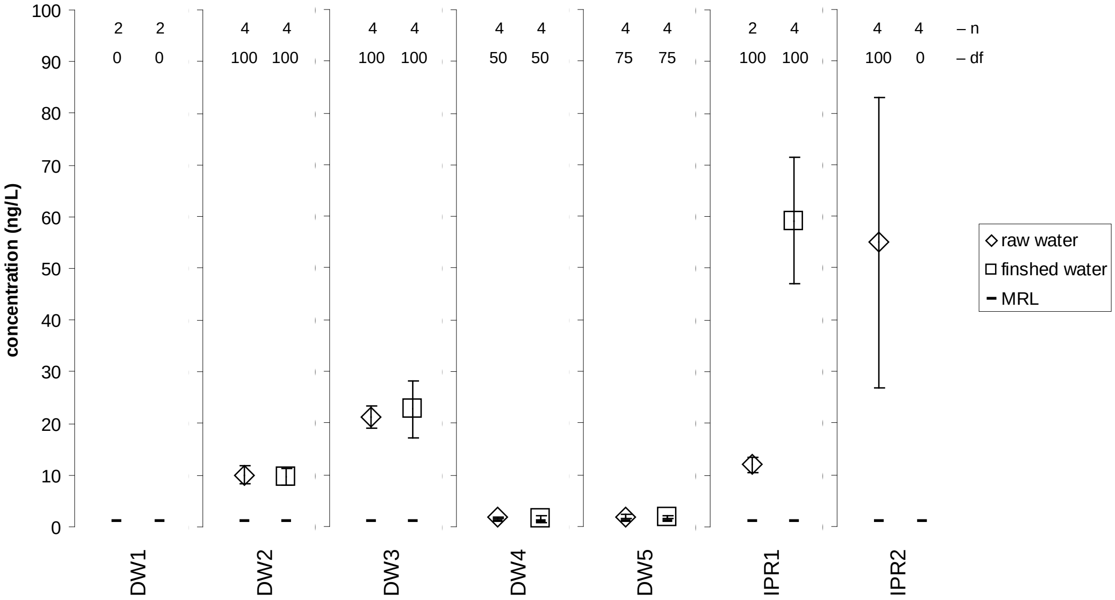


**Figure 4.26. PFOS concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.9 Primidone

Primidone, an anticonvulsant drug, was detected in all raw and finished water samples at DW2, DW3, and DW5, and in three raw water samples and three finished water samples at DW4 (Figure 4.27). Primidone was not detected in any samples from DW1. It was detected in all raw and finished water samples at IPR1. Primidone was also detected in all raw water samples and three finished water samples at IPR2. Measured concentrations at sites DW4 and DW5 were low and ranged from 1.0 to 2.5 ng/L in raw and finished water samples. Concentrations measured at site DW2 were slightly higher and ranged from 12 to 17 ng/L in raw water samples. Concentrations measured at site DW3 were the highest of all drinking water sites, and ranged from 27 to 50 ng/L in raw water samples. Measured primidone concentrations at the IPR1 site were 130 ng/L in source water samples. Primidone was not well removed at DW2, DW3, and DW4 sites (Table 4.2). Primidone was partially removed at DW5 (76.1%), where ozonation was primarily responsible for this reduction (Dickenson et al., 2009). Primidone was partially removed during IPR1 treatment (42.7%) and well removed during IPR2 treatment (99.3%); SAT and RO treatment, respectively, were primarily responsible for these reductions. Because primidone is traditionally persistent during SAT (Drewes et al., 2003), this reduction is likely due to dilution with ambient groundwater.

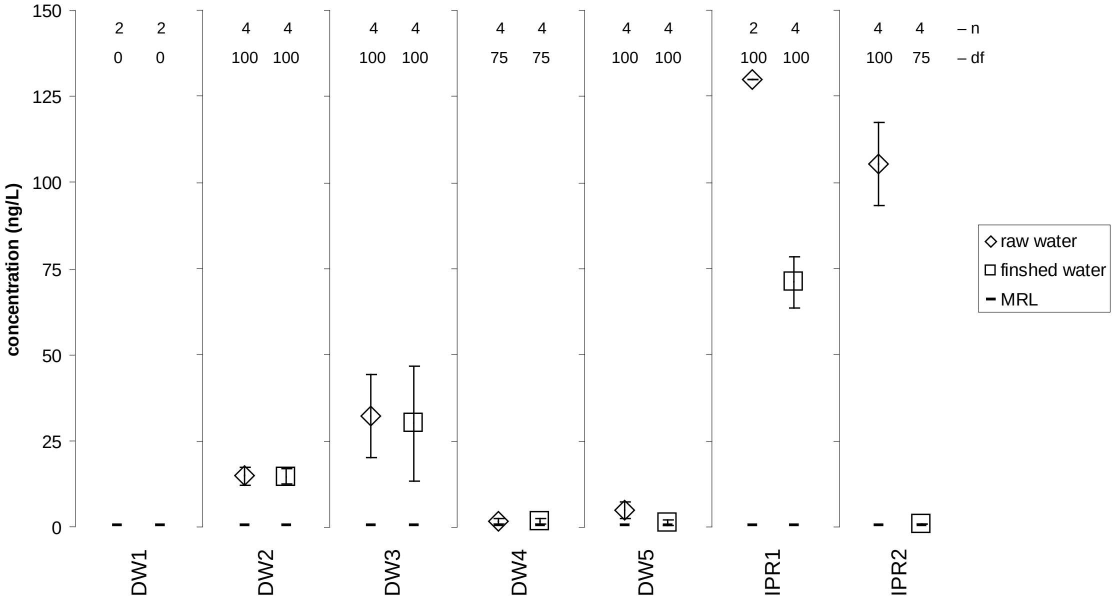


**Figure 4.27. Primidone concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.10 Sulfamethoxazole

Sulfamethoxazole, a sulfonamide antibiotic, was detected in all raw water samples (Figure 4.28). The reason for the presence of sulfamethoxazole in the source water at the control site (DW1) is not known, but it could indicate some unknown wastewater source influencing this site. It was also detected in two finished water samples from DW3, and all DW4 finished water samples. Sulfamethoxazole was not detected in the any finished water samples from DW1, DW2, or DW5. The sporadic but low detection of sulfamethoxazole at the DW sites is consistent with partial removal by chlorination (DW1–DW4) and good removal by ozone (DW5). It was detected in all raw and finished water samples at IPR1. It was also detected in all raw water samples and two finished water samples at IPR2. Measured concentrations in raw water samples ranged from 4.1 to 4.8 ng/L at site DW1, 18 to 24 ng/L at site DW2, 37 to 89 ng/L at site DW3, 2.5 to 24 ng/L at site DW4, and 16 to 38 ng/L at site DW5. Measured sulfamethoxazole concentrations at the IPR1 site ranged from 190 to 270 ng/L in source water samples. At the IPR2 site, measured concentrations ranged from 1,100 to 1,300 ng/L in source water samples. Sulfamethoxazole was well or partially removed at DW1 (94%), DW2 (99%), DW3 (99%), DW4 (73%), and DW5 (99%) sites (Table 4.2), which is due to chlorine (DW1–DW4) and ozone (DW5) oxidation processes employed at these sites. Sulfamethoxazole was partially removed during IPR1 treatment (57%) and well removed during IPR2 treatment (100%), where SAT and RO treatment, respectively, were primarily responsible for these reductions. Sulfamethoxazole has been shown to be relatively persistent through SAT (Snyder et al., 2004), so some of the reduction in concentration between raw and finished water is likely due to dilution.

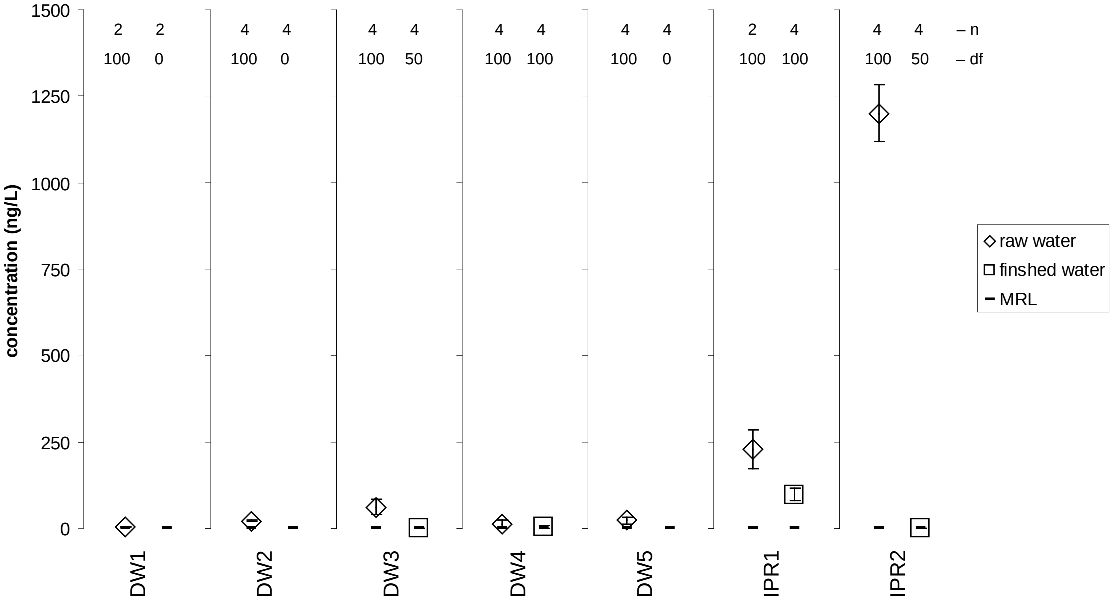


**Figure 4.28. Sulfamethoxazole concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.11 TCEP

TCEP, a chlorinated phosphate flame retardant, was detected in all raw and finished water samples from DW3, as well as one raw water sample from DW5 (Figure 4.29). TCEP was not detected in any other raw or finished drinking water samples. It was detected in all raw water samples from both IPR1 and IPR2, but was not detected in any finished water samples from either of these sites. Measured concentrations in raw water samples from site DW3 ranged from 210 to 1,300 ng/L. These concentrations would support a high degree of wastewater impact in DW3's source water. TCEP was also not well removed at DW3 (Table 4.2); thus this conventional water treatment system was rather inefficient at attenuating TCEP. The lone detected concentration in the source water of site DW5 was 16 ng/L. Measured TCEP concentrations ranged from 280 to 490 ng/L in IPR1 source water samples and 390 to 520 ng/L in IPR2 source water samples. TCEP was well removed by IPR1 (97%) and IPR2 (98%) treatment systems, where SAT and RO treatment, respectively, were primarily responsible for these reductions.

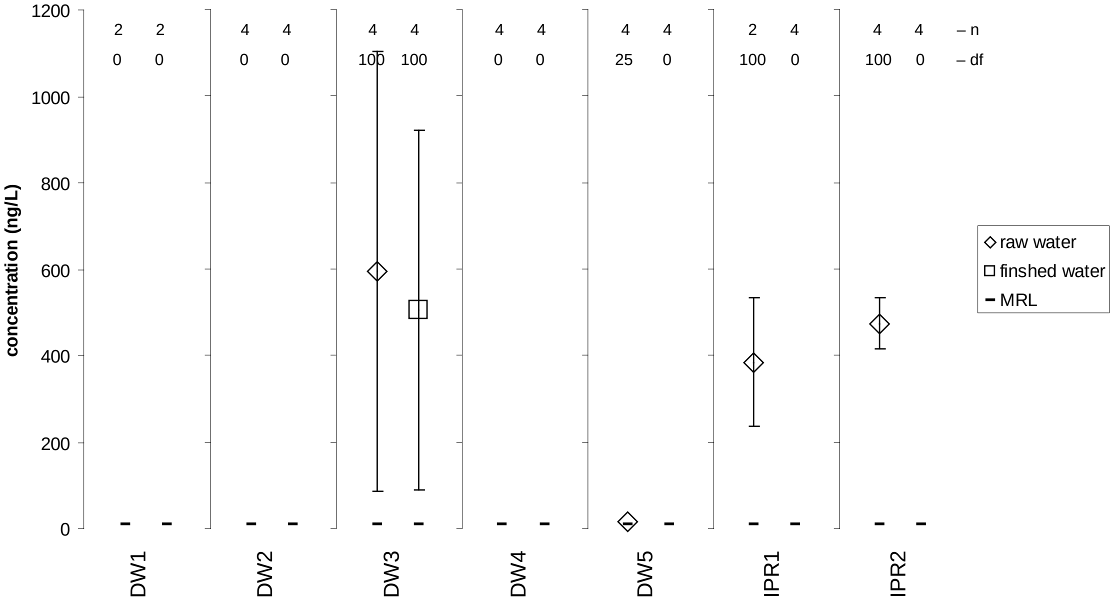


**Figure 4.29. TCEP concentrations (average ± standard deviation) for raw and finished water.**

### 4.4.12 TCPP

TCPP, a chlorinated flame retardant, exhibited an occurrence pattern similar to that of TCEP and was detected in all raw and finished water samples from DW3, as well as two raw water samples from DW4 (Figure 4.30). It was not detected in any other raw or finished drinking water samples. It was detected in all raw water samples from IPR1 and IPR2, but was not detected in any finished water samples from either of these sites. Measured concentrations in raw water samples from site DW3 ranged from 840 to 1,400 ng/L. TCPP was also not well removed at DW3 (Table 4.2); thus this conventional water treatment system was rather inefficient at attenuating TCPP. Both measured concentrations in the raw water of DW4 were 110 ng/L, just above the detection limit. Both measured TCPP concentrations in the source water samples for IPR1 were 1,200 ng/L and concentrations in source water samples for IPR2 ranged from 1,300 to 4,000 ng/L. TCPP was well removed by IPR1 (92%) and IPR2 (95%) treatment systems, where SAT and RO treatment, respectively, were primarily responsible for these reductions.

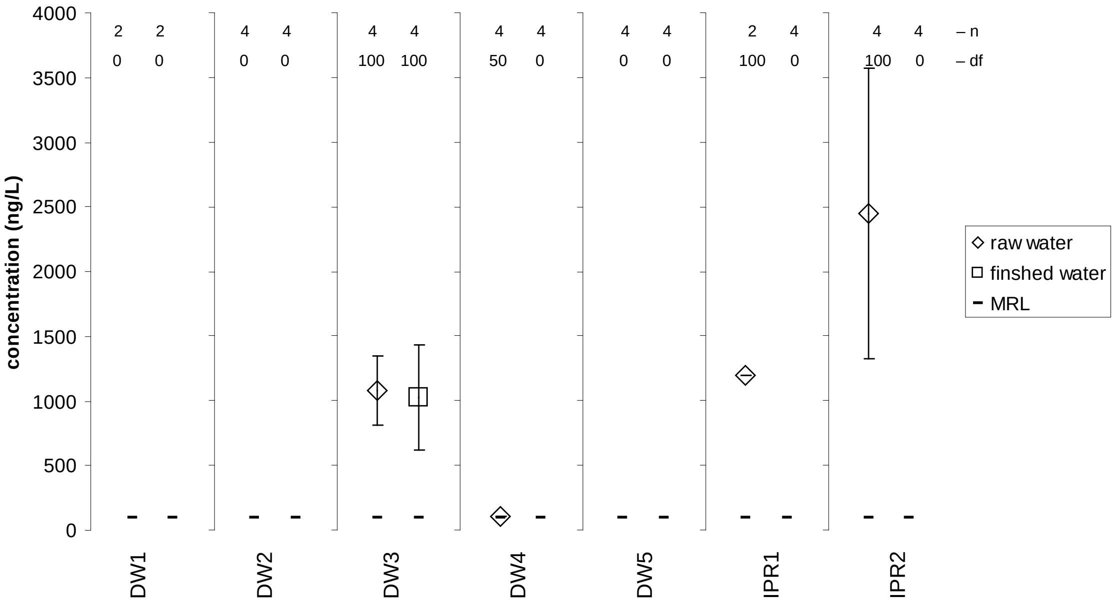


**Figure 4.30. TCPP concentrations (average ± standard deviation) for raw and finished water.**

*Chapter 5*

# Comparison of Indirect Potable Reuse and Conventional Finished Drinking Water Quality

## 5.1 Introduction

This chapter provides a direct comparison of finished water quality produced by two indirect potable reuse (IPR) systems and five conventional drinking water facilities, based on data compiled during this study and historic data collected by the participating utilities. Although IPR can be accomplished via multiple combinations of engineered and natural treatment systems, in this study two IPR systems were selected that practiced surface spreading via soil-aquifer treatment (SAT) and direct injection (after reverse osmosis and UV/$H_2O_2$ treatment) leading to groundwater recharge. The drinking water facilities that were selected employed conventional and advanced treatment processes using surface and groundwater supplies with various degrees of impact from upstream wastewater discharge. To account for the effect of the environmental buffer on finished water quality in IPR systems, two sampling locations were considered for the IPR study sites. An intermediate IPR sampling location represents water quality after treatment and retention in an environmental buffer with no or minimal blending with other sources. A final IPR sampling location takes into account the effect of the environmental buffer on the final water quality, which can include additional attenuation of certain parameters and blending with other source waters. Source waters used for blending in these systems represent native groundwater, surface water, and storm water.

Comparisons of the finished water quality for IPR and drinking water facilities are provided for individual parameters in the form of box-and-whisker diagrams. For some parameters, the national drinking water average (AVG) is also provided in these diagrams using the 1996 American Water Association (AWWA) drinking water quality database. When available, historical water quality data were included in data sets. The "*n*" and "df" in each box plot indicate the number of samples and the detection frequency, respectively. Data sets characterized by *n*=4 observations represent data collected from quarterly sampling performed during this study. Data sets characterized by $n > 4$ observations represent data collected from quarterly sampling performed during this study and historic data supplied by the participating utility. The box plot centerline indicates the median value, and the box includes the upper 75% and lower 25% quartiles. The outer lines or "whiskers" end at an observed value, which is at most 1.5 times the box width. Thus the whiskers include all values outside of the upper and lower quartiles that are within 1.5 times the box width. Values outside of the whiskers are generally considered outliers. The value of the detection limit is listed as the numeric value for nondetect results. Therefore, the lowest line on the box plot represents the detection limit for analytes with nondetect results. For analytes where only a single line is shown on the box plot for an analyte, this indicates that all results were below the detection limit.

### 5.1.1 Indirect Potable Reuse Systems

The site IPR1 practices surface spreading via SAT using a nitrified/denitrified tertiary-treated wastewater effluent leading to groundwater recharge. Details on the aboveground treatment can be found in Chapter 2 and are summarized in Table 4.1. Two downgradient groundwater monitoring wells were examined for this treatment operation: IPR1-A and IPR1-B. IPR1-A is a monitoring well (depth 16.8 meters) with a travel time of approximately 1.8 months representing water quality after tertiary wastewater treatment, surface spreading, and short-term SAT. IPR1-B is a monitoring well (depth 71.6 meters) with a travel time of approximately 21.2 months, representing the final water quality after additional retention in the environmental buffer, including blending with other source waters. The final water quality of IPR1-B was sampled prior to post-treatment disinfection.

IPR2 practices groundwater recharge via direct injection and utilizes non-nitrified secondary-treated effluent, followed by MF/RO and advanced oxidation (UV/AOP) treatment and final disinfection using chlorine. Details on the upstream treatment are presented in Chapter 2 and are summarized in Table 4.1. Two sampling locations were examined for this treatment operation: IPR2-A and IPR2-B. IPR2-A represents the water quality after advanced treatment and disinfection prior to direct injection. IPR2-B represents the water quality of a monitoring well (depth 16.8 meters) downgradient of injection wells representing a travel time of approximately 4 months. IPR2-B represents the final water quality for this operation after retention in the environmental buffer and blending with other source waters.

### 5.1.2 Drinking Water Systems

The five drinking water systems considered in this study are utilizing surface water and groundwater under the direct impact of surface water with various degrees of impact from upstream wastewater discharges. Although site DW1 serves as a control site with no known wastewater impact on its watershed, the exact degree of wastewater impact on sites DW2–DW5 is not known, but it likely ranges from 1% (DW2) up to 30% (DW3). The drinking water facilities studied employed conventional (coagulation/flocculation, sedimentation, filtration) and in some cases advanced treatment processes (oxidation with ozone). For comparison of water quality with IPR sites, the finished water quality after treatment and disinfection is presented and discussed in this chapter.

## 5.2 Finished Water Quality

### 5.2.1 General Water Quality

#### *5.2.1.1 Ammonia*

Although the source water of the indirect potable reuse site IPR1 exhibited an ammonia concentration comparable to that at the drinking water sites practicing chloramination (with ammonia addition) (Figure 3.1), the ammonia concentration in the final product water after SAT and blending (IPR1) was less than 0.1 mg/L and comparable to and in most cases lower than finished water quality of conventional drinking water sites (DW2, DW3, and DW5) (Figure 5.1). A direct comparison with the finished water quality of sites DW1 and DW4 was not possible, because ammonia was added and chloramination practiced at these sites. IPR2 exhibited the highest ammonia concentration in the source water of all sites studied (Figure 3.1). It is noteworthy that the final water quality at this site after treatment (RO/AOP) (IPR2A) was 1.1 mg-N/L, the highest ammonia concentration among all study sites. Only direct injection and blending reduced the concentration of ammonia to less than 0.5 mg/L (IPR2B), which was similar to that at DW1 and DW4. Because non-nitrified secondary effluent exhibiting ammonia concentrations of more than 30 mg-N/L in the source water is used at site IPR2, some ammonia can pass through reverse osmosis treatment and the remaining ammonia is not subsequently amended in the subsurface following direct injection.

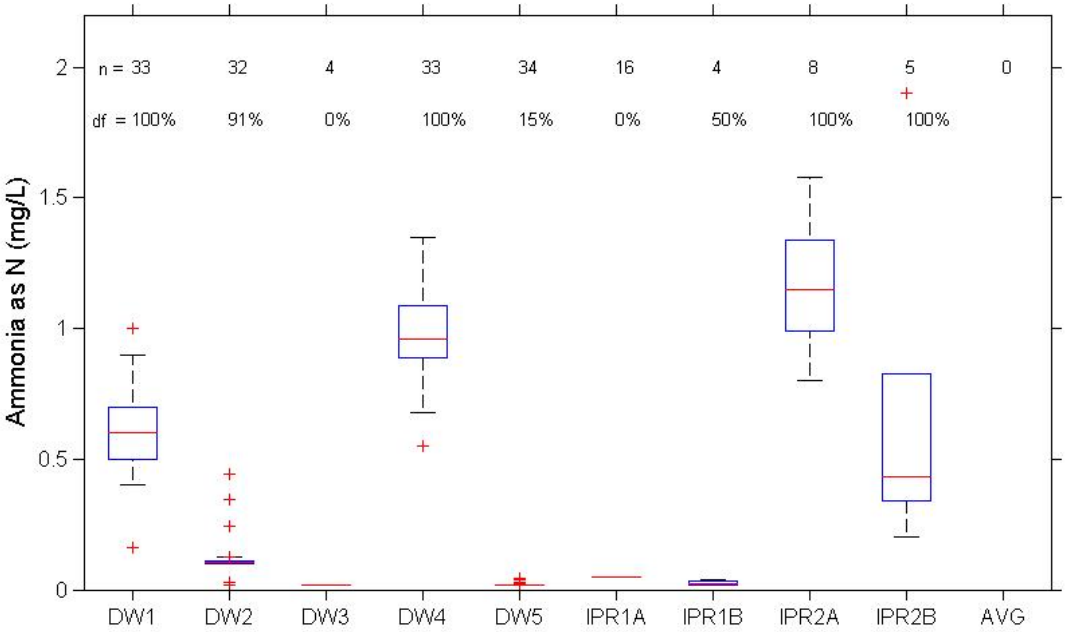


**Figure 5.1. Box plot of finished water ammonia concentrations.**

### *5.2.1.2 Nitrate*

Nitrate concentrations of less than 3 mg-N/L in the final product water of IPR1 were slightly higher than nitrate concentrations in the finished water of conventional drinking water plants and the national average (Figure 5.2). Nitrate concentrations measured in IPR1 product water were higher and statistically different from those at DW1 and DW4 and the national average (Table 5.3). However, with nitrate concentrations of 2 to 3 mg-N/L in the subsurface, the nitrate concentrations measured at site IPR1 were consistently lower than the EPA National Primary Drinking Water standard of 10 mg N/L and the CDPH groundwater recharge draft regulation requirement of 5 mg N/L. The nitrate concentrations of the final product water after aboveground treatment at site IPR2 were comparable to nitrate concentrations in conventional finished drinking waters and the national average (Figure 5.2). However, it is noteworthy that the highest concentrations of nitrate were observed after direct injection and blending. The source of this elevated nitrate concentration is unknown. Nevertheless, nitrate concentrations in product water at IPR2 were lower than EPA’s National Primary Drinking Water standard of 10 mg N/L.

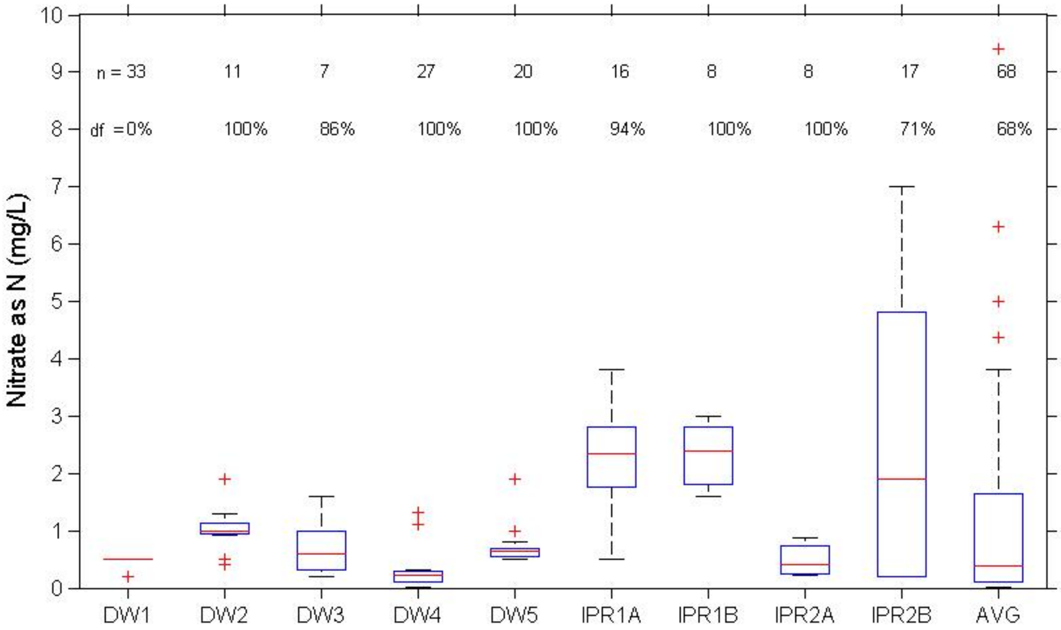


**Figure 5.2. Box plot of finished water nitrate concentrations at the five DW sites and two IPR sites as compared with the national average (AVG).**

### *5.2.1.3 Total Dissolved Solids and Conductivity*

The TDS concentrations and electrical conductivity (EC) in the product water of the indirect potable reuse site IPR1 after SAT and blending were higher than and statistically different from levels at DW1 and DW4 and the national average (Figures 5.3 and 5.4). TDS and conductivity concentrations in product water of IPR1, DW2, and DW5 were high and approaching or exceeding the EPA’s National Secondary Drinking Water standard of 500 mg/L. However, TDS and conductivity concentrations measured at site IPR1 were lower than concentrations measured in finished water at DW2 and DW5. The finished water qualities at sites DW2 and DW5 exceeded the EPA’s National Secondary Drinking Water standard. It is noteworthy that these sites use the same raw water supply, which is naturally elevated in TDS. TDS and conductivity levels in the final product water of IPR2 were comparable to concentrations observed at DW1, DW3, and DW4, as well as the national average (Figures 5.3 and 5.4). Similarly to IPR1, TDS and conductivity levels in IPR2 are lower than concentrations observed at DW2 and DW5. It is noteworthy that the TDS and conductivity concentrations increased after direct injection and blending (IPR2B), which is likely due to mixing with other dilution water that is elevated in TDS.

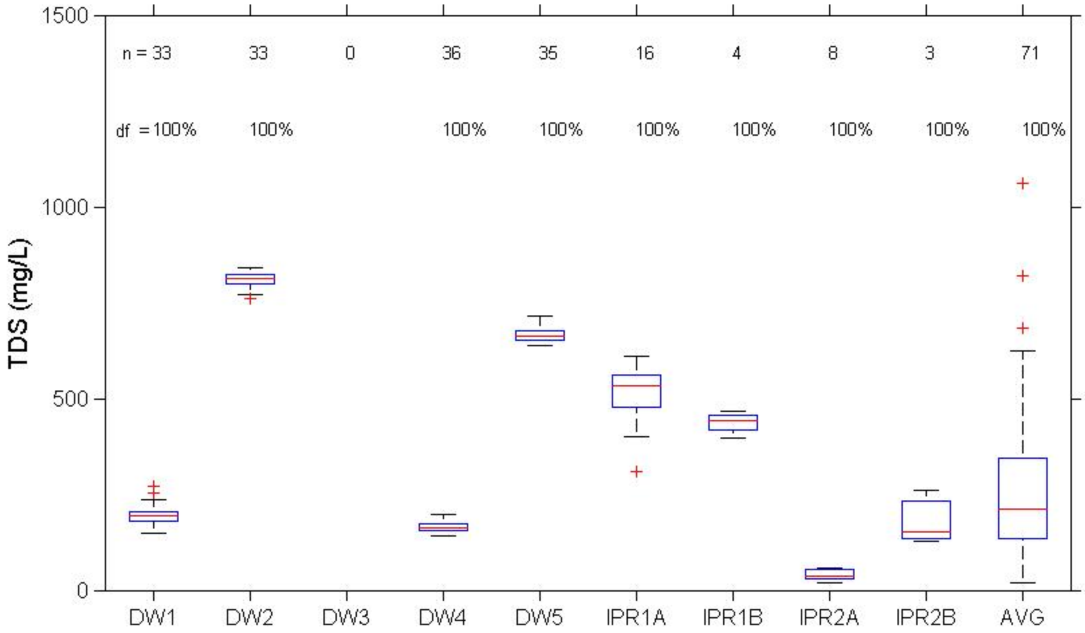


**Figure 5.3. Box plot of finished water TDS concentrations at the five DW sites and two IPR sites as compared with the national average (AVG).**

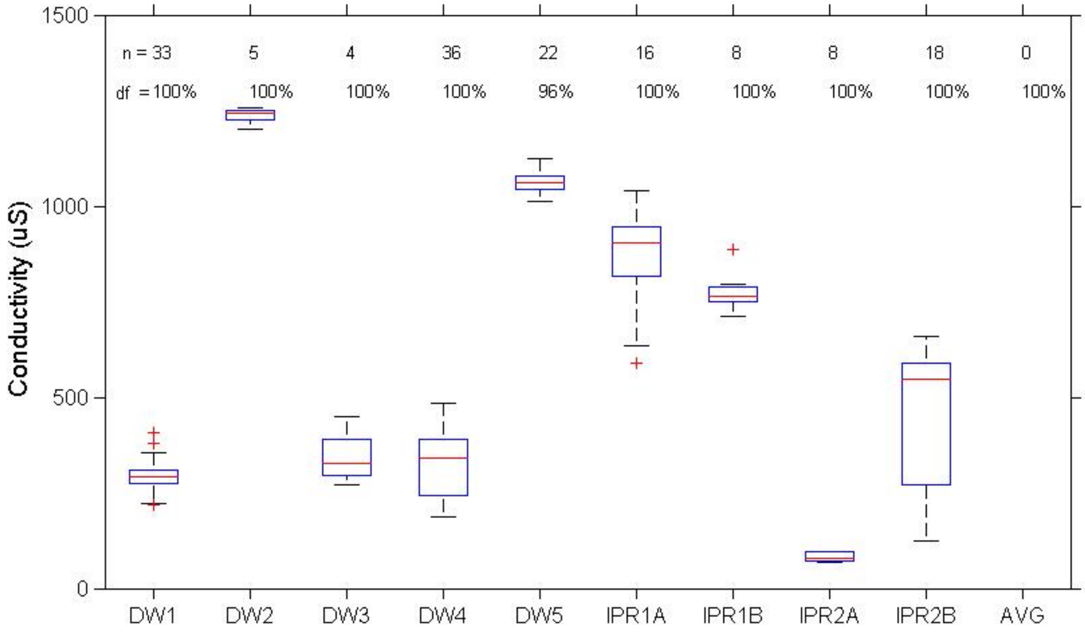


**Figure 5.4. Box plot of finished water conductivity levels at the five DW sites and two IPR sites.**

### *5.2.1.4 Phosphate*

The ortho-phosphate concentrations in the final product water for the IPR sites (IPR1 and IPR2) are indistinguishable from finished water qualities observed at drinking water sites DW1, DW2, and DW5 (Figure 5.5). Phosphate concentrations are relatively higher in finished water at drinking water sites DW3 and DW4, which is likely attributable to the application of phosphoric acid at site DW3 and ortho-polyphosphate at site DW4 for corrosion control prior to the clearwell (see site description in Chapter 2).

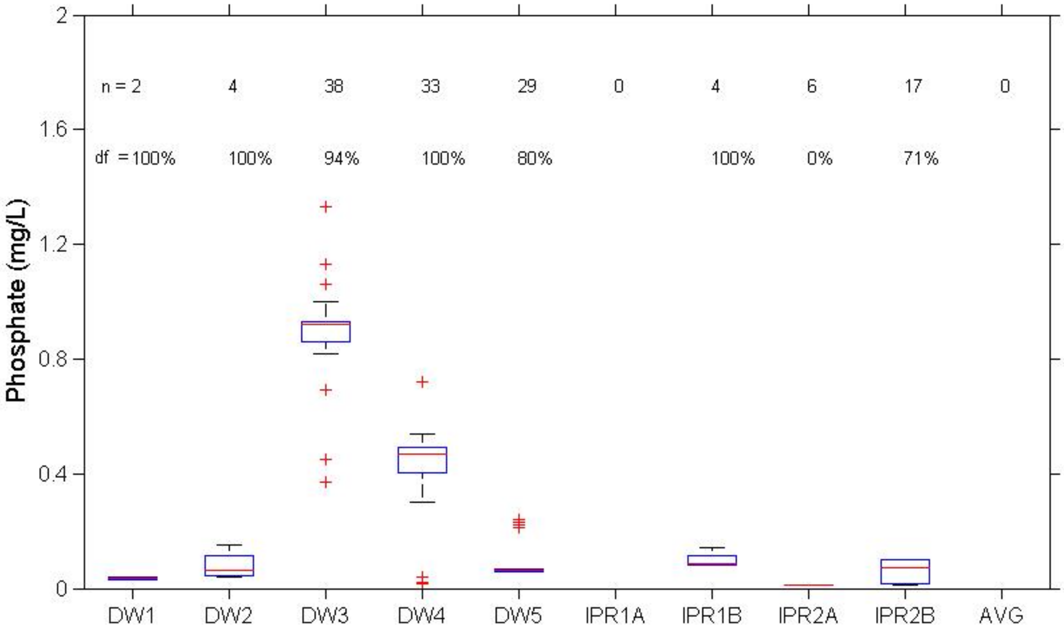


**Figure 5.5. Box plot of finished water phosphate concentrations as compared with the national average.**

### *5.2.1.5 Sulfate*

Sulfate concentrations in the final product water of IPR1 after SAT and blending are higher than concentrations observed in finished water at DW1, DW3, and DW4 (Figure 5.6). Sulfate concentrations at IPR1 are statistically different from concentrations observed at DW4 (Table 5.3). Sulfate concentrations in finished drinking water at sites DW2 and DW5 both exceed the EPA's National Secondary Drinking Water standard of 250 mg/L. These two sites utilize the same source water, which is naturally elevated in TDS, including sulfate. Sulfate concentrations in the final product water of IPR2 are indistinguishable from concentrations observed in finished drinking water at sites DW1, DW3, and DW4 (Figure 5.6) and IPR2 sulfate concentrations are less than the EPA's National Secondary Drinking Water standard. Similarly to IPR1, sulfate concentrations in IPR2 are statistically lower than concentrations in finished water at DW2 and DW5 (Table 5.5).

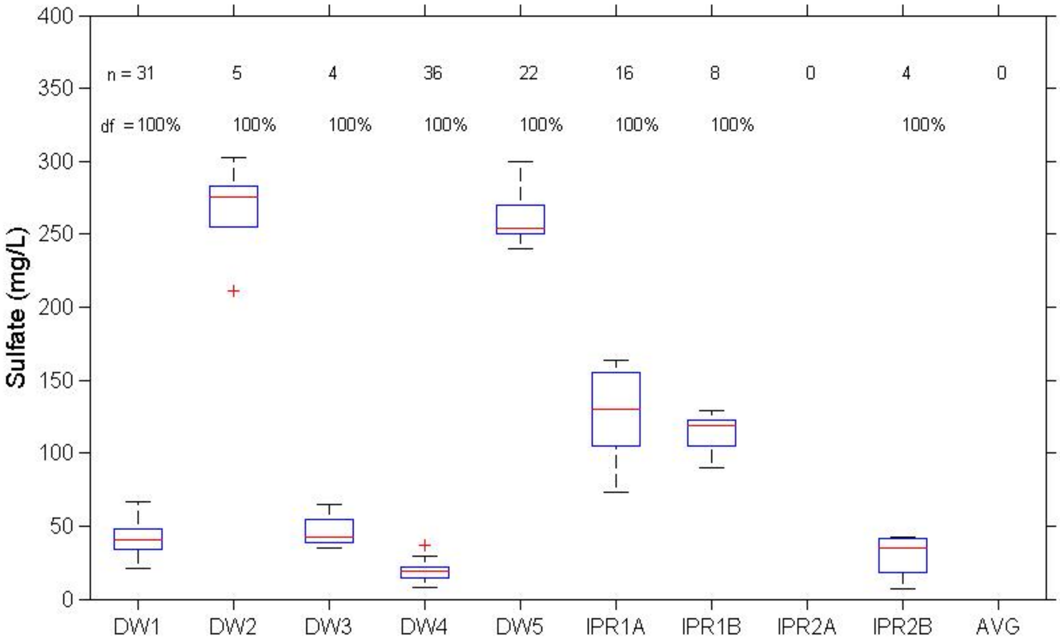


**Figure 5.6. Box plot of finished water sulfate concentrations as compared with the national average.**

#### *5.2.1.6 Regulated SOCs/VOCs*

Synthetic organic chemicals (SOC) and volatile organic chemicals (VOC) were measured for six sites, and observed concentrations of raw and finished water samples are summarized in Table 5.1. For the most part, no SOCs or VOCs were detected at any of the sites where historical data were provided. For DW3, DW5, and IPR2B no data were provided. At the indirect potable reuse site IPR1A after short-term SAT (shallow well downgradient of the surface spreading operation), the pesticide simazine was frequently detected, indicating some agricultural impacts for this well location, which might have been associated with landscape maintenance and urban runoff at this facility. A full list of all SOCs and VOCs that were analyzed at each site, along with their detection limits, is presented in Appendix B.

**Table 5.1. Summary of SOC and VOC Data**

| Site | Results | Sampling Events | Number of Analytes |
|---|---|---|---|
| DW1 | No SOCs/VOCs detected | One event in 2006 | 50 |
| DW2 | No SOCs/VOCs detected | Eleven events from 2005 to 2007 | 105 |
| DW3 | No SOC/VOC data provided | | NA |
| DW4 | No SOCs/VOCs detected | Two events from 2006 to 2007 | 108 |
| DW5 | No SOC/VOC data provided | | NA |
| IPR1A | No SOCs/VOCs detected, although the pesticide simazine was detected | Sixteen events from 2005 to 2008 | 66 |
| IPR1B | No SOCs/VOCs detected | Four events from 2006 to 2007 | 64 |
| IPR2A | No SOCs/VOCs detected | Three events from 2007 to 2008 | 153 |
| IPR2B | No SOC/VOC data provided | | NA |

*Notes:* IPR1A – Monitoring well, 1.8 month travel time; IPR1B – Monitoring well, 21.2 month travel time; IPR2A – RO/AOP treated water before direct injection.

## 5.2.2 Bulk Organic Matter

### *5.2.2.1 Total Organic Carbon*

The final product water quality of surface spreading operations (IPR1) exhibited TOC concentrations of less than 2 mg/L, which were lower than or comparable to TOC concentrations for conventional finished drinking waters and the national average (Figure 5.7). This result reveals that SAT is effective at reducing higher concentrations of TOC in reclaimed water (greater than 5 mg/L). The TOC concentration after SAT is also lower and statistically different from that at DW3, DW4, and DW5, which exhibit higher TOC concentrations in their finished drinking water (Table 5.3).

For site IPR2, TOC concentrations after aboveground treatment (IPR2A) are less than the TOC concentrations exhibited by any of the conventional finished drinking waters (Figure 5.7). The TOC concentration increased after direct injection (IPR2B), which is likely because of mixing with other source waters used for recharge in this aquifer that are elevated in TOC. The TOC concentration of IPR2 is also lower and statistically different from those at DW1, DW3, DW4, and DW5, as well as the national average (Table 5.5). The key removal process employed at IPR2, RO followed by advanced oxidation, is very effective at reducing TOC concentrations to less than 0.5 mg/L (IPR2A).

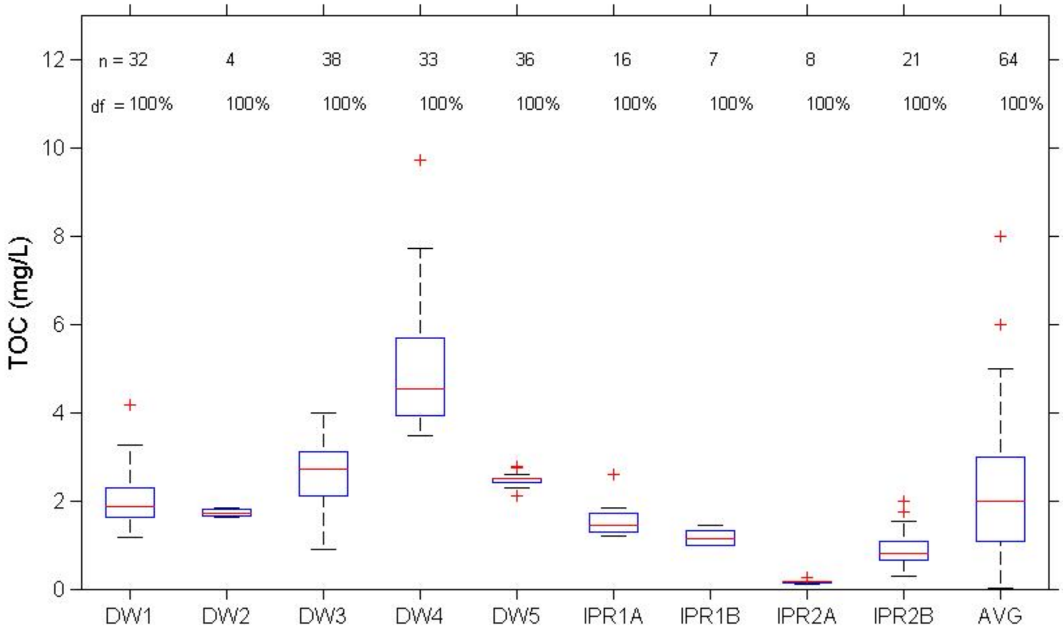


**Figure 5.7. Box plot of finished water TOC as compared with the national average (AVG).**

### *5.2.2.2 Specific UV Absorbance*

Organic matter in finished water samples is further characterized by the SUVA, a measure of aromaticity, which is defined as the ratio of UV absorbance at 254 nm to DOC. The SUVA value measured after surface spreading operation and natural treatment (IPR1) is comparable to the SUVA values reported for the DW4 site (~1.7 L $mg^{-1}$ $m^{-1}$) (Figure 5.8). The SUVA for IPR1 was higher than the SUVA for the other conventional finished drinking waters, indicating that IPR1 has a slightly higher aromatic content associated with the organic matter after SAT and blending in the subsurface. In general, SUVA values are less than 2 L $mg^{-1}$ $m^{-1}$ for conventionally finished treated drinking waters; therefore the final water quality at IPR1 resembles the finished water quality of the conventional drinking water sites. The SUVA value of the finished water after direct injection (IPR2) was consistently lower than the SUVA values for conventional finished drinking waters (Figure 5.8). Thus, the final water quality at IPR2 after blending in the subsurface has a lower aromatic content associated with the organic matter.

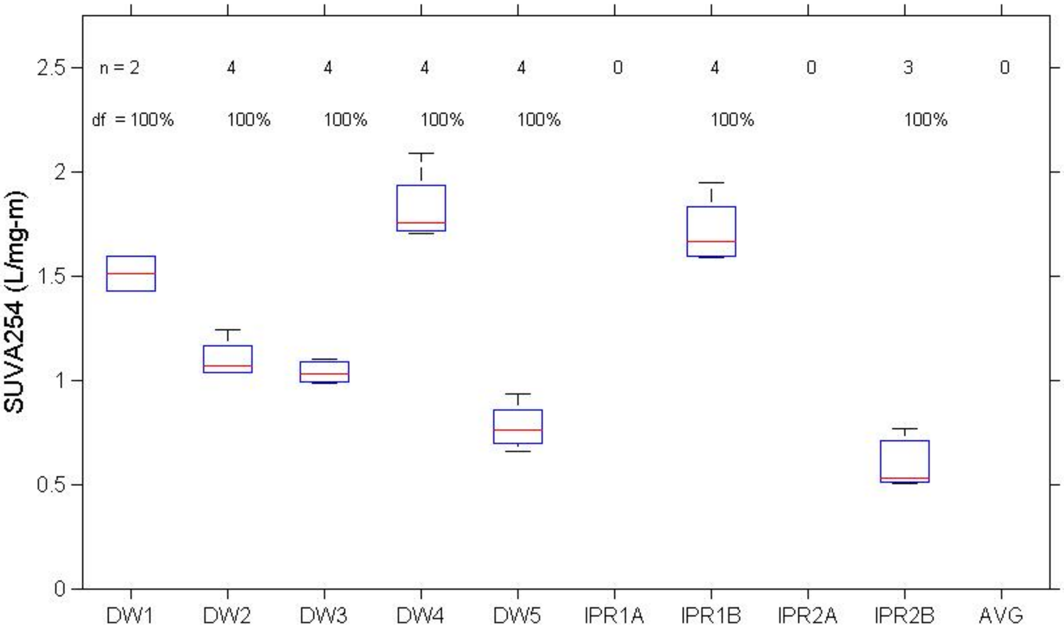


**Figure 5.8. Box plot of finished water SUVA levels as compared with the national average (AVG).**

### *5.2.2.3 Size-Exclusion Chromatography*

Organic matter can be further characterized by its size and key moieties using SEC with online DOC and UV detection. Based on the results of this analysis, DW4 and DW5 exhibited the highest contributions of high-molecular-weight organic compounds (~42 min retention time) in their finished water samples (Figures 5.3 and 5.4). The final water quality of the IPR site after SAT and blending (IPR1) resembles the TOC distribution in the size and character of DW1 and DW2, exhibiting much lower concentrations of humic substances than at impacted DW sites (DW3–5). These findings are confirmed by the SEC-UV absorbance results, in which the character of the final water quality of IPR1 was similar to those of DW1 and DW2. The final water quality of the IPR site after direct injection (IPR2) exhibited the lowest TOC concentration among all finished waters. The concentration was too low for a TOC chromatogram to be obtained for this sample. In terms of the UVA chromatogram, the signal from the IPR2 samples did not reveal any responses beyond the baseline of the instrument.

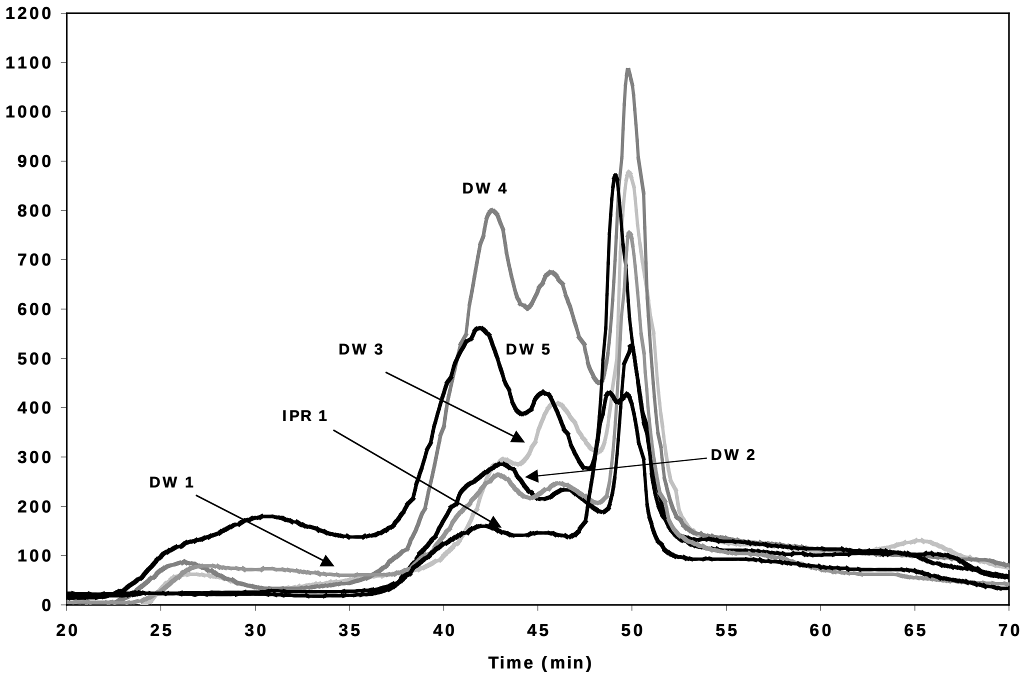


Figure 5.9. Comparison of SEC-TOC chromatograms of finished water samples for each site.

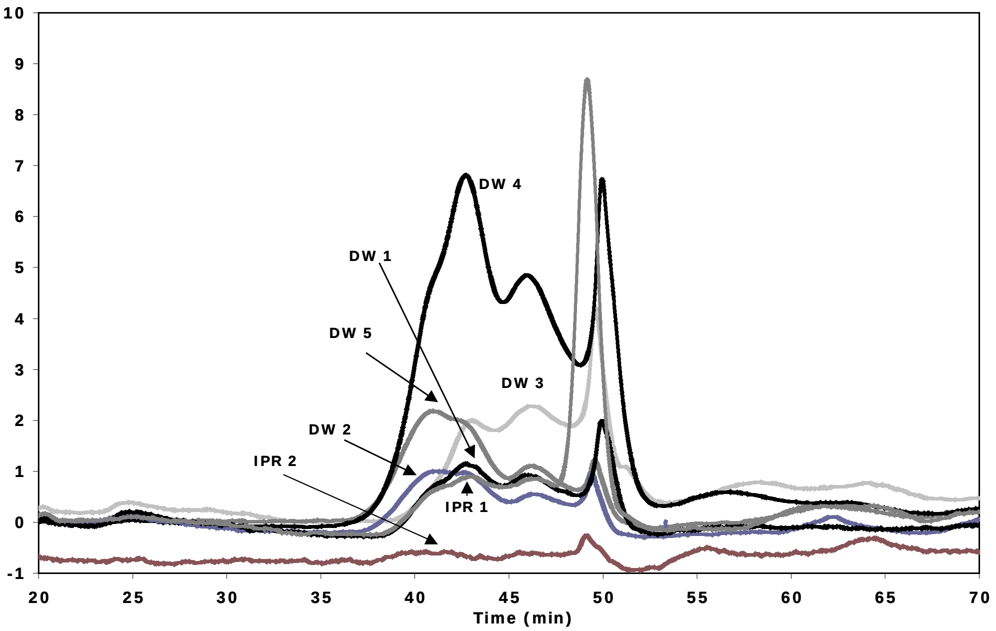


Figure 5.10. Comparison of SEC-UV chromatograms of finished water samples for each site.

### *5.2.2.4 Fluorescence Index*

FI is a qualitative measure of organic matter originating from microbial activities. The final water quality of the IPR site after SAT and blending (IPR1) exhibited the highest fluorescence index (Figure 5.5), followed by DW3, DW1, DW4, DW2, IPR2, and DW 5. As discussed in Chapter 4, higher FI is associated with microbially derived organic matter. The highest FI for source waters was for the DW3 site (Chapter 4), so even after treatment this site retained the same higher microbial character. After direct injection, the final water quality at the IPR2 site exhibited a fluorescence index of 1.28, which is comparable to the conventional finished drinking waters from sites DW2, DW4, and DW5. The FI for the DW sites was generally higher than that for source water indicating that terrestrial components were removed, resulting in a higher microbial signature.

### *5.2.2.5 Polarity*

Polarity analysis was performed for all final water qualities with the exception of the IPR2 site. In this case, the overall concentration of carbon was too low to allow for analysis. As described in Chapter 3, the polarity analysis was conducted under ambient conditions; therefore the polarity results are only applicable under those conditions.

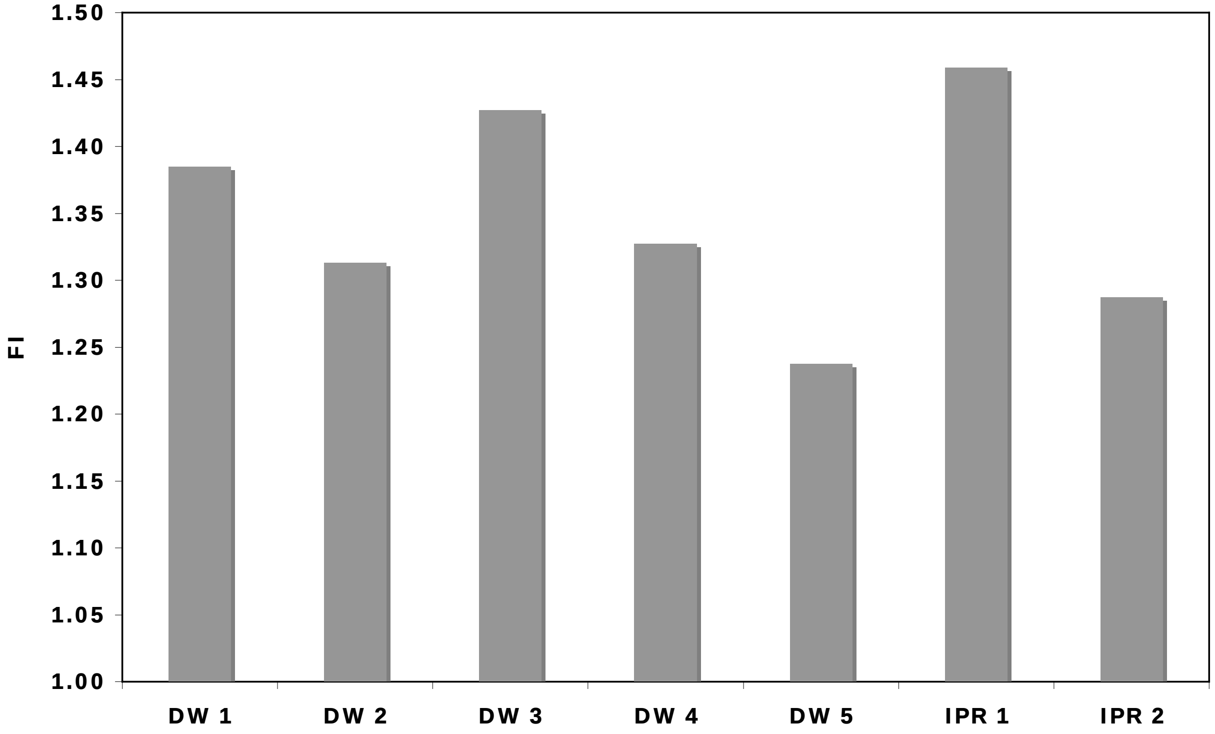


**Figure 5.11. Fluorescence index results for finished water samples.**

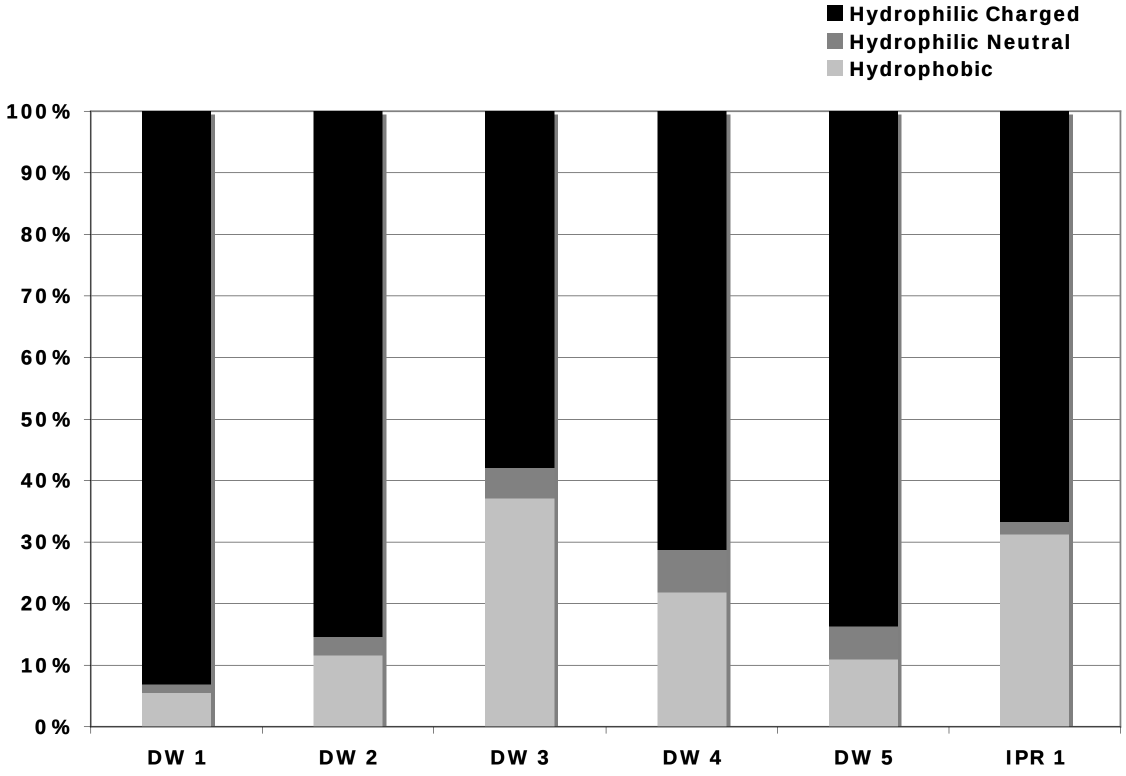


**Figure 5.12. PRAM results for finished water samples.**

The hydrophobic character of the final water quality after surface spreading and natural treatment (IPR1) was approximately 32% and similar to finished drinking water qualities for sites DW3 and DW4 (37% and 22% respectively). The other sites exhibited lower percentages of hydrophobic character, with the lowest percentage being found at the DW1 site. The hydrophilic charged character of the sites varied, with the highest value being found at the DW1 site and the lowest value at the DW 3 site.

No data are presented for the IPR2 site, as the limited amount of carbon inhibited the polarity analysis from being performed.

## 5.3 Finished Water Reactivity

The reactivity of the different finished water qualities was assessed by formation potential tests under standardized conditions.

### 5.3.1 Nitrosamine Formation Potential

The nitrosamine FP test determined the maximum nitrosamine formation by chloramination, which can be used as a surrogate to assess the amount of nitrosamine precursors present, and thus compare nitrosamine precursors in waters produced from conventional drinking waters and IPR systems. Nitrosamine FP tests are described in Chapter 3. Nitrosamine FP tests were performed with water samples from all of the sites except DW1 and DW4 to assess the total amounts of nitrosamine precursors present in the finished waters. In all, seven nitrosamines were measured, following nitrosamine FP tests. Nitrosamine FP tests were not performed for DW1 and DW4, as finished water could not be collected without a preexisting disinfectant residual, which would affect nitrosamine FP tests. Nitrosamines prior to applying chloramines were not detected in the water samples of the selected DW sites. The IPR2 site exhibited an initial background level of 2.1 ng/L NDMA.

Among all water qualities tested, the drinking water site DW3 exhibited the highest FP concentrations of nitrosamines, nitrosodimethylamine, and nitrosodiethylamine (Figure 4.13). The FP concentration of NDMA at DW3 was 14 ng/L, which is in excess of the California Department of Public Health's (CDPH's) notification level of 10 ng/L for drinking water. The final water quality after FP tests at IPR1 after SAT and blending had a nitrosodimethylamine concentration of 3 ng/L. For the direct injection site IPR2, the NDMA concentration for the formation potential test was approximately 4 ng/L. Thus, both IPR sites exhibited nitrosamine FPs in their final water samples that were below the CDPH action level of 10 ng/L.

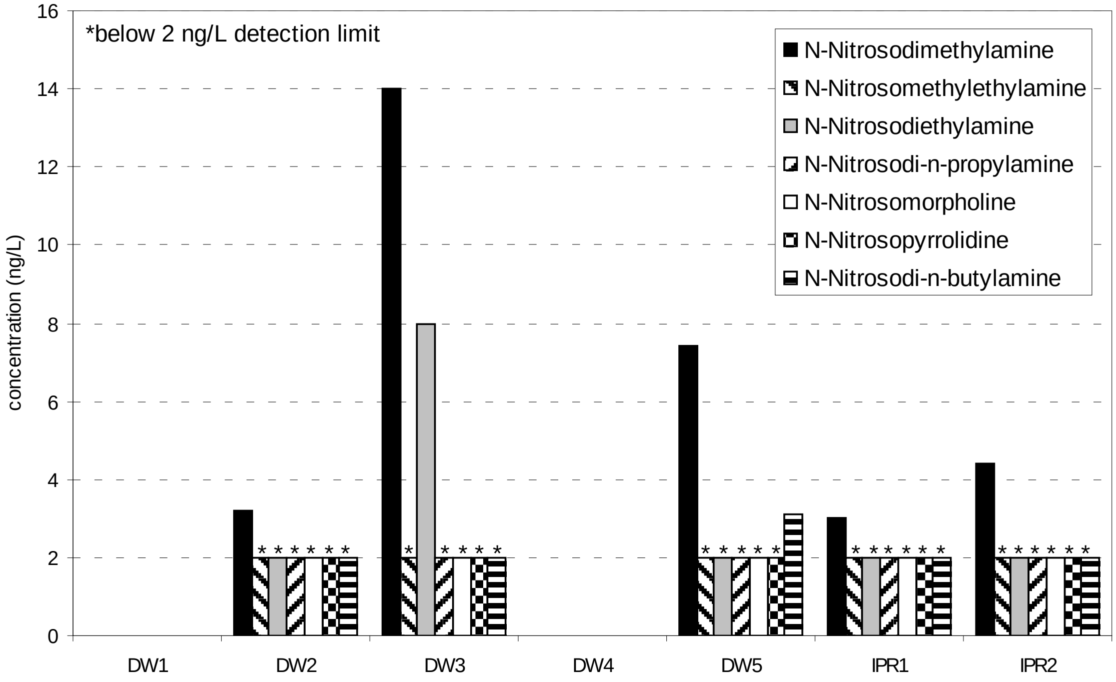


**Figure 5.13. Nitrosamine-FP concentrations for finished waters**.

### 5.3.2 Total Organic Halide Formation Potential

The TOX FP test was used to determine the maximum TOX formation by chlorination, which can be used as a surrogate to assess the amount of DBP precursors present, and thus compare DBP precursors in waters produced from conventional drinking waters and IPR systems. TOX FP tests were performed at all of the sites to assess the total amounts of halogenated byproduct precursors present in the finished waters with a contact time of 7 days targeting a final chlorine residual of 3 to 5 mg/L (SM 5710B). TOX FP tests were performed using bench-scale batch reactors with full-scale samples that were collected *prior* to secondary disinfection. Similarly to in-plant TOX levels, the drinking water site DW4 exhibited the highest level of TOX precursors in its finished drinking water among all sites investigated (Figure 5.14). The reactivity of the organic matter with chlorine (TOX normalized to carbon mass) present in the finished water of DW4 also exhibited the highest concentration among all sites (Figure 5.15). Findings of more comprehensive analytical tools characterized the organic matter in the finished water of DW4 as much more humic-like and aromatic than that in the other finished water samples, which might explain the higher degree of chlorine reactivity. The reactivity of the final product water of IPR1 with chlorine was slightly lower than or comparable to conventional finished drinking water qualities (Figure 5.15). The product water of the indirect potable reuse site after direct injection and blending (IPR2) exhibited the lowest amount of TOX precursors and reactivity (TOX normalized by carbon mass) of all conventional finished drinking water samples as well as the final product water of IPR1.

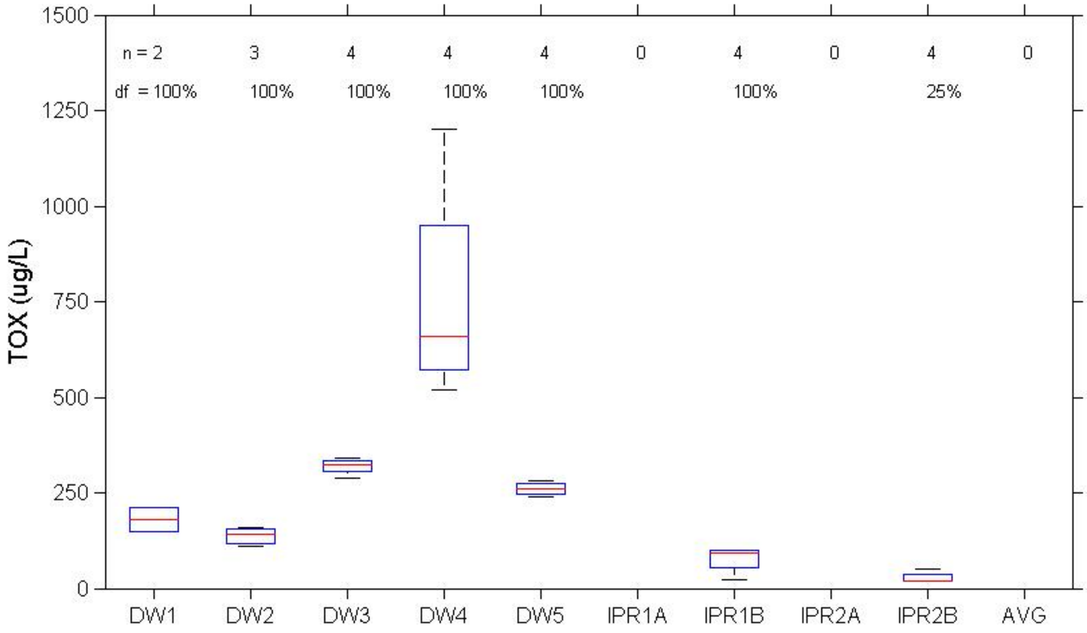


**Figure 5.14. Box plot for TOX-FP concentrations in finished water.**

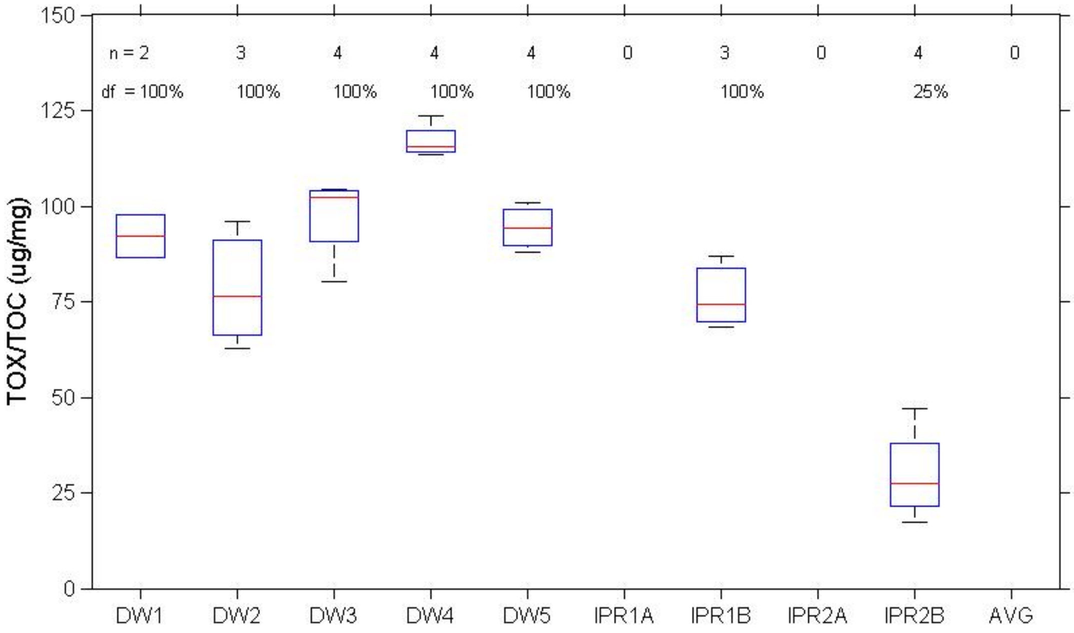


**Figure 5.15. Box plot of TOX reactivity levels (TOX-FP/TOC) in finished water.**

## 5.4 Trace Organic Compounds

A comparison of selected TOrC occurrences across different finished water types is summarized in Table 5.3 and box plots for selected compounds are shown in Figures 5.16 to 5.25. In general, concentrations in the final product water samples from conventional drinking waters were not detected or were near the detection limit. Certain compounds were commonly detected at low concentrations in finished conventional drinking waters, which included caffeine, carbamazepine, dilantin, meprobamate, PFOS, DEET, primidone, and sulfamethoxazole. Levels in drinking water samples were similar to levels previously observed in other U.S. drinking waters (Benotti et al., 2009; Snyder, 2010). The drinking water site DW3 exhibited the highest concentrations. The chlorinated flame retardants TCEP and TCPP were only detected in the finished water of DW3 at concentrations above 300 ng/L.

Similarly to conventional sites, most compounds were not detected in IRP1 finished water. Also, similar commonly detectable compounds, such as carbamazepine, dilantin, meprobamate, PFOS, primidone, and sulfamethoxazole, were detected in the IPR water and in DW finished waters. Among these compounds, sulfamethoxazole, carbamazepine, primidone, and PFOS were higher in the final product water from IPR1 than in finished conventional drinking water. In addition, sulfamethoxazole concentrations were approximately 100 times higher, but usually did not exceed 90 ng/L. However, some compounds were not detected in the IPR1 finished water, in contrast to DW finished waters. These compounds included caffeine, DEET, ibuprofen, gemfibrozil, naproxen, TCEP, TCPP, and trimethoprim.

The concentrations of TOrCs were near the detection limit or not detected in the final product water of IPR2. Detectable levels (less than 2 ng/L) were observed for carbamazepine, dilantin, meprobamate, primidone, and sulfamethoxazole, though these levels were lower than those observed at most DW sites and IPR1 site. The lower concentrations of TOrC observed in the final product water of IPR2 as compared to IPR1 is likely attributed to the higher degree of aboveground treatment employing RO followed by advanced oxidation prior to direct injection.

**Table 5.2. Average TOrC Concentrations (± Standard Deviation) in ng/L Observed in Final Product Water of Conventional Drinking Water and IPR Sites**

| | DW1 | DW2 | DW3 | DW4 | DW5 | IPR1 | IPR2 | Benotti et al. (2009)[a] | Stackelberg et al. (2007) | Ye et al. (2007)[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| Atenolol | <1 | <1 | 7.4 ± 5.2 | 4.1 ± na | <1 | 1.4 ± na | <1 | 1.2 (8) | | |
| Atorvastatin | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.25 | | |
| Atrazine | 3.8 ± 2.1 | 0.63 ± 0.09 | 300 ± 130 | 56 ± 83 | 0.50 ± 0.09 | 6.6 ± 2.9 | 0.37 ± 0.04 | 49 (15) | | |
| Benzophenone | <50 | <50 | <50 | <50 | <50 | <50 | <50 | | <500 | |
| BHA | <1 | <1 | <1 | <1 | <1 | <1 | <1 | | | |
| Bisphenol A | <5 | <5 | <5 | <5 | <5 | <5 | 34 ± 1 | 25 (1) | <1000 | |
| Caffeine | 6.6 ± 0.5 | 14 ± 3 | 20 ± 11 | 22 ± 7 | <5 | <5 | <5 | | <16 | |
| Carbamazepine | 1.8 ± 0.6 | 14 ± 3 | 51 ± 34 | 1.9 ± 1.1 | <0.5 | 110 ± 17 | 0.61 ± 0.08 | 6.0 (8) | 29 | |
| DEET | 36 ± 23 | <1 | 53 ± 12 | 15 ± 8 | 8.7 ± 14 | <1 | <1 | | 78 | |
| Diazepam | <0.25 | <0.25 | 0.63 ± na | <0.25 | <0.25 | 0.57 ± 0.05 | <0.25 | 0.33 (1) | | |
| Diclofenac | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.25 | | |
| Dilantin | 1.1 ± na | 4.5 ± 0.3 | 59 ± 18 | 3.0 ± 1.6 | 2.0 ± 0.4 | 26 ± 4 | 1.4 ± 0.4 | | | |
| Estradiol | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | | |
| Estrone | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | | |
| Ethynylestradiol | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1.0 | | |
| Fluoxetine | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.3 ± na | <0.5 | 0.71 (2) | <14 | |
| Gemfibrozil | 0.75 ± 0.64 | <0.25 | 1.4 ± 0.8 | 10 ± 10 | <0.25 | <0.25 | <0.25 | 0.48 (7) | | |
| Ibuprofen | <1 | <1 | 1.6 ± na | 10 ± na | <1 | <1 | <1 | | | |
| Iopromide | <10 | <10 | <10 | <10 | <10 | <10 | <10 | | | |
| Meprobamate | 1.5 ± 1.1 | 1.2 ± 0.4 | 120 ± 38 | 1.0 ± 0.8 | 8.9 ± 4.3 | 6.9 ± 2.1 | 1.7 ± 0.7 | 5.7 (4) | | |
| Musk Ketone | <25 | <25 | <25 | <25 | <25 | <25 | <25 | | | |
| Naproxen | 0.53 ± na | <0.5 | <0.5 | 4.1 ± 3.7 | <0.5 | <0.5 | <0.5 | <0.5 | | |
| Octylphenol | <25 | <25 | <25 | <25 | <25 | <25 | <25 | | | |
| PFOA | <1 | 11 ± 1 | 31 ± 6 | <1 | <1 | 18 ± 3 | 16 ± na | | | |
| PFOS | <1 | 9.7 ± 1.7 | 23 ± 5 | 1.5 ± 0.7 | 1.9 ± 0.3 | 59 ± 12 | <1 | | | |
| Primidone | <0.5 | 15 ± 2 | 30 ± 17 | 1.6 ± 0.8 | 1.2 ± 0.7 | 71 ± 8 | 0.75 ± 0.07 | | | |
| Progesterone | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 0.51 (1) | | |
| Sulfamethoxazole | <0.25 | <0.25 | 0.82 ± 0.26 | 3.4 ± 3.9 | <0.25 | 98 ± 17 | 0.60 ± 0.24 | 0.39 (4) | <10 | <5 (3) |
| TCEP | <10 | <10 | 510 ± 420 | <10 | <10 | <10 | <10 | 120 (7) | 4 | |
| TCPP | <100 | <100 | 1000 ± 410 | <100 | <100 | <100 | <100 | 210 (5) | | |
| Testosterone | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | | |
| Triclosan | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 1.2 (1) | <1000 | |
| Trimethoprim | <0.25 | <0.25 | <0.25 | 0.73 ± 0.53 | <0.25 | <0.25 | <0.25 | <0.25 | | <5 (3) |

*Note:* [a] Number in parentheses indicates number of plants.

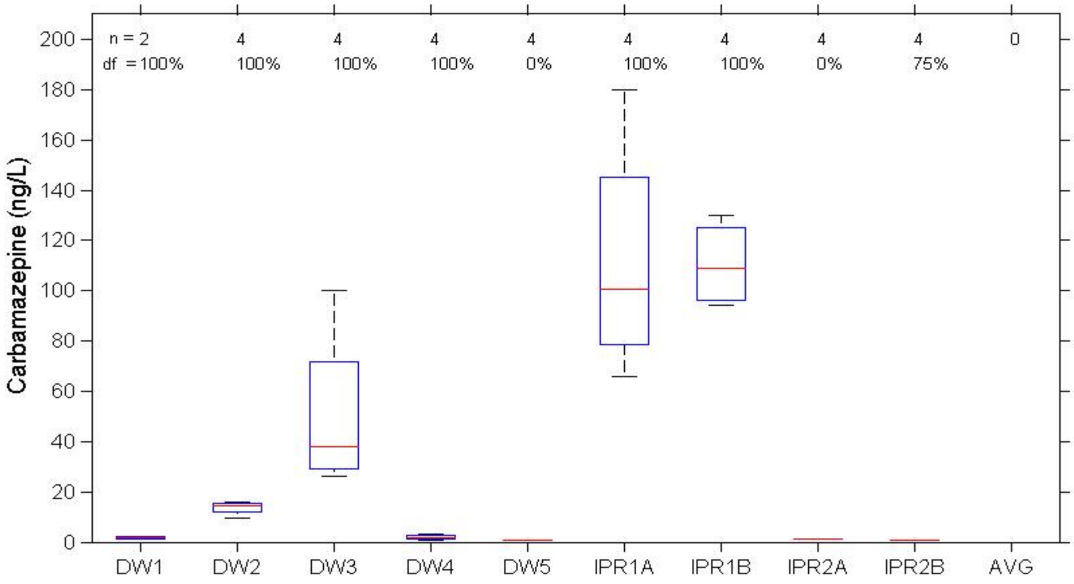


**Figure 5.16. Box plot of finished water carbamazepine concentrations.**

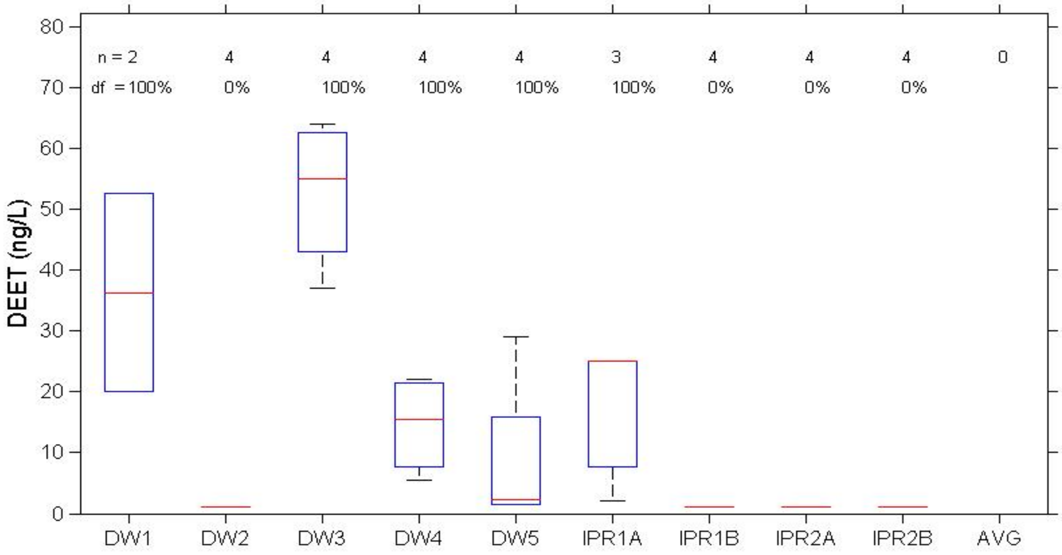


**Figure 5.17. Box plot of finished water DEET concentrations.**

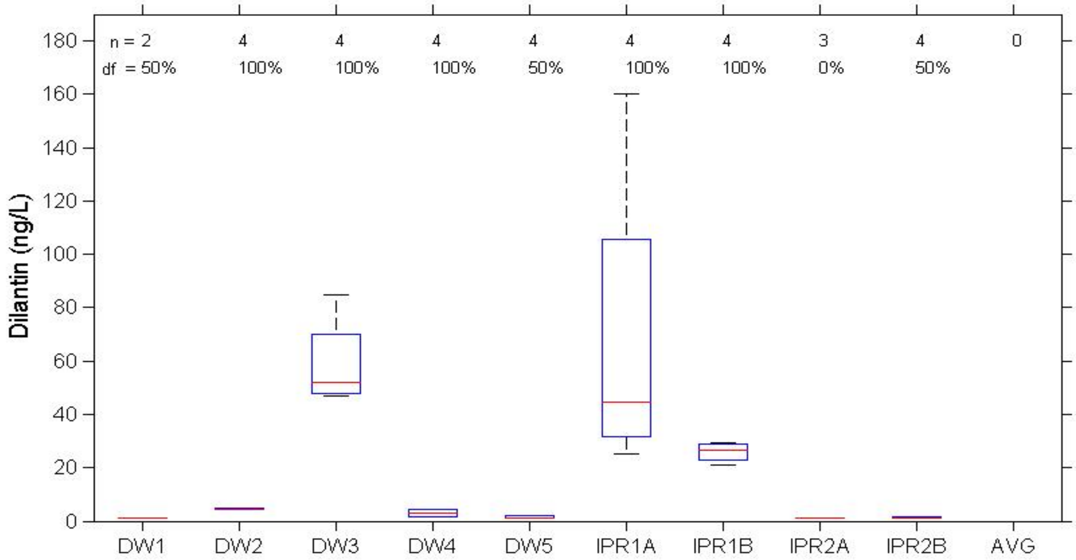


Figure 5.18. Box plot of finished water dilantin concentrations.

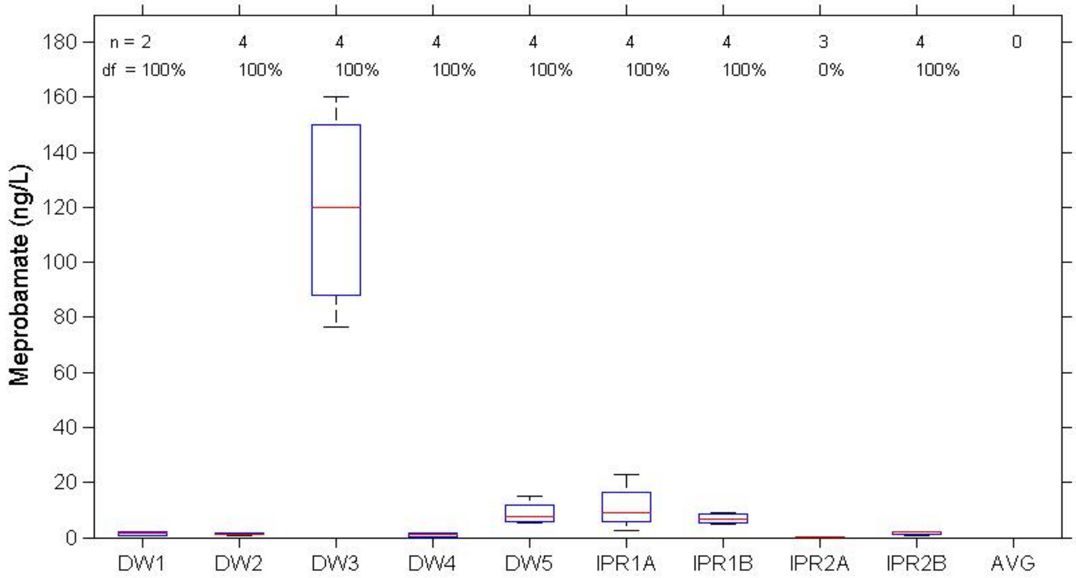


Figure 5.19. Box plot of finished water meprobamate concentrations.

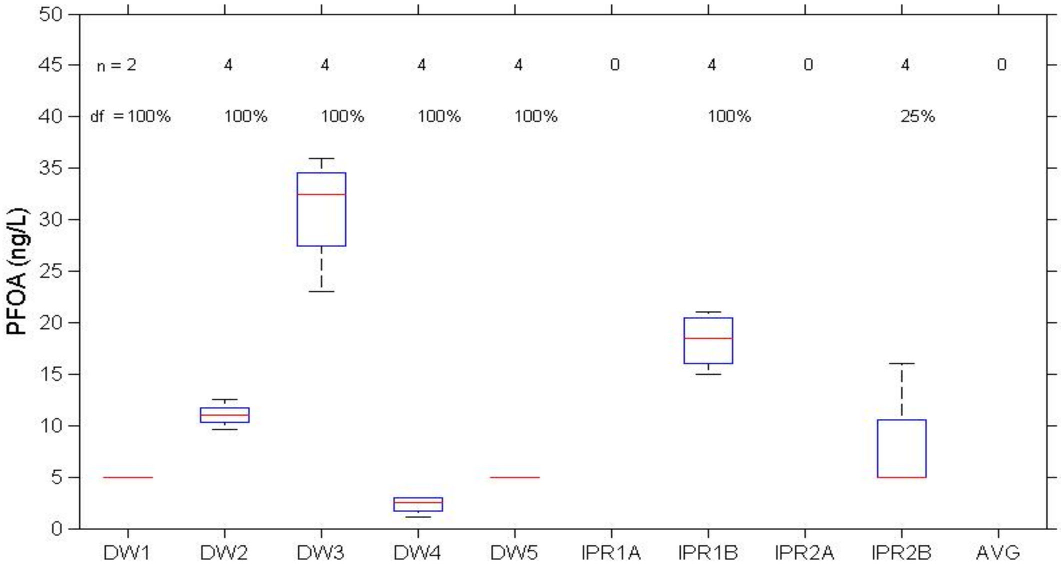


Figure 5.20. Box plot of finished water PFOA concentrations.

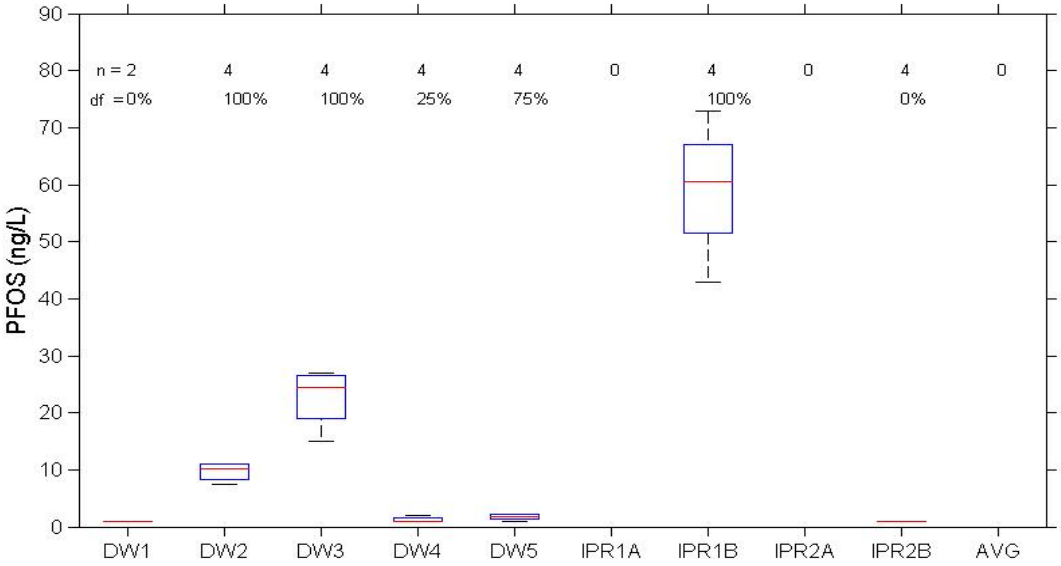


Figure 5.21. Box plot of finished water PFOS concentrations.

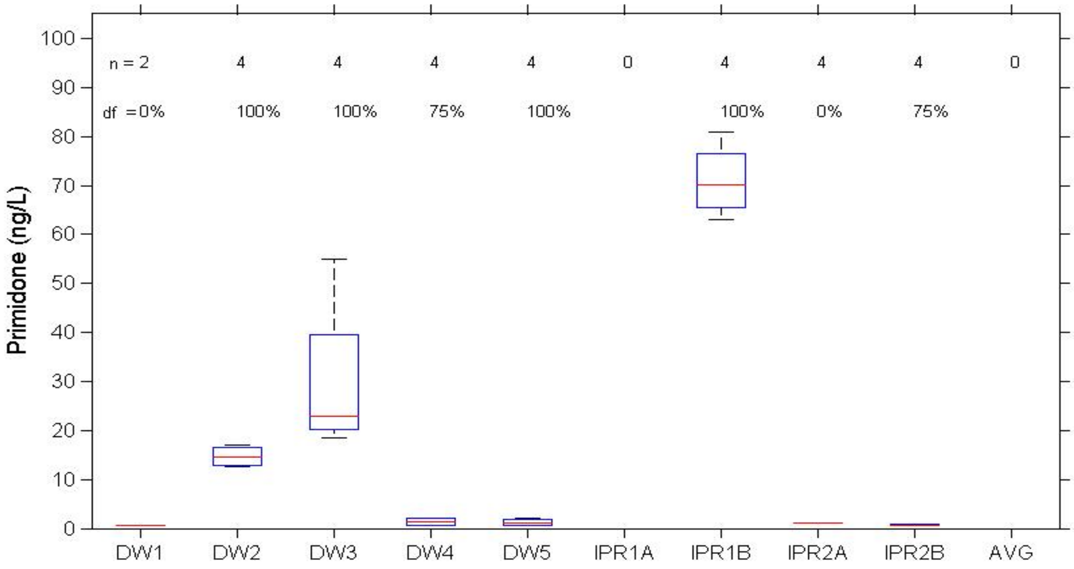


Figure 5.22. Box plot of finished water primidone concentrations.

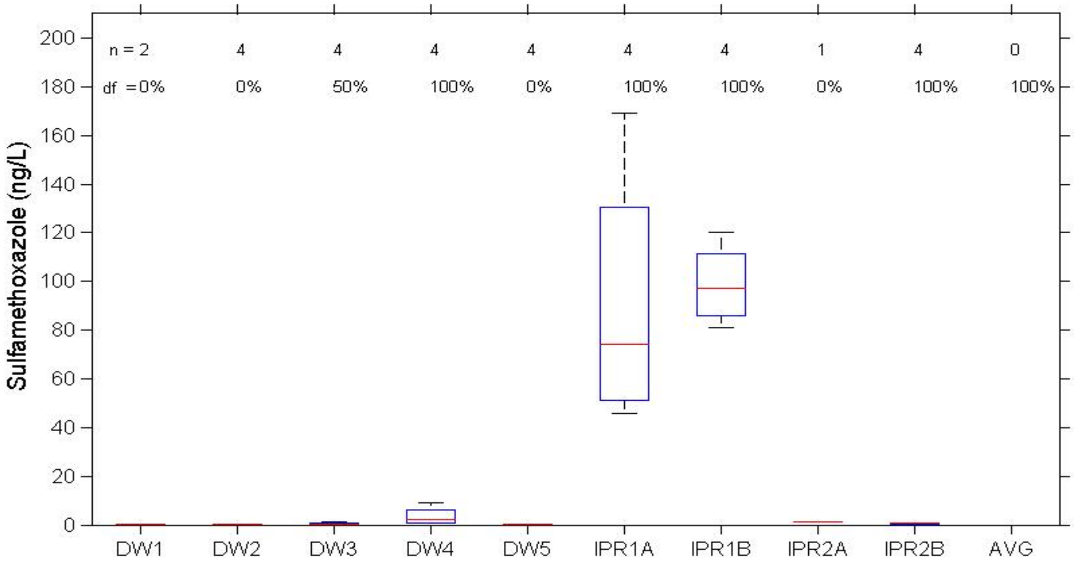


Figure 5.23. Box plot of finished water sulfamethoxazole concentrations.

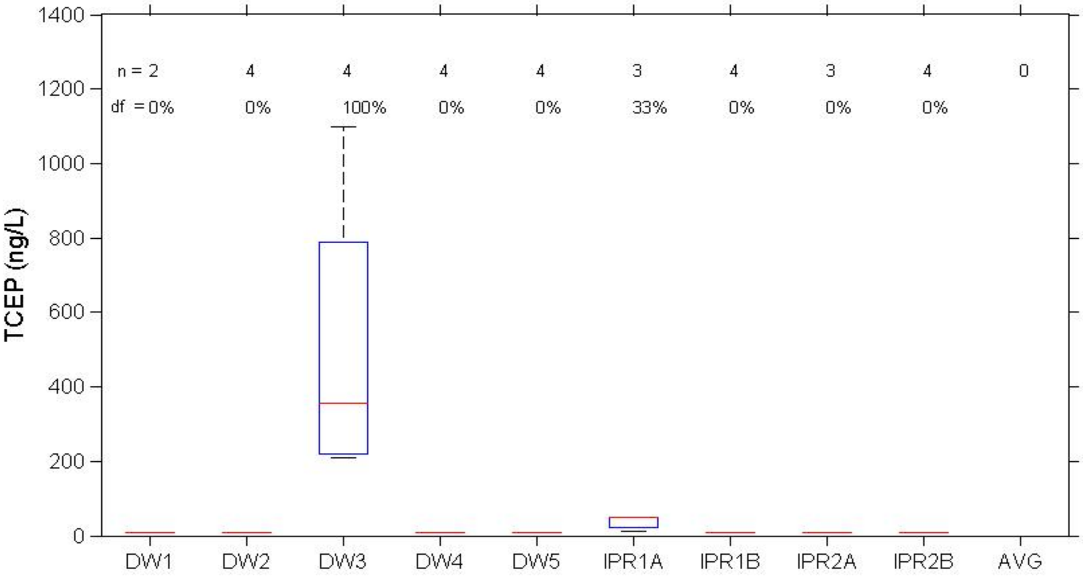


Figure 5.24. Box plot of finished water TCEP concentrations.

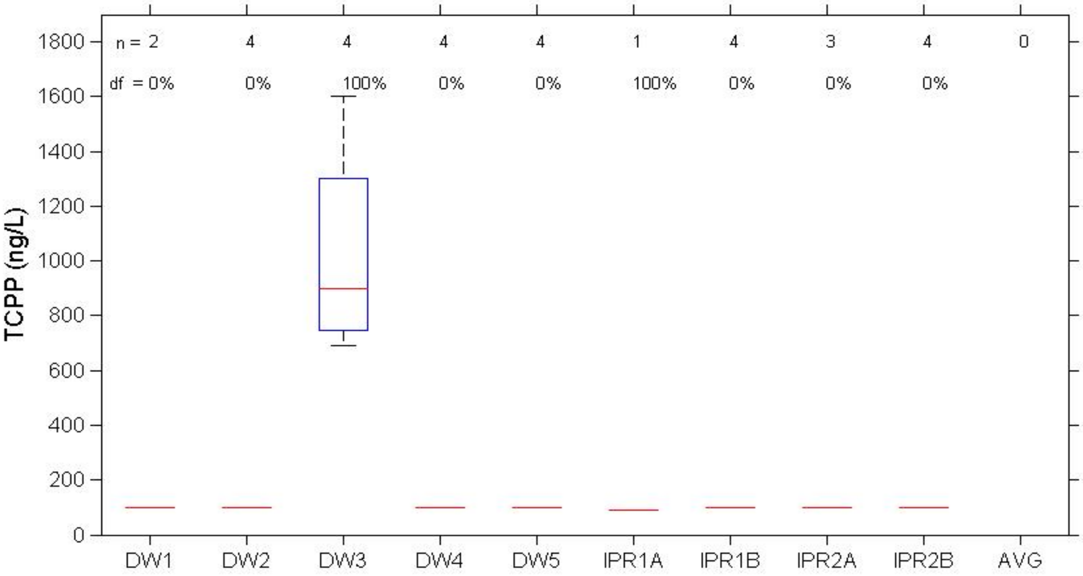


Figure 5.25. Box plot of finished water TCPP concentrations.

## 5.5 Comparison of Indirect Potable Reuse and Conventional Drinking Water Quality

The univariate nonparametric multiple-comparison Kruskal–Wallis test was performed for a suite of select analytes. The Kruskal–Wallis test compares the medians of two or more samples to determine if the samples have come from different populations. Analyte median values for IPR1 (Table 5.4) and IPR2 (Table 5.5) locations were compared with each DW site. In Tables 5.4 and 5.5, IPR > DW or IPR < DW indicate that the mean values are statistically different and the IPR mean value is greater or less than, respectively, the DW mean value. A "—" indicates that the means are not statistically different. See Section 3.5.2 for more information on the Kruskal–Wallis test. For the most part, analyte median levels were not statistically different between IPR and DW sites. However, some differences were observed for selected analytes. For the finished product water for IPR1 (IPR1B), analyte levels for PFOS, sulfamethoxazole, nitrate, and conductivity were statistically higher than at more than two drinking water sites. On the other hand, for the finished product water for IPR2 (IPR2B), analyte levels for atrazine, TOC, TOX-FP, conductivity, and phosphate and sulfate levels were statistically less than at more than two drinking water sites.

## Table 5.3. Summary of Kruskal–Wallis Multiple Comparison Test Results for Selected Analytes in IPR1[a]

| | IPR1A | | | | | | IPR1B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **DW1** | **DW2** | **DW3** | **DW4** | **DW5** | **National Average** | **DW1** | **DW2** | **DW3** | **DW4** | **DW5** | **National Average** |
| Atrazine | — | — | — | — | — | NA | — | — | — | — | — | NA |
| Caffeine | — | — | — | — | — | NA | — | — | — | — | — | NA |
| Carbamazepine | — | — | — | — | IPR > DW | NA | — | — | — | — | IPR > DW | NA |
| DEET | — | — | — | — | — | NA | — | — | IPR < DW | — | — | NA |
| Dilantin | — | — | — | — | — | NA | — | — | — | — | — | NA |
| Meprobamate | — | — | — | — | — | NA | — | — | — | — | — | NA |
| NDMA | — | — | — | — | — | NA | — | — | — | — | — | NA |
| PFOA | NA | NA | NA | NA | NA | NA | — | — | — | IPR > DW | — | NA |
| PFOS | NA | NA | NA | NA | NA | NA | IPR > DW | — | — | IPR > DW | — | NA |
| Primidone | NA | NA | NA | NA | NA | NA | IPR > DW | — | — | — | — | NA |
| Sulfamethoxazole | — | IPR > DW | — | — | IPR > DW | NA | — | IPR > DW | — | — | IPR > DW | NA |
| TCEP | — | — | — | — | — | NA | — | — | IPR < DW | — | — | NA |
| TCPP | — | — | IPR < DW | — | — | NA | — | — | IPR < DW | — | — | NA |
| TOC | — | — | IPR < DW | IPR < DW | IPR < DW | — | — | — | — | IPR < DW | — | — |
| TOXFP | NA | NA | NA | NA | NA | NA | — | — | — | IPR < DW | — | NA |
| TDS | — | IPR < DW | NA | IPR > DW | — | IPR > DW | — | — | NA | — | — | — |
| Conductivity | IPR > DW | — | — | IPR > DW | — | NA | IPR > DW | — | — | IPR > DW | — | NA |
| Nitrate | IPR > DW | — | — | IPR > DW | — | IPR > DW | IPR > DW | — | — | IPR > DW | — | IPR > DW |
| Phosphate | NA | NA | NA | NA | NA | NA | — | — | — | — | — | NA |
| Sulfate | — | — | — | IPR > DW | — | NA | — | — | — | IPR > DW | — | NA |
| pH | — | — | — | IPR < DW | IPR < DW | — | — | — | — | IPR < DW | — | — |

*Notes:* See Section 2.5.2 for more information on the Kruskal–Wallis test. "—" indicates that the means are not statistically different. NA=not available.

[a] IPR > DW or IPR < DW indicates that the mean values are statistically different and the IPR mean value is greater or less than, respectively, the DW mean value.

## Table 5.4. Summary of Kruskal–Wallis Multiple Comparison Test Results for Selected Analytes in IPR2[a]

| | IPR2A | | | | | | IPR2B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **DW1** | **DW2** | **DW3** | **DW4** | **DW5** | **National Average** | **DW1** | **DW2** | **DW3** | **DW4** | **DW5** | **National Average** |
| Atrazine | — | — | IPR < DW | IPR < DW | — | n/a | — | — | IPR < DW | IPR < DW | — | n/a |
| Caffeine | — | — | — | — | — | n/a | — | — | — | — | — | n/a |
| Carbamazepine | — | — | — | — | — | n/a | — | — | — | — | — | n/a |
| DEET | — | — | IPR < DW | — | — | n/a | — | — | IPR < DW | — | — | n/a |
| Dilantin | — | — | IPR < DW | — | — | n/a | — | — | IPR < DW | — | — | n/a |
| Meprobamate | — | — | IPR < DW | — | — | n/a | — | — | — | — | — | n/a |
| NDMA | — | — | — | — | — | n/a | — | — | — | — | — | n/a |
| PFOA | n/a | n/a | n/a | n/a | n/a | n/a | — | — | — | — | — | n/a |
| PFOS | n/a | n/a | n/a | n/a | n/a | n/a | — | — | — | — | — | n/a |
| Primidone | — | — | — | — | — | n/a | — | — | — | — | — | n/a |
| Sulfamethoxazole | — | — | — | — | — | n/a | — | — | — | — | — | n/a |
| TCEP | — | — | IPR < DW | — | — | n/a | — | — | IPR < DW | — | — | n/a |
| TCPP | — | — | IPR < DW | — | — | n/a | — | — | IPR < DW | — | — | n/a |
| TOC | IPR < DW | — | IPR < DW | IPR < DW | IPR < DW | IPR < DW | IPR < DW | — | IPR < DW | IPR < DW | IPR < DW | IPR < DW |
| TOXFP | n/a | n/a | n/a | n/a | n/a | n/a | — | — | IPR < DW | IPR < DW | — | n/a |
| TDS | — | IPR < DW | n/a | — | IPR < DW | IPR < DW | — | IPR < DW | n/a | — | — | — |
| Conductivity | — | IPR < DW | — | — | IPR < DW | n/a | — | IPR < DW | — | — | IPR < DW | n/a |
| Nitrate | — | — | — | — | — | — | — | — | — | IPR > DW | — | — |
| Phosphate | — | — | IPR < DW | IPR < DW | — | n/a | — | — | IPR < DW | IPR < DW | — | n/a |
| Sulfate | n/a | n/a | n/a | n/a | n/a | n/a | — | IPR < DW | — | — | IPR < DW | n/a |
| pH | — | — | — | IPR < DW | — | — | — | — | — | IPR < DW | IPR < DW | — |

*Notes:* See Section 2.5.2 for more information on the Kruskal–Wallis test. "—" indicates that the means are not statistically different. NA—not available.

[a] IPR > DW or IPR < DW indicates that the mean values are statistically different and the IPR mean value is greater or less than, respectively, the DW mean value.

## *Chapter 6*

# Summary, Conclusions, and Recommendations

## 6.1 Summary of Project Findings

The understanding of how water quality produced through engineered potable reuse systems compares with ambient (de facto reuse) water quality in urban areas is critical for public acceptance and perception. This is especially true for emerging contaminants for which no federal regulations exist for drinking water. However, it is not feasible to measure every inorganic and organic chemical constituent. It had been estimated in the late 1990s that approximately 87,000 chemicals in commerce had not been fully characterized for toxicity (Snyder et al., 2003). In consideration of pharmaceuticals alone, thousands of prescription pharmaceuticals are registered for use in the United States and even more are available as over-the-counter medicines. Relatively few pharmaceuticals have been monitored, yet several have been detectable in drinking water from the United States (Snyder, 2010). In addition, a great deal of scientific and public concern has been voiced regarding the potential for impacts on human and environmental health from chemicals that are not regulated and for which incomplete toxicity data exist (Novak et al., 2011). Considering the futility of monitoring for all possible CECs and transformation products, it is imperative to determine a limited subset of chemical indicators and surrogates that apply water quality from existing and trusted sources to waters produced from wastewater during planned potable reuse.

## 6.2 Selecting the Study Sites

Five conventional drinking water and two IPR sites were included for evaluation in this study. Drinking water agencies considered for this study were asked to estimate the quantity of wastewater within their source water, as well as describing the treatment process train. From the team’s initial survey, five drinking water facilities were selected, which ranged from self-reported wastewater contributions to source water of zero to 30%. One drinking water system reported no known wastewater contribution, two were considered very low (1–3%), one was considered low (5%), and one was considered moderately impacted (30%). One drinking water site relied on groundwater, whereas the other four utilized surface water. Treatment trains were generally conventional, though one drinking water site used ozone for primary disinfection and another powdered activated carbon (PAC). Two IPR systems were selected for evaluation, with one utilizing advanced water treatment including microfiltration, reverse osmosis, and UV-AOP and the other infiltration SAT. The sites agreed to provide water samples quarterly for one year.

## 6.3 The Analytical Roadmap

To characterize the chemical composition of water from both conventional drinking water and planned IPR, an analytical roadmap was developed. The analytical roadmap includes general water quality parameters, regulated constituents, unregulated constituents, and bulk parameters. When possible, standardized methods were employed for the analyses; however, for TOrCs and organic matter characterization, standard methods were not available. Therefore, the project relied on methods developed by project team members that have been successfully employed in other water research projects (Quiñones and Snyder, 2009; Rosario-Ortiz et al., 2007a, 2007b; Snyder et al., 2005; Trenholm et al., 2006; Vanderford and Snyder, 2006). Moreover, the team utilized historical data provided by each of the participating water agencies.

## 6.4 Treatment Efficacy of Drinking Water and Water Reuse Processes

The attenuation of various constituents and bulk water quality parameters were evaluated for each of the five drinking water systems and two IPR facilities.

### 6.4.1 Total Organic Carbon Occurrence and Attenuation

The TOrC removal trends documented in this report are in excellent agreement with previously published studies and reports (Benotti et al., 2009; Drewes et al., 2003, 2005a, 2005b, 2008; Snyder et al., 2004, 2006a, 2006b, 2007). In general, conventional processes including coagulation, flocculation, sedimentation, and filtration are not effective for the removal of TOrCs, whereas chlorine and chloramine are moderately effective (Snyder et al., 2003, 2008; Westerhoff et al., 2005). Conversely, the majority of TOrCs evaluated show high degrees of removal (transformation) during more powerful oxidation processes such as ozone and UV-AOP (Dickenson et al., 2009; Ikehata et al., 2008; Rosario-Ortiz et al., 2010; Snyder et al., 2006a, 2007). Activated carbon can be highly effective in the removal of TOrCs; however, the removal efficacy is strongly dependent upon the TOrC structure, water quality, activated carbon type, and operational parameters (Benotti et al., 2010; Redding et al., 2009; Snyder et al., 2007, 2008). Filtration membranes such as microfiltration (MF) and ultrafiltration (UF) generally are not effective for dissolved TOrC removal (Snyder et al., 2006b). However, desalting membranes such as nanofiltration (NF) and RO are highly effective for removing the vast majority of TOrCs (Drewes et al., 2005b, 2008; Snyder et al., 2006b, 2008; Yoon et al., 2006). Biological systems can also be highly effective in removal of TOrC; however, actual removal is strongly dependent on system parameters such as water quality, geology, infiltration rate, and redox conditions (Drewes et al., 2006; Laws et al., 2011; Mansell et al., 2004; Rauch and Drewes, 2006; Snyder et al., 2004). Therefore, expected removal of TOrC and changes in general water quality can be approximated a priori when considering treatment process trains and water quality conditions.

Thus, based on the seven water treatment systems evaluated in this project, we compare predicted to observed removals (Table 6.1). The predicted attenuation efficacy is based on primary processes previously demonstrated to be effective barriers for certain TOrC. For DW systems 1 to 3, the only significant barrier within the treatment process train is the disinfection step using chlorine. For the compounds detected at DW systems 1 to 3, agreement with attenuation predicted from the chlorination process was very good. This is especially the case when the data evaluated are summed from all monitoring during the project and thus include inherent variability in season and analysis. Attenuation of TOrC in DW4 is primarily due to PAC and chlorine; however, softening was the primary source of TDS reduction. Because TOC removal at DW4 was approximately 50%, we do not expect a higher degree of TOrC removal despite the previously reported high efficiencies for many organic constituents (Snyder et al., 2006b). Ozone and chlorine are the primary causes of TOrC removal at DW5, and agreement with predicted removal is reasonable. At IPR1 the primary TOrC removal mechanism is biological transformation (Laws et al., 2011; Snyder et al., 2004); however, sorption cannot be ruled out. At IPR2, the most significant barrier is RO, which has been shown previously to provide excellent rejection of the vast majority of TOrCs (Drewes et al., 2005b; Snyder et al., 2006b). Overall, predictions of TOrC and TDS removal were remarkably similar to observed removal.

# Table 6.1. Predicted Versus Observed Constituent Attenuation

| | **DW1** | | **DW2** | | **DW3** | | **DW4** | | **DW5** | | **IPR1** | | **IPR2** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Constituent*** | ***Predicted*** | ***Observed*** | ***Predicted*** | ***Observed*** | ***Predicted*** | ***Observed*** | ***Predicted*** | ***Observed*** | ***Predicted*** | ***Observed*** | ***Predicted*** | ***Observed*** | ***Predicted*** | ***Observed*** |
| **Atenolol** | Poor | ND | Poor | ND | Poor | Meager | Moderate | Moderate | High | Moderate | Excellent | Excellent | Excellent | Excellent |
| **Atorvastatin** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | Meager | Excellent | ND | Excellent | ND | Excellent | Excellent |
| **Atrazine** | Poor | Poor | Poor | Poor | Poor | Meager | Moderate | Poor | Meager | Moderate | Poor | Poor | Excellent | Excellent |
| **Benzophenone** | NA | ND | NA | ND | NA | Poor | NA | Meager | NA | ND | NA | Moderate | NA | Excellent |
| **BHA** | NA | ND | NA | ND | NA | Poor | NA | ND | NA | ND | NA | ND | NA | Excellent |
| **Bisphenol A** | Excellent | ND | Excellent | ND | Excellent | Meager | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | Moderate |
| **Caffeine** | Poor | Poor | Poor | ND | Poor | Poor | Moderate | Meager | Excellent | Poor | Excellent | Excellent | Excellent | Excellent |
| **Carbamazepine** | Poor | Poor | Poor | Meager | Poor | ND | Moderate | Meager | Excellent | Excellent | Meager | Meager | Excellent | Excellent |
| **DEET** | Poor | Poor | Poor | ND | Poor | ND | Moderate | Meager | Moderate | Meager | Excellent | Excellent | Excellent | Excellent |
| **Diazepam** | Meager | ND | Meager | ND | Meager | ND | Moderate | ND | Moderate | ND | Moderate | Moderate | Excellent | Excellent |
| **Diclofenac** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Moderate | ND | Excellent | Excellent |
| **Dilantin** | Poor | ND | Poor | Poor | Poor | Meager | Moderate | Poor | Moderate | Moderate | Meager | Excellent | Excellent | Excellent |
| **Estradiol** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | Excellent |
| **Estrone** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | Meager | Excellent | ND | Excellent | ND | Excellent | Excellent |
| **Ethynylestradiol** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND |
| **Fluoxetine** | Poor | ND | Poor | ND | Poor | ND | Moderate | ND | Excellent | ND | Excellent | Meager | Excellent | Excellent |
| **Gemfibrozil** | Moderate | Poor | Moderate | ND | Moderate | Moderate | Moderate | Poor | Excellent | Moderate | Excellent | Excellent | Excellent | Excellent |
| **Ibuprofen** | Poor | ND | Poor | ND | Poor | Meager | Moderate | Poor | Moderate | ND | Meager | Excellent | Excellent | Excellent |
| **Iopromide** | Poor | ND | Poor | ND | Poor | ND | Moderate | ND | Meager | ND | Excellent | Excellent | Excellent | Moderate |
| **Meprobamate** | Poor | Poor | Poor | Meager | Poor | Meager | Moderate | Meager | Meager | Moderate | Poor | Excellent | Excellent | Excellent |
| **Musk Ketone** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | ND | NA | ND | Excellent | Meager |
| **Naproxen** | Excellent | ND | Excellent | ND | Excellent | ND | Excellent | Moderate | Excellent | Moderate | Moderate | Excellent | Excellent | Excellent |
| **Octylphenol** | Moderate | ND | Moderate | ND | Moderate | ND | Moderate | ND | Excellent | ND | Moderate | ND | Excellent | Excellent |
| **PFOA** | Poor | ND | Poor | Poor | Poor | Poor | Moderate | Moderate | Poor | ND | Poor | Meager | Excellent | Moderate |
| **PFOS** | Poor | ND | Poor | Poor | Poor | Poor | Moderate | Poor | Poor | Poor | Poor | Poor | Excellent | Excellent |
| **Primidone** | Poor | ND | Poor | Poor | Poor | Poor | Moderate | Poor | Moderate | Moderate | Meager | Meager | Excellent | Excellent |
| **Progesterone** | Poor | ND | Poor | ND | Poor | ND | Moderate | ND | Excellent | ND | Excellent | ND | Excellent | Excellent |
| **Sulfamethoxazole** | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent | Moderate | Excellent | Excellent | Moderate | Moderate | Excellent | Excellent |
| **TCEP** | Poor | ND | Poor | ND | Poor | ND | Moderate | ND | Poor | Meager | Poor | Excellent | Excellent | Excellent |
| **TCPP** | Poor | ND | Poor | ND | Poor | ND | Moderate | Poor | Poor | ND | Poor | Excellent | Excellent | Excellent |
| **Testosterone** | Poor | ND | Poor | ND | Poor | ND | Moderate | ND | Excellent | ND | Excellent | ND | Excellent | ND |
| **Triclosan** | Excellent | ND | Excellent | ND | Excellent | ND | Moderate | Meager | Excellent | ND | Poor | Excellent | Excellent | Excellent |
| **Trimethoprim** | Excellent | ND | Excellent | ND | Excellent | ND | Moderate | Moderate | Excellent | Moderate | Moderate | Excellent | Excellent | Excellent |
| **TDS** | Poor | Poor | Poor | Poor | Poor | Poor | Poor | Moderate | Moderate | Poor | Poor | Poor | Excellent | Excellent |

## 6.4.2 General Water Quality

### 6.4.2.1 *Ammonia*

Although the source water of IPR1 exhibited an ammonia concentration comparable to those of the drinking water sites practicing chloramination (with ammonia addition), the ammonia concentration in the final product water after SAT and blending was less than 0.1 mg/L and comparable to and in most cases lower than finished water qualities of conventional drinking water sites.

*IPR2* exhibited the highest ammonia concentration in the source water of all sites studied. It is noteworthy that the final water quality at this site after treatment (RO/AOP) (IPR2A) was 1.1 mg-N/L, the highest ammonia concentration among all study sites. Only direct injection and blending reduced the concentration of ammonia to less than 0.5 mg/L (IPR2B), which was similar to those at sites DW1 and DW4. Because non-nitrified secondary effluent exhibiting ammonia concentrations of more than 30 mg-N/L in the source water is used at site IPR2, some ammonia can pass through RO treatment, and the remaining ammonia is not subsequently amended in the subsurface following direct injection.

### *6.4.2.2 Nitrate*

Nitrate concentrations of less than 3 mg-N/L in the final product water of IPR1 were higher than nitrate concentrations in finished water from conventional drinking water plants. However, with nitrate concentrations of 2 to 3 mg-N/L in the subsurface, the nitrate concentrations measured at site IPR1 were consistently less than the EPA National Primary Drinking Water standard of 10 mg N/L and the CDPH groundwater recharge draft regulation requirement of 5 mg N/L.

The nitrate concentrations in the final product water after aboveground treatment at site *IPR2* were comparable to nitrate concentrations in conventional finished drinking waters. However, it is noteworthy that the highest concentrations of nitrate were observed after direct injection and blending. The source of these elevated nitrate concentrations is unknown. Nevertheless, nitrate concentrations in product water of IPR2 were less than EPA's National Primary Drinking Water standard of 10 mg N/L.

### *6.4.2.3 Total Dissolved Solids*

TDS concentration in product water of IPR1 was high and approached or exceeded the EPA National Secondary Drinking water standard of 500 mg/L.

The TDS level in the final product water of *IPR2* was comparable to concentrations in conventional finished drinking waters. It is noteworthy that the TDS concentration increased after direct injection and blending (IPR2B), which is likely due to mixing with other dilution water that is elevated in TDS.

#### *6.4.2.4 Phosphate*

The ortho-phosphate concentrations in the final product water for the IPR sites (IPR1 and IPR2) are indistinguishable from finished water qualities observed at drinking water sites.

#### *6.4.2.5 Total Organic Carbon*

The final product water quality of surface spreading operations (IPR1) exhibited TOC concentrations of less than 2 mg/L, which were less than or comparable to TOC concentrations for conventional finished drinking waters. This result reveals that SAT is effective at reducing higher concentrations of TOC in reclaimed water (greater than 5 mg/L).

For site IPR2, TOC concentrations after aboveground treatment (IPR2A) are less than the TOC concentrations exhibited by any of the conventional finished drinking waters. The TOC concentration increased after direct injection (IPR2B), which likely is due to mixing with other source waters used for recharge in this aquifer that are elevated in TOC. The key removal process employed at IPR2, RO followed by advanced oxidation, is very effective at reducing TOC concentrations to less than 0.5 mg/L (IPR2A).

#### *6.4.2.6 Nitrosamine Formation Potential*

The final water quality after formation potential tests at IPR1 after SAT and blending had a NDMA concentration of 3 ng/L. For the direct injection site IPR2, the NDMA concentration for the formation potential test was approximately 4 ng/L. Thus, both indirect potable reuse sites exhibited nitrosamine formation potentials in their final water samples that were below the CDPH action level of 10 ng/L.

#### *6.4.2.7 TOX Formation Potential*

The reactivity of the final product water of IPR1 with chlorine was slightly lower than or comparable to that for conventional finished drinking water. The product water of the IPR site after direct injection and blending (IPR2) exhibited the lowest amount of TOX precursors and reactivity (TOX normalized by carbon mass) of all conventional finished drinking water samples as well as being lower than the final product water of IPR1.

## 6.5 Application of Surrogate and Indicator Approach

The concept of using surrogates and indicators for the monitoring of water quality systems has been introduced previously (Dickenson et al., 2009; Rauch and Drewes, 2005). An expert panel convened by the state of California recently suggested a matrix of surrogates and indicators for monitoring of potable reuse systems (Anderson, et al., 2010)). The summary figure from that report is reproduced in Table 6.2. In comparing the indicators suggested in Table 6.2 with values from Table 6.1, it is clear that expected removal matched well with observed removal for the indicators monitored. For instance, gemfibrozil, caffeine, DEET, and iopromide all were well removed in IPR1, which is as predicted for a properly functioning system. Unfortunately, sucralose was not monitored in this project. Likewise, for the direct injection system (IPR2), DEET and caffeine had excellent removal, as expected; however, NDMA and sucralose were not monitored in this study. In terms of surrogates, ammonia exhibited greater than 90% removal in

IPR1, whereas nitrate, TOC, and $UVA_{254}$ all exhibited >30% removal, as expected for a properly functioning infiltration system. For the direct injection system (IPR2), the removal of TDS and TOC both exceeded 90%, as would be indicated for a properly functioning RO-based direct injection system. Thus, the indicator and surrogate matrix worked exactly as predicted at IPR1 and IPR2, within the constraints of those indicators monitored in the current study.

**Table 6.2. Surrogate and Indicator Approach Suggested for California Potable Reuse Monitoring**

| Reuse Practice | Health-based Indicator | MRL (ng/L) | Performance-based Indicator | Expected Removal[8] | MRL (ng/L) | Surrogate | Method | Expected Removal[8] |
|---|---|---|---|---|---|---|---|---|
| Groundwater Recharge | 17β-estradiol[1] | 1 | Δgemfibrozil[5] | >90% | 10 | Δammonia | SM | >90% |
| SAT | Triclosan[2] | 50 | ΔDEET[6] | >90% | 10 | Δnitrate | SM | >30% |
| | Caffeine[3] | 50 | ΔCaffeine[3] | >90% | 50 | ΔDOC | SM | >30% |
| | NDMA[4] | 2 | Δiopromide[5] | >90% | 50 | ΔUVA | SM | >30% |
| | | | ΔSucralose[7] | <25% | 100 | | | |
| Direct Injection | 17β-estradiol[1] | 1 | ΔDEET | >90% | 10 | Δconductivity | SM | >90% |
| | Triclosan[2] | 50 | ΔSucralose | >90% | 100 | ΔDOC | SM | >90% |
| | Caffeine[3] | 50 | ΔNDMA | 25-50% | 2 | | | |
| | NDMA[4] | 2 | ΔCaffeine | >90% | 50 | | | |

## 6.6 Consideration of Human Health Relevance

The data from the current study largely confirm those from previous studies, which demonstrates that some TOrCs can and will be detectable in potable water supplies regardless of source. However, detection alone does not imply harm to public health. In fact, for the majority of TOrC indicators monitored, risk to human health has previously been considered and calculated. The maximum concentration detected in finished water was compared with published public health reference values (Table 6.3). Most monitored TOrCs were more than two orders of magnitude lower in mean maximum concentration than health reference values. Only atrazine, carbamazepine, PFOS, and TCEP had mean maximum concentrations less than two orders of magnitude below health reference values. The maximum mean concentrations for monitored TOrCs were greatest at DW3 > DW4=IPR1 > IPR2. Mean maximum TOrC concentrations at DW systems 1, 2, and 5 did not exceed those from other sites. Based upon currently available data, all DW and IPR systems exhibited TOrC concentrations that would not be expected to impact human health within the parameters tested in this study.

**Table 6.3. Health Reference Values for Measured TOrC Indicators**

| Compound | MRL (ng/L) | Max Mean Conc. (ng/L) | Location | Health Value (ng/L) | Ref | Exposure Factor | |
|---|---|---|---|---|---|---|---|
| Atenolol | 1 | 7.4 | DW3 | 70000 | AwwaRF 3085 | | 1.1E-04 |
| Atorvastatin | 0.5 | <0.5 | | 5000 | AUS Guideline | < | 1.0E-04 |
| Atrazine | 0.25 | 300 | DW3 | 3000 | EPA SDWA | | 1.0E-01 |
| Benzophenone | 50 | <50 | | NA | | | NA |
| BHA | 1 | <1 | | 580 | EPA CCL3 | < | 1.7E-03 |
| Bisphenol A | 5 | 34 | IPR2 | 350000 | EPA CCL3 | | 9.7E-05 |
| Caffeine | 5 | 22 | DW4 | 350 | AUS Guideline | | 6.3E-02 |
| Carbamazepine | 0.5 | 110 | IPR1 | 1000 | Schriks 2009 | | 1.1E-01 |
| DEET | 1 | 53 | DW3 | 2500 | AUS Guideline | | 2.1E-02 |
| Diazepam | 0.25 | 0.63 | DW3 | 1400 | EPA CCL3 | | 4.5E-04 |
| Diclofenac | 0.5 | <0.5 | | 1800 | AUS Guideline | < | 2.8E-04 |
| Dilantin | 1 | 59 | DW3 | 6800 | AwwaRF 3085 | | 8.7E-03 |
| Estradiol | 0.5 | <0.5 | | 0.9 | EPA CCL3 | < | 5.6E-01 |
| Estrone | 0.2 | <0.2 | | 350 | EPA CCL3 | < | 5.7E-04 |
| Ethynylestradiol | 1 | <1 | | 280 | EPA CCL3 | < | 3.6E-03 |
| Fluoxetine | 0.5 | 1.3 | IPR1 | 42000 | Schwab 2005 | | 3.1E-05 |
| Gemfibrozil | 0.25 | 10 | DW4 | 45000 | AwwaRF 3085 | | 2.2E-04 |
| Ibuprofen | 1 | 10 | DW4 | 400000 | AUS Guideline | | 2.5E-05 |
| Iopromide | 10 | <10 | | 750000 | AUS Guideline | < | 1.3E-05 |
| Meprobamate | 0.25 | 120 | DW3 | 260000 | AwwaRF 3085 | | 4.6E-04 |
| Musk Ketone | 25 | <25 | | 350000 | AUS Guideline | < | 7.1E-05 |
| Naproxen | 0.5 | 4.1 | DW4 | 220000 | AUS Guideline | | 1.9E-05 |
| Octylphenol | 25 | <25 | | 5300000 | AwwaRF 3085 | < | 4.7E-06 |
| PFOA | 5 | 31 | DW3 | 1100 | EPA CCL3 | | 2.8E-02 |
| PFOS | 1 | 59 | IPR1 | 200 | EPA CCL3 | | 3.0E-01 |
| Primidone | 0.5 | 71 | IPR1 | NA | | | NA |
| Progesterone | 0.5 | <0.5 | | 110000 | AUS Guideline | < | 4.5E-06 |
| Sulfamethoxazole | 0.25 | 98 | IPR1 | 35000 | AUS Guideline | | 2.8E-03 |
| TCEP | 10 | 510 | DW3 | 2500 | EPA CCL3 | | 2.0E-01 |
| TCPP | 100 | 1000 | DW3 | NA | | | NA |
| Testosterone | 0.5 | <0.5 | | 7000 | AUS Guideline | < | 7.1E-05 |
| Triclosan | 1 | <1 | | 350 | AUS Guideline | < | 2.9E-03 |
| Trimethoprim | 0.25 | 0.73 | DW4 | 61000 | EPA CCL3 | | 1.2E-05 |

## 6.7 Conclusions

IPR systems are capable of producing water quality that is generally equal to, or better than, the water quality produced in conventional drinking water systems with impact from wastewater discharge on their raw water supplies (de facto reuse). Although IPR2, which treats municipal wastewater effluent using RO and UV-AOP, produces a water of extraordinary purity, IPR1, using a primarily natural system, can produce a water that rivals the product of conventional drinking water systems. In fact, this study demonstrates that conventional drinking water systems with even a moderate degree of wastewater impact are likely to produce potable water with levels of TOrC exceeding those of IPR systems. This study also confirms that surrogate and indicator monitoring can provide a robust means for measuring IPR system performance. The study further demonstrates that the quality of water produced by a direct-injection IPR system is actually diminished in the subsurface, raising the possibility of direct potable reuse in maintaining and protecting the quality of water produced by RO with sequential UV-AOP. Although some TOrCs were detectable in finished waters, it should be noted that all scenarios produced water that was compliant with federal regulations and that all monitored TOrCs occurred at levels below health reference levels.

Water agencies considering potable reuse systems should consider the water quality goals and needs for the produced water carefully. As demonstrated here, groundwater recharge IPR schemes employing either surface spreading or direct injection can produce water of quality similar or superior to that of conventional drinking water systems. However, for reduction of TDS, desalting membrane systems will be required.

## 6.8 Future Research Needs

Although this study and others have demonstrated the efficacious removal of the vast number of TOrC in potable reuse situations, additional research is warranted to consider the aggregate health impacts from mixtures of contaminants present in water. This holds true for both engineered potable reuse and de facto potable water supplies. In addition, future research should also simultaneously consider microbiological contaminants, such as viruses, bacteria, and protozoa. Occurrence of antibiotic-resistant bacteria specifically should be considered in future monitoring and comparative risk assessment projects. Yet another class of contaminants that is the subject of increased concern is infectious prions. Data on prions are extremely sparse and deserve absolute and comparative analysis in water reuse systems. Likewise, potable distribution system impacts from potable reuse scenarios should be considered, including that of waterborne pathogens.

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## *Appendix A*

# Historic Data

## Table A.1. Historic Raw Water Quality for DW1

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/l | 1.78 | 2.02 | 1.96 | 3.54 | 2.89 | 2.05 | 1.7 | 1.58 | 1.74 | 2.39 | 2.34 | 2.32 | 1.93 | 2.1 | 1.89 | 2.5 | 2.03 | 2.79 | 3.88 | 3.52 | 2.75 | | 3.13 | 3.14 |
| $UV_{254}$ | cm | 0.044 | 0.047 | 0.051 | 0.051 | 0.048 | 0.051 | 0.042 | 0.043 | 0.052 | 0.058 | 0.073 | 0.064 | 0.052 | 0.062 | 0.048 | 0.048 | 0.049 | 0.121 | 0.142 | 0.109 | 0.069 | 0.065 | 0.09 | 0.105 |
| Cond. | us/cm | 260 | 390 | 280 | 300 | 376 | 293 | 307 | 260 | 273 | 319 | 294 | 304 | 288 | 255 | 274 | 357 | 303 | 249 | 215 | 231 | 267 | 270 | 311 | 218 |
| TDS | mg/l | 170 | 250 | 180 | 190 | 250 | 195 | 200 | 170 | 182 | 213 | 196 | 286 | 192 | 170 | 183 | 238 | 202 | 162 | 140 | 154 | 178 | 180 | 207 | 142 |
| $NH_3$ | mg/l | <0.1 | <0.1 | 0.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $NO_3$ | mg/l | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| $NO_2$ | mg/l | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| o-$PO_4^3$ | ug/l | 2.2 | 2.5 | 1.3 | 3.1 | 2.1 | 1.5 | 0.9 | 4.8 | 4.1 | 3 | 4.3 | 3.1 | 2.2 | 1.3 | 2.4 | 3.6 | 5 | 6.4 | 6.8 | 2.1 | | 4.3 | 1.9 | 6.7 |
| Alk. | mg/l | 54 | 70 | 66 | 67 | 94 | 65 | 50 | 44 | 54 | 75 | 73 | 76 | 76 | 62 | 70 | 96 | 82 | 65 | 63 | 67 | 72 | 74 | 56 | 65 |

## Table A.2. Historic Finished Water Quality for DW1

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/l | 1.57 | 1.66 | 1.63 | 1.81 | 2.66 | 1.75 | 1.46 | 1.6 | 1.38 | 1.93 | 1.93 | 2.05 | 1.61 | 1.81 | 1.62 | 2.28 | 1.64 | 2.29 | 3.25 | 2.92 | 2.28 | | 2.5 | 2.69 |
| $UV_{254}$ | abs/cm | 0.035 | 0.034 | | 0.036 | 0.041 | 0.037 | 0.035 | 0.034 | 0.032 | 0.039 | 0.042 | 0.045 | 0.038 | 0.039 | 0.035 | 0.039 | 0.036 | 0.048 | 0.068 | 0.06 | 0.043 | 0.043 | 0.052 | 0.063 |
| Cond. | us/cm | 274 | 290 | 298 | 303 | 408 | 313 | 306 | 309 | 282 | 355 | 293 | 296 | 301 | 352 | 353 | 379 | 298 | 273 | 222 | 230 | 281 | 263 | 221 | 220 |
| TDS | mg/l | 177 | 177 | 195 | 201 | 272 | 208 | 204 | 206 | 188 | 237 | 195 | 197 | 201 | 234 | 235 | 253 | 199 | 182 | 148 | 153 | 187 | 175 | 147 | 147 |
| $NH_3$ | mg/l | 0.16 | 0.4 | 0.5 | 0.8 | 0.5 | 0.5 | 0.7 | 0.5 | 0.7 | 0.6 | 0.6 | 0.6 | 0.7 | 0.6 | 0.5 | 0.5 | 0.5 | 0.73 | 0.53 | 0.82 | 0.5 | 0.9 | 0.9 | 1 |
| $NO_3$ | mg/l | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| $NO_2$ | mg/l | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| o-$PO_4^3$ | ug/l | | | | | | | | | | | | | | | | | | | | | | | | |
| Alk. | mg/l | 51 | 60 | 61 | 63 | 99 | 66 | 50 | 57 | 51 | 67 | 65 | 73 | 78 | 85 | 86 | 96 | 72 | 69 | 53 | 57 | 72 | 66 | 52 | 60 |
| TTHM* | ug/l | 17.8 | 12.3 | 11.1 | 12.6 | 13.1 | 12.7 | 11.3 | 15.3 | 17.5 | 17.1 | 19.4 | 13.4 | 13.4 | 13 | 18.8 | 10.5 | 10.6 | 20.6 | 18.6 | 20.3 | 16.2 | 15.9 | 17.5 | 18.2 |
| TTHM** | ug/l | | | 7.03 | 13.8 | 10.5 | 10.1 | 11.9 | 13.1 | 16.3 | 16.6 | 12.2 | 11.2 | 11 | 14.5 | 6.62 | 8.77 | 15 | 15.3 | 15.3 | 12.8 | | 11.1 | 15.6 | |
| HAA5* | ug/l | 21 | 18 | 16 | 17 | 18 | 15 | 17.1 | 15.7 | 22.7 | 22.4 | 21.4 | 25.2 | 20.5 | 18.2 | 16.2 | 11.4 | 12.3 | 19.8 | 25.1 | 27.9 | 19.5 | 25.7 | 26.8 | 33.3 |
| HAA5** | ug/l | | | 15 | 17 | 20 | 17 | 15.8 | 14.2 | 23.7 | 20.4 | 18.5 | 25.8 | 21.2 | 17.7 | 19.3 | 12.2 | 12.7 | 20.1 | 26.4 | 24.4 | 16.9 | 23.2 | 26.7 | |

## Table A.3. Historic Raw Water Quality for DW2

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | | | | 8.08 | 8.08 | 8.07 | 8.06 | 8.06 | 8.03 | 7.95 | 8.04 | 7.98 | 7.95 | 7.97 | 7.99 | 8.02 | 8.01 | 8.00 | 7.92 | 7.94 | 7.90 | 7.88 | 7.95 | 7.96 | 7.96 |
| Alkalinity | | | | 176 | 176 | 178 | 177 | 176 | 176 | 174 | 173 | 171 | 177 | 173 | 171 | 168 | 167 | 172 | 174 | 166 | 166 | 165 | 169 | 202 | 170 |
| Ammonia | mg/L N | | | 0.45 | 0.31 | 0.28 | 0.32 | 0.32 | 0.33 | 0.28 | 0.42 | 0.25 | 0.39 | 0.34 | 0.35 | 0.33 | 0.12 | 0.10 | 0.10 | 0.14 | 0.12 | 0.17 | 0.16 | 0.19 | 0.17 |
| TDS | mg/L | | | 8.6 | 827 | 822 | 798 | 812 | 805 | 805 | 800 | 794 | 710 | 780 | 798 | 809 | 815 | 833 | 833 | 811 | 817 | 822 | 827 | 804 | 810 |
| Hardness | mg/L as $CaCO_3$ | | | 334 | 337 | 338 | 340 | 340 | 335 | 334 | 330 | 331 | 319 | 329 | 332 | 332 | 335 | 336 | 342 | 341 | 341 | 331 | 326 | 325 | 326 |
| DO | mg/L | | | 8.0 | 7.7 | 7.9 | 7.9 | 7.7 | 7.7 | 8.3 | 8.8 | 8.47 | 8.6 | 8.6 | 8.7 | 8.7 | 9.04 | 9.17 | 9.44 | 9.40 | 9.06 | 8.60 | 8.80 | 8.18 | 8.26 |
| Arsenic | mg/L | 0.019/ 0.018 | 0.016 | 0.015/ 0.014 | 0.016/ 0.014 | 0.015/ 0.017 | 0.016/ 0.015 | 0.016/ 0.015/ 0.014 | 0.016/ 0.018 | 0.017/ 0.019 | 0.016/ 0.022/ 0.015 | 0.018/ 0.018 | 0.015/ 0.018 | 0.014 | | | | | | | | | | | |
| Calcium | mg/L | | | 134 | 135 | 135 | 136 | 134 | 134 | 134 | 131 | 131 | 131 | 131 | 131 | 133 | 135 | 135 | 137 | 137 | 136 | 133 | 130 | 130 | 130 |
| Iron | mg/L | <0.4/ <0.4 | <0.4 | <0.4/ <0.4 | <0.4/ <0.4 | <0.4/ <0.4 | <0.4/ <0.4 | <0.4/ <0.4/ <0.4 | <0.4/ <0.4 | <0.4/ <0.4 | <0.4/ <0.4/ <0.4 | <0.4/ <0.4 | <0.4/ <0.4 | <0.4 | | | | | | | | | | | |
| Manganese | mg/L | 0.484/ 0.489 | 0.524 | 0.489/ 0.469 | 0.463/ 0.438 | 0.423/ 0.394 | 0.446/ 0.377 | 0.400<br>0.60<br>0.387 | 0.380/ 0.362 | 0.340/ 0.330 | 0.32/ 0.33/ 0.33 | 0.37/ 0.34 | 0.34/ 0.34 | 0.35 | | | | | | | | | | | |

## Table A.4. Historic Finished Water Quality for DW2

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conductivity | µho/cm | | | | | | | | | | | | 1200 | | | | | | | | | | | | |
| pH | | | | 7.81 | 7.79 | 7.75 | 7.79 | 7.80 | 7.82 | 7.77 | 7.81 | 7.76 | 7.75 | 7.83 | 7.80 | 7.85 | 7.89 | 7.86 | 7.79 | 7.80 | 7.82 | 7.77 | 7.81 | 7.76 | 7.75 |
| Alkalinity | mg/L $CaCO_3$ | | | 169 | 169 | 170 | 171 | 171 | 170 | 169 | 166 | 165 | 169 | 168 | 165 | 162 | 166 | 168 | 171 | 171 | 170 | 169 | 166 | 165 | 169 |
| Ammonia | mg/L N | | | 0.10 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.12 | 0.12 | 0.12 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 |
| Nitrate | mg/L N | <1 | | | | | | | | | | | | | | | 0.92 | | | <1 | | | | | |
| Nitrite | mg/L | <0.01 | | | | | | | | | | | | | | | <1 | | | <0.01 | | | | | |
| Tot. reg. HAA (dist.sys.) | µg/L | 12.3 | | | | | | | | | | | | | | | 28 | 18 | | 10 | | 14 | 30 | | 12 |
| Tot. THM (dist. sys.) | µg/L | 59.1 | | | | | | | | | | | | | | | 64 | 59 | | 61.6 | | 63 | 87 | | 93.5 |
| Total THM (entry point) | µg/L | | | | | | | | | | | | | | | | | | | 35.1 | | | | | |
| Hardness | mg/L as $CaCO_3$ | | | 330 | 336 | 336 | 338 | 340 | 336 | 333 | 329 | 331 | 317 | 329 | 331 | 334 | 334 | 336 | 340 | 341 | 340 | 330 | 325 | 325 | 327 |
| TDS | mg/L | | | 823 | 832 | 825 | 812 | 822 | 816 | 808 | 804 | 1827 | 805 | 790 | 810 | 832 | 831 | 839 | 839 | 831 | 820 | 817 | 811 | 795 | 791 |
| Langlier index | | | | | | | | | | | | | 0.48 | | | | | | | | | | | | |
| Antimony | mg/L | | | <0.003 | | | | | | | | | | | | | | | | | | | | | |
| Arsenic | mg/L | 0.0064/0.0048 | 0.0034 | 0.0034<br>0.0039 | 0.0038/<0.003 | <0.003/0.0044 | 0.0045/0.0045 | 0.0060/0.0044/0.0046 | 0.0041/0.0049 | 0.0044/0.0054 | 0.0075/0.0060/0.0066 | 0.0057/0.0078 | 0.0068/0.0059 | 0.0048 | | | | | | | | | | | |
| Barium | mg/L | | | 0.0350 | | | | | | | | | | | | | | | | | | | | | |
| Beryllium | mg/L | | | <0.0005 | | | | | | | | | | | | | | | | | | | | | |
| Cadmium | mg/L | | | <0.0005 | | | | | | | | | | | | | | | | | | | | | |
| Calcium | mg/L | | | 132 | 134 | 135 | 136 | 136 | 135 | 133 | 130 | 131 | 131 | 131 | 131 | 133 | 134 | 135 | 136 | 137 | 136 | 132 | 130 | 1330 | 131 |
| Chromium | mg/L | | | <0.01 | | | | | | | | | | | | | | | | | | | | | |
| Cyanide | mg/L | | | <0.005 | | | | | | | | | | | | | | | | | | | | | |
| Fluoride | mg/L | | | 0.6300 | | | | | | | | | | | | | | | | | | | | | |
| Hexavalent chromium | mg/L | | | <0.015 | | | | | | | | | | | | | | | | | | | | | |
| Iron | mg/L | 0.0570/<0.04 | 0.0410 | <0.04/<0.04 | <0.04/<0.04 | <0.40/0.0780 | 0.0690/<0.04 | 0.1700/0.0590/0.1900 | <0.40/<0.40 | <0.40/<0.40 | <0.04/<0.04/<0.04 | <0.04/<0.04 | <0.04/<0.04 | <0.04 | | | | | | | | | | | |
| Manganese | mg/L | <0.10/<0.10 | <0.10 | <0.10/<0.10 | <0.10/<0.10 | <0.10/<0.10 | <0.10/<0.10 | <0.20/<0.20/<0.20 | <0.10/<0.10 | <0.10/<0.10 | <0.10/<0.10/<0.10 | <0.10/<0.10 | <0.10/<0.10 | <0.10 | | | | | | | | | | | |
| Mercury | mg/L | | | <0.0002 | | | | | | | | | | | | | | | | | | | | | |
| Nickel | mg/L | | | <.01 | | | | | | | | | | | | | | | | | | | | | |
| Selenium | mg/L | | | <.003 | | | | | | | | | | | | | | | | | | | | | |
| Thallium | mg/L | | | <0.001 | | | | | | | | | | | | | | | | | | | | | |

## Table A.5. Historic Raw Water Quality for DW3

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/L | 3.8 | 4.1 | 3.2 | 3.6 | 3.7 | 3.7 | 4.4 | 4.4 | 1.3 | 4.3 | 4.8 | 5.0 | 4.9 | 4.7 | 4.3 | 3.9 | 3.8 | 4.0 | 3.9 | 4.6 | 4.8 | 4.9 | 5.2 | 4.9 |
| Cond. | mho/cm | 256 | 285 | 281 | 280 | 262 | 286 | 282 | 282 | 338 | 322 | 307 | 321 | 325 | 353 | 338 | 342 | 313 | 338 | 313 | 370 | 412 | 449 | 449 | 448 |
| $NH_3$ | mg/L | 0 | 0 | 0.09 | 0 | 0 | 0 | 0.07 | 0.06 | 0 | 0.17 | 0.36 | 0.4 | 0.34 | 0.09 | 0.05 | 0.03 | 0.03 | 0.07 | 0.02 | 0.03 | 0 | 0.08 | 0.12 | 0.27 |
| $NO_3$ | mg/L | 1.1 | 1.3 | 1.3 | 1.8 | 13.8 | 1.9 | 0.5 | 0.5 | 0.2 | 0.4 | 0.4 | 0.7 | 1.0 | 1.5 | 2.0 | 2.3 | 2.1 | 0.3 | 1.4 | 0.7 | 0.1 | 0.2 | 0.9 | 0.3 |
| Alk. | mg/L | 26 | 42 | 28 | 29 | 27 | 36 | 36 | 20 | 28 | 42 | 42 | 40 | 36 | 39 | 37 | 36 | 35 | 33 | 41 | 35 | 52 | 35 | 22 | 59 |

## Table A.6. Historic Finished Water Quality for DW3

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/L | 2.2 | 2 | 1.8 | 1.9 | 1.9 | 2 | 2 | 2.1 | 2.4 | 2.1 | 2.3 | 2.3 | 2.7 | 2.7 | 2.6 | 3.3 | 2.8 | 2.2 | 3.1 | 2.5 | 2.8 | 2.9 | 3.1 | 2.8 |
| $NO_3^-$ | mg/L | | | | | 0.39 | | | | | | | | | | | | 0.29 | | | | | | | |
| $o\text{-}PO_4^{3-}$ | mg/L | 1.13 | 1.06 | 0.95 | 0.9 | 0.89 | 0.93 | 0.93 | 0.92 | 0.92 | 0.92 | 0.92 | 0.84 | 0.85 | 0.83 | 0.83 | 0.87 | 0.94 | 0.93 | 0.89 | 0.91 | 0.93 | 0.92 | 0.92 | 0.92 |
| Alk. | mg/L | 24 | 22 | 23 | 24 | 24 | 24 | 25 | 24 | 24 | 24 | 22 | 23 | 24 | 24 | 25 | 28 | 25 | 26 | 33 | 32 | 34 | 37 | 33 | 35 |
| TTHM | ug/L | | | | | | | | | | | | | | | | 15.2 | | | | | | 38.7 | | 28 |
| HAA5 | ug/L | | | | | | | | | | | | | | | | 24.6 | | | | | | 33.1 | | 31 |

## Table A.7. Historic Raw Water Quality for DW4

| | **Units** | **Nov 05** | **Dec 05** | **Jan 06** | **Feb 06** | **Mar 06** | **Apr 06** | **May 06** | **Jun 06** | **Jul 06** | **Aug 06** | **Sep 06** | **Oct 06** | **Nov 06** | **Dec 06** | **Jan 07** | **Feb 07** | **Mar 07** | **Apr 07** | **May 07** | **Jun 07** | **Jul 07** | **Aug 07** | **Sep 07** | **Oct 07** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/L | 8.2 | 8.5 | 7.0 | 6.9 | 6.7 | 8.9 | 10.9 | 6.3 | 6.4 | 5.7 | 6.0 | -NA- | -NA- | -NA- | 6.6 | 7.0 | 8.7 | 11.0 | 11.2 | 11.6 | 8.1 | 7.8 | 8.7 | 12.6 |
| Color | | 40 | 38 | 31 | 27 | 30 | 52 | 66 | 46 | 35 | 36 | 29 | 22 | 20 | 19 | 22 | 17 | 44 | 65 | 47 | 45 | 33 | 30 | 27 | 76 |
| Cond. | uS | 207 | 232 | 221 | 226 | 223 | 189 | 190 | 198 | 216 | 235 | 231 | 221 | 227 | 244 | 262 | 264 | 267 | 211 | 195 | 180 | 208 | 228 | 233 | 215 |
| TDS | mg/L | 324 | 269 | 273 | 300 | 324 | 320 | 394 | 297 | 284 | 264 | 275 | 374 | 316 | 304 | 363 | 332 | 278 | 269 | 364 | 295 | 325 | 381 | 274 | 301 |
| $NH_3$ | mg/L | 0.1 | 0.37 | 0.25 | 0.35 | 0.3 | 0.26 | 0.26 | 0.26 | 0.95 | 0.16 | 0.25 | 0.2 | 0.28 | 0.16 | 0.55 | 0.40 | 0.33 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| $NO_3^-$ | mg/L | 0.18 | 0.18 | 0.28 | 0.27 | 0.24 | 0.23 | 0.25 | 0.26 | 0.05 | 0.01 | 0.07 | 0.07 | 0.11 | 0.25 | 0.298 | 0.280 | 0.280 | 0.217 | 0.072 | 0.081 | 0.097 | -- | 0.136 | 0.700 |
| $NO_2^-$ | mg/L | 0.004 | 0.006 | 0.006 | 0.003 | 0.01 | 0.008 | 0.004 | 0.007 | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 | 0.005 | 0.006 | 0.007 | 0.009 | 0.010 | 0.005 | 0.004 | 0.004 | -- | 0.017 | 0.021 |
| o-$PO_4^{3-}$ | mg/L | 0.06 | 0.09 | 0.06 | 0.06 | 0.07 | 0.07 | 0.05 | 0.06 | 0.03 | 0.07 | 0.08 | 0.03 | 0.02 | 0.02 | 0.18 | 0.13 | 0.18 | 0.3 | 0.26 | 0.21 | 0.25 | 0.27 | 0.39 | 0.003 |
| Alk. | | 160 | 176 | 180 | 192 | 182 | 131 | 133 | 155 | 167 | 163 | 164 | 184 | 188 | 199 | 201 | 216 | 160 | 124 | 156 | 153 | 167 | 160 | 156 | 134 |

## Table A.8. Historic Finished Water Quality for DW4

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/L | 3.9 | 4.6 | 3.8 | 4.1 | 3.7 | 4.5 | 5.8 | 3.6 | 3.9 | 3.5 | 3.7 | | | | 4.1 | 4.4 | 4.5 | 5.7 | 5.2 | 5.7 | 4.5 | 4.0 | 4.3 | 6.2 |
| Color | | 4 | 5 | 5 | 5 | 4 | 5 | 8 | 7 | 6 | 5 | 4 | 1 | 1 | 1 | 2 | 1 | 2 | 4 | 3 | 3 | 2 | 2 | 2 | 5 |
| Cond. | uS | 350 | 393 | 390 | 418 | 398 | 299 | 302 | 346 | 369 | 373 | 382 | 404 | 410 | 442 | 459 | 483 | 388 | 289 | 337 | 320 | 362 | 383 | 388 | 333 |
| TDS | mg/L | 155 | 165 | 155 | 167 | 191 | 152 | 156 | 156 | 171 | 173 | 160 | 157 | 157 | 173 | 160 | 179 | 196 | 168 | 140 | 135 | 157 | 160 | 140 | 146 |
| $NH_3$ | mg/L | 1.03 | 1.25 | 0.9 | 1.12 | 1.1 | 0.98 | 0.88 | 0.96 | 1.08 | 0.96 | 0.89 | 0.84 | 1.03 | 1.35 | 1.3 | 1.07 | 0.97 | 1.29 | 0.9 | 0.95 | 0.9 | 0.86 | 0.81 | 0.9 |
| $NO_3$ | mg/L | 0.2 | 0.31 | 0.27 | 0.27 | 0.24 | 0.23 | 0.25 | 0.26 | 0.05 | 0.01 | 0.07 | 0.07 | 0.11 | 0.25 | 0.29 | 0.29 | 0.29 | 0.20 | 0.09 | 0.08 | 0.10 | | 0.14 | 0.70 |
| $NO_2$ | mg/L | 0.002 | 0.005 | 0.003 | 0.001 | 0.003 | 0.005 | 0.001 | 0.003 | 0 | 0 | 0.005 | 0.001 | 0 | 0.003 | 0.004 | 0.002 | 0.001 | 0.006 | 0.000 | 0.004 | 0.004 | | 0.017 | 0.021 |
| $o\text{-}PO_4^3$ | mg/L | 38 | 45 | 44 | 45 | 40 | 34 | 37 | 36 | 40 | 40 | 31 | 37 | 40 | 41 | 45 | 45 | 46 | 36 | 32 | 36 | 41 | 35 | 26 | 30 |
| TTHM* | ug/L | 20.6 | | | 12.4 | | 31.4 | | | 32.3 | | | | 9.1 | | | 11.0 | | 52.9 | | | 38.2 | | | |
| TTHM** | ug/L | 25.8 | | | 14.4 | | 34.9 | | | 34.7 | | | | 10.4 | | | 12.1 | | 58.1 | | | 40.2 | | | |
| HAA5* | ug/L | 26.1 | | | 11.9 | | 25.6 | | | 19.5 | | | | 5.0 | | | 7.5 | | 44.4 | | | 27.6 | | | |
| HAA5** | ug/L | 28 | | | 12.9 | | 36 | | | 25.8 | | | | 7.3 | | | 8.9 | | 54.7 | | | 34.6 | | | |

## Table A.9. Historic Raw Water Quality for DW5

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/L | 2.6 | 2.5 | 2.3 | 2.5 | 2.7 | 2.6 | 2.6 | 2.7 | 2.7 | 2.6 | 2.5 | 2.5 | 2.4 | 2.6 | 2.5 | 2.5 | 2.6 | 2.6 | 3 | 2.6 | 2.9 | 2.6 | 2.7 | 2.6 |
| Color | | | 5 | 10 | | | 5 | | | 5 | | | 5 | | | 0 | | | 0 | | | 4 | | | 5 |
| Cond. | us/cm | | 1093 | 1074 | | | 1063 | | | 1042 | | | 1035 | | | 1024 | | | 1034 | | | 1041 | | | 1043 |
| TDS | mg/L | 649 | 706 | 689 | 674 | 672 | 656 | 660 | 680 | 648 | 664 | 660 | 660 | 652 | 668 | 670 | 652 | 662 | 644 | 646 | 630 | 642 | 648.2 | 641.8 | 624.4 |
| $NH_3$ | mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 0.035 | <.02 | <.02 | <.02 | 0.026 | 0.038 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 |
| $NO_3$ | mg/L | | 0.66 | 0.69 | | | 0.57 | | | 0.52 | | | 0.47 | | | 0.59 | | | 0.63 | | | 0.55 | | | 0.49 |
| $NO_2$ | mg/L | | <.05 | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 |
| $o\text{-}PO_4^{3}$ | mg/L | 0.003 | 0.004 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.003 | <.002 | 0.002 | 0.003 | <.002 | <.002 | <.002 | 0.004 | 0.006 | 0.003 | 0.002 | 0.003 | 0.003 | 0.00291 |
| Alk. | mg/L | 140 | 131 | 132 | 135 | 135 | 138 | 137 | 139 | 139 | 139 | 139 | 139 | 139 | 131 | 135 | 131 | 131 | 140 | 138 | 139 | 139 | 135 | 139 | 140 |

## Table A.10. Historic Finished Water Quality for DW5

| | Units | Nov 05 | Dec 05 | Jan 06 | Feb 06 | Mar 06 | Apr 06 | May 06 | Jun 06 | Jul 06 | Aug 06 | Sep 06 | Oct 06 | Nov 06 | Dec 06 | Jan 07 | Feb 07 | Mar 07 | Apr 07 | May 07 | Jun 07 | Jul 07 | Aug 07 | Sep 07 | Oct 07 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | mg/L | 2.4 | 2.5 | 2.1 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.3 | 2.3 | 2.4 | 2.3 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.5 | 2.4 | 2.5 | 2.3 |
| Color | PCU | | 2.5 | 7.5 | | | 2.5 | | | 2.5 | | | 2.5 | | | 0 | | | 0 | | | 0 | | | 2.5 |
| Cond. | us/cm | | 1123 | 1099 | | | 1080 | | | 1078 | | | 1058 | | | 1059 | | | 1063 | | | 1068 | | | 1070 |
| TDS | mg/L | 668 | 714 | 702 | 682 | 684 | 668 | 666 | 686 | 666 | 678 | 664 | 664 | 660 | 680 | 684 | 662 | 678 | 650 | 656 | 662 | 650 | 653.4 | 664 | 647.2 |
| $NH_3$ | mg/L | <0.020 | <0.020 | <0.020 | <0.020 | <0.020 | <0.020 | 0.022 | <.02 | 0.037 | <.02 | 0.027 | 0.042 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 |
| $NO_3$ | mg/L | | 0.51 | 0.66 | | | 0.56 | | | 0.54 | | | 0.5 | | | 0.63 | | | 0.67 | | | 0.57 | | | 0.54 |
| $NO_2$ | mg/L | | <.05 | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 | | | <.05 |
| o-$PO_4^3$ | mg/L | 0.068 | 0.061 | 0.0645 | 0.0588 | 0.0596 | 0.0644 | 0.0695 | 0.0566 | 0.0616 | 0.0608 | 0.0669 | 0.064 | 0.0561 | 0.0599 | 0.06 | 0.0609 | 0.0617 | 0.0624 | 0.064 | 0.0589 | 0.0632 | 0.0609 | 0.0637 | 0.0667 |
| Alk. | mg/L | 137 | 130 | 131 | 134 | 135 | 136 | 136 | 138 | 140 | 137 | 138 | 139 | 138 | 134 | 133 | 130 | 131 | 138 | 137 | 137 | 139 | 136 | 138 | 140 |
| TTHMs | mg/L | 0.014* | | 0.014 | | | 0.013 | | | 0.012 | | | 0.016 | | | 0.0082 | | | 0.018 | | | 0.0096 | | | 0.027 |
| HAAs | mg/L | 0.009* | | NA | | | 0.0085 | | | 0.0062 | | | 0.01 | | | 0.0052 | | | 0.01 | | | 0.0062 | | | 0.01 |

## Table A.11. Historic Source Water Quality for IPR1

| | Units | Dec 05 | Feb 06 | Aug 06 | Dec 06 | Feb 07 | Jun 07 |
|---|---|---|---|---|---|---|---|
| Bromodichloromethane | | <0.5 | <0.5 | <0.5 | 0.8 | <0.5 | 1.2 |
| Bromoform | | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chlorodibromomethane | | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 0.7 |
| Chloroform | | 0.7 | <0.5 | 1.0 | 2.0 | 0.5 | 1.9 |
| pH | | 8.2 | 8.1 | 8.5 | 8.1 | 7.9 | 8.3 |
| Alkalinity | | 153 | 111 | 139 | 144 | 105 | 142 |
| Ammonia | | 0.79 | 0.23 | 0.13 | 0.88 | 0.267 | 0.3 |
| Conductiance | | 930 | 777 | 1000 | 999 | 640 | 999 |
| TOC | | 12.2 | 4.1 | 5.6 | 6.9 | 6.4 | 6.2 |
| Bicarbonate | | 186 | 130 | 170 | 180 | 130 | 170 |
| Carbonate | | <2 | <2 | 3.5 | <2 | <2 | 2.2 |
| BOD | | 5.3 | <5 | <5 | <5 | 3.1 | <5 |
| COD | | 31 | 10 | 18 | 20 | 19 | 15 |
| Hardness | | 267 | 200 | 230 | 220 | 180 | 220 |
| Org-N | | 1.91 | 0.6 | 1.2 | 0.92 | 0.83 | 0.9 |
| TDS | | 490 | 448 | 590 | 588 | 384 | 658 |
| Color | | 40 | 20 | 25 | 20 | 20 | 10 |
| Ag (Silver) | | <0.0005 | <0.0005 | 0.00053 | <0.0005 | 0.001 | <0.0005 |
| Al (Aluminum) | | 0.033 | 0.086 | 0.025 | 0.0056 | 0.45 | 0.025 |
| As (Arsenic) | | 0.002 | 0.0017 | 0.002 | 0.002 | 0.0018 | 0.0017 |
| B (Boron) | | 0.25 | 0.21 | 0.31 | 0.25 | 0.17 | 0.33 |
| Ba (Barium) | | 0.057 | 0.055 | 0.038 | 0.054 | 0.05 | 0.039 |
| Be (Beryllium) | | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Ca (Calcium) | | 67 | 52 | 59 | 60 | 44 | 55 |
| Cd (Cadmium) | | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| $Cl^-$ (Chloride) | | 97.8 | 95 | 125 | 150 | 89 | 140 |
| $CN^-$ (Cyanide) | | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Cr (IV) (hexavalent chromium) | | 0.0004 | <0.0001 | <0.0001 | 0.00014 | 0.00013 | 0.00016 |
| Cr (Total Chromium) | | 0.0016 | <0.001 | <0.001 | <0.001 | 0.0041 | 0.001 |
| Cu (Copper) | | 0.0051 | 0.003 | 0.0039 | 0.0048 | 0.0057 | 0.0028 |
| $F^-$ (Fluoride) | | 0.38 | 0.073 | 0.29 | 0.36 | 0.21 | 0.35 |
| Fe (Iron) | | 0.12 | 0.16 | 0.048 | 0.11 | 0.34 | 0.066 |
| Hg (Mercury) | | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |
| K (Potassium) | | 9.3 | 5.7 | 11 | 10 | 6.1 | 13 |
| Mg (Magnesium) | | 22 | 19 | 21 | 17 | 16 | 21 |
| Mn (Manganese) | | 0.073 | 0.058 | 0.067 | 0.05 | 0.034 | 0.027 |
| Na (Sodium) | | 93 | 77 | 110 | 110 | 61 | 120 |
| Ni (Nickel) | | 0.009 | <0.005 | 0.0099 | <0.005 | <0.0005 | 0.0052 |

## Table A.11. Historic Source Water Quality for IPR1 (continued)

| | Units | Dec 05 | Feb 06 | Aug 06 | Dec 06 | Feb 07 | Jun 07 |
|---|---|---|---|---|---|---|---|
| $NO_2^-$ (Nitrite) | | 0.52 | 0.23 | 0.55 | 0.77 | 0.34 | <0.5 |
| $NO_3^-$ (Nitrate) | | 3.5 | 1.2 | 4 | 4 | 1.7 | 3.2 |
| Pb (Lead) | | 0.00075 | 0.00062 | 0.00053 | 0.00064 | 0.0022 | 0.00052 |
| Sb (Antimony) | | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Se (Selenium) | | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| $SO_4^{-2}$ (Sulfate) | | 150 | 130 | 140 | 100 | 69 | 150 |
| Tl (Thallium) | | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Zn (Zinc) | | 0.034 | 0.027 | 0.034 | 0.049 | 0.034 | 0.037 |

## Table A.12. Historic Finished Water Quality for IPR1

| | Units | Apr 06 | Oct 06 | Jun 07 | Oct 07 |
|---|---|---|---|---|---|
| pH | | 7.9 | 7.6 | 7.6 | 7.6 |
| Alkalinity | | 133 | 127 | 145 | 149 |
| Ammonia | | | | | |
| Nitrite | | <0.5 | <0.5 | <0.5 | <0.5 |
| Nitrate | | 2.9 | 3.0 | 2.7 | 2.1 |
| Sulfate | | 110 | 90 | 100 | 118 |
| Specific conductance | | 765 | 710 | 745 | 754 |
| TOC | | 0.97 | 1 | 18.5 | 1 |
| Bromodichloromethane | | <0.5 | <0.5 | <0.5 | <0.5 |
| Bromoform | | <0.5 | <0.5 | <0.5 | <0.5 |
| Dibromochloromethane | | <0.5 | <0.5 | <0.5 | <0.5 |
| Chloroform | | <0.5 | <0.5 | <0.5 | <0.5 |
| Bicarbonate | | 160 | 150 | 180 | 180 |
| Carbonate | | <2 | <2 | <2 | <2 |
| Hardness | | 200 | 180 | 220 | 220 |
| TDS | | 440 | 396 | 446 | 468 |
| Color | | 3 | <3 | 3 | <3 |
| Aluminum | | <0.025 | <0.025 | <0.025 | <0.025 |
| Antimony | | <0.001 | <0.001 | <0.001 | <0.001 |
| Arsenic | | 0.0011 | 0.0011 | <0.001 | <0.001 |
| Barium | | 0.073 | 0.071 | 0.078 | 0.080 |
| Beryllium | | <0.001 | <0.001 | <0.001 | <0.001 |
| Boron | | 0.23 | 0.28 | 0.26 | 0.21 |
| Cadmium | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| Calcium | | 54 | 51 | 60 | 61 |
| Chloride | | 84 | 75.2 | 82 | 87 |
| Fluoride | | 0.48 | 0.46 | 0.36 | 0.36 |
| Iron | | <0.02 | <0.02 | <0.02 | <0.02 |
| Lead | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| Magnesium | | 15 | 14 | 16 | 16 |
| Manganese | | 24 | 24 | 24 | 27 |
| Mercury | | <0.0002 | <0.0002 | <0.0002 | <0.0002 |
| Nickel | | <0.005 | <0.005 | <0.005 | <0.005 |
| Potassium | | 4.2 | 4.4 | 4.2 | 4.3 |
| Selenium | | <0.005 | <0.005 | <0.005 | <0.005 |
| Silver | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| Sodium | | 77 | 75 | 77 | 79 |
| Sulfur | | <0.001 | <0.001 | <0.001 | <0.001 |
| Zinc | | <0.005 | <0.005 | <0.005 | <0.005 |

## Table A.13. Historic Finished Water Quality for IPR2

| | Units | Jan 03 | Mar 03 | May 03 | Jul 03 | Sep 03 | Nov 03 | Jan 04 | Mar 04 | May 04 | Jul 04 | Sep 04 | Feb 05 | Jun 05 | Sep 05 | Mar 06 | Sep 06 | Feb 07 | Aug 07 | Mar 08 | Apr 08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specific conductance | | 494 | 492 | 527 | | 654 | | | 581 | | | 660 | 589 | | 643 | 602 | 591 | 582 | 589 | 258 | 160 |
| Color | | 4 | <3 | <3 | <3 | 4 | <3 | <3 | <3 | 5 | <3 | 3 | 3 | 3 | 3 | <3 | 5 | <3 | <3 | <3 | <3 |
| TDS | | 260 | | | | | | | | | | | | | | | | | | 152 | 128 |
| TOC | | 0.66 | 0.75 | 0.61 | 0.8 | | | 1.52 | 0.93 | | 1.73 | 1.36 | 0.75 | 1.04 | 1.02 | 0.88 | 0.8 | 0.72 | 0.63 | 0.35 | 0.28 |
| NDMA | | | 3.4 | 2.7 | <2 | 3.6 | 2.4 | | 3.4 | 6 | 3.2 | 3.3 | 2.6 | 4.3 | 2.5 | 4.8 | 3.4 | 2.2 | <2 | 2.2 | 2.6 |
| Alkalinity | | 131 | 130 | | | 136 | | | 138 | | | 94.3 | 84.8 | | 85.5 | 85.4 | 88.8 | 92.1 | 98.9 | 55.8 | 43.5 |
| Ammonia | | | | | | 1.9 | | | | | | | | | | | | | | | |
| Nitrite | | <0.3 | <0.3 | | | <0.3 | | | <0.3 | | | <0.3 | <0.3 | | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 1.1 | 0.4 |
| Nitrate | | <0.2 | <0.2 | | | <0.2 | | | <0.2 | | | 4.5 | 6.7 | | 5.8 | 3.7 | 1.1 | 0.7 | <0.2 | 6.1 | 7 |
| Phosphate | | <0.1 | <0.1 | | | <0.1 | | | <0.1 | | | <0.1 | <0.1 | | <0.1 | <0.1 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 |
| Aluminum | | | | | | | | | | | | | | | | | | | | 0.0019 | 0.0022 |
| Antimony | | | | | | | | | | | | | | | | | | | | <0.0005 | <0.0005 |
| Arsenic | | | | | | | | | | | | | | | | | | | | <0.001 | 0.0011 |
| Barium | | | | | | | | | | | | | | | | | | | | 0.0766 | 0.164 |
| Beryllium | | | | | | | | | | | | | | | | | | | | <0.0005 | <0.0005 |
| Boron | | 0.18 | 0.18 | | | 0.17 | | | 0.16 | | | 0.14 | 0.16 | | 0.19 | 0.18 | 0.18 | 0.16 | 0.15 | 0.2 | 0.2 |
| Cadmium | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Chromium | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Cobalt | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Copper | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Iron | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Lead | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Magnesium | | 3.1 | 3.4 | | | 6 | | | 4.8 | | | 6 | 5 | | 6.8 | 5.7 | 5.8 | 5.1 | 5.1 | 1.5 | 1 |
| Manganese | | | | | | | | | | | | | 0.012 | | 0.14 | 0.012 | 0.0049 | 0.007 | 0.0168 | 0.0022 | 0.0013 |
| Mercury | | | | | | | | | | | | | | | | | | | | <0.0001 | <0.0001 |
| Nickel | | | | | | | | | | | | | | | | | | | | <0.001 | <0.001 |
| Silver | | | | | | | | | | | | | | | | | | | | 0.0011 | <0.001 |
| Sodium | | | | | | | | | | | | | | | | | | | | <0.0001 | <0.0001 |
| Tin | | | | | | | | | | | | | | | | | | | | <0.0005 | <0.0005 |
| Vanadium | 0.001 | | | | | | | | | | | | | | | | | | | 0.002 | 0.0024 |
| Zinc | 0.001 | | | | | | | | | | | | | | | | | | | <0.001 | 0.0025 |

# *Appendix B*

# Raw Data

**Table B.1. Pharmaceutical and EDC Concentrations from DW1**

| | | **Raw Water Samples** | | **Finished Water Samples** | |
|---|---|---|---|---|---|
| **Compound** | **MDL** | **3/4/2008** | **8/5/2008** | **3/4/2008** | **8/5/2008** |
| Atenolol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 2.9 | 4.8 | 2.3 | 5.3 |
| Benzophenone | 50 ng/L | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | <5.0 | <5.0 | <5.0 | <5.0 |
| Caffeine | 5 ng/L | 5.9 | 7.0 | 6.2 | 7.0 |
| Carbamazepine | 0.5 ng/L | 2.0 | 1.1 | 2.2 | 1.4 |
| DEET | 1 ng/L | 22 | 44 | 20 | 53 |
| Diazepam | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 |
| Diclofenac | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | <1.0 | <1.0 | 1.1 | <1.0 |
| Estradiol | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | 1.3 | 0.26 | 1.2 | 0.30 |
| Ibuprofen | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 2.3 | 0.69 | 2.3 | 0.68 |
| Musk ketone | 25 ng/L | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | 0.78 | <0.50 | 0.53 | <0.50 |
| Octylphenol | 25 ng/L | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Progesterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 4.8 | 4.1 | <0.25 | <0.25 |
| TCEP | 10 ng/L | <10 | <10 | <10 | <10 |
| TCPP | 100 ng/L | <100 | <100 | <100 | <100 |
| Testosterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 |

### Table B.2. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from DW1

| | | **Raw Water Samples** | | **Finished Water Samples** | |
|---|---|---|---|---|---|
| | **MDL** | **3/4/2008** | **8/5/2008** | **3/4/2008** | **8/5/2008** |
| $ClO_4^-$ | 0.05 µg/L | 0.90 | 0.07 | 0.31 | 0.08 |
| $ClO_3^-$ | 0.1 µg/L | 0.10 | 0.63 | 210 | 260 |
| PFOA | 5 ng/L | <5.0 | <5.0 | <5.0 | <5.0 |
| PFOS | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 |
| TOX | 20 µg/L | <20 | <20 | 93 | 81 |
| TOBr | 20 µg/L | <20 | <20 | 28 | 30 |
| TOCl | 20 µg/L | 32 | <20 | 110 | 55 |
| TOFl | 20 µg/L | <20 | <20 | <20 | <20 |
| TOI | 20 µg/L | <20 | <20 | <20 | <20 |
| TN | 0.2 mg/L | <0.5 | <0.5 | 0.78 | 0.94 |
| Tot. reg. HAA | 1 µg/L | <1 | <1 | 5.8 | 8.6 |
| BAA | 1 µg/L | <1 | <1 | <1 | 1.1 |
| CAA | 2 µg/L | <2 | <2 | <1 | <2 |
| DBAA | 2 µg/L | <2 | <2 | <2 | <2 |
| DCAA | 1 µg/L | <1 | <1 | 4.0 | 6.0 |
| TCAA | 1 µg/L | <1 | <1 | 1.8 | 2.6 |
| Bromodichloromethane | 0.5 µg/L | <0.5 | <0.5 | 2.1 | 1.3 |
| Bromoform | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 |
| Chlorodibromomethane | 0.5 µg/L | <0.5 | <0.5 | 1.1 | 0.6 |
| Chloroform | 0.5 µg/L | <0.5 | <0.5 | 2.4 | 3.0 |
| Tot. THM | 0.5 µg/L | <0.5 | <0.5 | 5.6 | 4.9 |

**Table B.3. General Water Quality Parameters from DW1**

| | | Raw Water Samples | | Finished Water Samples | |
|---|---|---|---|---|---|
| | **MDL** | **3/4/2008** | **8/5/2008** | **3/4/2008** | **8/5/2008** |
| Conductivity | | 297 | 302 | 288 | 317 |
| TOC | 0.2 mg/L | 2.2 | 2.7 | 1.7 | 2.2 |
| DOC (filtered) | 0.2 mg/L | 2.1 | 2.7 | 1.6 | 2.3 |
| UV 254 (filtered) | 1/cm | 0.028 | 0.048 | 0.023 | 0.036 |
| UV 272 (filtered) | 1/cm | 0.021 | 0.037 | 0.012 | 0.021 |
| UV 436 (filtered) | 1/cm | 0.00020 | 0.0029 | 0 | 0.0023 |
| pH | | 7.8 | 6.8 | 7.2 | 6.6 |
| Alkalinity | 10 mg/L | 50 | 65 | 56 | 67 |
| NDMA | 2 ng/L | - | - | - | <2 |
| $F^-$ | 0.05 mg/L | 0.97 | 0.73 | 0.92 | 0.73 |
| $Cl^-$ | 0.05 mg/L | 16 | 16 | 18 | 19 |
| $Br^-$ | 0.1 mg/L | 0.20 | <0.1 | <0.1 | <0.1 |
| $NH_3$ | 0.02 mg/L | 0.04 | 0.03 | 0.42 | 0.56 |
| $NO_3^-$ | 0.05 mg/L | 0.32 | 0.26 | 0.27 | 0.15 |
| $PO_4^{3-}$ | 0.02 mg/L | 0.030 | 0.030 | 0.030 | 0.040 |
| $SO_4^{2-}$ | 1 mg/L | 46 | 45 | 49 | 50 |

## Table B.4. Concentrations of Dissolved Cations and Metals in Waters from DW1

| | | Raw Water Samples | | Finished Water Samples | |
|---|---|---|---|---|---|
| | MDL | 3/4/2008 | 8/5/2008 | 3/4/2008 | 8/5/2008 |
| Ag | 0.0024 mg/L | <0.0024 | <0.0024 | <0.0024 | <0.0024 |
| Al | 0.018 mg/L | <0.018 | 0.031 | <0.018 | 0.040 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | <0.008 | 0.056 | <0.008 | 0.044 |
| Ba | 0.0003 mg/L | 0.034 | 0.040 | 0.034 | 0.041 |
| Be | 0.00031 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| Ca | 0.01 mg/L | 31 | 32 | 31 | 33 |
| Cd | 0.0009 mg/L | 0.0012 | <0.0009 | <0.0009 | <0.0009 |
| Co | 0.005 mg/L | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.0036 | 0.024 | 0.025 | 0.026 |
| Fe | 0.0021 mg/L | 0.0062 | 0.0022 | <0.0021 | 0.0034 |
| K | 0.094 mg/L | 3.4 | 1.9 | 3.3 | 2.4 |
| Li | 0.0021 mg/L | 0.0099 | 0.0064 | 0.011 | 0.0069 |
| Mg | 0.011 mg/L | 6.3 | 7.1 | 6.3 | 7.3 |
| Mn | 0.0003 mg/L | 0.0054 | <0.0003 | 0.00068 | <0.0003 |
| Mo | 0.004 mg/L | 0.018 | 0.019 | 0.017 | 0.020 |
| Na | 0.007 mg/L | 14 | 15 | 13 | 16 |
| Ni | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 |
| P | 0.16 mg/L | <0.16 | <0.16 | <0.16 | <0.16 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 15 | 16 | 16 | 18 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | <0.033 | <0.033 | <0.033 | <0.033 |
| Si | 0.004 mg/L | 3.9 | 2.4 | 3.8 | 2.3 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 0.22 | 0.24 | 0.22 | 0.25 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | 1.2 | <1 | 1.0 | <1 |
| V | 0.0012 mg/L | <0.0012 | <0.0012 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.0033 | 0.0026 | 0.0076 | 0.0044 |

## Table B.5. Pharmaceutical and EDC Concentrations from DW2

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MDL | 11/5/2007 | 2/25/2008 | 5/14/2008 | 8/18/2008 | 11/5/2007 | 2/25/2008 | 5/14/2008 | 8/18/2008 |
| Atenolol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 0.75 | 0.59 | 0.72 | 0.52 | 0.60 | 0.64 | 0.75 | 0.53 |
| Benzophenone | 50 ng/L | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | <5.0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Caffeine | 5 ng/L | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Carbamazepine | 0.5 ng/L | 16 | 21 | 20 | 18 | 14 | 16 | 15 | 9.8 |
| DEET | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Diazepam | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 |
| Diclofenac | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | 4.5 | 4.2 | 5.7 | 4.3 | 4.8 | 4.2 | 4.5 | 4.4 |
| Estradiol | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 |
| Ibuprofen | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 2.8 | 1.2 | 1.9 | 1.6 | 1.7 | 0.70 | 1.3 | 1.3 |
| Musk ketone | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Octylphenol | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | 12 | 17 | 17 | 13 | 13 | 17 | 16 | 13 |
| Progesterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 18 | 24 | 23 | 19 | <0.25 | <0.25 | <0.25 | <0.25 |
| TCEP | 10 ng/L | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| TCPP | 100 ng/L | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 |
| Testosterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 |

**Table B.6. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from DW2**

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/5/2007** | **2/25/2008** | **5/14/2008** | **8/18/2008** | **11/5/2007** | **2/25/2008** | **5/14/2008** | **8/18/2008** |
| $ClO_4^-$ | 0.05 µg/L | 0.37 | 0.45 | 0.27 | 0.28 | 0.35 | 0.46 | 0.61 | 0.36 |
| $ClO_3^-$ | 0.1 µg/L | 2.2 | 3.5 | 4.1 | 3.2 | 4.7 | 3.5 | 4.3 | 2.7 |
| PFOA | 5 ng/L | 11 | 13 | 11 | 9.1 | 11 | 13 | 11 | 9.6 |
| PFOS | 1 ng/L | 10 | 7.7 | 12 | 10 | 9.3 | 7.4 | 11 | 11 |
| TOX | 20 µg/L | 21 | 21 | <20 | 28 | 240 | 350 | 170 | 240 |
| TOBr | 20 µg/L | <20 | <20 | <20 | <20 | 82 | 110 | 87 | 70 |
| TOCl | 20 µg/L | 27 | 25 | <20 | 44 | 100 | 230 | 110 | 190 |
| TOFl | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TOI | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TN | 0.2 mg/L | 0.74 | 0.97 | 0.99 | 0.85 | 0.86 | 0.96 | 1.0 | 0.81 |
| Tot. reg. HAA | 1 µg/L | - | <1 | <1 | <1 | - | 5.4 | 4.8 | 4.2 |
| BAA | 1 µg/L | - | <1 | <1 | <1 | - | <1 | <1 | <1 |
| CAA | 2 µg/L | - | <2 | <2 | <2 | - | <2 | <2 | <2 |
| DBAA | 2 µg/L | - | <2 | <2 | <2 | - | 5.4 | 4.8 | 4.2 |
| DCAA | 1 µg/L | - | <1 | <1 | <1 | - | <1 | <1 | <1 |
| TCAA | 1 µg/L | - | <1 | <1 | <1 | - | <1 | <1 | <1 |
| Bromodichloromethane | 0.5 µg/L | - | <0.5 | <0.5 | <0.5 | - | 4.9 | 4.7 | 4.4 |
| Bromoform | 0.5 µg/L | - | <0.5 | <0.5 | <0.5 | - | 12 | 11 | 8.3 |
| Chlorodibromomethane | 0.5 µg/L | - | <0.5 | <0.5 | <0.5 | - | 14 | 13 | 11 |
| Chloroform | 0.5 µg/L | - | <0.5 | <0.5 | <0.5 | - | 1.0 | 0.89 | 0.91 |
| Tot. THM | 0.5 µg/L | - | <0.5 | <0.5 | <0.5 | - | 31 | 30 | 25 |

### Table B.7. General Water Quality Parameters from DW2

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/5/2007** | **2/25/2008** | **5/14/2008** | **8/18/2008** | **11/5/2007** | **2/25/2008** | **5/14/2008** | **8/18/2008** |
| Conductivity | | 1150 | 1231 | 1233 | 1236 | 1250 | 1256 | 1242 | 1233 |
| TOC | 0.2 mg/L | 2.0 | 1.7 | 1.8 | 1.7 | 1.8 | 1.8 | 1.6 | 1.7 |
| DOC (filtered) | 0.2 mg/L | 2.1 | 1.7 | 1.7 | 1.8 | 1.7 | 1.7 | 1.7 | 1.7 |
| UV 254 (filtered) | 1/cm | 0.0228 | 0.0232 | 0.0252 | 0.0257 | 0.0212 | 0.0179 | 0.0187 | 0.0179 |
| UV 272 (filtered) | 1/cm | 0.0164 | 0.0176 | 0.0190 | 0.0197 | 0.0163 | 0.0134 | 0.0127 | 0.0117 |
| UV 436 (filtered) | 1/cm | -0.0036 | 0.0001 | 0.0007 | 0.0004 | 0.0007 | 0.0000 | 0.0000 | 0.0000 |
| pH | | 7.28 | 7.61 | 7.56 | 7.14 | 7.31 | 7.78 | 7.93 | 7.36 |
| Alkalinity | 10 mg/L | 150 | 138 | 162 | 160 | 146 | 147 | 149 | 152 |
| NDMA | 2 ng/L | - | - | - | - | - | - | <2 | - |
| $F^-$ | 0.05 mg/L | 0.50 | 0.63 | 0.57 | 0.61 | 0.50 | 0.63 | 0.58 | 0.62 |
| $Cl^-$ | 0.05 mg/L | 117.2 | 146.2 | 132.3 | 130.7 | 132.7 | 138.9 | 136.0 | 131.9 |
| $Br^-$ | 0.1 mg/L | <0.1 | 0.2 | 0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $NH_3$ | 0.02 mg/L | 0.25 | 0.14 | 0.15 | 0.13 | 0.03 | 1256 | 1242 | 0.02 |
| $NO_3^-$ | 0.5 mg/L | 5.1 / 0.9 | 1.3 | 0.80 | 1.6 | 1.8 / 1.9 | 1.3 | 1.1 | 0.50 |
| $PO_4^{3-}$ | 0.02 mg/L | 0.09 / 0.08 | 0.06 | 0.10 | 0.25 | 0.13 / 0.08 | 0.04 | 0.05 | 0.15 |
| $SO_4^{2-}$ | 1 mg/L | 264 | 297 | 274 | 276 | 269 | 303 | 276 | 276 |

## Table B.8. Concentrations of Dissolved Cations and Metals in Waters from DW2

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/5/2007** | **2/25/2008** | **5/14/2008** | **8/18/2008** | **11/5/2007** | **2/25/2008** | **5/14/2008** | **8/18/2008** |
| Ag | 0.0024 mg/L | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 |
| Al | 0.018 mg/L | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | 0.25 | 0.17 | 0.48 | 0.22 | 0.26 | 0.16 | 0.48 | 0.21 |
| Ba | 0.0003 mg/L | 0.050 | 0.038 | 0.044 | 0.042 | 0.045 | 0.033 | 0.042 | 0.040 |
| Be | 0.00031 mg/L | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 |
| Ca | 0.01 mg/L | 78 | 84 | 83 | 80 | 82 | 83 | 83 | 79 |
| Cd | 0.0009 mg/L | 0.0027 | 0.0032 | <0.0009 | 0.0027 | 0.0024 | 0.0026 | <0.0009 | 0.0022 |
| Co | 0.005 mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 | 0.0032 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.0056 | 0.0018 | <0.0009 | 0.015 | 0.0081 | 0.0020 | 0.0026 | 0.019 |
| Fe | 0.0021 mg/L | <0.0021 | <0.0021 | <0.0021 | <0.0021 | 0.050 | <0.0021 | <0.0021 | 0.0021 |
| K | 0.094 mg/L | 5.1 | 2.9 | 4.1 | 4.8 | 5.1 | 3.2 | 4.0 | 4.6 |
| Li | 0.0021 mg/L | 0.057 | 0.055 | 0.057 | 0.056 | 0.061 | 0.054 | 0.058 | 0.054 |
| Mg | 0.011 mg/L | 30 | 32 | 32 | 31 | 32 | 32 | 33 | 30 |
| Mn | 0.0003 mg/L | 0.33 | 0.27 | 0.23 | 0.25 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| Mo | 0.004 mg/L | 0.027 | 0.019 | 0.013 | 0.010 | 0.021 | 0.020 | 0.015 | 0.013 |
| Na | 0.007 mg/L | 130 | 150 | 150 | 130 | 140 | 140 | 150 | 130 |
| Ni | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| P | 0.16 mg/L | <0.16 | <0.16 | <0.16 | <0.16 | <0.16 | <0.16 | <0.16 | <0.16 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 82 | 99 | 90 | 97 | 86 | 97 | 89 | 94 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | 0.034 | <0.033 |
| Si | 0.004 mg/L | 8.9 | 8.3 | 7.6 | 9.4 | 9.3 | 8.1 | 7.5 | 9.0 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 1.2 | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.3 | 1.2 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| V | 0.0012 mg/L | 0.0030 | 0.0014 | <0.0012 | 0.0025 | <0.0012 | <0.0012 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.029 | 0.0047 | <0.0033 | 0.0082 | 0.012 | 0.0036 | <0.0033 | 0.015 |

**Table B.9. Pharmaceutical and EDC Concentrations from DW3**

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| Atenolol | 1 ng/L | 17 | 6.8 | <0.50 | <1.0 | 11 | 3.7 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 560 | 470 | 440 | 150 | 430 | 260 | 360 | 130 |
| Benzophenone | 50 ng/L | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | <5.0 | 5.4 | 7.85 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Caffeine | 5 ng/L | 4.8 | 17 | 29.5 | 19 | 5.4 | 22 | 33 | 21 |
| Carbamazepine | 0.5 ng/L | 110 | 57 | 51.5 | 52 | 100 | 33 | 43 | 26 |
| DEET | 1 ng/L | 63 | 65 | 71 | 37 | 61 | 49 | 64 | 37 |
| Diazepam | 0.25 ng/L | 0.64 | 0.30 | <0.25 | <0.25 | 0.63 | <0.25 | <0.25 | <0.25 |
| Diclofenac | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | 150 | 75 | 80 | 60 | 85 | 47 | 55 | 49 |
| Estradiol | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | 4.4 | 6.6 | 5.9 | 2.7 | 1.0 | 2.6 | 1.4 | 0.78 |
| Ibuprofen | 1 ng/L | 2.5 | <1.0 | <1.0 | <1.0 | 1.6 | <1.0 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 180 | 100 | 130 | 140 | 160 | 77 | 100 | 140 |
| Musk ketone | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | 0.69 | 1.0 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Octylphenol | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | 50 | 24 | 27 | 27 | 55 | 19 | 22 | 24 |
| Progesterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 65 | 89 | 54 | 37 | 1.0 | 0.63 | <0.25 | <0.25 |
| TCEP | 10 ng/L | 1300 | 640 | 230 | 210 | 1100 | 480 | 210 | 230 |
| TCPP | 100 ng/L | 1200 | 840 | 880 | 1400 | 1000 | 690 | 800 | 1600 |
| Testosterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | 1.0 | 1.9 | 1.1 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 |

## Table B.10. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from DW3

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| $ClO_4^-$ | 0.05 µg/L | 0.11 | 0.45 | 0.27 | 0.28 | 0.17 | 0.17 | 0.65 | 0.35 |
| $ClO_3^-$ | 0.1 µg/L | 45 | 3.5 | 4.1 | 3.2 | 390 | 520 | 780 | 980 |
| PFOA | 5 ng/L | 36 | 13 | 11 | 9.1 | 36 | 23 | 33 | 32 |
| PFOS | 1 ng/L | 23 | 7.7 | 12 | 10 | 26 | 23 | 15 | 27 |
| TOX | 20 µg/L | 110 | 21 | <20 | 28 | 530 | 360 | 400 | 360 |
| TOBr | 20 µg/L | <20 | <20 | <20 | <20 | 46 | 35 | 36 | 34 |
| TOCl | 20 µg/L | 90 | 25 | <20 | 44 | 510 | 320 | 440 | 360 |
| TOFl | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TOI | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | 13 | <20 |
| TN | 0.2 mg/L | 1.90 | 0.97 | 0.99 | 0.85 | 1.7 | 0.80 | 1.7 | 0.40 |
| Tot. reg. HAA | 1 µg/L | 32 | <1 | <1 | <1 | 34 | 19 | 29 | 23 |
| BAA | 1 µg/L | 1.7 | <1 | <1 | <1 | 1.2 | <1 | 4.2 | 1.5 |
| CAA | 2 µg/L | 2.5 | <2 | <2 | <2 | 6 | <2 | <2 | <2 |
| DBAA | 2 µg/L | 1.2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 |
| DCAA | 1 µg/L | 15 | <1 | <1 | <1 | 14 | 9.5 | 12 | 11 |
| TCAA | 1 µg/L | 12 | <1 | <1 | <1 | 13 | 9.4 | 13 | 11 |
| Bromodichloromethane | 0.5 µg/L | 11 | <0.5 | <0.5 | <0.5 | 10 | 9.1 | 12 | 7.9 |
| Bromoform | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chlorodibromomethane | 0.5 µg/L | 3.8 | <0.5 | <0.5 | <0.5 | 3.7 | 3.1 | 4.4 | 3 |
| Chloroform | 0.5 µg/L | 12 | <0.5 | <0.5 | <0.5 | 11 | 14 | 20 | 10 |
| Tot. THM | 0.5 µg/L | 27 | <0.5 | <0.5 | <0.5 | 25 | 26 | 37 | 21 |

**Table B.11. General Water Quality Parameters from DW3**

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| Conductivity | | 447 | 285 | 311 | 332 | 449 | 270 | 324 | 333 |
| TOC | 0.2 mg/L | 5.5 | 5.1 | 4.8 | 6.2 | 4.0 | 2.8 | 3.3 | 3.3 |
| DOC (filtered) | 0.2 mg/L | 5.2 | 4.9 | 4.8 | 5.5 | 4.0 | 2.8 | 3.2 | 3.4 |
| UV 254 (filtered) | 1/cm | 0.10 | 0.10 | 0.10 | 0.10 | 0.042 | 0.027 | 0.036 | 0.033 |
| UV 272 (filtered) | 1/cm | 0.084 | 0.082 | 0.083 | 0.078 | 0.031 | 0.019 | 0.025 | 0.022 |
| UV 436 (filtered) | 1/cm | 0.0061 | 0.0055 | 0.0052 | 0.0038 | -0.00020 | 0.00040 | 0.00010 | 0.00020 |
| pH | | 7.5 | 7.4 | 8.6 | 7.2 | 7.1 | 7.2 | 7.0 | 6.7 |
| Alkalinity | 10 mg/L | 63 | 55 | 61 | 58 | 34 | 26 | 34 | 46 |
| NDMA | 2 ng/L | - | - | - | - | - | - | <2 | - |
| $F^-$ | 0.05 mg/L | 0.35 | 0.26 | 0.37 | 0.44 | <0.05 | 0.71 | 0.89 | 0.86 |
| $Cl^-$ | 0.05 mg/L | 68 | 40 | 45 | 49 | 71 | 36 | 50 | 50 |
| $Br^-$ | 0.1 mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $NH_3$ | 0.02 mg/L | 0.10 | 0.090 | 0.070 | 0.060 | <0.02 | <0.02 | <0.02 | <0.02 |
| $NO_3^-$ | 0.05 mg/L | 1.6 | 0.80 | 0.092 | 0.15 | 1.5 | 0.63 | 0.14 | 0.17 |
| $PO_4^{3-}$ | 0.02 mg/L | 0.10 | 0.030 | 0.050 | <0.02 | 0.82 | 0.45 | 0.37 | 0.69 |
| $SO_4^{2-}$ | 1 mg/L | 48 | 24 | 22 | 25 | 65 | 35 | 41 | 44 |

**Table B.12. Concentrations of Dissolved Cations and Metals in Waters from DW3**

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| Ag | 0.0024 mg/L | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 |
| Al | 0.018 mg/L | <0.018 | 0.021 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | 0.20 | 0.53 | 0.17 | 0.42 | 0.20 | 0.52 | 0.13 | 0.25 |
| Ba | 0.0003 mg/L | 0.049 | 0.039 | 0.030 | 0.0063 | 0.050 | 0.036 | 0.026 | 0.058 |
| Be | 0.00031 mg/L | <0.00031 | <0.00031 | 0.00034 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 |
| Ca | 0.01 mg/L | 13 | 11 | 11 | 91 | 16 | 12 | 11 | 26 |
| Cd | 0.0009 mg/L | <0.0009 | <0.0009 | 0.0018 | <0.0009 | <0.0009 | <0.0009 | 0.0015 | <0.0009 |
| Co | 0.005 mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.097 | 0.060 | 0.0057 | <0.0009 | 0.033 | 0.014 | 0.033 | <0.0009 |
| Fe | 0.0021 mg/L | 0.062 | 0.11 | <0.0021 | 0.19 | <0.0021 | <0.0021 | 0.13 | <0.0021 |
| K | 0.094 mg/L | 12 | 6.4 | 5.7 | 20 | 12 | 5.5 | 5.9 | 2.5 |
| Li | 0.0021 mg/L | 0.015 | <0.0021 | 0.0022 | <0.0021 | 0.0082 | <0.0021 | <0.0021 | <0.0021 |
| Mg | 0.011 mg/L | 4.5 | 3.2 | 3.2 | 24 | 4.7 | 2.9 | 3.3 | 2.9 |
| Mn | 0.0003 mg/L | 0.013 | 0.0071 | 0.00040 | 0.043 | <0.0003 | <0.0003 | 0.0026 | <0.0003 |
| Mo | 0.004 mg/L | 0.0063 | <0.004 | 0.0061 | 0.017 | 0.0069 | <0.004 | <0.004 | <0.004 |
| Na | 0.007 mg/L | 65 | 38 | 39 | 232 | 67 | 33 | 38 | 29 |
| Ni | 0.003 mg/L | 0.0059 | <0.003 | <0.003 | <0.003 | 0.0052 | <0.003 | <0.003 | <0.003 |
| P | 0.16 mg/L | <0.16 | <0.16 | <0.16 | 0.49 | 0.64 | <0.16 | <0.16 | <0.16 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 14 | 8.7 | 14 | 80 | 21 | 13 | 7.6 | 15 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 |
| Si | 0.004 mg/L | - | 2.2 | 4.6 | 13 | - | 2.3 | 4.5 | 7.0 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 0.078 | 0.061 | 0.064 | 0.64 | 0.088 | 0.055 | 0.063 | 0.19 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | 1 | 1 | 1 | 1 | <1 | <1 | <1 | <1 |
| V | 0.0012 mg/L | <0.0012 | <0.0012 | 0.0017 | <0.0012 | <0.0012 | <0.0012 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.018 | 0.0085 | 0.014 | 0.0032 | 0.0083 | 0.0024 | 0.0016 | <0.0006 |

## Table B.13. Pharmaceutical and EDC Concentrations from DW4

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **12/18/2007** | **4/22/2008** | **6/23/2008** | **9/2/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| Atenolol | 1 ng/L | 16 | 3.6 | 1.7 | <1.0 | 4.1 | 1.2 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | 0.67 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 22 | 11 | 200 | 23 | 12 | 9.3 | 180 | 22 |
| Benzophenone | 50 ng/L | 88 | <50 | 87 | <50 | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Caffeine | 5 ng/L | 59 | 31 | 16 | 35 | 27 | 18 | 13 | 28 |
| Carbamazepine | 0.5 ng/L | 5.1 | 0.74 | 1.6 | 7.4 | 2.1 | 0.61 | 1.5 | 3.3 |
| DEET | 1 ng/L | 17 | 7.5 | 34 | 29 | 10 | 5.5 | 22 | 21 |
| Diazepam | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 |
| Diclofenac | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | 4.1 | 1.6 | 2.3 | 4.4 | 4.4 | 1.5 | 1.7 | 4.3 |
| Estradiol | 0.5 ng/L | <0.50 | * | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | <0.20 | * | 0.4 | 0.33 | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | * | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | 26 | 7.0 | 2.5 | 8.1 | 21 | 6.8 | 2.3 | 6.7 |
| Ibuprofen | 1 ng/L | 9.4 | 2.0 | <1.0 | <1.0 | 10 | 2.3 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 1.9 | 0.36 | 0.53 | 2.1 | 1.6 | 0.38 | 0.39 | 1.8 |
| Musk ketone | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | 14 | 4.4 | 1.6 | 2.8 | 6.7 | 2.4 | <0.50 | 1.4 |
| Octylphenol | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | 1.9 | <0.50 | 0.64 | 2.4 | 2.0 | <0.50 | 0.65 | 2.1 |
| Progesterone | 0.5 ng/L | <0.50 | * | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 18 | 3.8 | 2.5 | 24 | 9.0 | 0.53 | 0.74 | 3.5 |
| TCEP | 10 ng/L | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| TCPP | 100 ng/L | <100 | <100 | 110 | 110 | <100 | <100 | <100 | <100 |
| Testosterone | 0.5 ng/L | <0.50 | * | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | 2.9 | 1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | 5.0 | 0.82 | <0.25 | 1.6 | 1.1 | 0.27 | <0.25 | 0.35 |

*Sample lost.

**Table B.14. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from DW4**

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **12/18/2007** | **4/22/2008** | **6/23/2008** | **9/2/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| $ClO_4^-$ | 0.05 µg/L | 0.10 | 0.06 | 0.06 | 0.08 | 0.11 | 0.10 | 0.13 | 0.1 |
| $ClO_3^-$ | 0.1 µg/L | 1.4 | 0.5 | 1.0 | 9.1 | 0.75 | 1.1 | 0.81 | 55 |
| PFOA | 5 ng/L | <5.0 | <5.0 | <5.0 | 9.0 | 1.1 | 3.0 | 2.2 | 2.9 |
| PFOS | 1 ng/L | 1.7 | <1.0 | <1.0 | 1.8 | 1.0 | <1.0 | <1.0 | 2.0 |
| TOX | 20 µg/L | <20 | <20 | 140 | <20 | 260 | 580 | 910 | 250 |
| TOBr | 20 µg/L | <20 | <20 | <20 | <20 | 30 | <20 | <20 | 49 |
| TOCl | 20 µg/L | <20 | 130 | 110 | 28 | 280 | 540 | 900 | 290 |
| TOFl | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TOI | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TN | 0.2 mg/L | 1.5 | 1.4 | 1.3 | 0.5 | 2.0 | 2.1 | 2.2 | 1.2 |
| Tot. reg. HAA | 1 µg/L | <1 | <1 | <1 | <1 | 26 | 44 | 75 | 26 |
| BAA | 1 µg/L | <1 | <1 | <1 | <1 | <1 | 1.1 | <1 | 1.7 |
| CAA | 2 µg/L | <2 | <2 | <2 | <2 | <2 | 2.7 | 4.3 | <2 |
| DBAA | 2 µg/L | <2 | <2 | <1 | <2 | <2 | <2 | <1 | <2 |
| DCAA | 1 µg/L | <1 | <1 | <1 | <1 | 21 | 32 | 48 | 18 |
| TCAA | 1 µg/L | <1 | <1 | <1 | <1 | 5.1 | 8.3 | 23 | 7 |
| Bromodichloromethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | 2.4 | 2.4 | 4.2 | 7.1 |
| Bromoform | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chlorodibromomethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.4 |
| Chloroform | 0.5 µg/L | <0.5 | 0.06 | 0.06 | 0.08 | 7.5 | 32 | 73 | 20 |
| Tot. THM | 0.5 µg/L | <0.5 | <0.5 | 0.64 | <0.5 | 9.9 | 35 | 77 | 29 |

## Table B.15. General Water Quality Parameters from DW4

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **12/18/2007** | **4/22/2008** | **6/23/2008** | **9/2/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| Conductivity | | 425 | 276 | 341 | 426 | 257 | 186 | 245 | 242 |
| TOC | 0.2 mg/L | 11 | 12 | 17 | 8.2 | 5.38 | 6.05 | 9.71 | 4.59 |
| DOC (filtered) | 0.2 mg/L | 11 | 12 | 17 | 7.7 | 5.36 | 6.01 | 9.32 | 4.75 |
| UV 254 (filtered) | 1/cm | 0.30 | 0.36 | 0.57 | 0.20 | 0.0911 | 0.1041 | 0.1947 | 0.0842 |
| UV 272 (filtered) | 1/cm | 0.24 | 0.30 | 0.47 | 0.15 | 0.0609 | 0.0705 | 0.1409 | 0.0548 |
| UV 436 (filtered) | 1/cm | 0.014 | 0.020 | 0.029 | 0.0067 | 0.0013 | 0.0005 | 0.0034 | 0.0001 |
| pH | | 7.8 | 7.7 | 7.8 | 8.0 | 8.54 | 8.89 | 8.72 | 8.73 |
| Alkalinity | 10 mg/L | 176 | 115 | 132 | 144 | 40 | 46 | 54 | 25 |
| NDMA | 2 ng/L | - | - | - | - | - | - | 4.5 | 2.4 |
| $F^-$ | 0.05 mg/L | 0.11 | 0.10 | 2.7 | 0.13 | 0.74 | 0.82 | 2.7 | 0.83 |
| $Cl^-$ | 0.05 mg/L | 18 | 14 | 12 | 118 | 26 | 20 | 21 | 32 |
| $Br^-$ | 0.1 mg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $NH_3$ | 0.02 mg/L | 0.29 | 0.25 | 0.31 | 0.11 | 0.68 | 0.69 | 0.7 | 0.55 |
| $NO_3^-$ | 0.05 mg/L | 1.3 | 0.68 | 0.46 | 0.044 | 1.3 | 0.75 | 0.51 | 0.054 |
| $PO_4^{3-}$ | 0.02 mg/L | 0.13 | 0.080 | 0.13 | 0.21 | 0.48 | 0.46 | 0.38 | 0.51 |
| $SO_4^{2-}$ | 1 mg/L | 19 | 13 | 11 | 44 | 29 | 23 | 23 | 37 |

## Table B.16. Concentrations of Dissolved Cations and Metals in Waters from DW4

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **12/18/2007** | **4/22/2008** | **6/23/2008** | **9/2/2008** | **1/22/2008** | **4/14/2008** | **7/15/2008** | **10/7/2008** |
| Ag | 0.0024 mg/L | <0.0024 | <0.0024 | 0.0042 | <0.0024 | 0.0027 | 0.0031 | 0.0060 | <0.0024 |
| Al | 0.018 mg/L | 0.019 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | 0.070 | 0.59 | 0.12 | 0.054 | 0.058 | 0.53 | 0.10 | 0.039 |
| Ba | 0.0003 mg/L | 0.072 | 0.039 | 0.036 | 0.046 | 0.012 | 0.0069 | 0.0096 | 0.0077 |
| Be | 0.00031 mg/L | <0.00031 | <0.00031 | 0.00074 | <0.00031 | 0.00082 | <0.00031 | <0.00031 | <0.00031 |
| Ca | 0.01 mg/L | 54 | 34 | 41 | 47 | 27 | 23 | 31 | 19 |
| Cd | 0.0009 mg/L | 0.0024 | 0.0014 | 0.0035 | 0.0019 | 0.0011 | 0.0058 | 0.0022 | <0.0009 |
| Co | 0.005 mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.0030 | 0.0034 | 0.0063 | <0.0009 | 0.0019 | 0.0026 | 0.0056 | <0.0009 |
| Fe | 0.0021 mg/L | 0.16 | 0.19 | 0.15 | <0.0021 | <0.0021 | <0.0021 | 0.0038 | <0.0021 |
| K | 0.094 mg/L | 3.1 | 2.6 | 0.29 | 2.4 | 3.5 | 3.0 | 1.4 | 3.1 |
| Li | 0.0021 mg/L | 0.0059 | <0.0021 | 0.051 | 0.0039 | 0.0071 | <0.0021 | 0.012 | 0.0041 |
| Mg | 0.011 mg/L | 19 | 11 | 14 | 19 | 4.6 | 3.7 | 4.1 | 6.7 |
| Mn | 0.0003 mg/L | 0.042 | 0.0054 | 0.0027 | 0.00041 | 0.00053 | <0.0003 | 0.00042 | <0.0003 |
| Mo | 0.004 mg/L | 0.0091 | <0.004 | 0.018 | 0.010 | <0.004 | <0.004 | 0.0049 | <0.004 |
| Na | 0.007 mg/L | 13 | 8.6 | 8.1 | 16 | 13 | 7.9 | 7.7 | 17 |
| Ni | 0.003 mg/L | <0.003 | <0.003 | 0.0043 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| P | 0.16 mg/L | <0.16 | <0.16 | <0.16 | <0.16 | 0.30 | <0.16 | 0.25 | 0.39 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 7.4 | 5.0 | 4.3 | 11 | 10 | 8.6 | 8.6 | 8.4 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 |
| Si | 0.004 mg/L | 6.3 | 4.1 | 6.0 | 5.3 | 4.2 | 3.2 | 3.9 | 2.3 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 0.11 | 0.063 | 0.084 | 0.10 | 0.071 | 0.048 | 0.068 | 0.068 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| V | 0.0012 mg/L | <0.0012 | <0.0012 | <0.0012 | <0.0012 | <0.0012 | 0.0015 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.0054 | 0.0052 | 0.014 | 0.0052 | 0.0024 | 0.00075 | 0.0014 | 0.0034 |

## Table B.17. Pharmaceutical and EDC Concentrations from DW5

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** |
| Atenolol | 1 ng/L | 16 | 5.5 | 3.6 | 1.9 | <1.0 | <1.0 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 1.4 | 1.3 | 1.2 | 0.93 | 0.59 | 0.55 | 0.47 | 0.38 |
| Benzophenone | 50 ng/L | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Caffeine | 5 ng/L | 6.1 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Carbamazepine | 0.5 ng/L | 11 | 4.8 | 4.6 | 3.5 | <0.50 | <0.50 | <0.50 | <0.50 |
| DEET | 1 ng/L | 16 | 6.0 | 5.8 | 4.5 | 29 | 2.8 | 1.6 | 1.5 |
| Diazepam | 0.25 ng/L | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 | <0.25 |
| Diclofenac | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | 9.9 | 4.3 | 4.0 | 3.0 | 2.3 | 1.7 | <1.0 | <1.0 |
| Estradiol | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | 1.3 | 1 | 0.85 | 0.31 | <0.25 | <0.25 | <0.25 | <0.25 |
| Ibuprofen | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 33 | 16 | 14 | 10 | 15 | 8.7 | 6.8 | 5.2 |
| Musk ketone | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | 1.1 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Octylphenol | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | 8.0 | 5.1 | 3.6 | 2.7 | 2.2 | 1.3 | 0.64 | 0.67 |
| Progesterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 38 | 20 | 20 | 16 | <0.25 | <0.25 | <0.25 | <0.25 |
| TCEP | 10 ng/L | 16 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| TCPP | 100 ng/L | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 |
| Testosterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | 1.5 | 0.87 | 0.67 | 0.35 | <0.25 | <0.25 | <0.25 | <0.25 |

## Table B.18. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from DW5

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** |
| $ClO_4^-$ | 0.05 µg/L | 7.5 | 2.4 | 2.3 | 1.4 | 6.5 | 2.3 | 2.6 | 1.0 |
| $ClO_3^-$ | 0.1 µg/L | 25 | 7.4 | 6.2 | 7.5 | 100 | 210 | 170 | 190 |
| PFOA | 5 ng/L | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| PFOS | 1 ng/L | 2.5 | 2.0 | <1.0 | 1.5 | 2.2 | 2.0 | <1.0 | 1.6 |
| TOX | 20 µg/L | 21 | 35 | <20 | 36 | 220 | 320 | 230 | 250 |
| TOBr | 20 µg/L | <20 | <20 | <20 | <20 | 66 | 65 | 29 | 52 |
| TOCl | 20 µg/L | <20 | <20 | <20 | 28 | 210 | 290 | 245 | 180 |
| TOFl | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TOI | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 | <20 | <20 |
| TN | 0.2 mg/L | 1.2 | 0.77 | 0.72 | 0.69 | 1.2 | 0.83 | 0.70 | 0.71 |
| Tot. reg. HAA | 1 µg/L | <1 | <1 | <1 | <1 | 1.2 | 9.7 | 1.1 | 6.9 |
| BAA | 1 µg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| CAA | 2 µg/L | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 |
| DBAA | 2 µg/L | <2 | <2 | <2 | <2 | 3.7 | 3.2 | 2.9 | 3.4 |
| DCAA | 1 µg/L | <1 | <1 | <1 | <1 | 4.8 | 3.9 | 4.4 | 4.3 |
| TCAA | 1 µg/L | <1 | <1 | <1 | <1 | 3.1 | 2.6 | 2.5 | 1.9 |
| Bromodichloromethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | 12 | 11 | 9.4 | 10 |
| Bromoform | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | 2.8 | 2.5 | 2.0 | 2.7 |
| Chlorodibromomethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | 12 | 11 | 9.4 | 11 |
| Chloroform | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | 7.4 | 6.2 | 5.7 | 6.1 |
| Tot. THM | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | 34 | 30 | 27 | 30 |

**Table B.19. General Water Quality Parameters from DW5.**

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** |
| Conductivity | | 1012 | 935 | 966 | 1004 | 1035 | 1025 | 1013 | 1038 |
| TOC | 0.2 mg/L | 3.0 | 3.0 | 2.8 | 2.9 | 2.7 | 2.8 | 2.7 | 2.8 |
| DOC (filtered) | 0.2 mg/L | 3.0 | 2.9 | 2.8 | 2.9 | 2.7 | 2.7 | 2.9 | 2.8 |
| UV 254 (filtered) | 1/cm | 0.043 | 0.038 | 0.047 | 0.045 | 0.025 | 0.018 | 0.022 | 0.021 |
| UV 272 (filtered) | 1/cm | 0.023 | 0.027 | 0.036 | 0.034 | 0.019 | 0.011 | 0.016 | 0.021 |
| UV 436 (filtered) | 1/cm | 0.00080 | 0.00030 | 0.0012 | 0.00060 | 0.00060 | 0.00010 | 0.00010 | 0 |
| pH | | 8.0 | 8.0 | 8.1 | 7.4 | 7.7 | 7.7 | 7.8 | 7.4 |
| Alkalinity | 10 mg/L | 122 | 133 | 131 | 151 | 125 | 125 | 123 | 145 |
| Ammonia | 0.02 mg/L | <0.02 | 0.050 | 0.030 | 0.030 | 0.020 | 0.020 | 0.020 | 0.030 |
| $F^-$ | 0.05 mg/L | 0.28 | 0.32 | 0.29 | 0.30 | 0.65 | 0.73 | 0.70 | 0.72 |
| $Cl^-$ | 0.05 mg/L | 97 | 88 | 77 | 83 | 108 | 97 | 87 | 90 |
| $Br^-$ | 0.1 mg/L | 0.11 | <0.1 | <0.1 | 0.10 | <0.1 | <0.1 | <0.1 | <0.1 |
| $NO_3^-$ | 0.05 mg/L | 1.2 | 0.65 | 0.60 | 0.63 | 1.2 | 0.76 | 0.62 | 0.64 |
| $PO_4^{3-}$ | 0.2 mg/L | 0.030 | 0.060 | 0.060 | 0.020 | 0.22 | 0.21 | 0.23 | 0.24 |
| $SO_4^{2-}$ | 1 mg/L | 276 | 259 | 246 | 250 | 279 | 258 | 249 | 249 |

## Table B.20. Concentrations of Dissolved Cations and Metals in Waters from DW5

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** | **11/28/2007** | **3/10/2008** | **5/19/2008** | **8/27/2008** |
| Ag | 0.0024 mg/L | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 |
| Al | 0.018 mg/L | 0.029 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | 0.28 | 0.12 | 0.42 | 0.14 | 0.22 | 0.11 | 0.45 | 0.13 |
| Ba | 0.0003 mg/L | 0.15 | 0.13 | 0.14 | 0.13 | 0.14 | 0.12 | 0.15 | 0.13 |
| Be | 0.00031 mg/L | 0.013 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| Ca | 0.01 mg/L | 79 | 77 | 78 | 79 | 80 | 76 | 82 | 78 |
| Cd | 0.0009 mg/L | 0.014 | 0.0018 | 0.0020 | 0.0010 | 0.0037 | 0.0012 | 0.0029 | 0.0013 |
| Co | 0.005 mg/L | 0.012 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | 0.0071 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.029 | 0.0019 | 0.0016 | 0.013 | 0.0065 | 0.0024 | <0.0009 | 0.013 |
| Fe | 0.0021 mg/L | 0.026 | <0.0021 | <0.0021 | <0.0021 | 0.0081 | <0.0021 | <0.0021 | <0.0021 |
| K | 0.094 mg/L | 5.9 | 3.3 | 5.1 | 4.9 | 6.0 | 3.4 | 7.3 | 4.6 |
| Li | 0.0021 mg/L | 0.079 | 0.046 | 0.046 | 0.044 | 0.053 | 0.045 | 0.047 | 0.042 |
| Mg | 0.011 mg/L | 30 | 28 | 28 | 28 | 31 | 28 | 30 | 27 |
| Mn | 0.0003 mg/L | 0.013 | 0.00064 | <0.0003 | 0.00060 | 0.0022 | 0.00043 | <0.0003 | <0.0003 |
| Mo | 0.004 mg/L | 0.11 | 0.020 | 0.010 | 0.01 | 0.035 | 0.016 | 0.0082 | 0.010 |
| Na | 0.007 mg/L | 100 | 95 | 97 | 92 | 107 | 100 | 110 | 95 |
| Ni | 0.003 mg/L | 0.026 | <0.003 | <0.003 | 0.0033 | 0.0044 | <0.003 | 0.0031 | BDL |
| P | 0.16 mg/L | <0.16 | <0.16 | <0.16 | <0.16 | <0.16 | 0.20 | <0.16 | <0.16 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 85 | 87 | 80 | 88 | 85 | 86 | 85 | 86 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | 0.043 | <0.033 | 0.040 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 |
| Si | 0.004 mg/L | 3.8 | 3.9 | 3.7 | 4.2 | 3.9 | 3.8 | 4.1 | 4.3 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 1.3 | 1.1 | 1.2 | 1.2 | 1.3 | 1.1 | 1.2 | 1.1 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| V | 0.0012 mg/L | 0.013 | 0.0013 | <0.0012 | 0.0027 | 0.0038 | <0.0012 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.027 | 0.0048 | 0.0048 | 0.0082 | 0.20 | 0.089 | 0.15 | 0.20 |

## Table B.21. Pharmaceutical and EDC Concentrations from IPR1

| | | Raw Water Samples | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|
| | **MDL** | **2/21/2008** | **4/24/2008** | **1/29/2008** | **4/24/2008** | **7/21/2008** | **10/14/2008** |
| Atenolol | 1 ng/L | 660 | 690 | <1.0 | 1.0 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 5.0 | 6.0 | 11 | 5.0 | 5.0 | 5.0 |
| Benzophenone | 50 ng/L | 130 | 150 | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | 32 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Caffeine | 5 ng/L | 290 | 57 | <5.0 | <5.0 | <5.0 | <5.0 |
| Carbamazepine | 0.5 ng/L | 190 | 230 | 130 | 120 | 94 | 98 |
| DEET | 1 ng/L | 95 | 180 | <1.0 | <1.0 | <1.0 | <1.0 |
| Diazepam | 0.25 ng/L | 1.0 | 2.0 | 0.62 | 1.0 | 1.0 | 1.0 |
| Diclofenac | 0.5 ng/L | 21 | <0.50 | <0.25 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | 190 | 150 | 28 | 30 | 25 | 21 |
| Estradiol | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | 3 .0 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | 2.0 | 1.0 | 1.3 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | 560 | 690 | <0.25 | <0.25 | <0.25 | <0.25 |
| Ibuprofen | 1 ng/L | 48 | 3.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | 680 | 830 | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 310 | 380 | 8.2 | 9.0 | 5.0 | 5.0 |
| Musk ketone | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | 24 | 17 | <0.50 | <0.50 | <0.50 | <0.50 |
| Octylphenol | 25 ng/L | <25 | <25 | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | 130 | 130 | 81 | 68 | 63 | 72 |
| Progesterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 270 | 190 | 120 | 81 | 91 | 103 |
| TCEP | 10 ng/L | 280 | 490 | <10 | <10 | <10 | <10 |
| TCPP | 100 ng/L | 1200 | 1200 | <100 | <100 | <100 | <100 |
| Testosterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | 4.0 | 7.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | 89 | 81 | <0.25 | <0.25 | <0.25 | <0.25 |

**Table B.22. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from IPR1**

| | | **Raw Water Samples** | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|
| | **MDL** | **2/21/2008** | **4/24/2008** | **1/29/2008** | **4/24/2008** | **7/21/2008** | **10/14/2008** |
| $ClO_4^-$ | 0.05 µg/L | <1.0 | <1.0 | 0.07 | 0.09 | 0.03 | 0.06 |
| $ClO_3^-$ | 0.1 µg/L | 0.71 | 0.54 | 2.7 | 3.7 | 1.2 | 1.3 |
| PFOA | 5 ng/L | 110 | 79 | 17 | 21 | 20 | 15 |
| PFOS | 1 ng/L | 28 | 25 | 73 | 61 | 43 | 60 |
| TOX | 20 µg/L | 13 | 11 | 27 | <20 | <20 | <20 |
| TOBr | 20 µg/L | 140 | 89 | <20 | <20 | <20 | <20 |
| TOCl | 20 µg/L | <20 | <20 | 30 | <20 | <20 | <20 |
| TOFl | 20 µg/L | 180 | 63 | <20 | <20 | <20 | <20 |
| TOI | 20 µg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| TN | 0.2 mg/L | <20 | <20 | 2.1 | 2.2 | <0.2 | 1.7 |
| Tot. reg. HAA | 1 µg/L | 5.2 | 4.7 | <1 | <1 | <1 | <1 |
| BAA | 1 µg/L | 11 | 5.6 | <1 | <1 | <1 | <1 |
| CAA | 2 µg/L | <1 | <1 | <2 | <2 | <2 | <2 |
| DBAA | 2 µg/L | <2 | <2 | <2 | <2 | <2 | <2 |
| DCAA | 1 µg/L | <2 | <2 | <1 | <1 | <1 | <1 |
| TCAA | 1 µg/L | 2 | 1.5 | <1 | <1 | <1 | <1 |
| Bromodichloromethane | 0.5 µg/L | 9.2 | 4.1 | <0.5 | <0.5 | <0.5 | <0.5 |
| Bromoform | 0.5 µg/L | 1.9 | 0.81 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chlorodibromomethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chloroform | 0.5 µg/L | 0.91 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Tot. THM | 0.5 µg/L | 3.4 | 1.8 | <0.5 | <0.5 | <0.5 | <0.5 |

## Table B.23. General Water Quality Parameters from IPR1

| | | Raw Water Samples | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|
| | **MDL** | **2/21/2008** | **4/24/2008** | **1/29/2008** | **4/24/2008** | **7/21/2008** | **10/14/2008** |
| Conductivity | | 964 | 1052 | 796 | 784 | 886 | 761 |
| TOC | 0.2 mg/L | 6.2 | 6.8 | 1.5 | 1.4 | 1.1 | 1.2 |
| DOC (filtered) | 0.2 mg/L | 6.0 | 6.6 | 1.5 | 1.6 | 1.2 | 1.3 |
| UV 254 (filtered) | 1/cm | 0.10 | 0.098 | 0.024 | 0.025 | 0.024 | 0.022 |
| UV 272 (filtered) | 1/cm | 0.082 | 0.078 | 0.018 | 0.019 | 0.018 | 0.017 |
| UV 436 (filtered) | 1/cm | 0.0038 | 0.0044 | 0.00010 | 0.0013 | 0.0075 | 0.00030 |
| pH | | 7.8 | 8.4 | 7.3 | 7.3 | 7.4 | 7.0 |
| Alkalinity | 10 mg/L | 145 | 155 | 126 | 118 | 150 | 132 |
| NDMA | 2 ng/L | - | - | - | - | - | <2 |
| $F^-$ | 0.05 mg/L | 0.43 | 0.40 | 0.36 | 0.40 | 0.38 | 0.35 |
| $Cl^-$ | 0.05 mg/L | 131 | 134 | 79 | 94 | 96 | 89 |
| $Br^-$ | 0.1 mg/L | 0.20 | 0.19 | 0.20 | 0.16 | 0.20 | 0.18 |
| $NH_3$ | 0.02 mg/L | 0.65 | 0.19 | <0.02 | 0.02 | 0.03 | 0.04 |
| $NO_3^-$ | 0.05 mg/L | 4.7 | 3.6 | 1.7 | 2.0 | 1.7 | 1.8 |
| $PO_4^{3-}$ | 0.02 mg/L | 0.24 | 0.070 | 0.09 | 0.08 | 0.14 | 0.08 |
| $SO_4^{2-}$ | 1 mg/L | 171 | 180 | 120 | 122 | 129 | 124 |

*Note:* All concentrations are presented in ng/L.

**Table B.24. Concentrations of Dissolved Cations and Metals in Waters from IPR1**

| | | **Raw Water Samples** | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|
| | **MDL** | **2/21/2008** | **4/24/2008** | **1/29/2008** | **4/24/2008** | **7/21/2008** | **10/14/2008** |
| Ag | 0.0024 mg/L | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 | <0.0024 |
| Al | 0.018 mg/L | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | 0.27 | 0.83 | 0.20 | 0.76 | 0.26 | 0.22 |
| Ba | 0.0003 mg/L | 0.048 | 0.054 | 0.064 | 0.091 | 0.078 | 0.055 |
| Be | 0.00031 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| Ca | 0.01 mg/L | 73 | 71 | 56 | 63 | 63 | 66 |
| Cd | 0.0009 mg/L | 0.0027 | 0.0017 | 0.0030 | 0.0026 | 0.0023 | <0.0009 |
| Co | 0.005 mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.0048 | 0.0047 | 0.0038 | 0.0024 | 0.020 | <0.0009 |
| Fe | 0.0021 mg/L | 0.0066 | 0.011 | <0.0021 | <0.0021 | <0.0021 | <0.0021 |
| K | 0.094 mg/L | 11 | 13 | 3.8 | 4.4 | 4.2 | 3.7 |
| Li | 0.0021 mg/L | 0.014 | 0.016 | 0.0028 | <0.0021 | <0.0021 | <0.0021 |
| Mg | 0.011 mg/L | 25 | 26 | 16 | 18 | 17 | 17 |
| Mn | 0.0003 mg/L | 0.015 | 0.00088 | 0.021 | 0.032 | 0.030 | <0.0003 |
| Mo | 0.004 mg/L | 0.026 | 0.013 | 0.021 | 0.013 | 0.019 | <0.004 |
| Na | 0.007 mg/L | 112 | 118 | 74 | 77 | 76 | 75 |
| Ni | 0.003 mg/L | 0.0052 | <0.003 | 0.0078 | 0.0034 | 0.0043 | <0.003 |
| P | 0.16 mg/L | <0.016 | 0.20 | <0.16 | <0.16 | <0.16 | <0.16 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 59 | 62 | 39 | 40 | 42 | 39 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 | <0.033 |
| Si | 0.004 mg/L | 9.2 | 5.6 | 9.8 | 8.8 | 10 | 8.9 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 0.56 | 0.59 | 0.48 | 0.54 | 0.55 | 0.48 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| V | 0.0012 mg/L | 0.0019 | 0.0017 | 0.0013 | 0.0017 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.043 | 0.030 | 0.0060 | 0.0045 | 0.0059 | <0.0006 |

**Table B.25. Pharmaceutical and EDC Concentrations from IPR2**

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **6/18/2008** | **7/29/2008** | **9/15/2008** | **10/28/2008** | **6/18/2008** | **7/29/2008** | **9/15/2008** | **10/28/2008** |
| Atenolol | 1 ng/L | 1600 | 1700 | 1700 | 1600 | <1.0 | <0.25 | <1.0 | <1.0 |
| Atorvastatin | 0.5 ng/L | 65 | 79 | 62 | 66 | <0.50 | <0.50 | <0.50 | <0.50 |
| Atrazine | 0.25 ng/L | 3.7 | 4.2 | 3.8 | 3.8 | <0.25 | <0.25 | 0.40 | 0.34 |
| Benzophenone | 50 ng/L | 670 | 410 | 330 | 330 | <50 | <50 | <50 | <50 |
| BHA | 1 ng/L | 220 | 100 | 150 | 150 | <1.0 | <1.0 | <1.0 | <1.0 |
| Bisphenol A | 5 ng/L | 210 | 520 | 11 | 10 | <5.0 | <5.0 | 33 | 34 |
| Caffeine | 5 ng/L | 540 | 340 | 270 | 260 | <5.0 | <5.0 | <5.0 | <5.0 |
| Carbamazepine | 0.5 ng/L | 180 | 180 | 230 | 240 | <0.50 | 0.55 | 0.70 | 0.58 |
| DEET | 1 ng/L | 550 | 1700 | 1100 | 1100 | <1.0 | <1.0 | <1.0 | <1.0 |
| Diazepam | 0.25 ng/L | 3.8 | 2.0 | 1.5 | 1.6 | <0.25 | <0.25 | <0.25 | <0.25 |
| Diclofenac | 0.5 ng/L | 230 | 200 | 150 | 140 | <0.50 | <0.50 | <0.50 | <0.50 |
| Dilantin | 1 ng/L | 130 | 85 | 160 | 150 | <1.0 | <1.0 | 1.7 | 1.1 |
| Estradiol | 0.5 ng/L | 8.4 | 4.8 | 1.5 | 5.6 | <0.50 | <0.50 | <0.50 | <0.50 |
| Estrone | 0.2 ng/L | 69 | 73 | 57 | 51 | <0.20 | <0.20 | <0.20 | <0.20 |
| Ethynylestradiol | 1 ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Fluoxetine | 0.5 ng/L | 32 | 29 | 25 | 23 | <0.50 | <0.50 | <0.50 | <0.50 |
| Gemfibrozil | 0.25 ng/L | 3700 | 3200 | 2800 | 2900 | <0.25 | <0.25 | <0.25 | <0.25 |
| Ibuprofen | 1 ng/L | 500 | 370 | 400 | 410 | <1.0 | <1.0 | <1.0 | <1.0 |
| Iopromide | 10 ng/L | 45 | 110 | 15 | 11 | <10 | <10 | <10 | <10 |
| Meprobamate | 0.25 ng/L | 320 | 310 | 340 | 340 | 0.63 | 2.0 | 2.2 | 2.0 |
| Musk ketone | 25 ng/L | 45 | 35 | 42 | 42 | <25 | <25 | <25 | <25 |
| Naproxen | 0.5 ng/L | 490 | 160 | 850 | 860 | <0.50 | <0.50 | <0.50 | <0.50 |
| Octylphenol | 25 ng/L | 210 | 200 | <25 | <25 | <25 | <25 | <25 | <25 |
| Primidone | 0.5 ng/L | 94 | 97 | 120 | 110 | <0.50 | 0.72 | 0.83 | 0.71 |
| Progesterone | 0.5 ng/L | 18 | 14 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulfamethoxazole | 0.25 ng/L | 1300 | 1100 | 1200 | 1200 | 0.27 | 0.60 | 0.77 | 0.79 |
| TCEP | 10 ng/L | 385 | 520 | 500 | 490 | <10 | <10 | <10 | <10 |
| TCPP | 100 ng/L | 1300 | 4000 | 2300 | 2200 | <100 | <100 | <100 | <100 |
| Testosterone | 0.5 ng/L | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 |
| Triclosan | 1 ng/L | 270 | 380 | 450 | 480 | <1.0 | <1.0 | <1.0 | <1.0 |
| Trimethoprim | 0.25 ng/L | 560 | 610 | 560 | 560 | <0.25 | <0.25 | <0.25 | <0.25 |

## Table B.26. Oxyhalide, Perfluorinated Compound, Organic Halogen, and Regulated DBP Concentrations from IPR2

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MDL | 6/18/2008 | 7/29/2008 | 9/15/2008 | 10/28/2008 | 6/18/2008 | 7/29/2008 | 9/15/2008 | 10/28/2008 |
| $ClO_4^-$ | 0.05 µg/L | 1.1 | 1.3 | 0.56 | 1.2 | 0.06 | 0.10 | 0.19 | 0.1 |
| $ClO_3^-$ | 0.1 µg/L | 2.3 | 1.3 | 5.7 | 2.8 | 2.6 | 11 | 21 | 1.3 |
| PFOA | 5 ng/L | 28 | 25 | 15 | 17 | <5.0 | 16 | <5.0 | <5.0 |
| PFOS | 1 ng/L | 90 | 61 | 23 | 46 | <1.0 | <1.0 | <1.0 | <1.0 |
| TOX | 20 µg/L | 78 | 69 | 74 | 68 | 30 | <20 | 40 | 35 |
| TOBr | 20 µg/L | <20 | <20 | <20 | <20 | 51 | <20 | 20 | <20 |
| TOCl | 20 µg/L | 69 | 78 | 64 | 76 | <20 | <20 | <20 | <20 |
| TOFl | 20 µg/L | <20 | <20 | <20 | <20 | 45 | <20 | <20 | 27 |
| TOI | 20 µg/L | <20 | 34 | <20 | <20 | <20 | <20 | <20 | <20 |
| TN | 0.2 mg/L | 31 | 30 | 26 | 26 | <20 | <20 | <20 | <20 |
| Tot. reg. HAA | 1 µg/L | 16 | 15 | 14 | 12 | <1 | <1 | <1 | <1 |
| BAA | 1 µg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| CAA | 2 µg/L | <2 | <2 | <2 | <2 | <1 | <1 | <1 | <1 |
| DBAA | 2 µg/L | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 |
| DCAA | 1 µg/L | 1.8 | 1.6 | 1.6 | 1.4 | <2 | <2 | <2 | <2 |
| TCAA | 1 µg/L | 14 | 14 | 12 | 11 | <1 | <1 | <1 | <1 |
| Bromodichloromethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <1 | <1 | <1 | <1 |
| Bromoform | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 0.68 | 0.72 | 0.64 |
| Chlorodibromomethane | 0.5 µg/L | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Chloroform | 0.5 µg/L | 1.2 | 0.92 | 0.96 | 0.64 | <0.5 | 0.62 | 0.64 | 0.54 |
| Tot. THM | 0.5 µg/L | 1.2 | 0.92 | 0.96 | 0.64 | 0.57 | 1.9 | 1.9 | 1.8 |

**Table B.27. General Water Quality Parameters from IPR2**

| | | Raw Water Samples | | | | Finished Water Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **6/18/2008** | **7/29/2008** | **9/15/2008** | **10/28/2008** | **6/18/2008** | **7/29/2008** | **9/15/2008** | **10/28/2008** |
| Conductivity | | 1736 | 1663 | 1402 | 1491 | 124 | 250 | 272 | 301 |
| TOC | 0.2 mg/L | 12 | 14 | 14 | 12 | 2.0 | 0.43 | 0.69 | 1.2 |
| DOC (filtered) | 0.2 mg/L | 12 | 13 | 13 | 12 | 1.2 | 0.55 | 0.45 | 1.3 |
| UV 254 (filtered) | 1/cm | 0.22 | 0.21 | 0.18 | 0.20 | 0.0058 | 0.0042 | 0.010 | 0.0067 |
| UV 272 (filtered) | 1/cm | 0.18 | 0.18 | 0.16 | 0.17 | 0.0043 | 0.0029 | 0.0073 | 0.0051 |
| UV 436 (filtered) | 1/cm | 0.019 | 0.019 | 0.016 | 0.016 | 0 | 0.0080 | 0.0010 | 0 |
| pH | | 7.1 | 7.1 | 7.2 | 7.3 | 7.3 | 7.3 | 7.1 | 7.2 |
| Alkalinity | 10 mg/L | 238 | 253 | 252 | 301 | 42 | 46 | 44 | 48 |
| NDMA | 2 ng/L | - | - | - | - | | | | |
| $F^-$ | 0.05 mg/L | 0.95 | 0.78 | 0.70 | 0.70 | 3.7 | 0.49 | 0.36 | 0.31 |
| $Cl^-$ | 0.05 mg/L | 225 | 239 | 177 | 186 | 8.1 | 19 | 24 | 23 |
| $Br^-$ | 0.1 mg/L | 0.25 | 0.29 | 0.25 | 0.21 | <0.1 | <0.1 | <0.1 | <0.1 |
| $NH_3$ | 0.02 mg/L | 27 | 24 | 20 | 22 | 0.20 | 0.39 | 0.47 | 0.43 |
| $NO_3^-$ | 0.05 mg/L | 1.1 | 1.5 | 1.8 | 0.77 | 1.9 | 1.9 | 2.2 | 1.9 |
| $PO_4^{3-}$ | 0.02 mg/L | 2.5 | 2.4 | 1.6 | 1.1 | 0.070 | 0.070 | 0.050 | 0.030 |
| $SO_4^{2-}$ | 1 mg/L | 218 | 221 | 206 | 190 | 7.1 | 30 | 41 | 43 |

**Table B.28. Concentrations of Dissolved Cations and Metals in Waters from IPR2**

| | | **Raw Water Samples** | | | | **Finished Water Samples** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MDL** | **6/18/2008** | **7/29/2008** | **9/15/2008** | **10/28/2008** | **6/18/2008** | **7/29/2008** | **9/15/2008** | **10/28/2008** |
| Ag | 0.0024 mg/L | 0.0046 | <0.0024 | <0.0024 | <0.0024 | 0.0048 | <0.0024 | <0.0024 | <0.0024 |
| Al | 0.018 mg/L | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| As | 0.032 mg/L | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 | <0.032 |
| B | 0.008 mg/L | 0.47 | 0.39 | 0.43 | 0.42 | 0.31 | 0.25 | 0.26 | 0.25 |
| Ba | 0.0003 mg/L | 0.018 | 0.019 | 0.017 | 0.0063 | 0.33 | 0.16 | 0.091 | 0.058 |
| Be | 0.00031 mg/L | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 | <0.00031 |
| Ca | 0.01 mg/L | 73 | 70 | 72 | 91 | 5.4 | 13 | 21 | 26 |
| Cd | 0.0009 mg/L | 0.0050 | 0.0039 | 0.0030 | <0.0009 | 0.0037 | 0.0023 | 0.0021 | <0.0009 |
| Co | 0.005 mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Cr | 0.003 mg/L | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Cu | 0.0009 mg/L | 0.0055 | <0.0009 | <0.0009 | <0.0009 | 0.0012 | <0.0009 | <0.0009 | <0.0009 |
| Fe | 0.0021 mg/L | 0.17 | 0.14 | 0.14 | 0.19 | <0.0021 | <0.0021 | <0.0021 | <0.0021 |
| K | 0.094 mg/L | 17 | 16 | 16 | 20 | 0.67 | 1.2 | 2.3 | 2.5 |
| Li | 0.0021 mg/L | 0.021 | 0.016 | 0.0099 | <0.0021 | 0.0036 | 0.0040 | <0.0021 | <0.0021 |
| Mg | 0.011 mg/L | 21 | 20 | 20 | 24 | 0.58 | 1.5 | 2.4 | 2.9 |
| Mn | 0.0003 mg/L | 0.046 | 0.046 | 0.041 | 0.043 | 0.0012 | 0.0031 | 0.0035 | <0.0003 |
| Mo | 0.004 mg/L | 0.033 | 0.018 | 0.046 | 0.017 | <0.004 | <0.004 | 0.012 | <0.004 |
| Na | 0.007 mg/L | 209 | 194 | 190 | 232 | 18 | 28 | 31 | 29 |
| Ni | 0.003 mg/L | 0.0058 | <0.003 | 0.0061 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| P | 0.16 mg/L | 0.85 | 0.85 | 0.71 | 0.49 | <0.16 | <0.16 | <0.16 | <0.16 |
| Pb | 0.02 mg/L | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| S | 0.11 mg/L | 75 | 72 | 74 | 80 | 2.7 | 10 | 15 | 15 |
| Sb | 0.015 mg/L | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 | <0.015 |
| Se | 0.033 mg/L | 0.033 | <0.033 | <0.033 | <0.033 | 0.041 | <0.033 | <0.033 | <0.033 |
| Si | 0.004 mg/L | 11 | 12 | 12 | 13 | 6.5 | 7.1 | 6.7 | 7.0 |
| Sn | 0.014 mg/L | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 | <0.014 |
| Sr | 0.0003 mg/L | 0.57 | 0.57 | 0.59 | 0.64 | 0.051 | 0.12 | 0.20 | 0.19 |
| Ti | 0.0003 mg/L | <0.0003 | <0.0003 | <0.0003 | <0.0003 | 0.00032 | <0.0003 | <0.0003 | <0.0003 |
| U | 1 mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| V | 0.0012 mg/L | <0.0012 | 0.0024 | <0.0012 | <0.0012 | 0.0014 | 0.0020 | <0.0012 | <0.0012 |
| Zn | 0.0033 mg/L | 0.033 | 0.020 | 0.017 | 0.0032 | 0.016 | 0.0016 | 0.0033 | <0.0006 |

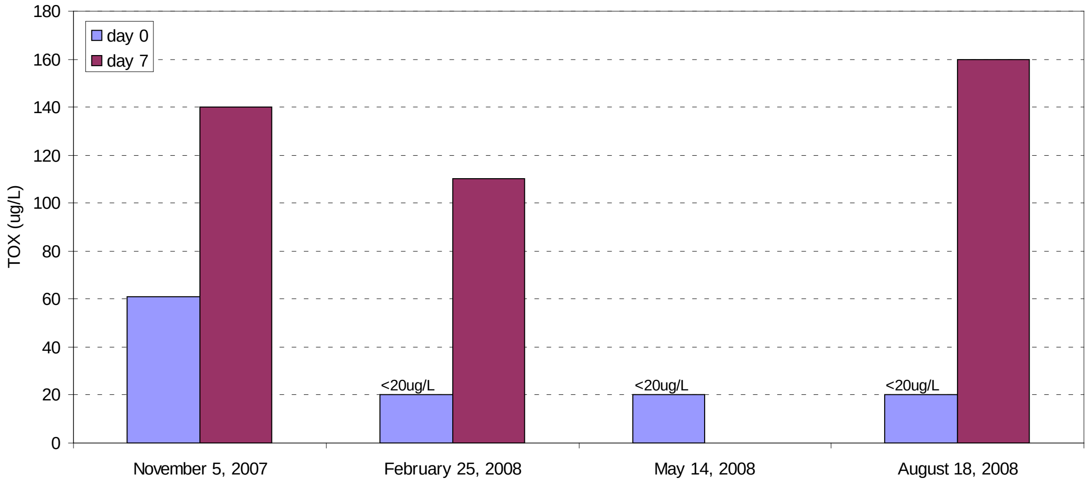


Figure B.1. TOX-FP tests for DW2.

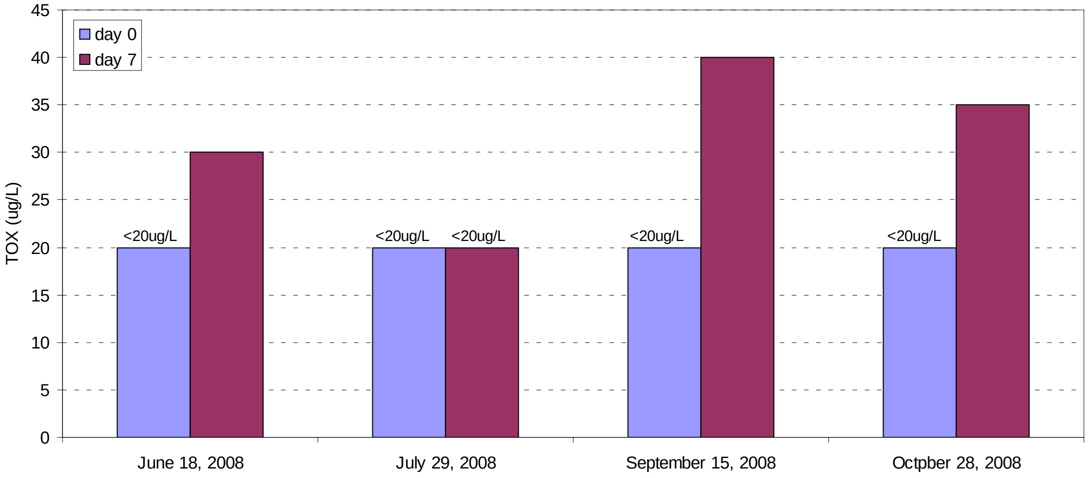


Figure B.2. TOX-FP tests for IPR2.

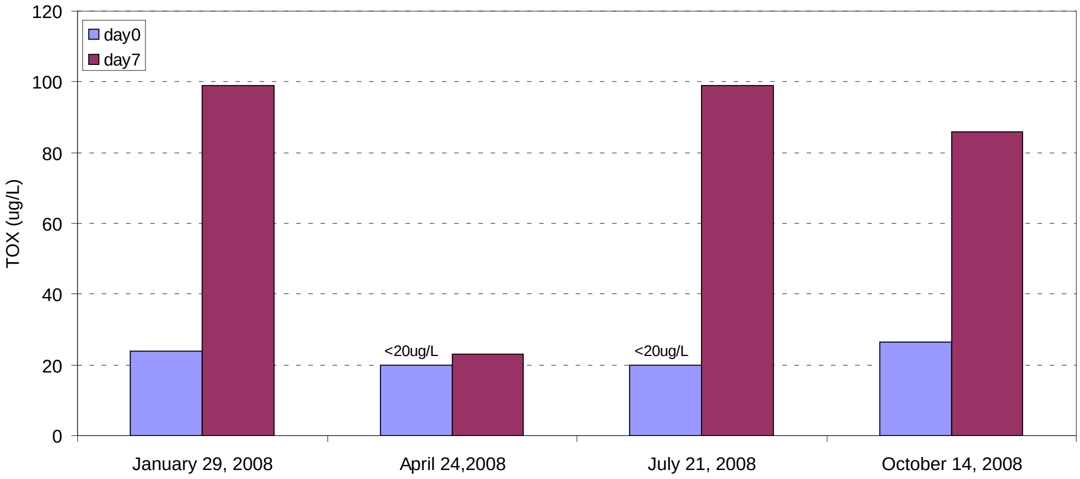


Figure B.3. TOX-FP tests for IPR1.

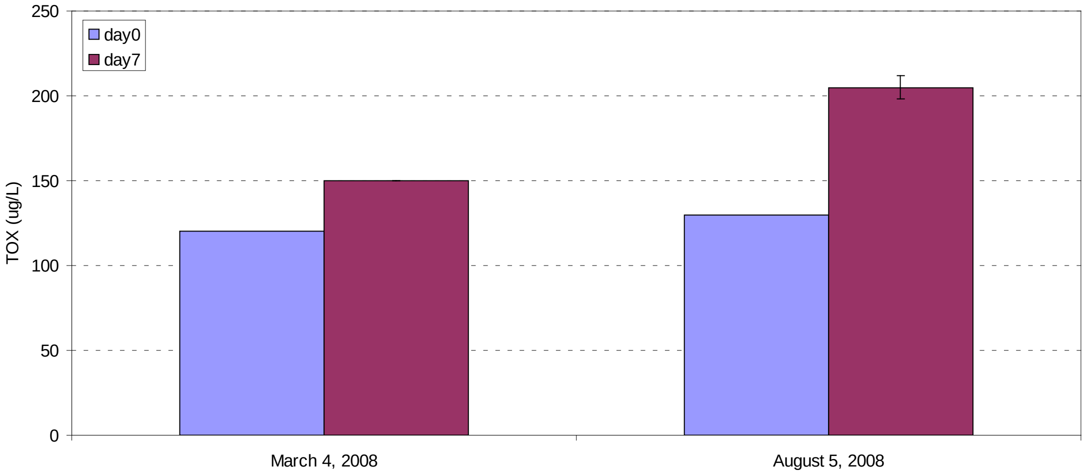


Figure B.4. TOX-FP tests for DW1.

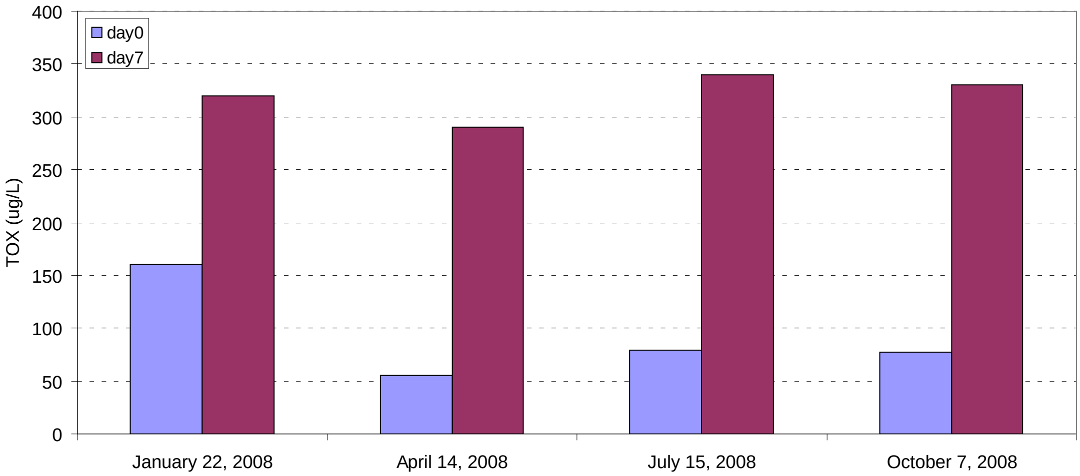


**Figure B.5. TOX-FP tests for DW3.**

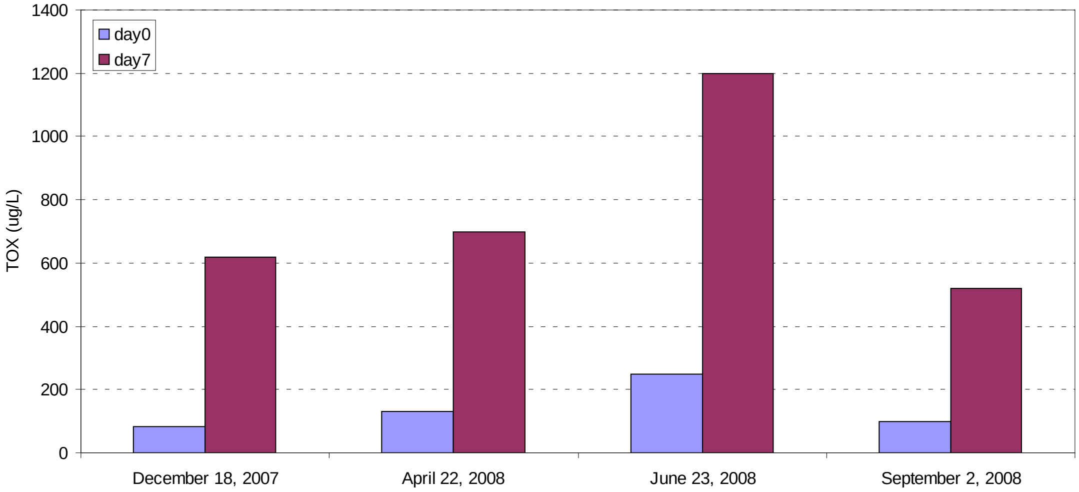


**Figure B.6. TOX-FP tests for DW4.**

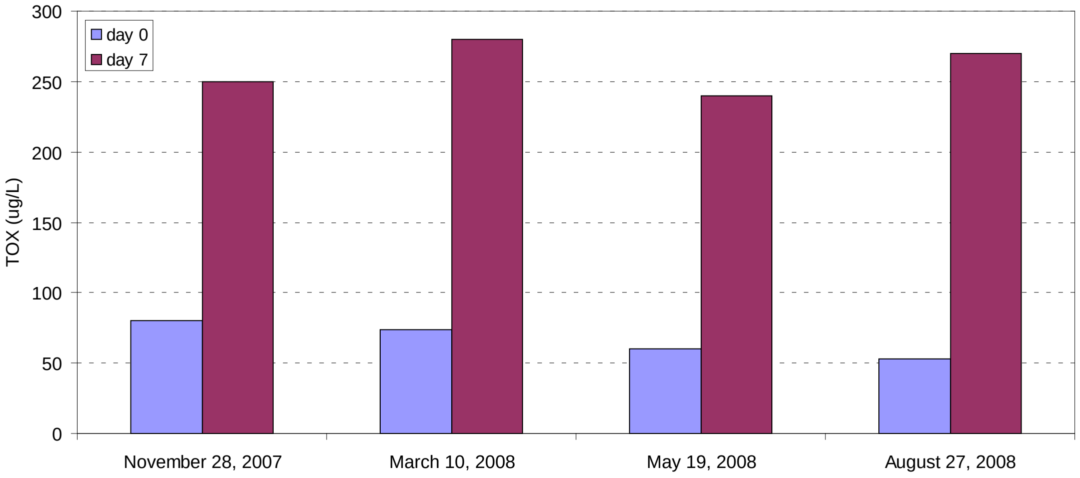


**Figure B.7. TOX-FP tests for DW5.**

## *Appendix C*

# Statistical Data

**Table C.1. Multiple Comparison Test for Total Dissolved Solids (mg/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | IPR1A | -170 | -57 | 57 | no | |
| DW2 | IPR1A | -38 | 76 | 189 | no | |
| DW4 | IPR1A | -202 | -89 | 24 | no | |
| DW5 | IPR1A | -73 | 40 | 154 | no | |
| DW1 | IPR1B | -132 | -67 | -1 | yes | IPR1B > DW1 |
| DW2 | IPR1B | 0.2 | 66 | 131 | yes | DW2 > IPR1B |
| DW4 | IPR1B | -164 | -99 | -35 | yes | IPR1B > DW4 |
| DW5 | IPR1B | -34 | 30 | 95 | no | |
| DW1 | IPR2A | -103 | 27 | 156 | no | |
| DW2 | IPR2A | 30 | 159 | 288 | yes | DW2 > IPR2A |
| DW4 | IPR2A | -135 | -6 | 123 | no | |
| DW5 | IPR2A | -5 | 124 | 253 | no | |
| DW1 | IPR2B | -3 | 82 | 166 | no | |
| DW2 | IPR2B | 130 | 214 | 299 | yes | DW2 > IPR2B |
| DW4 | IPR2B | -35 | 49 | 133 | no | |
| DW5 | IPR2B | 95 | 179 | 263 | yes | DW5 > IPR2B |
| IPR1A | AVG | -57 | 53 | 163 | no | |
| IPR1B | AVG | 4 | 63 | 123 | yes | IPR1B > AVG |
| IPR2A | AVG | -156 | -30 | 96 | no | |
| IPR2B | AVG | -165 | -85 | -5 | yes | AVG > IPR2B |
| IPR1A | IPR2B | 7 | 138 | 270 | yes | IPR1A > IPR2B |
| IPR1B | IPR2B | 56 | 149 | 241 | yes | IPR1B > IPR2B |
| IPR2A | IPR2B | -90 | 55 | 200 | no | |
| IPR1A | IPR1B | -130 | -10 | 110 | no | |
| IPR1A | IPR2A | -81 | 83 | 247 | no | |
| IPR1B | IPR2A | -42 | 93 | 228 | no | |
| DW1 | AVG | -49 | -3 | 42 | no | |
| DW2 | AVG | 84 | 129 | 174 | yes | DW2 > AVG |
| DW4 | AVG | -80 | -36 | 8 | no | |
| DW5 | AVG | 49 | 94 | 138 | yes | DW5> AVG |
| DW1 | DW2 | -185 | -132 | -79 | yes | DW2 > DW1 |
| DW1 | DW4 | -19 | 33 | 84 | no | |
| DW2 | DW4 | 113 | 165 | 217 | yes | DW2 > DW4 |
| DW1 | DW5 | -149 | -97 | -45 | yes | DW5 > DW1 |
| DW2 | DW5 | -17 | 35 | 87 | no | |
| DW4 | DW5 | -181 | -130 | -79 | yes | DW5 > DW4 |

### Table C.2. Multiple Comparison Test for Dissolved Organic Carbon (mg/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -20 | 0 | 20 | no | |
| DW1 | DW3 | -28 | -9 | 11 | no | |
| DW1 | DW4 | -33 | -13 | 7 | no | |
| DW1 | DW5 | -25 | -6 | 14 | no | |
| DW1 | IPR1A | -14 | 5 | 25 | no | |
| DW1 | IPR2A | -10.9 | 9 | 28 | no | |
| DW2 | DW3 | -24 | -9 | 7 | no | |
| DW2 | DW4 | -29 | -13 | 3 | no | |
| DW2 | DW5 | -21 | -6 | 10 | no | |
| DW2 | IPR1A | -11 | 5 | 21 | no | |
| DW2 | IPR2A | -7 | 9 | 25 | no | |
| DW3 | DW4 | -20 | -5 | 11 | no | |
| DW3 | DW5 | -13 | 3 | 19 | no | |
| DW3 | IPR1A | -2 | 14 | 30 | no | |
| DW3 | IPR2A | 1 | 17 | 33 | **yes** | DW3 > IPR2A |
| DW4 | DW5 | -8 | 8 | 23 | no | |
| DW4 | IPR1A | 2 | 18 | 34 | **yes** | DW4 > IPR1A |
| DW4 | IPR2A | 6 | 22 | 38 | **yes** | DW4 > IPR2A |
| DW5 | IPR1A | -5 | 11 | 27 | no | |
| DW5 | IPR2A | -2 | 14 | 30 | no | |
| IPR1A | IPR2A | -13 | 3 | 19 | no | |

**Table C.3. Multiple Comparison Test for Total Organic Carbon (mg/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -102 | 24 | 150 | no | |
| DW1 | DW3 | -105 | -48 | 9 | no | |
| DW1 | DW4 | -182 | -123 | -64 | yes | DW4 > DW1 |
| DW1 | DW5 | -100 | -42 | 15 | no | |
| DW1 | IPR1A | -53 | 41 | 135 | no | |
| DW1 | IPR1B | -34.6 | 38 | 111 | no | |
| DW1 | IPR2A | 11 | 78 | 145 | yes | DW1 > IPR2A |
| DW1 | IPR2B | 14 | 108 | 202 | yes | DW1 > IPR2B |
| DW1 | AVG | -60 | -9 | 43 | no | |
| DW2 | DW3 | -197 | -72 | 53 | no | |
| DW2 | DW4 | -273 | -147 | -21 | yes | DW4 > DW2 |
| DW2 | DW5 | -191 | -66 | 59 | no | |
| DW2 | IPR1A | -129 | 17 | 163 | no | |
| DW2 | IPR1B | -118 | 15 | 147 | no | |
| DW2 | IPR2A | -76 | 54 | 184 | no | |
| DW2 | IPR2B | -61 | 84 | 230 | no | |
| DW2 | AVG | -155 | -32 | 90 | no | |
| DW3 | DW4 | -132 | -75 | -19 | yes | DW4 > DW3 |
| DW3 | DW5 | -50 | 6 | 61 | no | |
| DW3 | IPR1A | -4 | 89 | 181 | no | |
| DW3 | IPR1B | 15 | 86 | 157 | yes | DW3 > IPR1B |
| DW3 | IPR2A | 61 | 126 | 190 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 63 | 156 | 248 | yes | DW3 > IPR2B |
| DW3 | AVG | -9 | 39 | 88 | no | |
| DW4 | DW5 | 24 | 81 | 138 | yes | DW4 > DW5 |
| DW4 | IPR1A | 70 | 164 | 258 | yes | DW4 > IPR1A |
| DW4 | IPR1B | 89 | 162 | 234 | yes | DW4 > IPR1B |
| DW4 | IPR2A | 135 | 201 | 268 | yes | DW4 > IPR2A |
| DW4 | IPR2B | 138 | 231 | 325 | yes | DW4 > IPR2B |
| DW4 | AVG | 64 | 115 | 166 | yes | DW4 > AVG |
| DW5 | IPR1A | -10 | 83 | 176 | no | |
| DW5 | IPR1B | 9 | 81 | 152 | yes | DW5 > IPR1B |
| DW5 | IPR2A | 55 | 120 | 185 | yes | DW5 > IPR2A |
| DW5 | IPR2B | 57 | 150 | 243 | yes | DW5 > IPR2B |
| DW5 | AVG | -16 | 34 | 83 | no | |
| IPR1A | IPR1B | -106 | -3 | 100 | no | |
| IPR1A | IPR2A | -62 | 37 | 136 | no | |
| IPR1A | IPR2B | -52 | 67 | 186 | no | |
| IPR1A | AVG | -138 | -49 | 40 | no | |
| IPR1B | IPR2A | -39 | 40 | 119 | no | |
| IPR1B | IPR2B | -33 | 70 | 173 | no | |
| IPR1B | AVG | -113 | -47 | 20 | no | |
| IPR2A | IPR2B | -69 | 30 | 129 | no | |
| IPR2A | AVG | -146 | -86 | -27 | yes | AVG > IPR2A |
| IPR2B | AVG | -206 | -116 | -27 | yes | AVG > IPR2B |

**Table C.4. Multiple Comparison Test for Nitrate as N (mg/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -116 | -47 | 21 | no | |
| DW1 | DW3 | -96 | -15 | 67 | no | |
| DW1 | DW4 | -6 | 45 | 96 | no | |
| DW1 | DW5 | -90 | -35 | 21 | no | |
| DW1 | IPR1A | -168 | -91 | -13 | yes | IPR1A > DW1 |
| DW1 | IPR1B | -144.8 | -85 | -25 | yes | IPR1B > DW1 |
| DW1 | IPR2A | -109 | -50 | 8 | no | |
| DW1 | IPR2B | -78 | 0 | 77 | no | |
| DW1 | AVG | -44 | -2 | 40 | no | |
| DW2 | DW3 | -62 | 33 | 128 | no | |
| DW2 | DW4 | 22 | 93 | 163 | yes | DW2 > DW4 |
| DW2 | DW5 | -61 | 13 | 87 | no | |
| DW2 | IPR1A | -134 | -43 | 48 | no | |
| DW2 | IPR1B | -114 | -38 | 39 | no | |
| DW2 | IPR2A | -79 | -3 | 73 | no | |
| DW2 | IPR2B | -44 | 47 | 138 | no | |
| DW2 | AVG | -18 | 46 | 109 | no | |
| DW3 | DW4 | -23 | 60 | 143 | no | |
| DW3 | DW5 | -106 | -20 | 66 | no | |
| DW3 | IPR1A | -177 | -76 | 26 | no | |
| DW3 | IPR1B | -159 | -70 | 19 | no | |
| DW3 | IPR2A | -124 | -36 | 52 | no | |
| DW3 | IPR2B | -87 | 14 | 116 | no | |
| DW3 | AVG | -65 | 13 | 91 | no | |
| DW4 | DW5 | -138 | -80 | -22 | yes | DW5 > DW4 |
| DW4 | IPR1A | -215 | -136 | -57 | yes | IPR1A > DW4 |
| DW4 | IPR1B | -192 | -130 | -68 | yes | IPR1B > DW4 |
| DW4 | IPR2A | -156 | -96 | -35 | yes | IPR2A > DW4 |
| DW4 | IPR2B | -124 | -45 | 34 | no | |
| DW4 | AVG | -92 | -47 | -2 | yes | AVG > DW4 |
| DW5 | IPR1A | -138 | -56 | 26 | no | |
| DW5 | IPR1B | -116 | -50 | 15 | no | |
| DW5 | IPR2A | -81 | -16 | 49 | no | |
| DW5 | IPR2B | -48 | 34 | 116 | no | |
| DW5 | AVG | -17 | 33 | 83 | no | |
| IPR1A | IPR1B | -79 | 6 | 91 | no | |
| IPR1A | IPR2A | -44 | 40 | 124 | no | |
| IPR1A | IPR2B | -8 | 90 | 188 | no | |
| IPR1A | AVG | 15 | 89 | 162 | yes | IPR1A > AVG |

## Table C.4. Multiple Comparison Test for Nitrate as N (mg/L) (continued)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| IPR1B | IPR2A | -34 | 34 | 103 | no | |
| IPR1B | IPR2B | 0 | 85 | 170 | no | |
| IPR1B | AVG | 29 | 83 | 138 | yes | IPR1B > AVG |
| IPR2A | IPR2B | -34 | 50 | 134 | no | |
| IPR2A | AVG | -5 | 49 | 102 | no | |
| IPR2B | AVG | -75 | -2 | 72 | no | |

## Table C.5. Multiple Comparison Test for Total Nitrogen (mg/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -21 | -2 | 16 | no | |
| DW1 | DW3 | -21 | -3 | 16 | no | |
| DW1 | DW4 | -30 | -11 | 8 | no | |
| DW1 | DW5 | -18 | 0 | 19 | no | |
| DW1 | IPR1A | -26.0 | -7 | 11 | no | |
| DW1 | IPR2A | -36 | -16 | 4 | no | |
| DW2 | DW3 | -16 | 0 | 15 | no | |
| DW2 | DW4 | -24 | -9 | 7 | no | |
| DW2 | DW5 | -13 | 3 | 18 | no | |
| DW2 | IPR1A | -20 | -5 | 10 | no | |
| DW2 | IPR2A | -30 | -14 | 3 | no | |
| DW3 | DW4 | -24 | -8 | 7 | no | |
| DW3 | DW5 | -12 | 3 | 18 | no | |
| DW3 | IPR1A | -20 | -5 | 11 | no | |
| DW3 | IPR2A | -30 | -13 | 3 | no | |
| DW4 | DW5 | -4 | 11 | 27 | no | |
| DW4 | IPR1A | -12 | 4 | 19 | no | |
| DW4 | IPR2A | -21 | -5 | 12 | no | |
| DW5 | IPR1A | -23 | -8 | 8 | no | |
| DW5 | IPR2A | -33 | -16 | 0 | no | |
| IPR1A | IPR2A | -25 | -9 | 8 | no | |

**Table C.6. Multiple Comparison Test for pH**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different (α = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -110 | -54 | 1 | no | |
| DW1 | DW3 | -55 | 64 | 183 | no | |
| DW1 | DW4 | -200 | -146 | -91 | **yes** | DW4 > DW1 |
| DW1 | DW5 | -134 | -80 | -27 | **yes** | DW5 > DW1 |
| DW1 | IPR1A | -81 | 7 | 95 | no | |
| DW1 | IPR1B | -64.4 | 4 | 72 | no | |
| DW1 | IPR2A | -67 | 52 | 171 | no | |
| DW1 | IPR2B | -143 | -24 | 94 | no | |
| DW1 | AVG | -85 | -37 | 10 | no | |
| DW2 | DW3 | 0 | 119 | 237 | no | |
| DW2 | DW4 | -146 | -91 | -37 | **yes** | DW4 > DW2 |
| DW2 | DW5 | -80 | -26 | 28 | no | |
| DW2 | IPR1A | -27 | 61 | 150 | no | |
| DW2 | IPR1B | -10 | 58 | 127 | no | |
| DW2 | IPR2A | -12 | 107 | 225 | no | |
| DW2 | IPR2B | -89 | 30 | 149 | no | |
| DW2 | AVG | -30 | 17 | 64 | no | |
| DW3 | DW4 | -328 | -210 | -92 | **yes** | DW4 > DW3 |
| DW3 | DW5 | -262 | -144 | -26 | **yes** | DW5 > DW3 |
| DW3 | IPR1A | -194 | -57 | 80 | no | |
| DW3 | IPR1B | -186 | -60 | 65 | no | |
| DW3 | IPR2A | -171 | -12 | 147 | no | |
| DW3 | IPR2B | -247 | -89 | 70 | no | |
| DW3 | AVG | -217 | -102 | 14 | no | |
| DW4 | DW5 | 13 | 65 | 118 | **yes** | DW4 > DW5 |
| DW4 | IPR1A | 65 | 153 | 240 | **yes** | DW4 > IPR1A |
| DW4 | IPR1B | 82 | 150 | 217 | **yes** | DW4> IPR1B |
| DW4 | IPR2A | 80 | 198 | 316 | **yes** | DW4> IPR2A |
| DW4 | IPR2B | 3 | 121 | 240 | **yes** | DW4 > IPR2B |
| DW4 | AVG | 62 | 108 | 155 | **yes** | DW4 > AVG |
| DW5 | IPR1A | 0 | 87 | 175 | no | |
| DW5 | IPR1B | 17 | 84 | 151 | **yes** | DW5 > IPR1B |
| DW5 | IPR2A | 14 | 132 | 250 | **yes** | DW5 > IPR1B |
| DW5 | IPR2B | -62 | 56 | 174 | no | |
| DW5 | AVG | -3 | 43 | 88 | no | |
| IPR1A | IPR1B | -100 | -3 | 94 | no | |
| IPR1A | IPR2A | -92 | 45 | 182 | no | |
| IPR1A | IPR2B | -169 | -31 | 106 | no | |
| IPR1A | AVG | -128 | -44 | 39 | no | |
| IPR1B | IPR2A | -77 | 48 | 174 | no | |
| IPR1B | IPR2B | -154 | -28 | 97 | no | |

## Table C.6. Multiple Comparison Test for pH (continued)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| IPR1B | AVG | -103 | -41 | 21 | no | |
| IPR2A | IPR2B | -235 | -77 | 82 | no | |
| IPR2A | AVG | -205 | -90 | 26 | no | |
| IPR2B | AVG | -128 | -13 | 102 | no | |

**Table C.7. Multiple Comparison Test for Conductance (μmho/cm)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different (α = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -168 | -103 | -39 | yes | DW2 > DW1 |
| DW1 | DW3 | -86 | -15 | 57 | no | |
| DW1 | DW4 | -41 | -9 | 24 | no | |
| DW1 | DW5 | -127 | -90 | -52 | yes | DW5 > DW1 |
| DW1 | IPR1A | -115 | -62 | -8 | yes | IPR1A > DW1 |
| DW1 | IPR1B | -110.3 | -69 | -28 | yes | IPR1B > DW1 |
| DW1 | IPR2A | -66 | -27 | 13 | no | |
| DW1 | IPR2B | -13 | 40 | 93 | no | |
| DW2 | DW3 | -2 | 89 | 179 | no | |
| DW2 | DW4 | 30 | 95 | 159 | yes | DW2 > DW4 |
| DW2 | DW5 | -53 | 14 | 80 | no | |
| DW2 | IPR1A | -35 | 42 | 119 | no | |
| DW2 | IPR1B | -35 | 34 | 103 | no | |
| DW2 | IPR2A | 8 | 77 | 145 | yes | DW2 > IPR2A |
| DW2 | IPR2B | 67 | 144 | 220 | yes | DW2 > IPR2B |
| DW3 | DW4 | -65 | 6 | 77 | no | |
| DW3 | DW5 | -148 | -75 | -2 | yes | DW5 > DW3 |
| DW3 | IPR1A | -129 | -47 | 36 | no | |
| DW3 | IPR1B | -130 | -54 | 21 | no | |
| DW3 | IPR2A | -86 | -12 | 63 | no | |
| DW3 | IPR2B | -28 | 55 | 138 | no | |
| DW4 | DW5 | -117 | -81 | -44 | yes | DW5 > DW4 |
| DW4 | IPR1A | -105 | -53 | -0.1 | yes | IPR2A > DW4 |
| DW4 | IPR1B | -101 | -61 | -20 | yes | IPR1B > DW4 |
| DW4 | IPR2A | -57 | -18 | 21 | no | |
| DW4 | IPR2B | -4 | 49 | 102 | no | |
| DW5 | IPR1A | -28 | 28 | 84 | no | |
| DW5 | IPR1B | -24 | 20 | 65 | no | |
| DW5 | IPR2A | 20 | 63 | 106 | yes | DW5 > IPR2A |
| DW5 | IPR2B | 74 | 130 | 185 | yes | DW5 > IPR2B |
| IPR1A | IPR1B | -66 | -8 | 51 | no | |
| IPR1A | IPR2A | -22 | 35 | 92 | no | |
| IPR1A | IPR2B | 34 | 102 | 169 | yes | IPR1A > IPR2B |
| IPR1B | IPR2A | -4 | 43 | 89 | no | |
| IPR1B | IPR2B | 51 | 109 | 168 | yes | IPR1B > IPR2B |
| IPR2A | IPR2B | 10 | 67 | 124 | yes | IPR2A > IPR2B |

**Table C.8. Multiple Comparison Test for Alkalinity**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -199 | -132 | -65 | yes | DW2 > DW1 |
| DW1 | DW3 | 29 | 94 | 159 | yes | DW1 > DW3 |
| DW1 | DW4 | -5 | 60 | 126 | no | |
| DW1 | DW5 | -151 | -85 | -20 | yes | DW5 > DW1 |
| DW1 | IPR1A | -188 | -81 | 26 | no | |
| DW1 | IPR1B | -141.6 | -59 | 24 | no | |
| DW1 | IPR2A | -98 | -17 | 64 | no | |
| DW1 | IPR2B | -32 | 75 | 182 | no | |
| DW1 | AVG | -74 | -17 | 40 | no | |
| DW2 | DW3 | 161 | 226 | 291 | yes | DW2 > DW3 |
| DW2 | DW4 | 127 | 192 | 258 | yes | DW2 > DW4 |
| DW2 | DW5 | -19 | 47 | 112 | no | |
| DW2 | IPR1A | -56 | 51 | 158 | no | |
| DW2 | IPR1B | -10 | 73 | 156 | no | |
| DW2 | IPR2A | 33 | 115 | 196 | yes | DW2 > IPR2A |
| DW2 | IPR2B | 100 | 207 | 314 | yes | DW2 > IPR2B |
| DW2 | AVG | 57 | 115 | 172 | yes | DW2 > AVG |
| DW3 | DW4 | -97 | -34 | 29 | no | |
| DW3 | DW5 | -242 | -179 | -116 | yes | DW5 > DW3 |
| DW3 | IPR1A | -281 | -175 | -70 | yes | IPR1A > DW3 |
| DW3 | IPR1B | -234 | -153 | -72 | yes | IPR1B > DW3 |
| DW3 | IPR2A | -191 | -111 | -32 | yes | IPR2A > DW3 |
| DW3 | IPR2B | -125 | -19 | 87 | no | |
| DW3 | AVG | -166 | -111 | -57 | yes | AVG > DW3 |
| DW4 | DW5 | -210 | -146 | -82 | yes | DW5 > DW4 |
| DW4 | IPR1A | -248 | -142 | -36 | yes | IPR1A > DW4 |
| DW4 | IPR1B | -201 | -119 | -38 | yes | IPR1B > DW4 |
| DW4 | IPR2A | -158 | -78 | 2 | no | |
| DW4 | IPR2B | -91 | 15 | 121 | no | |
| DW4 | AVG | -133 | -78 | -22 | yes | AVG > DW4 |
| DW5 | IPR1A | -102 | 4 | 110 | no | |
| DW5 | IPR1B | -55 | 26 | 108 | no | |
| DW5 | IPR2A | -12 | 68 | 148 | no | |
| DW5 | IPR2B | 54 | 160 | 266 | yes | DW5 > IPR2B |
| DW5 | AVG | 12 | 68 | 123 | yes | DW5 > AVG |
| IPR1A | IPR1B | -95 | 23 | 140 | no | |
| IPR1A | IPR2A | -53 | 64 | 180 | no | |
| IPR1A | IPR2B | 21 | 156 | 292 | yes | |
| IPR1A | AVG | -37 | 64 | 165 | no | |
| IPR1B | IPR2A | -53 | 41 | 136 | no | |
| IPR1B | IPR2B | 16 | 134 | 252 | yes | IPR1B > IPR2B |
| IPR1B | AVG | -34 | 41 | 117 | no | |
| IPR2A | IPR2B | -24 | 92 | 209 | no | |
| IPR2A | AVG | -73 | 0.05 | 73 | no | |
| IPR2B | AVG | -194 | -92 | 9 | no | |

## Table C.9. Multiple Comparison Test for Color

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -14 | 6 | 25 | no | |
| DW1 | DW3 | -16 | 4 | 23 | no | |
| DW1 | DW4 | -24 | -4 | 15 | no | |
| DW1 | DW5 | -17 | 3 | 22 | no | |
| DW1 | IPR1A | -23 | -4 | 15 | no | |
| DW1 | IPR2A | -19.3 | 0 | 19 | no | |
| DW2 | DW3 | -18 | -2 | 14 | no | |
| DW2 | DW4 | -26 | -10 | 6 | no | |
| DW2 | DW5 | -18 | -3 | 13 | no | |
| DW2 | IPR1A | -25 | -10 | 6 | no | |
| DW2 | IPR2A | -21 | -6 | 10 | no | |
| DW3 | DW4 | -24 | -8 | 8 | no | |
| DW3 | DW5 | -16 | -1 | 15 | no | |
| DW3 | IPR1A | -23 | -8 | 8 | no | |
| DW3 | IPR2A | -19 | -4 | 12 | no | |
| DW4 | DW5 | -9 | 7 | 23 | no | |
| DW4 | IPR1A | -15 | 0.3 | 16 | no | |
| DW4 | IPR2A | -11 | 4 | 20 | no | |
| DW5 | IPR1A | -23 | -7 | 9 | no | |
| DW5 | IPR2A | -18 | -3 | 13 | no | |
| IPR1A | IPR2A | -12 | 4 | 20 | no | |

**Table C.10. Multiple Comparison Test for UVA 254**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | 2 | 28 | 53 | yes | DW1 > DW2 |
| DW1 | DW3 | -18 | 8 | 33 | no | |
| DW1 | DW4 | -45 | -19 | 6 | no | |
| DW1 | DW5 | -1 | 25 | 50 | no | |
| DW1 | IPR1A | -4 | 21 | 47 | no | |
| DW1 | IPR2A | 7.3 | 33 | 58 | yes | DW1 > IPR2A |
| DW2 | DW3 | -54 | -20 | 14 | no | |
| DW2 | DW4 | -81 | -47 | -13 | yes | DW4 > DW2 |
| DW2 | DW5 | -37 | -3 | 31 | no | |
| DW2 | IPR1A | -40 | -6 | 28 | no | |
| DW2 | IPR2A | -29 | 5 | 39 | no | |
| DW3 | DW4 | -61 | -27 | 7 | no | |
| DW3 | DW5 | -17 | 17 | 51 | no | |
| DW3 | IPR1A | -20 | 14 | 47 | no | |
| DW3 | IPR2A | -9 | 25 | 59 | no | |
| DW4 | DW5 | 10 | 44 | 78 | yes | DW4 > DW5 |
| DW4 | IPR1A | 7 | 40.5 | 74 | yes | DW4 > IPR1A |
| DW4 | IPR2A | 18 | 52 | 86 | yes | DW4 > IPR2A |
| DW5 | IPR1A | -37 | -3 | 31 | no | |
| DW5 | IPR2A | -26 | 8 | 42 | no | |
| IPR1A | IPR2A | -22 | 12 | 45 | no | |

## Table C.11. Multiple Comparison Test for UVA 272

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different (α = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -16 | 4 | 23 | no | |
| DW1 | DW3 | -27 | -8 | 12 | no | |
| DW1 | DW4 | -32 | -12 | 8 | no | |
| DW1 | DW5 | -19 | 1 | 20 | no | |
| DW1 | IPR1A | -21 | -1 | 18 | no | |
| DW1 | IPR2A | -9.5 | 10 | 30 | no | |
| DW2 | DW3 | -27 | -11 | 5 | no | |
| DW2 | DW4 | -32 | -16 | 0 | no | |
| DW2 | DW5 | -19 | -3 | 13 | no | |
| DW2 | IPR1A | -21 | -5 | 11 | no | |
| DW2 | IPR2A | -10 | 6 | 22 | no | |
| DW3 | DW4 | -20 | -5 | 11 | no | |
| DW3 | DW5 | -8 | 8 | 24 | no | |
| DW3 | IPR1A | -10 | 6 | 22 | no | |
| DW3 | IPR2A | 2 | 18 | 33 | yes | DW3 > IPR2A |
| DW4 | DW5 | -3 | 13 | 28 | no | |
| DW4 | IPR1A | -5 | 10.8 | 27 | no | |
| DW4 | IPR2A | 6 | 22 | 38 | yes | DW4 > IPR2A |
| DW5 | IPR1A | -18 | -2 | 14 | no | |
| DW5 | IPR2A | -6 | 10 | 25 | no | |
| IPR1A | IPR2A | -5 | 11 | 27 | no | |

**Table C.12. Multiple Comparison Test for Phosphate (mg/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha = 0.05$) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -122 | -21 | 80 | no | |
| DW1 | DW3 | -182 | -97 | -13 | yes | DW3 > DW1 |
| DW1 | DW4 | -145 | -60 | 25 | no | |
| DW1 | DW5 | -107 | -21 | 64 | no | |
| DW1 | IPR1A | -138 | -37 | 65 | no | |
| DW1 | IPR2A | -107.1 | -20 | 67 | no | |
| DW1 | IPR2B | -85 | 10 | 106 | no | |
| DW2 | DW3 | -138 | -77 | -15 | yes | DW3 > DW2 |
| DW2 | DW4 | -101 | -39 | 23 | no | |
| DW2 | DW5 | -63 | -1 | 62 | no | |
| DW2 | IPR1A | -98 | -16 | 67 | no | |
| DW2 | IPR2A | -64 | 1 | 66 | no | |
| DW2 | IPR2B | -44 | 31 | 106 | no | |
| DW3 | DW4 | 10 | 37 | 65 | yes | DW3 > DW4 |
| DW3 | DW5 | 47 | 76 | 105 | yes | DW3 > DW5 |
| DW3 | IPR1A | 0 | 61 | 122 | no | |
| DW3 | IPR2A | 44 | 78 | 112 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 56 | 108 | 159 | yes | DW3 > IPR2B |
| DW4 | DW5 | 9 | 39 | 68 | yes | DW4 > DW5 |
| DW4 | IPR1A | -38 | 24 | 85 | no | |
| DW4 | IPR2A | 5 | 40 | 75 | yes | DW4 > IPR2A |
| DW4 | IPR2B | 19 | 70 | 122 | yes | DW4 > IPR2B |
| DW5 | IPR1A | -77 | -15 | 47 | no | |
| DW5 | IPR2A | -34 | 2 | 37 | no | |
| DW5 | IPR2B | -21 | 32 | 84 | no | |
| IPR1A | IPR2A | -48 | 17 | 82 | no | |
| IPR1A | IPR2B | -29 | 47 | 122 | no | |
| IPR2A | IPR2B | -25 | 30 | 86 | no | |

### Table C.13. Multiple Comparison Test for Sulfate (mg/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha = 0.05$) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -115 | -62 | -9 | yes | DW2 > DW1 |
| DW1 | DW3 | -63 | -5 | 54 | no | |
| DW1 | DW4 | 8 | 35 | 62 | yes | DW1 > DW4 |
| DW1 | DW5 | -88 | -57 | -26 | yes | DW5 > DW1 |
| DW1 | IPR1A | -72 | -28 | 16 | no | |
| DW1 | IPR1B | -68.1 | -34 | 0 | no | |
| DW1 | IPR2A | -43 | 16 | 75 | no | |
| DW2 | DW3 | -17 | 57 | 131 | no | |
| DW2 | DW4 | 44 | 97 | 150 | yes | DW2 > DW4 |
| DW2 | DW5 | -50 | 5 | 60 | no | |
| DW2 | IPR1A | -30 | 34 | 97 | no | |
| DW2 | IPR1B | -29 | 28 | 84 | no | |
| DW2 | IPR2A | 3 | 78 | 152 | yes | DW2 > IPR2A |
| DW3 | DW4 | -19 | 40 | 98 | no | |
| DW3 | DW5 | -112 | -52 | 8 | no | |
| DW3 | IPR1A | -91 | -24 | 44 | no | |
| DW3 | IPR1B | -91 | -29 | 32 | no | |
| DW3 | IPR2A | -58 | 21 | 99 | no | |
| DW4 | DW5 | -122 | -92 | -62 | yes | DW5 > DW4 |
| DW4 | IPR1A | -106 | -63 | -20 | yes | IPR1A > DW4 |
| DW4 | IPR1B | -102 | -69 | -36 | yes | IPR1B > DW4 |
| DW4 | IPR2A | -77 | -19 | 39 | no | |
| DW5 | IPR1A | -17 | 28 | 74 | no | |
| DW5 | IPR1B | -14 | 23 | 59 | no | |
| DW5 | IPR2A | 12 | 73 | 133 | yes | DW5 > IPR2A |
| IPR1A | IPR1B | -54 | -6 | 42 | no | |
| IPR1A | IPR2A | -24 | 44 | 112 | no | |
| IPR1B | IPR2A | -12 | 50 | 112 | no | |

**Table C.14. Multiple Comparison Test for Total THMs (Entry Point)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different (α = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -111 | -52 | 7 | no | |
| DW1 | DW3 | -112 | -42 | 28 | no | |
| DW1 | DW4 | -118 | -48 | 22 | no | |
| DW1 | DW5 | -70 | -32 | 5 | no | |
| DW1 | IPR1A | -23 | 47 | 117 | no | |
| DW1 | IPR2A | -39.3 | 31 | 101 | no | |
| DW1 | IPR2B | -14 | 45 | 104 | no | |
| DW1 | AVG | -63 | -34 | -5 | yes | AVG > DW1 |
| DW2 | DW3 | -75 | 10 | 94 | no | |
| DW2 | DW4 | -80 | 4 | 89 | no | |
| DW2 | DW5 | -41 | 20 | 80 | no | |
| DW2 | IPR1A | 15 | 99 | 184 | yes | DW2 > IPR1A |
| DW2 | IPR2A | -2 | 83 | 167 | no | |
| DW2 | IPR2B | 21 | 97 | 173 | yes | DW2 > IPR2B |
| DW2 | AVG | -38 | 18 | 74 | no | |
| DW3 | DW4 | -98 | -6 | 87 | no | |
| DW3 | DW5 | -62 | 10 | 81 | no | |
| DW3 | IPR1A | -3 | 90 | 182 | no | |
| DW3 | IPR2A | -20 | 73 | 165 | no | |
| DW3 | IPR2B | 2 | 87 | 172 | yes | DW3 > IPR2B |
| DW3 | AVG | -59 | 8 | 76 | no | |
| DW4 | DW5 | -56 | 16 | 87 | no | |
| DW4 | IPR1A | 2 | 95 | 188 | yes | DW4 > IPR1A |
| DW4 | IPR2A | -14 | 78 | 171 | no | |
| DW4 | IPR2B | 8 | 93 | 177 | yes | DW4 > IPR2B |
| DW4 | AVG | -54 | 14 | 81 | no | |
| DW5 | IPR1A | 8 | 80 | 151 | yes | DW5 > IPR1A |
| DW5 | IPR2A | -9 | 63 | 134 | no | |
| DW5 | IPR2B | 16 | 77 | 138 | yes | DW5 > IPR2B |
| DW5 | AVG | -35 | -2 | 31 | no | |
| IPR1A | IPR2A | -109 | -17 | 76 | no | |
| IPR1A | IPR2B | -87 | -3 | 82 | no | |
| IPR1A | AVG | -149 | -81 | -14 | yes | AVG > IPR1A |
| IPR2A | IPR2B | -70 | 14 | 99 | no | |
| IPR2A | AVG | -132 | -65 | 3 | no | |
| IPR2B | AVG | -135 | -79 | -23 | yes | AVG > IPR2B |

**Table C.15. Multiple Comparison Test for HAA5 (Entry Point)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -3 | 36 | 75 | no | |
| DW1 | DW3 | -48 | -13 | 21 | no | |
| DW1 | DW4 | -54 | -19 | 15 | no | |
| DW1 | DW5 | 4 | 23 | 41 | yes | DW1 > DW5 |
| DW1 | IPR1A | 9 | 44 | 78 | yes | DW1 > IPR1A |
| DW1 | IPR2A | 9.4 | 44 | 78 | yes | DW1 > IPR2A |
| DW1 | IPR2B | 9 | 44 | 78 | yes | DW1 > IPR2B |
| DW2 | DW3 | -98 | -49 | 0 | yes | DW3 > DW2 |
| DW2 | DW4 | -104 | -55 | -6 | yes | DW4 > DW2 |
| DW2 | DW5 | -53 | -13 | 27 | no | |
| DW2 | IPR1A | -41 | 8 | 57 | no | |
| DW2 | IPR2A | -41 | 8 | 57 | no | |
| DW2 | IPR2B | -41 | 8 | 57 | no | |
| DW3 | DW4 | -51 | -6 | 39 | no | |
| DW3 | DW5 | 1 | 36 | 71 | yes | DW3 > DW5 |
| DW3 | IPR1A | 12 | 57 | 102 | yes | DW3 > IPR1A |
| DW3 | IPR2A | 12 | 57 | 102 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 12 | 57 | 102 | yes | DW3 > IPR2B |
| DW4 | DW5 | 7 | 42 | 77 | yes | DW4 > DW5 |
| DW4 | IPR1A | 18 | 63 | 108 | yes | DW4 > IPR1A |
| DW4 | IPR2A | 18 | 63 | 108 | yes | DW4 > IPR2A |
| DW4 | IPR2B | 18 | 63 | 108 | yes | DW4 > IPR2B |
| DW5 | IPR1A | -14 | 21 | 56 | no | |
| DW5 | IPR2A | -14 | 21 | 56 | no | |
| DW5 | IPR2B | -14 | 21 | 56 | no | |
| IPR1A | IPR2A | -45 | 0 | 45 | no | |
| IPR1A | IPR2B | -45 | 0 | 45 | no | |
| IPR2A | IPR2B | -45 | 0 | 45 | no | |

## Table C.16. Multiple Comparison Test for TOX FP

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -18 | 2 | 21 | no | |
| DW1 | DW3 | -26 | -8 | 11 | no | |
| DW1 | DW4 | -30 | -12 | 7 | no | |
| DW1 | DW5 | -22 | -4 | 15 | no | |
| DW1 | IPR1A | -13 | 6 | 25 | no | |
| DW1 | IPR2A | -9.5 | 9 | 28 | no | |
| DW2 | DW3 | -26 | -9 | 7 | no | |
| DW2 | DW4 | -30 | -13 | 3 | no | |
| DW2 | DW5 | -22 | -5 | 11 | no | |
| DW2 | IPR1A | -12 | 4 | 21 | no | |
| DW2 | IPR2A | -9 | 8 | 24 | no | |
| DW3 | DW4 | -19 | -4 | 11 | no | |
| DW3 | DW5 | -11 | 4 | 19 | no | |
| DW3 | IPR1A | -2 | 13 | 29 | no | |
| DW3 | IPR2A | 1 | 17 | 32 | yes | DW3 > IPR2A |
| DW4 | DW5 | -7 | 8 | 23 | no | |
| DW4 | IPR1A | 2 | 17 | 33 | yes | DW4 > IPR1A |
| DW4 | IPR2A | 5 | 21 | 36 | yes | DW4 > IPR2A |
| DW5 | IPR1A | -6 | 9 | 25 | no | |
| DW5 | IPR2A | -3 | 13 | 28 | no | |
| IPR1A | IPR2A | -12 | 4 | 19 | no | |

## Table C.17. Multiple Comparison Test for TOX

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha = 0.05$) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -25 | -6 | 14 | no | |
| DW1 | DW3 | -32 | -13 | 6 | no | |
| DW1 | DW4 | -31 | -12 | 8 | no | |
| DW1 | DW5 | -25 | -6 | 14 | no | |
| DW1 | IPR1A | -13 | 6 | 26 | no | |
| DW1 | IPR2A | -15.9 | 4 | 23 | no | |
| DW2 | DW3 | -23 | -8 | 8 | no | |
| DW2 | DW4 | -22 | -6 | 10 | no | |
| DW2 | DW5 | -16 | 0 | 16 | no | |
| DW2 | IPR1A | -4 | 12 | 28 | no | |
| DW2 | IPR2A | -7 | 9 | 25 | no | |
| DW3 | DW4 | -15 | 1 | 17 | no | |
| DW3 | DW5 | -9 | 7 | 23 | no | |
| DW3 | IPR1A | 3 | 19 | 35 | yes | DW3 > IPR1A |
| DW3 | IPR2A | 1 | 17 | 33 | yes | DW3 > IPR2A |
| DW4 | DW5 | -10 | 6 | 22 | no | |
| DW4 | IPR1A | 2 | 18 | 34 | yes | DW4 > IPR1A |
| DW4 | IPR2A | 0 | 16 | 31 | no | |
| DW5 | IPR1A | -4 | 12 | 28 | no | |
| DW5 | IPR2A | -7 | 9 | 25 | no | |
| IPR1A | IPR2A | -19 | -3 | 13 | no | |

## Table C.18. Multiple Comparison Test for TOBr

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -31 | -12 | 7 | no | |
| DW1 | DW3 | -23 | -4 | 15 | no | |
| DW1 | DW4 | -18 | 1 | 20 | no | |
| DW1 | DW5 | -25 | -7 | 12 | no | |
| DW1 | IPR1A | -12 | 7 | 26 | no | |
| DW1 | IPR2A | -12.2 | 7 | 26 | no | |
| DW2 | DW3 | -7 | 8 | 23 | no | |
| DW2 | DW4 | -2 | 14 | 29 | no | |
| DW2 | DW5 | -10 | 6 | 21 | no | |
| DW2 | IPR1A | 4 | 19 | 34 | yes | DW2 > IPR1A |
| DW2 | IPR2A | 4 | 19 | 34 | yes | DW2 > IPR2A |
| DW3 | DW4 | -10 | 6 | 21 | no | |
| DW3 | DW5 | -18 | -2 | 13 | no | |
| DW3 | IPR1A | -4 | 11 | 26 | no | |
| DW3 | IPR2A | -4 | 11 | 26 | no | |
| DW4 | DW5 | -23 | -8 | 8 | no | |
| DW4 | IPR1A | -10 | 5 | 21 | no | |
| DW4 | IPR2A | -10 | 5 | 21 | no | |
| DW5 | IPR1A | -2 | 13 | 29 | no | |
| DW5 | IPR2A | -2 | 13 | 29 | no | |
| IPR1A | IPR2A | -15 | 0 | 15 | no | |

### Table C.19. Multiple Comparison Test for TOCl

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha = 0.05$) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -22 | -3 | 17 | no | |
| DW1 | DW3 | -32 | -12 | 7 | no | |
| DW1 | DW4 | -31 | -12 | 8 | no | |
| DW1 | DW5 | -25 | -6 | 14 | no | |
| DW1 | IPR1A | -12 | 7 | 27 | no | |
| DW1 | IPR2A | -15.3 | 4 | 24 | no | |
| DW2 | DW3 | -26 | -10 | 6 | no | |
| DW2 | DW4 | -25 | -9 | 7 | no | |
| DW2 | DW5 | -19 | -3 | 13 | no | |
| DW2 | IPR1A | -6 | 10 | 26 | no | |
| DW2 | IPR2A | -9 | 7 | 23 | no | |
| DW3 | DW4 | -16 | 0.4 | 16 | no | |
| DW3 | DW5 | -10 | 6 | 22 | no | |
| DW3 | IPR1A | 4 | 20 | 35 | yes | DW3 > IPR1A |
| DW3 | IPR2A | 1 | 17 | 32 | yes | DW3 > IPR2A |
| DW4 | DW5 | -10 | 6 | 22 | no | |
| DW4 | IPR1A | 3 | 19 | 35 | yes | DW4 > IPR1A |
| DW4 | IPR2A | 0.2 | 16 | 32 | yes | DW4 > IPR2A |
| DW5 | IPR1A | -3 | 13 | 29 | no | |
| DW5 | IPR2A | -6 | 10 | 26 | no | |
| IPR1A | IPR2A | -19 | -3 | 13 | no | |

**Table C.20. Multiple Comparison Test for Atrazine (ng/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -21 | 6 | 33 | no | |
| DW1 | DW3 | -40 | -12 | 15 | no | |
| DW1 | DW4 | -36 | -9 | 19 | no | |
| DW1 | DW5 | -18 | 9 | 37 | no | |
| DW1 | IPR1A | -32 | -5 | 23 | no | |
| DW1 | IPR1B | -26.9 | 1 | 28 | no | |
| DW1 | IPR2A | -13 | 15 | 42 | no | |
| DW1 | IPR2B | -9 | 17 | 43 | no | |
| DW2 | DW3 | -41 | -18 | 4 | no | |
| DW2 | DW4 | -37 | -15 | 8 | no | |
| DW2 | DW5 | -19 | 3 | 26 | no | |
| DW2 | IPR1A | -33 | -11 | 12 | no | |
| DW2 | IPR1B | -28 | -6 | 17 | no | |
| DW2 | IPR2A | -14 | 9 | 31 | no | |
| DW2 | IPR2B | -10 | 11 | 32 | no | |
| DW3 | DW4 | -19 | 4 | 26 | no | |
| DW3 | DW5 | -1 | 22 | 44 | no | |
| DW3 | IPR1A | -15 | 8 | 30 | no | |
| DW3 | IPR1B | -10 | 13 | 35 | no | |
| DW3 | IPR2A | 4 | 27 | 49 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 8 | 29 | 50 | yes | DW3 > IPR2B |
| DW4 | DW5 | -5 | 18 | 40 | no | |
| DW4 | IPR1A | -18 | 4 | 26 | no | |
| DW4 | IPR1B | -13 | 9 | 31 | no | |
| DW4 | IPR2A | 1 | 23 | 45 | yes | DW4 > IPR2A |
| DW4 | IPR2B | 4 | 26 | 47 | yes | DW4 > IPR2B |
| DW5 | IPR1A | -36 | -14 | 9 | no | |
| DW5 | IPR1B | -31 | -9 | 14 | no | |
| DW5 | IPR2A | -17 | 5 | 28 | no | |
| DW5 | IPR2B | -13 | 8 | 29 | no | |
| IPR1A | IPR1B | -17 | 5 | 27 | no | |
| IPR1A | IPR2A | -3 | 19 | 41 | no | |
| IPR1A | IPR2B | 0.3 | 22 | 43 | yes | IPR1A > IPR2B |
| IPR1B | IPR2A | -8 | 14 | 36 | no | |
| IPR1B | IPR2B | -5 | 17 | 38 | no | |
| IPR2A | IPR2B | -19 | 3 | 24 | no | |

## Table C.21. Multiple Comparison Test for Caffeine (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -9 | 12 | 32 | no | |
| DW1 | DW3 | -24 | -4 | 17 | no | |
| DW1 | DW4 | -24 | -4 | 16 | no | |
| DW1 | DW5 | -9 | 12 | 32 | no | |
| DW1 | IPR1A | -9 | 12 | 32 | no | |
| DW1 | IPR1B | -36.4 | -8 | 21 | no | |
| DW1 | IPR2A | -9 | 12 | 32 | no | |
| DW1 | IPR2B | -10 | 12 | 33 | no | |
| DW2 | DW3 | -32 | -15 | 1 | no | |
| DW2 | DW4 | -32 | -16 | 1 | no | |
| DW2 | DW5 | -17 | 0 | 17 | no | |
| DW2 | IPR1A | -17 | 0 | 17 | no | |
| DW2 | IPR1B | -45 | -19 | 7 | no | |
| DW2 | IPR2A | -17 | 0 | 17 | no | |
| DW2 | IPR2B | -18 | 0 | 18 | no | |
| DW3 | DW4 | -17 | 0 | 16 | no | |
| DW3 | DW5 | -1 | 15 | 32 | no | |
| DW3 | IPR1A | -1 | 15 | 32 | no | |
| DW3 | IPR1B | -30 | -4 | 23 | no | |
| DW3 | IPR2A | -1 | 15 | 32 | no | |
| DW3 | IPR2B | -3 | 15 | 33 | no | |
| DW4 | DW5 | -1 | 16 | 32 | no | |
| DW4 | IPR1A | -1 | 16 | 32 | no | |
| DW4 | IPR1B | -30 | -4 | 23 | no | |
| DW4 | IPR2A | -1 | 16 | 32 | no | |
| DW4 | IPR2B | -3 | 16 | 34 | no | |
| DW5 | IPR1A | -17 | 0 | 17 | no | |
| DW5 | IPR1B | -45 | -19 | 7 | no | |
| DW5 | IPR2A | -17 | 0 | 17 | no | |
| DW5 | IPR2B | -18 | 0 | 18 | no | |
| IPR1A | IPR1B | -45 | -19 | 7 | no | |
| IPR1A | IPR2A | -17 | 0 | 17 | no | |
| IPR1A | IPR2B | -18 | 0 | 18 | no | |
| IPR1B | IPR2A | -7 | 19 | 45 | no | |
| IPR1B | IPR2B | -8 | 19 | 46 | no | |
| IPR2A | IPR2B | -18 | 0 | 18 | no | |

## Table C.22. Multiple Comparison Test for Carbamazepine (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha = 0.05$) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -32 | -5 | 22 | no | |
| DW1 | DW3 | -37 | -10 | 17 | no | |
| DW1 | DW4 | -25 | 1 | 28 | no | |
| DW1 | DW5 | -14 | 13 | 39 | no | |
| DW1 | IPR1A | -42 | -15 | 12 | no | |
| DW1 | IPR1B | -40.7 | -14 | 13 | no | |
| DW1 | IPR2A | -17 | 9 | 36 | no | |
| DW1 | IPR2B | -23 | 4 | 31 | no | |
| DW2 | DW3 | -27 | -5 | 17 | no | |
| DW2 | DW4 | -16 | 6 | 28 | no | |
| DW2 | DW5 | -4 | 18 | 39 | no | |
| DW2 | IPR1A | -32 | -10 | 12 | no | |
| DW2 | IPR1B | -31 | -9 | 13 | no | |
| DW2 | IPR2A | -8 | 14 | 36 | no | |
| DW2 | IPR2B | -13 | 9 | 31 | no | |
| DW3 | DW4 | -11 | 11 | 33 | no | |
| DW3 | DW5 | 1 | 23 | 44 | yes | DW3 > DW5 |
| DW3 | IPR1A | -27 | -5 | 17 | no | |
| DW3 | IPR1B | -26 | -4 | 18 | no | |
| DW3 | IPR2A | -3 | 19 | 41 | no | |
| DW3 | IPR2B | -8 | 14 | 36 | no | |
| DW4 | DW5 | -11 | 11 | 33 | no | |
| DW4 | IPR1A | -38 | -16 | 6 | no | |
| DW4 | IPR1B | -37 | -15 | 7 | no | |
| DW4 | IPR2A | -14 | 8 | 30 | no | |
| DW4 | IPR2B | -19 | 3 | 25 | no | |
| DW5 | IPR1A | -49 | -28 | -6 | yes | IPR1A > DW5 |
| DW5 | IPR1B | -48 | -27 | -5 | yes | IPR1B > DW5 |
| DW5 | IPR2A | -25 | -3 | 19 | no | |
| DW5 | IPR2B | -30 | -9 | 13 | no | |
| IPR1A | IPR1B | -21 | 1 | 23 | no | |
| IPR1A | IPR2A | 2 | 24 | 46 | yes | IPR1A > IPR2A |
| IPR1A | IPR2B | -3 | 19 | 41 | no | |
| IPR1B | IPR2A | 1 | 23 | 45 | yes | IPR1B > IPR2A |
| IPR1B | IPR2B | -4 | 18 | 40 | no | |
| IPR2A | IPR2B | -27 | -5 | 17 | no | |

### Table C.23. Multiple Comparison Test for DEET (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -6 | 19 | 43 | no | |
| DW1 | DW3 | -28 | -4 | 20 | no | |
| DW1 | DW4 | -20 | 4 | 28 | no | |
| DW1 | DW5 | -18 | 6 | 31 | no | |
| DW1 | IPR1A | -6 | 19 | 43 | no | |
| DW1 | IPR1B | -22.8 | 3 | 29 | no | |
| DW1 | IPR2A | -6 | 19 | 43 | no | |
| DW1 | IPR2B | -6 | 19 | 43 | no | |
| DW2 | DW3 | -42 | -23 | -3 | yes | DW3 > DW2 |
| DW2 | DW4 | -34 | -15 | 5 | no | |
| DW2 | DW5 | -32 | -12 | 8 | no | |
| DW2 | IPR1A | -20 | 0 | 20 | no | |
| DW2 | IPR1B | -37 | -16 | 6 | no | |
| DW2 | IPR2A | -20 | 0 | 20 | no | |
| DW2 | IPR2B | -20 | 0 | 20 | no | |
| DW3 | DW4 | -12 | 8 | 28 | no | |
| DW3 | DW5 | -10 | 10 | 30 | no | |
| DW3 | IPR1A | 3 | 23 | 42 | yes | DW3 > IPR1A |
| DW3 | IPR1B | -15 | 7 | 29 | no | |
| DW3 | IPR2A | 3 | 23 | 42 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 3 | 23 | 42 | yes | DW3 > IPR2B |
| DW4 | DW5 | -18 | 2 | 22 | no | |
| DW4 | IPR1A | -5 | 15 | 34 | no | |
| DW4 | IPR1B | -23 | -1 | 21 | no | |
| DW4 | IPR2A | -5 | 15 | 34 | no | |
| DW4 | IPR2B | -5 | 15 | 34 | no | |
| DW5 | IPR1A | -8 | 12 | 32 | no | |
| DW5 | IPR1B | -25 | -3 | 18 | no | |
| DW5 | IPR2A | -8 | 12 | 32 | no | |
| DW5 | IPR2B | -8 | 12 | 32 | no | |
| IPR1A | IPR1B | -37 | -16 | 6 | no | |
| IPR1A | IPR2A | -20 | 0 | 20 | no | |
| IPR1A | IPR2B | -20 | 0 | 20 | no | |
| IPR1B | IPR2A | -6 | 16 | 37 | no | |
| IPR1B | IPR2B | -6 | 16 | 37 | no | |
| IPR2A | IPR2B | -20 | 0 | 20 | no | |

## Table C.24. Multiple Comparison Test for Dilantin (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -38 | -12 | 14 | no | |
| DW1 | DW3 | -49 | -23 | 3 | no | |
| DW1 | DW4 | -34 | -8 | 18 | no | |
| DW1 | DW5 | -28 | -2 | 24 | no | |
| DW1 | IPR1A | -43 | -17 | 9 | no | |
| DW1 | IPR1B | -47.2 | -21 | 4 | no | |
| DW1 | IPR2A | -27 | -1 | 25 | no | |
| DW1 | IPR2B | -25 | 3 | 30 | no | |
| DW2 | DW3 | -32 | -11 | 10 | no | |
| DW2 | DW4 | -17 | 4 | 25 | no | |
| DW2 | DW5 | -11 | 10 | 31 | no | |
| DW2 | IPR1A | -26 | -5 | 16 | no | |
| DW2 | IPR1B | -31 | -10 | 12 | no | |
| DW2 | IPR2A | -10 | 11 | 32 | no | |
| DW2 | IPR2B | -8 | 14 | 37 | no | |
| DW3 | DW4 | -6 | 15 | 36 | no | |
| DW3 | DW5 | 0 | 21 | 42 | no | |
| DW3 | IPR1A | -15 | 6 | 27 | no | |
| DW3 | IPR1B | -19 | 2 | 23 | no | |
| DW3 | IPR2A | 1 | 22 | 43 | yes | |
| DW3 | IPR2B | 3 | 26 | 48 | yes | |
| DW4 | DW5 | -15 | 6 | 27 | no | |
| DW4 | IPR1A | -30 | -9 | 12 | no | |
| DW4 | IPR1B | -35 | -14 | 8 | no | |
| DW4 | IPR2A | -14 | 7 | 28 | no | |
| DW4 | IPR2B | -12 | 10 | 33 | no | |
| DW5 | IPR1A | -36 | -15 | 6 | no | |
| DW5 | IPR1B | -40 | -19 | 2 | no | |
| DW5 | IPR2A | -20 | 1 | 22 | no | |
| DW5 | IPR2B | -18 | 5 | 27 | no | |
| IPR1A | IPR1B | -25 | -4 | 17 | no | |
| IPR1A | IPR2A | -5 | 16 | 37 | no | |
| IPR1A | IPR2B | -3 | 20 | 42 | no | |
| IPR1B | IPR2A | -1 | 21 | 42 | no | |
| IPR1B | IPR2B | 1 | 24 | 47 | yes | |
| IPR2A | IPR2B | -19 | 3 | 26 | no | |

## Table C.25. Multiple Comparison Test for Meprobamate (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -24 | 2 | 28 | no | |
| DW1 | DW3 | -45 | -20 | 6 | no | |
| DW1 | DW4 | -22 | 4 | 30 | no | |
| DW1 | DW5 | -38 | -12 | 14 | no | |
| DW1 | IPR1A | -36 | -10 | 16 | no | |
| DW1 | IPR1B | -38.5 | -13 | 13 | no | |
| DW1 | IPR2A | -27 | -1 | 25 | no | |
| DW1 | IPR2B | -17 | 10 | 37 | no | |
| DW2 | DW3 | -43 | -22 | -1 | yes | DW3 > DW2 |
| DW2 | DW4 | -20 | 2 | 23 | no | |
| DW2 | DW5 | -35 | -14 | 7 | no | |
| DW2 | IPR1A | -34 | -13 | 9 | no | |
| DW2 | IPR1B | -36 | -15 | 6 | no | |
| DW2 | IPR2A | -24 | -3 | 18 | no | |
| DW2 | IPR2B | -15 | 8 | 31 | no | |
| DW3 | DW4 | 2 | 23 | 44 | yes | DW3 > DW4 |
| DW3 | DW5 | -13 | 8 | 29 | no | |
| DW3 | IPR1A | -12 | 9 | 30 | no | |
| DW3 | IPR1B | -14 | 7 | 28 | no | |
| DW3 | IPR2A | -2 | 19 | 40 | no | |
| DW3 | IPR2B | 7 | 30 | 52 | yes | DW3 > IPR2B |
| DW4 | DW5 | -37 | -16 | 6 | no | |
| DW4 | IPR1A | -35 | -14 | 7 | no | |
| DW4 | IPR1B | -37 | -16 | 5 | no | |
| DW4 | IPR2A | -26 | -5 | 17 | no | |
| DW4 | IPR2B | -17 | 6 | 29 | no | |
| DW5 | IPR1A | -20 | 2 | 23 | no | |
| DW5 | IPR1B | -22 | -1 | 20 | no | |
| DW5 | IPR2A | -10 | 11 | 32 | no | |
| DW5 | IPR2B | -1 | 22 | 45 | no | |
| IPR1A | IPR1B | -23 | -2 | 19 | no | |
| IPR1A | IPR2A | -12 | 10 | 31 | no | |
| IPR1A | IPR2B | -3 | 20 | 43 | no | |
| IPR1B | IPR2A | -9 | 12 | 33 | no | |
| IPR1B | IPR2B | 0 | 23 | 45 | no | |
| IPR2A | IPR2B | -12 | 11 | 34 | no | |

## Table C.26. Multiple Comparison Test for PFOA (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -26 | -7 | 13 | no | |
| DW1 | DW3 | -35 | -16 | 4 | no | |
| DW1 | DW4 | -13 | 7 | 26 | no | |
| DW1 | DW5 | -19 | 0 | 19 | no | |
| DW1 | IPR1A | -30 | -11 | 8 | no | |
| DW1 | IPR2A | -21.6 | -3 | 17 | no | |
| DW2 | DW3 | -25 | -9 | 7 | no | |
| DW2 | DW4 | -3 | 13 | 29 | no | |
| DW2 | DW5 | -9 | 7 | 22 | no | |
| DW2 | IPR1A | -20 | -5 | 11 | no | |
| DW2 | IPR2A | -12 | 4 | 20 | no | |
| DW3 | DW4 | 6 | 22 | 38 | yes | DW3 > DW4 |
| DW3 | DW5 | 0 | 16 | 31 | no | |
| DW3 | IPR1A | -11 | 4 | 20 | no | |
| DW3 | IPR2A | -3 | 13 | 29 | no | |
| DW4 | DW5 | -22 | -7 | 9 | no | |
| DW4 | IPR1A | -33 | -18 | -2 | yes | IPR1A > DW4 |
| DW4 | IPR2A | -25 | -9 | 7 | no | |
| DW5 | IPR1A | -27 | -11 | 4 | no | |
| DW5 | IPR2A | -18 | -3 | 13 | no | |
| IPR1A | IPR2A | -7 | 9 | 24 | no | |

## Table C.27. Multiple Comparison Test for PFOS (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -30 | -11 | 8 | no | |
| DW1 | DW3 | -34 | -15 | 4 | no | |
| DW1 | DW4 | -21 | -2 | 17 | no | |
| DW1 | DW5 | -24 | -5 | 14 | no | |
| DW1 | IPR1A | -38 | -19 | -0.04 | yes | IPR1A > DW1 |
| DW1 | IPR2A | -19.0 | 0 | 19 | no | |
| DW2 | DW3 | -19 | -4 | 11 | no | |
| DW2 | DW4 | -6 | 9 | 25 | no | |
| DW2 | DW5 | -10 | 6 | 21 | no | |
| DW2 | IPR1A | -23 | -8 | 7 | no | |
| DW2 | IPR2A | -4 | 11 | 26 | no | |
| DW3 | DW4 | -2 | 13 | 29 | no | |
| DW3 | DW5 | -6 | 10 | 25 | no | |
| DW3 | IPR1A | -19 | -4 | 11 | no | |
| DW3 | IPR2A | -0.5 | 15 | 30 | no | |
| DW4 | DW5 | -19 | -4 | 12 | no | |
| DW4 | IPR1A | -33 | -17 | -2 | yes | IPR1A > DW4 |
| DW4 | IPR2A | -14 | 2 | 17 | no | |
| DW5 | IPR1A | -29 | -14 | 2 | no | |
| DW5 | IPR2A | -10 | 5 | 21 | no | |
| IPR1A | IPR2A | 4 | 19 | 34 | yes | IPR1A > IPR2A |

## Table C.28. Multiple Comparison Test for Primidone (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha = 0.05$) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -41 | -18 | 5 | no | |
| DW1 | DW3 | -45 | -22 | 1 | no | |
| DW1 | DW4 | -31 | -8 | 15 | no | |
| DW1 | DW5 | -32 | -9 | 14 | no | |
| DW1 | IPR1A | -49 | -26 | -3 | yes | IPR1A > DW1 |
| DW1 | IPR2A | -27.9 | -5 | 18 | no | |
| DW1 | IPR2B | -33 | -10 | 13 | no | |
| DW2 | DW3 | -23 | -4 | 15 | no | |
| DW2 | DW4 | -9 | 10 | 29 | no | |
| DW2 | DW5 | -10 | 9 | 28 | no | |
| DW2 | IPR1A | -27 | -8 | 11 | no | |
| DW2 | IPR2A | -6 | 13 | 32 | no | |
| DW2 | IPR2B | -11 | 8 | 27 | no | |
| DW3 | DW4 | -5 | 14 | 33 | no | |
| DW3 | DW5 | -6 | 13 | 32 | no | |
| DW3 | IPR1A | -23 | -4 | 15 | no | |
| DW3 | IPR2A | -2 | 17 | 36 | no | |
| DW3 | IPR2B | -7 | 12 | 31 | no | |
| DW4 | DW5 | -20 | -1 | 18 | no | |
| DW4 | IPR1A | -37 | -18 | 1 | no | |
| DW4 | IPR2A | -16 | 3 | 22 | no | |
| DW4 | IPR2B | -21 | -2 | 17 | no | |
| DW5 | IPR1A | -36 | -17 | 2 | no | |
| DW5 | IPR2A | -15 | 4 | 23 | no | |
| DW5 | IPR2B | -20 | -1 | 18 | no | |
| IPR1A | IPR2A | 2 | 21 | 40 | yes | IPR1A > IPR2A |
| IPR1A | IPR2B | -3 | 16 | 35 | no | |
| IPR2A | IPR2B | -24 | -5 | 14 | no | |

**Table C.29. Multiple Comparison Test for Sulfamethoxazole (ng/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -24 | 0 | 24 | no | |
| DW1 | DW3 | -30 | -6 | 18 | no | |
| DW1 | DW4 | -36 | -13 | 11 | no | |
| DW1 | DW5 | -24 | 0 | 24 | no | |
| DW1 | IPR1A | -45 | -22 | 2 | no | |
| DW1 | IPR1B | -44.2 | -21 | 3 | no | |
| DW1 | IPR2A | -33 | -10 | 14 | no | |
| DW1 | IPR2B | -48 | -14 | 20 | no | |
| DW2 | DW3 | -25 | -6 | 13 | no | |
| DW2 | DW4 | -32 | -13 | 7 | no | |
| DW2 | DW5 | -19 | 0 | 19 | no | |
| DW2 | IPR1A | -41 | -22 | -2 | yes | IPR1A > DW2 |
| DW2 | IPR1B | -40 | -21 | -1 | yes | IPR1B > DW2 |
| DW2 | IPR2A | -29 | -10 | 10 | no | |
| DW2 | IPR2B | -45 | -14 | 17 | no | |
| DW3 | DW4 | -26 | -7 | 13 | no | |
| DW3 | DW5 | -13 | 6 | 25 | no | |
| DW3 | IPR1A | -35 | -16 | 4 | no | |
| DW3 | IPR1B | -34 | -15 | 5 | no | |
| DW3 | IPR2A | -23 | -4 | 15 | no | |
| DW3 | IPR2B | -39 | -8 | 22 | no | |
| DW4 | DW5 | -7 | 13 | 32 | no | |
| DW4 | IPR1A | -28 | -9 | 10 | no | |
| DW4 | IPR1B | -27 | -8 | 11 | no | |
| DW4 | IPR2A | -17 | 3 | 22 | no | |
| DW4 | IPR2B | -32 | -2 | 29 | no | |
| DW5 | IPR1A | -41 | -22 | -2 | yes | IPR1A > DW5 |
| DW5 | IPR1B | -40 | -21 | -1 | yes | IPR1B > DW5 |
| DW5 | IPR2A | -29 | -10 | 10 | no | |
| DW5 | IPR2B | -45 | -14 | 17 | no | |
| IPR1A | IPR1B | -18 | 1 | 20 | no | |
| IPR1A | IPR2A | -8 | 12 | 31 | no | |
| IPR1A | IPR2B | -23 | 8 | 38 | no | |
| IPR1B | IPR2A | -9 | 11 | 30 | no | |
| IPR1B | IPR2B | -24 | 7 | 37 | no | |
| IPR2A | IPR2B | -35 | -4 | 26 | no | |

**Table C.30. Multiple Comparison Test for TCEP (ng/L)**

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -18 | 0 | 18 | no | |
| DW1 | DW3 | -36 | -18 | 1 | no | |
| DW1 | DW4 | -18 | 0 | 18 | no | |
| DW1 | DW5 | -18 | 0 | 18 | no | |
| DW1 | IPR1A | -18 | 0 | 18 | no | |
| DW1 | IPR1B | -33.2 | -14 | 5 | no | |
| DW1 | IPR2A | -18 | 0 | 18 | no | |
| DW1 | IPR2B | -19 | 0 | 19 | no | |
| DW2 | DW3 | -32 | -18 | -3 | yes | DW3 > DW2 |
| DW2 | DW4 | -15 | 0 | 15 | no | |
| DW2 | DW5 | -15 | 0 | 15 | no | |
| DW2 | IPR1A | -15 | 0 | 15 | no | |
| DW2 | IPR1B | -30 | -14 | 2 | no | |
| DW2 | IPR2A | -15 | 0 | 15 | no | |
| DW2 | IPR2B | -16 | 0 | 16 | no | |
| DW3 | DW4 | 3 | 18 | 32 | yes | DW3 > DW4 |
| DW3 | DW5 | 3 | 18 | 32 | yes | DW3 > DW5 |
| DW3 | IPR1A | 3 | 18 | 32 | yes | DW3 > IPR1A |
| DW3 | IPR1B | -13 | 4 | 20 | no | |
| DW3 | IPR2A | 3 | 18 | 32 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 1 | 18 | 34 | yes | DW3 > IPR2B |
| DW4 | DW5 | -15 | 0 | 15 | no | |
| DW4 | IPR1A | -15 | 0 | 15 | no | |
| DW4 | IPR1B | -30 | -14 | 2 | no | |
| DW4 | IPR2A | -15 | 0 | 15 | no | |
| DW4 | IPR2B | -16 | 0 | 16 | no | |
| DW5 | IPR1A | -15 | 0 | 15 | no | |
| DW5 | IPR1B | -30 | -14 | 2 | no | |
| DW5 | IPR2A | -15 | 0 | 15 | no | |
| DW5 | IPR2B | -16 | 0 | 16 | no | |
| IPR1A | IPR1B | -30 | -14 | 2 | no | |
| IPR1A | IPR2A | -15 | 0 | 15 | no | |
| IPR1A | IPR2B | -16 | 0 | 16 | no | |
| IPR1B | IPR2A | -2 | 14 | 30 | no | |
| IPR1B | IPR2B | -3 | 14 | 31 | no | |
| IPR2A | IPR2B | -16 | 0 | 16 | no | |

### Table C.31. Multiple Comparison Test for TCPP (ng/L)

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different ($\alpha$ = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -15 | 0 | 15 | no | |
| DW1 | DW3 | -30 | -15 | 1 | no | |
| DW1 | DW4 | -15 | 0 | 15 | no | |
| DW1 | DW5 | -15 | 0 | 15 | no | |
| DW1 | IPR1A | -15 | 0 | 15 | no | |
| DW1 | IPR1B | -8.7 | 13 | 35 | no | |
| DW1 | IPR2A | -15 | 0 | 15 | no | |
| DW1 | IPR2B | -16 | 0 | 16 | no | |
| DW2 | DW3 | -27 | -15 | -2 | yes | DW3 > DW2 |
| DW2 | DW4 | -13 | 0 | 13 | no | |
| DW2 | DW5 | -13 | 0 | 13 | no | |
| DW2 | IPR1A | -13 | 0 | 13 | no | |
| DW2 | IPR1B | -7 | 13 | 33 | no | |
| DW2 | IPR2A | -13 | 0 | 13 | no | |
| DW2 | IPR2B | -14 | 0 | 14 | no | |
| DW3 | DW4 | 2 | 15 | 27 | yes | DW3 > DW4 |
| DW3 | DW5 | 2 | 15 | 27 | yes | DW3 > DW5 |
| DW3 | IPR1A | 2 | 15 | 27 | yes | DW3 > IPR1A |
| DW3 | IPR1B | 8 | 28 | 47 | yes | DW3 > IPR1B |
| DW3 | IPR2A | 2 | 15 | 27 | yes | DW3 > IPR2A |
| DW3 | IPR2B | 1 | 15 | 28 | yes | DW3 > IPR2B |
| DW4 | DW5 | -13 | 0 | 13 | no | |
| DW4 | IPR1A | -13 | 0 | 13 | no | |
| DW4 | IPR1B | -7 | 13 | 33 | no | |
| DW4 | IPR2A | -13 | 0 | 13 | no | |
| DW4 | IPR2B | -14 | 0 | 14 | no | |
| DW5 | IPR1A | -13 | 0 | 13 | no | |
| DW5 | IPR1B | -7 | 13 | 33 | no | |
| DW5 | IPR2A | -13 | 0 | 13 | no | |
| DW5 | IPR2B | -14 | 0 | 14 | no | |
| IPR1A | IPR1B | -7 | 13 | 33 | no | |
| IPR1A | IPR2A | -13 | 0 | 13 | no | |
| IPR1A | IPR2B | -14 | 0 | 14 | no | |
| IPR1B | IPR2A | -33 | -13 | 7 | no | |
| IPR1B | IPR2B | -33 | -13 | 7 | no | |
| IPR2A | IPR2B | -14 | 0 | 14 | no | |

### Table C.32. Multiple Comparison Test for NDMA

| Site 1 | Site 2 | Lower 95% Confidence | Mean Difference (Site 1 - Site 2) | Upper 95% Confidence | Means Are Different (α = 0.05) | Result |
|---|---|---|---|---|---|---|
| DW1 | DW2 | -56 | 0 | 56 | no | |
| DW1 | DW3 | -56 | 0 | 56 | no | |
| DW1 | DW4 | -73 | -24 | 24 | no | |
| DW1 | DW5 | -56 | 0 | 56 | no | |
| DW1 | IPR1A | -56 | 0 | 56 | no | |
| DW1 | IPR1B | -42.8 | -2 | 39 | no | |
| DW1 | IPR2A | -62 | -21 | 20 | no | |
| DW1 | IPR2B | -45 | -4 | 38 | no | |
| DW2 | DW3 | -56 | 0 | 56 | no | |
| DW2 | DW4 | -73 | -24 | 24 | no | |
| DW2 | DW5 | -56 | 0 | 56 | no | |
| DW2 | IPR1A | -56 | 0 | 56 | no | |
| DW2 | IPR1B | -43 | -2 | 39 | no | |
| DW2 | IPR2A | -62 | -21 | 20 | no | |
| DW2 | IPR2B | -45 | -4 | 38 | no | |
| DW3 | DW4 | -73 | -24 | 24 | no | |
| DW3 | DW5 | -56 | 0 | 56 | no | |
| DW3 | IPR1A | -56 | 0 | 56 | no | |
| DW3 | IPR1B | -43 | -2 | 39 | no | |
| DW3 | IPR2A | -62 | -21 | 20 | no | |
| DW3 | IPR2B | -45 | -4 | 38 | no | |
| DW4 | DW5 | -24 | 24 | 73 | no | |
| DW4 | IPR1A | -24 | 24 | 73 | no | |
| DW4 | IPR1B | -7 | 22 | 52 | no | |
| DW4 | IPR2A | -26 | 3 | 33 | no | |
| DW4 | IPR2B | -11 | 21 | 52 | no | |
| DW5 | IPR1A | -56 | 0 | 56 | no | |
| DW5 | IPR1B | -43 | -2 | 39 | no | |
| DW5 | IPR2A | -62 | -21 | 20 | no | |
| DW5 | IPR2B | -45 | -4 | 38 | no | |
| IPR1A | IPR1B | -43 | -2 | 39 | no | |
| IPR1A | IPR2A | -62 | -21 | 20 | no | |
| IPR1A | IPR2B | -45 | -4 | 38 | no | |
| IPR1B | IPR2A | -32 | -19 | -5 | yes | IPR2A > IPR1B |
| IPR1B | IPR2B | -19 | -2 | 16 | no | |
| IPR2A | IPR2B | 1 | 17 | 34 | yes | IPR2A > IPR2B |

# *Appendix D*

# Fluorescence Excitation–Emission Matrix

The fluorescence was recorded using a PTI fluorometer (Birmingham, NJ). Fluorescence EEM parameters were as follows: excitation from 220 to 460 nm in 5 nm steps, emission from 280 to 580 nm in 4 nm steps, 2 nm bandwidth, and 0.1 s integration time. The intensity of all EEM spectra was normalized on a daily basis by dividing by the intensity of the Raman water line using 350 nm excitation and 397 nm emission wavelengths. First- and second-order inner filtering effects were corrected following MacDonald et al. (1997). Data processing was done using Matlab (version 7.4.0.287, R2007a, Natick, MA). Figures D1–D7 show the 3-D fluorescence EEM spectra for all of the samples collected in this project.

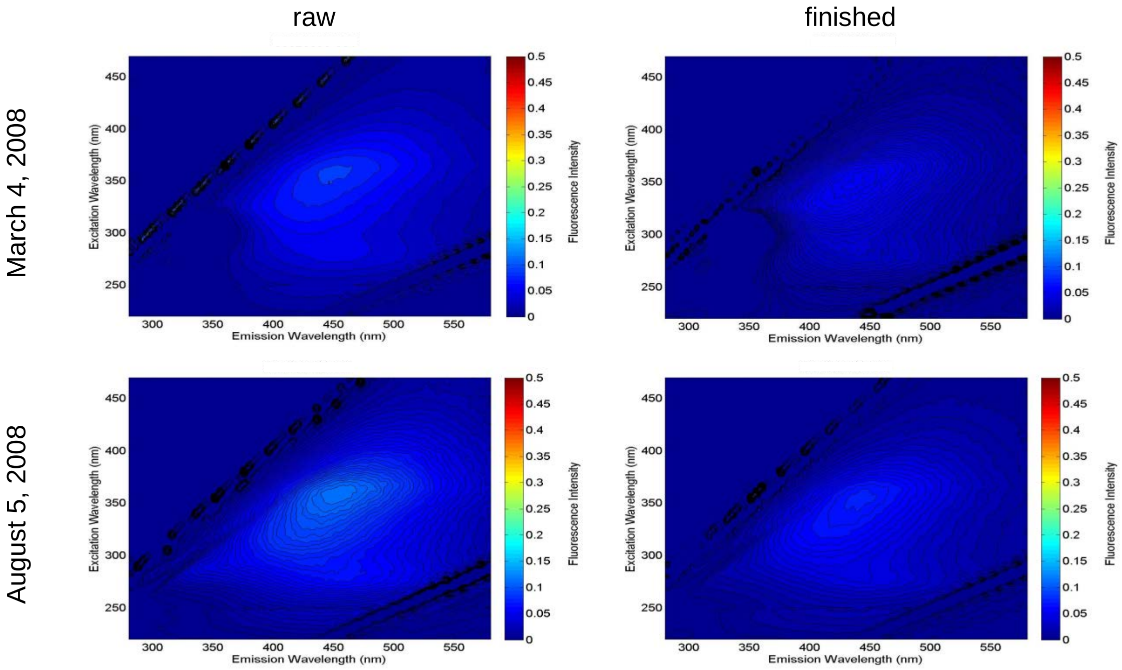
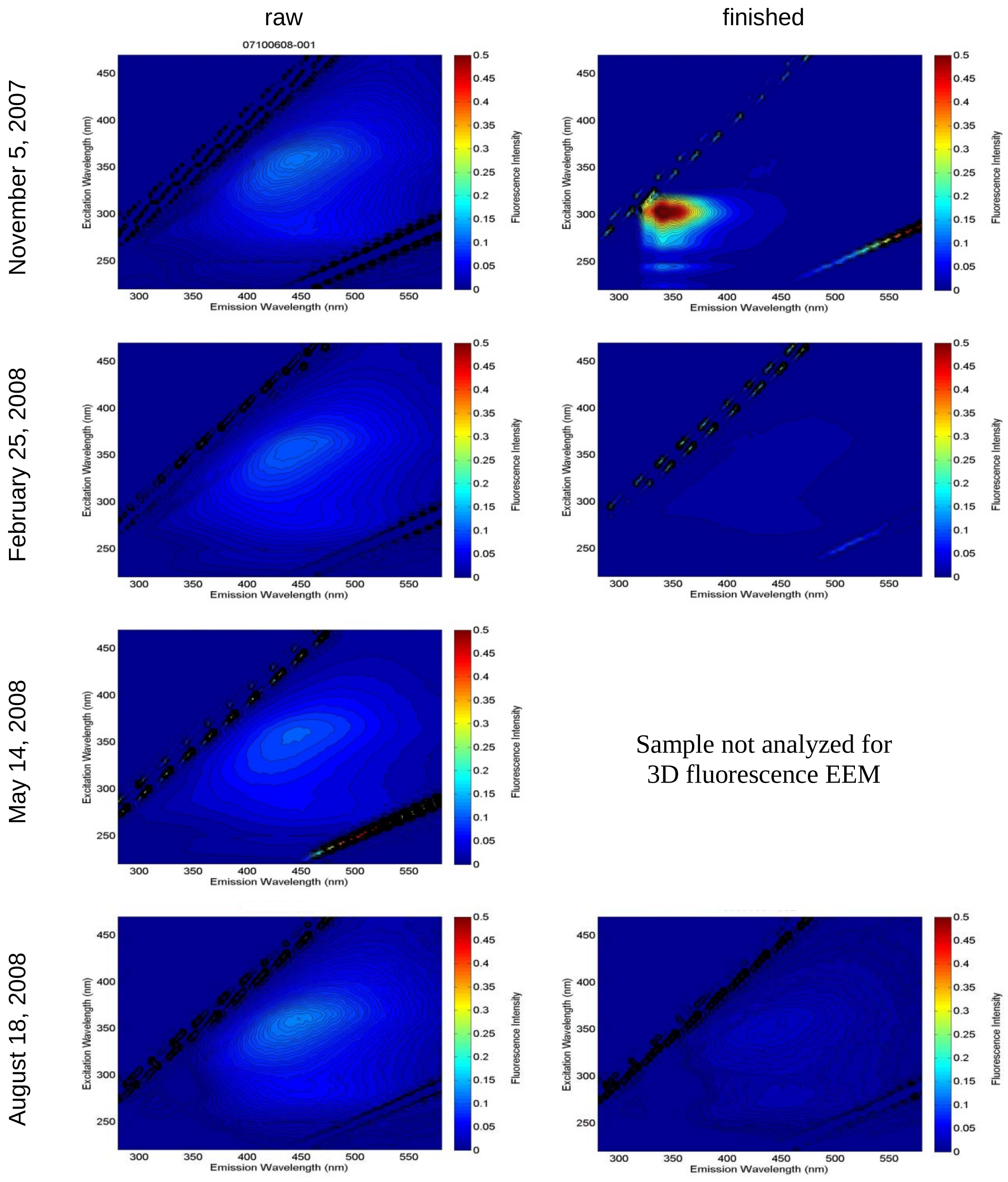


**Figure D1. 3-D fluorescence EEM spectra for DW1.**



Sample not analyzed for
3D fluorescence EEM

**Figure D2. 3-D fluorescence EEM spectra for DW2.**

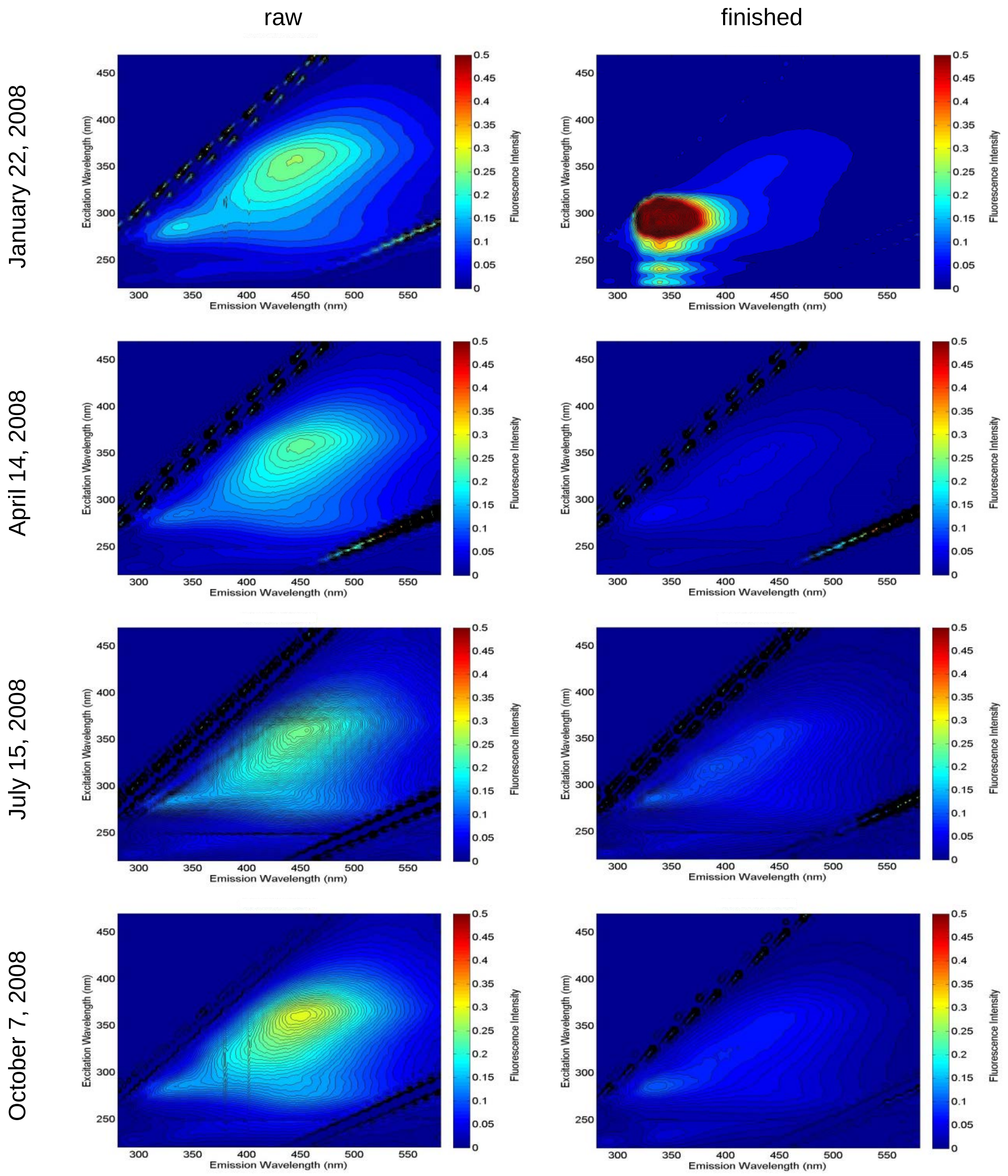


**Figure D3. 3-D fluorescence EEM spectra for DW3.**

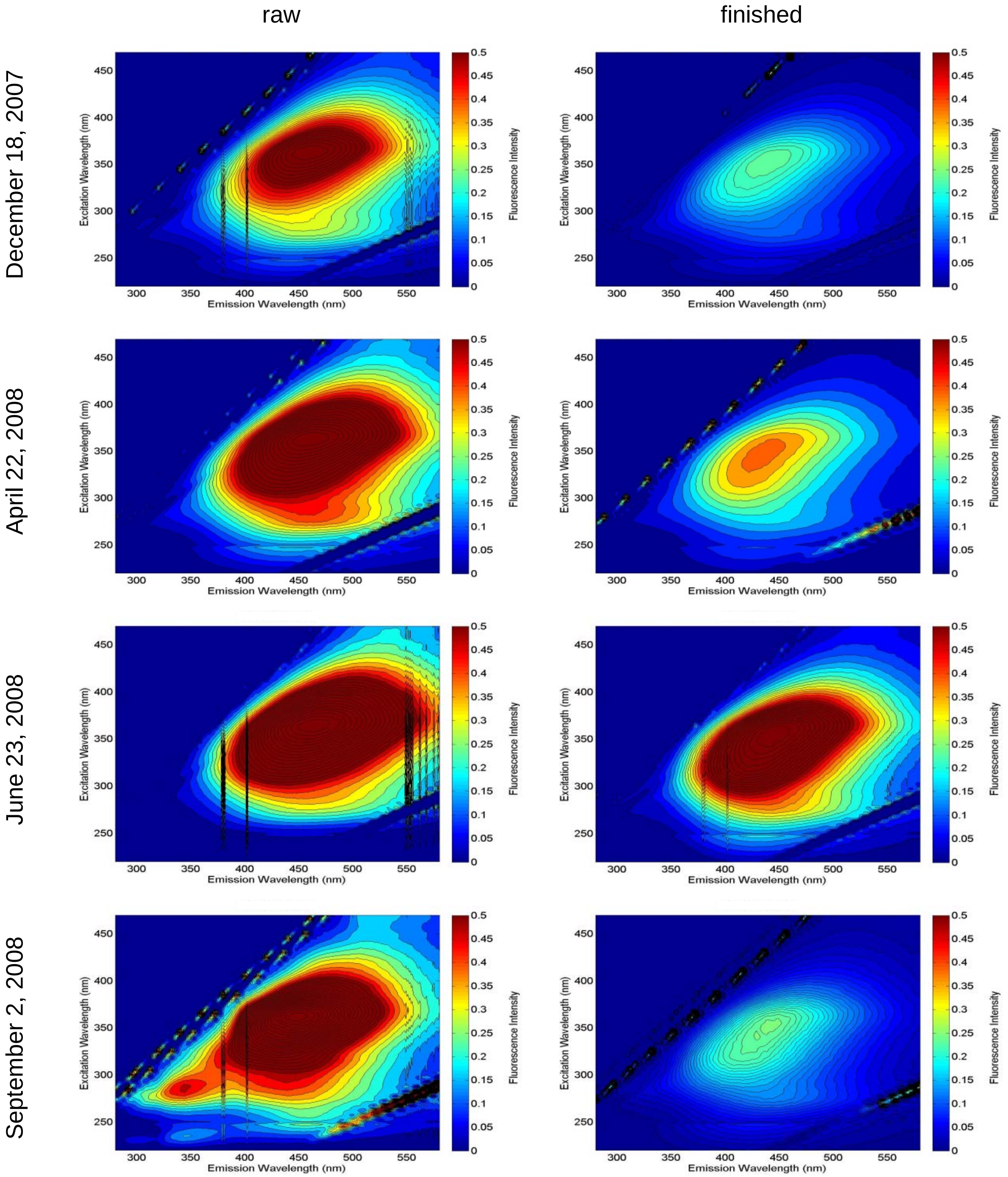


**Figure D4. 3-D fluorescence EEM spectra for DW4.**

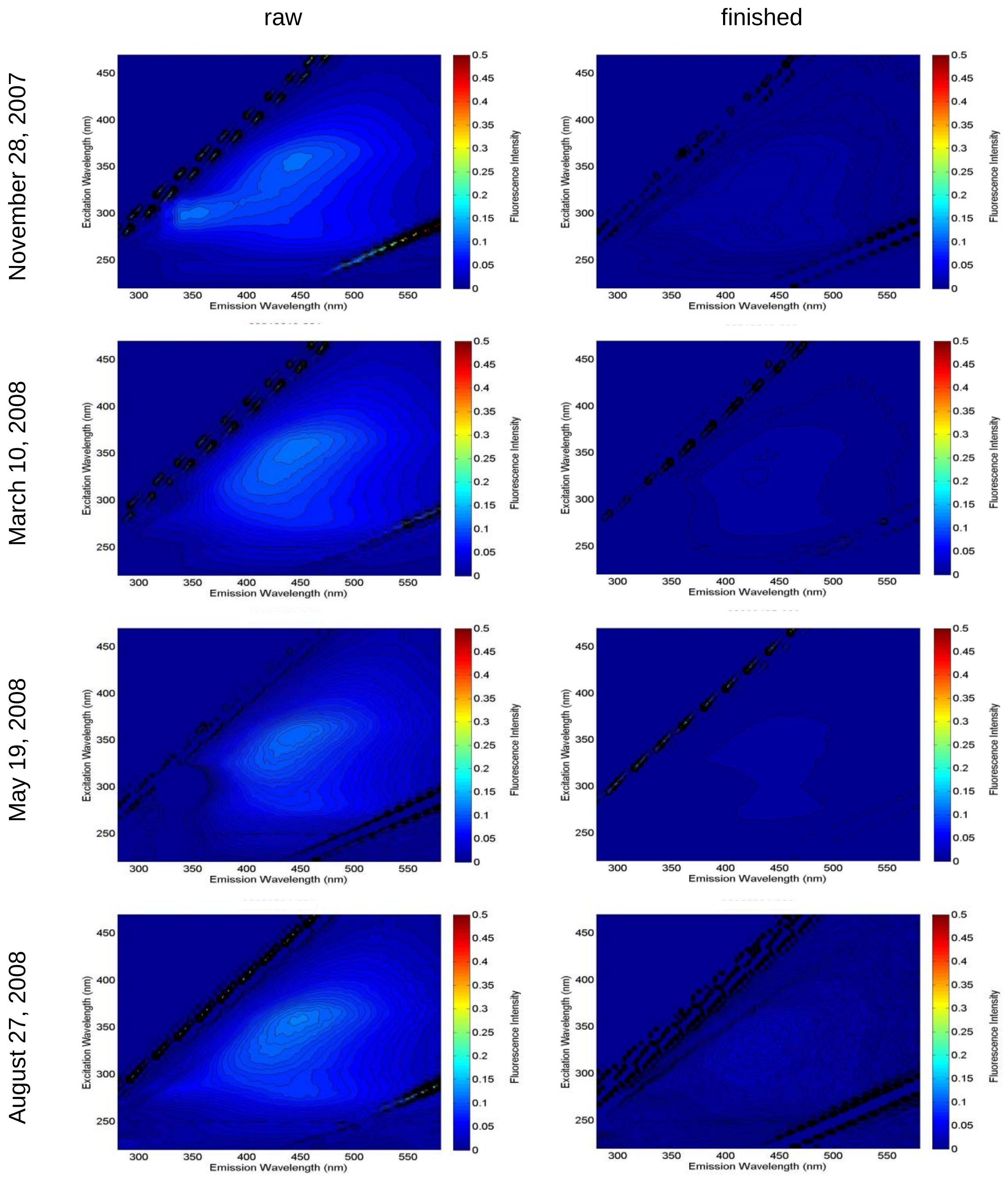


**Figure D5. 3-D fluorescence EEM spectra for DW5**

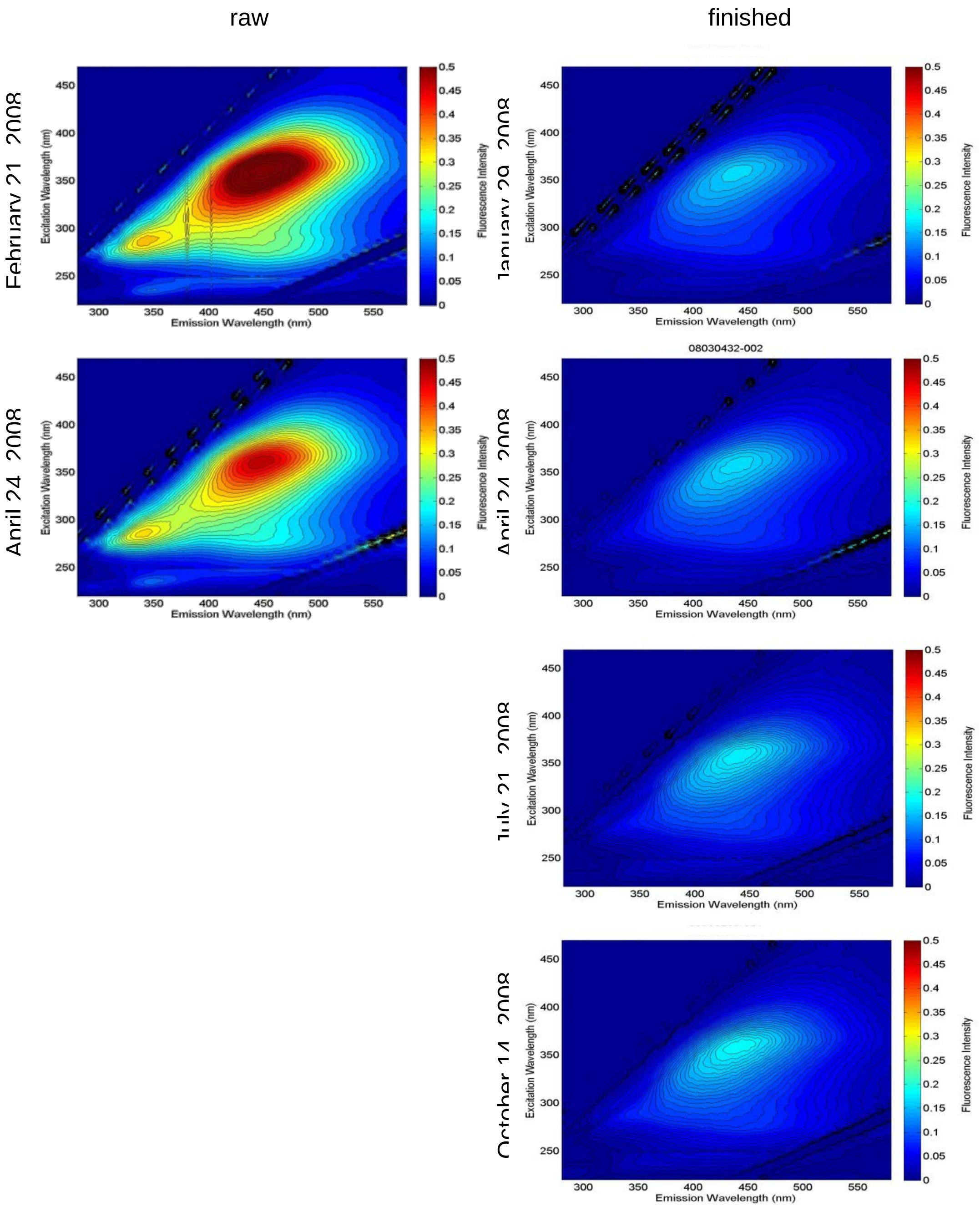


**Figure D6. 3-D fluorescence EEM spectra for IPR1.**

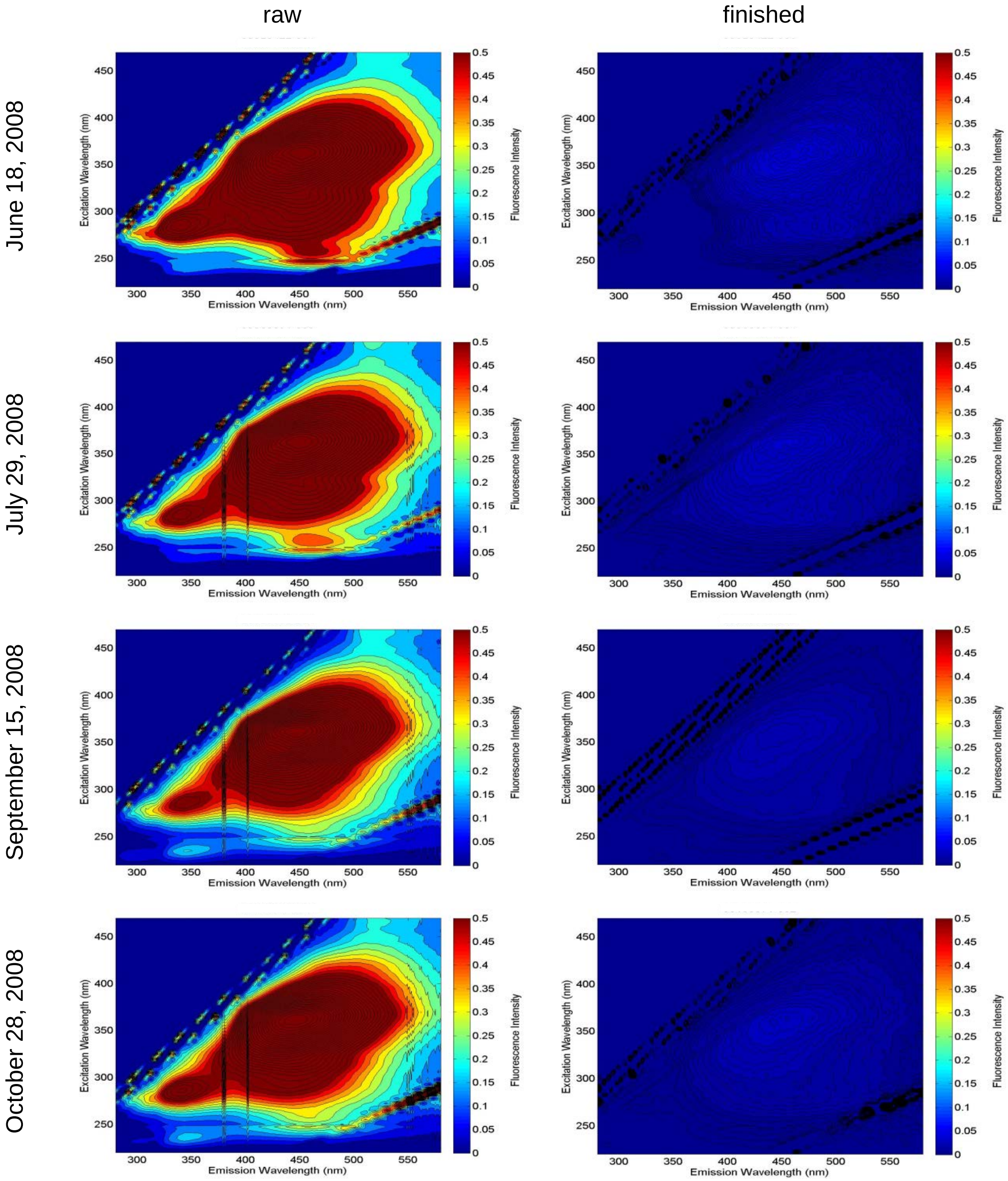


**Figure D7. 3-D fluorescence EEM spectra for IPR2.**

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