



## CITY OF RALEIGH PUBLIC UTILITIES DEPARTMENT



## Neuse River Water Quality Sampling

*Final Report*

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**CDM  
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# Executive Summary

## Neuse River Water Quality Sampling

### E.1 Study Summary

This study characterized microbial indicators, chemical constituents, and genotoxicity along the Neuse River as part of an assessment to support consideration of changes to North Carolina regulations to allow the potential for future potable water reuse.

### E.2 Study Overview

The City of Raleigh Public Utilities Department (City) has been examining a range of water reuse alternatives as a means of meeting projected future demands on the City's drinking water resources. Among the several options available, the City is evaluating expansion of the existing reuse water system for non-potable uses, as well as indirect and/or direct potable reuse (IPR and DPR) to supplement existing water supply sources. Currently there are regulatory restrictions on potable reuse in North Carolina. To explore potable reuse, among a suite of other options, the City wishes to demonstrate that potable reuse is equivalent to or better than currently used sources of drinking water in terms of public-health related water quality criteria.

The first step in this evaluation was to establish a baseline understanding of the water quality of the Neuse River, which is the receiving water for highly treated effluent from the City's Neuse River Wastewater Treatment Plant (WWTP), and the source water for downstream communities.

In the fall of 2013 the City of Raleigh conducted a study to examine the presence of trace wastewater constituents collected from eight locations along the Neuse River between Falls Lake and Goldsboro. One of the sampling locations was located in the river, at the point of discharge of Raleigh's Neuse River WWTP. Samples were collected from these eight locations three times in the fall of 2013 and were evaluated for:

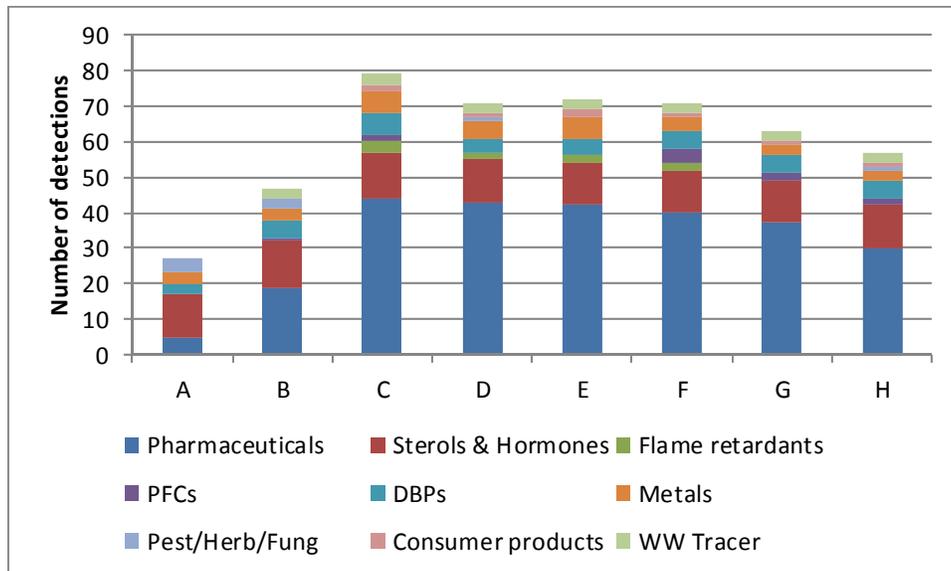
- six microorganisms,
- 110 chemical constituents (including pharmaceuticals, hormones, flame retardants, perfluorinated compounds, nonylphenols, disinfection byproducts (DBPs), volatile organic compounds (VOCs), metals, agricultural chemicals, and consumer products and manufacturing additives), and
- bulk genotoxicity.

### E.3 Key Results

The following are the key results from this study:

- The Neuse River has **acceptable water quality for use as a drinking water supply source**. All of the samples taken in this study met North Carolina Surface Water Quality Standards for the designated uses at each stretch of the river studied. Likewise, the Neuse River WWTP effluent samples during the study period met all permit discharge requirements.

- **The Neuse River WWTP is not a significant source of microbial contamination** of the river. Also, as expected, the **river does not appear to be further improving the microbiological quality** downstream from site C (near the Neuse River WWTP discharge).
- Site C, near the WWTP discharge, had the greatest number of chemical detections, where 72% of the 110 chemical compounds tested were detected in at least one sample. **Figure E-1** shows the number of compounds detected at each of the eight locations, labeled A (upstream) through H (downstream). Site A is at the spillway of Falls Lake, a source of Raleigh’s drinking water. Site H is upstream of Goldsboro. Chemicals were detected at all locations along the river, including at Falls Lake (site A).



**Figure E-1. Chemical Detections by Site for all Three Sampling Events**

- Chemicals that were detected in the river were present at very low concentrations – around one part per trillion, which is similar to river water concentrations found in other published studies. The compound detected at the highest concentration, sulfamethoxazole, an antibiotic, was detected at a maximum concentration of 0.0011 mg/L. To consume a single therapeutic dose of sulfamethoxazole at this concentration, a person would have to drink two liters of untreated river water every day for 500 years.
- Moving downstream from site C, concentrations of most chemicals decreased, largely due to dilution along the river, but also potentially due to removal mechanisms such as sorption to solids.
- **The flame retardant** TCEP was detected in several samples. TCEP is reported to be one of the top 11 chemicals detected in drinking water because it is very resistant to environmental degradation and present in many consumer products (Benotti et al., 2009). TCEP is a suspected endocrine disruptor, but is currently not regulated by the EPA.
- In order to look for unknown chemicals, a test was conducted on samples to examine whether the water contained potentially mutagenic unknown chemicals. Some of the samples (from sites A, B, C, G, and H) demonstrated **genotoxic effects**. While a positive result indicates that some chemicals in water samples have some mutagenic potential, the assay cannot determine

whether water samples would be mutagenic to humans – the method uses a certain bacterial strain susceptible to mutagenicity. This finding is consistent with other studies on river water.

- There is evidence of human impact at all sites along the river as demonstrated by data collected in this study.

It is important to emphasize that trace chemical constituents, including pharmaceuticals, have been found in rivers and lakes around the world, and have been detected in drinking water. The World Health Organization recently concluded the risk from pharmaceuticals detected in studies of drinking water is very unlikely to result in appreciable adverse risks to human health.

## E.4 Recommendations for Future Work

The following components are recommended for ongoing assessment of potable reuse in Raleigh:

1. Conduct a risk assessment to further evaluate the potential for potable reuse in Raleigh, including potential risks from pathogens, unknown chemicals, and known chemicals that currently lack toxicological data important to understanding low-level chronic and acute exposure impacts. Such a risk assessment should compare the risks due to potable reuse against the risk associated with current *de facto* reuse experienced today along the Neuse River.
2. Assess the effectiveness of a potential industrial source control program to prevent undesirable chemicals from entering a treatment system.
3. Evaluate storage options using environmental or engineered buffers.
4. Investigate operational practices and response strategies that would ensure system reliability.
5. Investigate appropriate monitoring strategies to ensure deviations in treatment performance are detected, triggering immediate and proportional response strategies.
6. Weigh cost and non-cost factors of potable reuse.
7. Involve a wide range of stakeholders in evaluating potable reuse.
8. Design a pilot potable reuse system that involves multiple barriers to fully remove all trace chemical constituents and to provide redundancy to ensure robust pathogen removal.

# Section 1

## Introduction

This section provides background information for this project, describes the project objectives and report format, and introduces the constituents of interest in this study.

### 1.1 Project Background

The City of Raleigh (City) operates a robust water reuse program that includes supply of reclaimed water in bulk at several of the City's treatment facilities, as well as supply of reclaimed water through two hydraulically separate water reuse distribution systems that deliver reclaimed water to parks, athletic fields, golf courses, municipal facilities, and private industrial and commercial facilities for irrigation, cooling, industrial process, concrete production, vehicle washing, and toilet flushing.

The City's Reuse Water System Master Plan is currently being updated to reflect changes in reclaimed water regulations and the area's economic climate since the previous Master Plan was completed, as well as to examine a range of water reuse alternatives in order to reduce pressures on the City's drinking water resources in the future. As part of the second phase of the Master Plan update, the City is evaluating alternatives for expansion of the current reuse water system for non-potable uses. The City is also evaluating the concept of indirect and/or direct potable reuse (IPR and/or DPR) and how it may or may not apply as a potential option for management of water supply needs.

The City's current reuse program falls under the North Carolina Administrative Code (NCAC) Title 15A, Subchapter 2U rules for reclaimed water, which allow for non-potable uses of reclaimed water including irrigation, industrial/commercial uses including toilet flushing and fire protection, cooling, general construction, wetlands augmentation, and others. The state rules currently prohibit reclaimed water for direct reuse as a raw potable water supply. However, the City is pursuing legislative changes to the rules through the North Carolina General Assembly to allow for consideration of indirect and/or direct potable reuse. Should the prohibition for potable reuse be lifted, additional regulation and monitoring above and beyond what is currently required for non-potable reuse would need to be developed and implemented for any potential IPR or DPR project.

The Neuse River is the receiving water for highly treated effluent from the City's Neuse River Wastewater Treatment Plant (WWTP). In addition to the Neuse River WWTP, approximately 15 other large (greater than 1 million gallons per day) municipal WWTPs discharge into the Neuse River basin. Five major drinking water treatment plants withdraw source water along the same 185 mile stretch of the Neuse River. Therefore, current practices within the basin may be characterized as *de facto* water reuse (EPA, 2012b). In order to establish an understanding of this system, and form a basis for evaluating planned potable reuse, the City has initiated this study to document the characteristic water quality of the Neuse River and to consider the environmental fate and transport of potential contaminants in the river.

The drinking water treatment plants along the Neuse River provide water that meets drinking water standards. However, there are a number of non-regulated compounds of wastewater origin that are not monitored and a greater understanding of these compounds may reveal more about the fate, transport and transformation of treated wastewater effluent that is discharged into surface water

supplies. In order to provide a better understanding of this system, and to help inform the legislative changes that are being proposed to the reuse rules, the City has commissioned this water quality study to evaluate a broad range of water quality parameters including pathogen indicators, chemical indicators and contaminants in the Neuse River.

## 1.2 Study Objectives and Report Format

The objective of this study is to define the baseline water quality in the upper Neuse River by characterizing a selected list of constituents and evaluating the environmental fate and transport of these parameters, in a defined study period that represents the highest contribution of treated effluent in the system. Specifically, this study focuses on the Neuse River between Falls Lake and Goldsboro.

To support this objective, CDM Smith and City staff collaborated to develop and implement a sampling and analysis plan (SAP) to conduct water quality sampling and analysis on the Neuse River during the fall of 2013. This report presents the results of the Neuse River water quality sampling and is organized as follows:

**Section 1 – Introduction.** The remainder of Section 1 provides an overview of the constituents identified for this study.

**Section 2 – Water Quality of the Neuse River.** This section provides background information on Neuse River water quality from regularly monitored sample sites, as well as a summary of data from other relevant, peer-reviewed, water quality studies conducted on the Neuse River.

**Section 3 – Water Quality of the Neuse River WWTP Effluent.** This section provides a summary of historical Neuse River WWTP compliance data and data from a U.S. Environmental Protection Agency (EPA) study which examined unregulated chemical constituents in the Neuse River WWTP effluent.

**Section 4 – Study Design.** This section describes the selection of analytes, sample locations and timing of the sampling program for this study.

**Section 5 – Neuse River Study Methods.** This section describes the sample collection and analytical methods used for this study.

**Section 6 – Neuse River Study Results and Discussion.** This section presents results of the sampling program by analyte and discusses sampling results in the context of historical data and what the results may or may not indicate about environmental fate and transport of constituents along the Neuse River.

**Section 7 – Potable Reuse Overview.** This section summarizes current potable reuse practices in the U.S., provides an overview of relevant treatment technologies for potable reuse, and discusses regulatory and public relations aspects of potable reuse.

**Section 8 – Conclusions and Recommendations.** This section summarizes the characterization of water quality and environmental fate and transport of potential contaminants from the sampling program and provides recommendations for the next steps that the City may take related to this work.

**Section 9 – References**

**Section 10 – Acronyms**

## 1.3 Constituents of Interest in the Neuse River

While there are many constituents that can be measured to develop a baseline of water quality in the Neuse River, this study is primarily focused on chemical and microbiological constituents of wastewater origin that have been previously measured in wastewater, and are generally unregulated. These constituents will be examined in surface water impacted by treated wastewater effluent to elucidate their fate and transport and provide insight into the current *de facto* water reuse within the Neuse River basin. Several groups of constituents were evaluated during this study including:

**Microbial indicator organisms.** These are present in raw wastewater and can be removed to below detection limits through various treatment technologies. Pathogens may also be present in water bodies, such as rivers, due to agricultural runoff, impact from partially treated wastewater, or other sources.

**Trace chemical constituents.** These constituents include a broad range of individual chemicals and classes of compounds present at trace concentrations that are detectable due to advances in analytical instrumentation and techniques. These constituents are also sometimes referred to as contaminants of emerging concern (CECs), trace organic chemicals (TrOCs), or microconstituents. Many of these names may be confusing or misleading (i.e. constituents are not always present at the ‘micro’ level, or may not always be a ‘concern’ for ecological and/or human health effects) and this report will use the terminology “trace chemical constituents.”

Trace chemical constituents can be categorized by end use (e.g. pharmaceuticals and personal care products [PPCPs], household chemicals, flame retardants, plasticizers, and biocides), by environmental or human effect, if any (e.g. endocrine disruptors [EDs] or endocrine disrupting compounds [EDCs]), or by type of compound (e.g. phenolic versus polycyclic aromatic hydrocarbons) (EPA, 2012b). Table 4-4 in Section 4 of this report provides a summary of trace chemical constituents that are included in this study, categorized by end use.

This group of constituents include compounds that may derive from wastewater, agricultural runoff, industrial discharge, or other sources, and have been detected in aquatic ecosystems around the world and in drinking water (Wells et al, 2008; Wells et al, 2009; Wells et al, 2010; Bell et al, 2011; da Silva et al, 2012; and da Silva et al, 2013; Kolpin et al, 2002; Donn et al, 2008). It is important to note that the concentrations detected are on the order of tens of nanograms per liter (ng/L) to hundreds of micrograms per liter ( $\mu\text{g/L}$ ) in environmental samples, and on the order of a few ng/L in drinking water, which is 3 to 6 orders of magnitude lower than other chemicals, such as chlorine, typically found in drinking water. (A nanogram is on billionth ( $10^{-9}$ ) of a gram and a microgram is one millionth ( $10^{-6}$ ) of a gram.) Our ability to detect such low concentrations of these constituents has been significantly advanced over the past decade by dramatic improvements in analytical methods. Whether these constituents pose risks to ecological or human health is a current area of research and is discussed further in Section 2.3.

Selection of specific constituents for sampling and analysis for this project is discussed in Section 4. In addition to microbial indicators and trace chemical constituents, a number of conventional parameters were also measured in the Neuse River water samples.

## Section 2

# Water Quality of the Neuse River

The Neuse River begins northeast of the City of Raleigh, North Carolina as a series of small creeks that flow into Falls Lake, with some contribution of treated wastewater from Durham. Falls Lake is the primary drinking water supply for a population of approximately half a million people in the greater Raleigh area. The river continues downstream of the dam for approximately 185 miles in a southeasterly direction, past the cities of Raleigh, Smithfield, Goldsboro, and Kinston and discharges to the tidal estuary near Street's Ferry which empties into the Pamlico Sound. The Neuse River drainage basin spans 19 counties and includes fresh-water lakes and streams, urban treated and untreated wastewaters, brackish waters, and coastal (salt-water) estuaries.

Most of the 6,192 square miles in the Neuse River basin is agricultural or forest, with the only major area of protected forest associated with the Croatan National Forest. The cities of Durham, Raleigh, Clayton, Goldsboro, Kinston, and New Bern account for rapidly expanding urban land use (NCDENR, 2006). Pollution in the Neuse River, similar to many waterways in North America, can be attributed to rural runoff (including constituents from pesticide application, turkey and hog farms, and septic tanks) and urban inputs (including constituents from industrial and domestic WWTP effluents as well as non-point runoff) (Jones-Lepp et al, 2000).

The greater Raleigh metropolitan area lies in the northern half of the Upper Neuse subbasin (HUC 03020201) (**Appendix A**). Major tributary subbasins in this area are Crabtree Creek, Walnut Creek (including Lakes Johnson and Raleigh) and Swift Creek (including Lakes Wheeler and Benson). Smaller streams in these areas have a tendency to dry up under low flow conditions. Aggressive urbanization in the northern part of this subbasin toward the Wake County line and east of Raleigh, as well as in the southern area around Clayton, has rapidly increased the percentage of urban land use, reducing the forested and wetland coverage, which has an adverse effect on stream water quality in and around these urban areas.

Several studies have evaluated conventional water quality parameters in the Neuse River. The North Carolina Department of Environment and Natural Resources (NCDENR) monitors many sites throughout the Neuse Basin below Falls Lake Dam. Forty-eight sites are monitored in cooperation with the Lower Neuse Basin Association (LNBA) (NCDENR, n.d.-a), in addition to 7 voluntary sites (funded by the City of Raleigh), and sites under the Ambient Monitoring System (AMS). A summary of NCDENR and LNBA data is provided in Sections 2.1 and 2.2.

CDM Smith conducted a literature review to locate existing studies related to trace chemical constituents in water sources in North Carolina or outside the state, as a point of comparison to constituents found in the Neuse River. An introduction to the concept of trace chemical constituents was presented in Section 1.3. A summary of these literature studies on the Neuse River is provided in Section 2.3. An overall summary of the water quality of the Neuse River is included in Section 2.4.

## 2.1 NCDENR Data

The NCDENR basinwide report provides results of detailed biological assessments (collections of benthic macroinvertebrates, fish community structure, and fish tissue analyses), the AMS analyses (including temporal and spatial trends of chemical, hydrological, and physical data), and whole effluent toxicity (WET) testing by facilities with permits that require WET compliance (NCDENR, 2006).

These studies have demonstrated that the Neuse River water quality is generally satisfactory for most designated uses. Local events of low dissolved oxygen (DO) and elevated nutrient levels are high enough to allow algal growth (Harned, 1982; NCDENR 2006; NCDENR, 2011). There are also locations with elevated iron, manganese, cadmium, and lead, where concentrations are periodically elevated above criterion levels for domestic water supply sources, with problem areas scattered throughout the basin. Elevated iron, manganese, copper, and zinc concentrations were the most common violations in the Upper Neuse, whereas in the Upper Middle Neuse, the most common violation was low DO. Interestingly, in the Lower Middle Neuse, there were no low DO violations; violations were only for elevated iron and copper concentrations. Consistent with cumulative nutrient loading, the most common violation for the Lower Neuse was elevated chlorophyll a concentrations.

The following sections provide additional information and maps showing recent DO, chlorophyll a, fecal coliform, metals, and polychlorinated biphenyl (PCB) exceedances.

### 2.1.1 Dissolved oxygen and chlorophyll exceedances

In the early 1990's, several high-profile fish kill events occurred in the Neuse River, which resulted in implementation of a Total Maximum Daily Load (TMDL) for total nitrogen in 2001. The goal of the TMDL is to reduce total nitrogen inputs from multiple point sources in order to reduce chlorophyll concentrations (as a surrogate for algal population size) which, when elevated, can result in fish kills. The NCDENR 2006 basinwide report concluded that chlorophyll concentrations in the Neuse estuary do not appear to have changed significantly in the past 25 years (through 2005) (NCDENR, 2006). A similar longitudinal study was not conducted for the 2011 basinwide report, but localized areas of low DO and elevated chlorophyll a were reported (**Figures 2-1 and 2-2**) (NCDENR, 2011).

### 2.1.2 Fecal coliform exceedances

The fecal coliform standard for human health-designated uses applies to waters from which humans may consume fish. The standard for freshwater is a 100 milliliter (mL) sample shall not exceed a geometric mean of 200 membrane filter fecal coliform count (MFFCC) of fecal coliform, nor exceed 400 MFFCC/100 mL in over 20 percent of samples. This standard requires that a minimum of five samples be collected in a 30-day period. It is important to note that because the AMS and LNBA monitoring does not provide the minimum number of samples collected in a 30-day period, fecal coliform exceedances reported through the AMS/LNBA system do not indicate a violation of the standard. Nonetheless, geographic locations of fecal coliform results exceeding the numeric level indicated in this standard are presented in **Figure 2-3**.

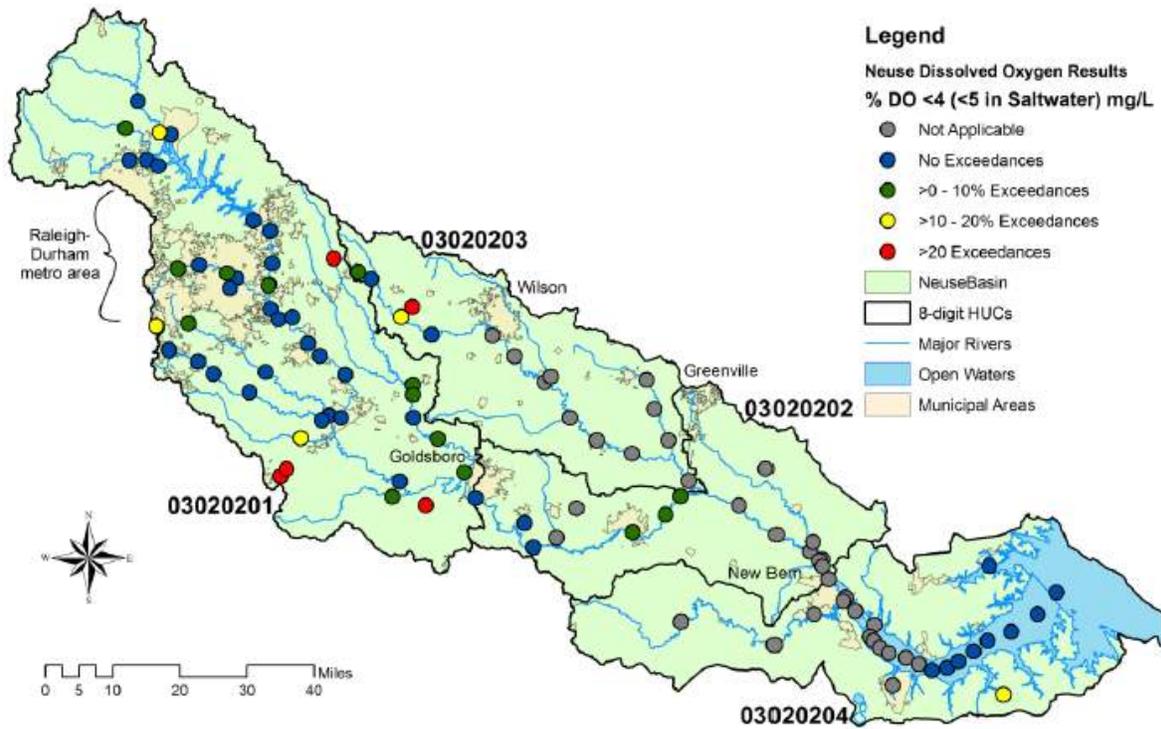


Figure 2-1. Geographic Distribution of DO Exceedances in the Neuse River Basin, 2006 – 2010 (Evaluation Levels: <4 mg/L in freshwater, <5 mg/L in saltwater) (Source: NCDENR, 2011)

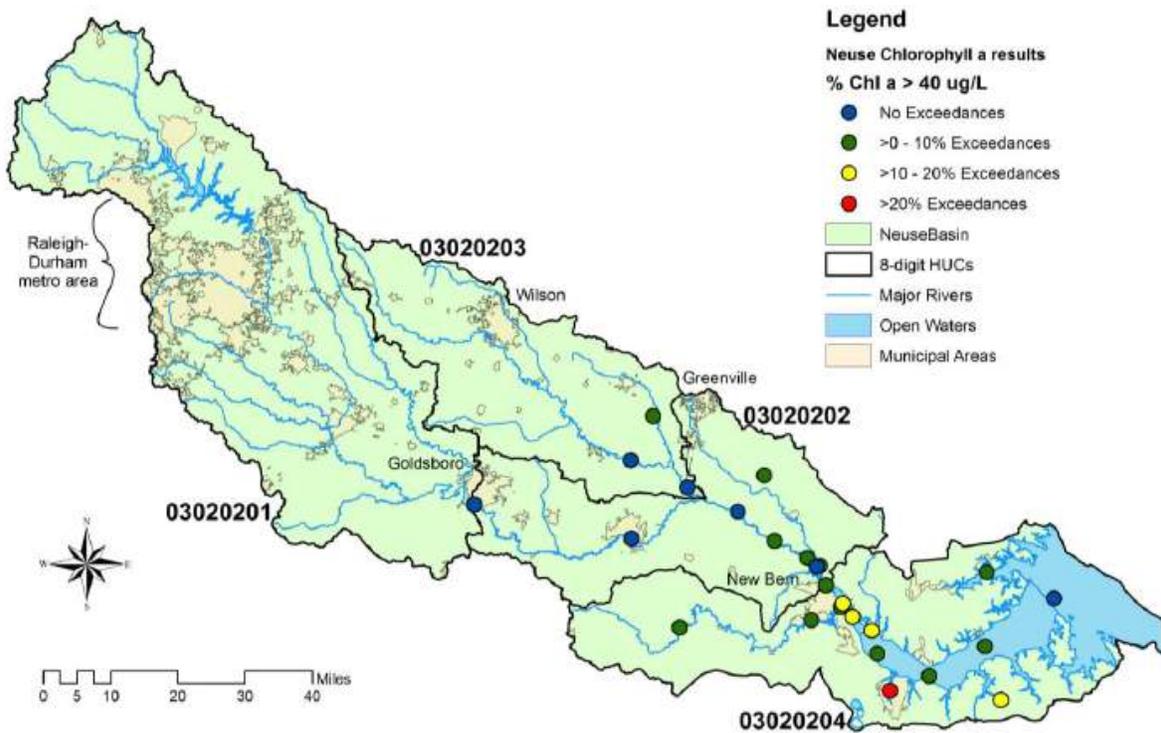


Figure 2-2. Geographic Distribution of Chlorophyll Exceedances in the Neuse River Basin, 2006 – 2010. (Source: NCDENR, 2011)

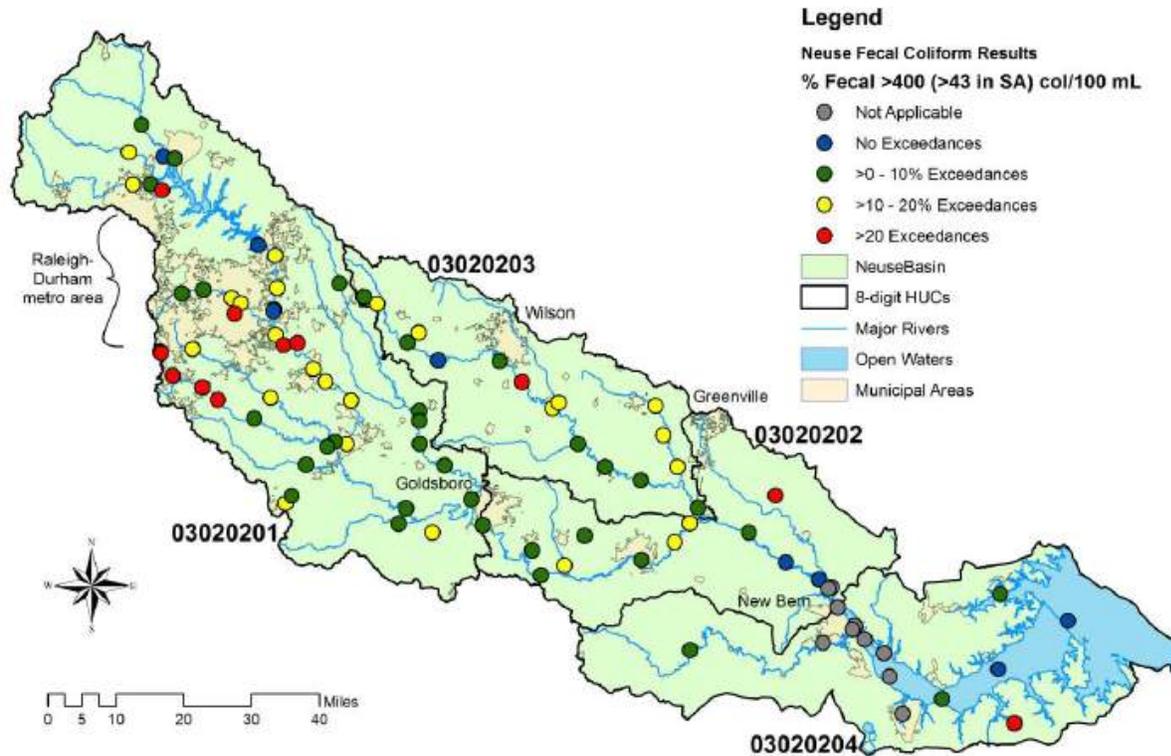


Figure 2-3. Geographic Distribution of Fecal Coliform Exceedances in the Neuse River Basin, 2006 – 2010. (Source: NCDENR, 2011)

### 2.1.3 Metals and industrial pollutants

Copper, zinc, and PCBs are listed as the cause of impairment of waterways within the Neuse River basin as reported on the North Carolina 303(d) List Category 5. Streams that are listed as impaired for high levels of copper, zinc, and PCBs are generally located in the vicinity of the Raleigh-Durham metropolitan area, as shown in **Figure 2-4**.

Copper and zinc contamination is primarily attributed to urban stormwater runoff. The source of PCB contamination is the former Ward Transformer facility located north of the Raleigh Durham International airport. This site was included on the National Priorities List/Superfund List in April 2003. A more detailed map showing impaired waterways in relation to the LNBA and AMS sampling sites, the sampling sites selected for this study, and permitted National Pollutant Discharge Elimination System (NPDES) discharge locations is included in Appendix A.

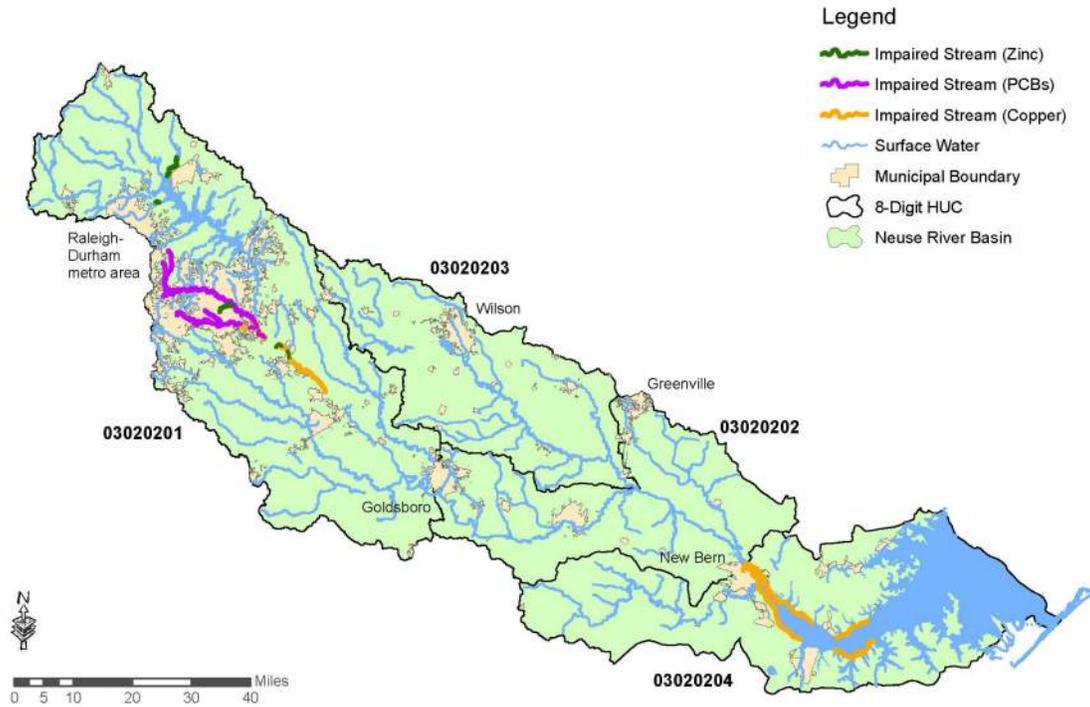


Figure 2-4. Geographic Distribution of Copper, Zinc, and PCB Violations in the Neuse River Basin, 2012. (Source: NCDENR, n.d.-b)

## 2.2 LNBA Historical Data

This section presents monthly LNBA data collected over the past five years, in order to provide a baseline to compare to this study. Most LNBA stations are sampled monthly, with a subset sampled on a weekly basis. Monitoring includes measurement of DO, pH, temperature, salinity, turbidity, total suspended solids (TSS), nutrients, and fecal coliform. Of the eight sampling locations for this study, five are AMS or LNBA sites – sites A, B, E, F and G. Site A (AMS site J1890000) represents the drinking water source at Falls Lake. Site B (LNBA site J4050000) is upstream of the Neuse River WWTP (which is site C). Sites E (LNBA site J4170000), F (LNBA site J4190000), and G (AMS site J4370000) are downstream of the Neuse River WWTP, with site F just upstream of the Johnston County WTP. Sites C, D, and H do not have direct LNBA or AMS sites to compare to, but the historical WWTP effluent data is a point of comparison for site C (presented in Section 3).

**Table 2-1** provides a summary of the minimum, maximum, and mean values for LNBA and AMS data gathered at sites A, B, E, F, and G from January 2008 through August 2013. AMS site J1070000 is also included for comparison. This site is located upstream of Falls Lake and represents pristine conditions. **Table 2-2** provides a similar summary over the same date range, but examining October months only, in order to compare the samples from this study (taken in October 2013) to LNBA measurements during the same month over the past five years. **Appendix B** contains individual graphs of each constituent during the reported date range.

**Table 2-1. Water Quality Ranges for Sites A, B, E, F, G, and AMS Site J1070000 (Data Range: 1/25/2008-9/30/2013)**

Site	Result	Temp (°C)	DO (mg/L)	pH (S.U.)	Conductivity (µmhos/cm)	Fecal coliform (CFU/100mL)	TSS (mg/L)	Turbidity (NTU)	NH <sub>3</sub> as N (mg/L)	TKN as N (mg/L)	NO <sub>3</sub> + NO <sub>2</sub> as N (mg/L)	TP (mg/L)
<b>Exceedance Criteria</b>		<b>&gt;32</b>	<b>&lt;4.0</b>	<b>&lt;6, &gt;9</b>	<b>N/A</b>	<b>&gt;400</b>	<b>N/A</b>	<b>&gt;50</b>	<b>N/A</b>	<b>N/A</b>	<b>&gt;10</b>	<b>N/A</b>
<b>AMS J1070000<sup>1</sup></b>	Average	15.5	8.7	7.0	--	188.6	10.4	11.5	--	0.23	--	0.02
	No. of Exceedances/ Total Samples	0/33	0/32	0/33	--	3/33	--	1/33	--	--	--	--
<b>A</b>	Average	18.2	9.0	7.1	--	14.0	9.3	6.6	0.13	0.65	0.10	0.04
	No. of Exceedances/ Total Samples	0/34	0/34	0/34	--	0/33	--	0/34	--	--	0/20	--
<b>B</b>	Average	19.2	8.1	7.0	138.3	313.6	17.2	19.5	0.09	0.65	0.25	0.06
	No. of Exceedances/ Total Samples	1/52	0/52	0/52	--	18/37	--	3/37	--	--	0/37	--
<b>E</b>	Average	19.0	8.0	7.1	184.1	280.1	21.3	20.1	0.09	0.74	0.49	0.23
	No. of Exceedances/ Total Samples	0/99	0/99	0/99	--	11/70	--	1/70	--	--	0/70	--
<b>F</b>	Average	19.0	8.1	7.1	176.4	367.3	28.9	24.5	0.08	0.77	0.50	0.23
	No. of Exceedances/ Total Samples	1/99	0/99	0/99	--	15/70	--	5/70	--	--	0/70	--
<b>G</b>	Average	17.8	8.3	7.2	186.4	339.6	20.7	19.7	0.04	0.56	0.50	0.22
	No. of Exceedances/ Total Samples	0/38	0/38	0/38	--	6/38	--	1/38	--	--	0/38	--

**Note:**

1) Represents pristine location upstream of the reservoir. The data range for AMS J1070000 is from 1/25/2008 – 8/28/2013; however, there is only one data point for TKN and one data point for TP during this range.

Table 2-2. Water Quality Ranges for Sites A, B, E, F, G and AMS Site J1070000 During October Months (Data Range: October Months During 2008-2012)

Site	Result	Temp (°C)	DO (mg/L)	pH (S.U.)	Conductivity (µmhos/cm)	Fecal coliform (CFU/100mL)	TSS (mg/L)	Turbidity (NTU)	NH <sub>3</sub> as N (mg/L)	TKN as N (mg/L)	NO <sub>3</sub> + NO <sub>2</sub> as N (mg/L)	TP (mg/L)
<b>Exceedance Criteria</b>		<b>&gt;32</b>	<b>&lt;4.0</b>	<b>&lt;6, &gt;9</b>	<b>N/A</b>	<b>&gt;400</b>	<b>N/A</b>	<b>&gt;50</b>	<b>N/A</b>	<b>N/A</b>	<b>&gt;10</b>	<b>N/A</b>
<b>AMS J1070000<sup>1</sup></b>	Average	14.3	6.9	6.9	--	47.0	8.5	5.9	--	0.23	--	0.02
	No. of Exceedances/ Total Samples	0/5	0/5	0/5	--	0/5	--	0/5	--	--	--	--
<b>A</b>	Average	22.4	8.1	7.0	--	13.0	--	4.1	0.11	0.58	0.02	0.02
	No. of Exceedances/ Total Samples	0/5	0/5	0/5	--	0/5	--	0/5	--	--	0/5	--
<b>B</b>	Average	18.5	8.0	7.0	117.8	386.7	15.5	18.8	0.05	0.69	0.28	0.05
	No. of Exceedances/ Total Samples	0/5	0/5	0/5	--	1/5	--	0/5	--	--	0/5	--
<b>E</b>	Average	18.9	7.7	7.1	159.5	266.7	24.0	20.2	0.06	0.66	0.47	0.16
	No. of Exceedances/ Total Samples	0/5	0/5	0/5	--	1/5	--	0/5	--	--	0/5	--
<b>F</b>	Average	18.7	7.9	7.2	150.8	280.3	23.5	26.1	0.04	0.78	0.52	0.21
	No. of Exceedances/ Total Samples	0/5	0/5	0/5	--	2/5	--	0/5	--	--	0/5	--
<b>G</b>	Average	16.2	8.6	7.4	218.0	233.2	21.1	14.6	0.03	0.46	0.62	0.29
	No. of Exceedances/ Total Samples	0/5	0/5	0/5	--	1/5	--	0/5	--	--	0/5	--

**Note:**

1) As noted in the footnote above, the data range for AMS J1070000 is from 1/25/2008 – 8/28/2013; however, there is only one data point for TKN and one data point for TP during this range. The data points for TKN and TP occur during an October date.

The LNBA data shows that the river has a seasonal pattern for temperature and DO, with temperature being higher during the summer months and dropping to a low point in November through February. DO is inversely correlated to temperature; lower in the summer months and peaking in November through February. The other parameters (conductivity, pH, TSS, nitrogen species, and total phosphorus (TP)) do not show a seasonal pattern.

The median temperature and DO values for October fall slightly below the annual median values, but are well above the minimum values. Sites B, E, F, and G also have similar temperature and DO ranges. Likewise, the three sites have similar median values for pH, TSS, turbidity, ammonia (NH<sub>3</sub>), and total Kjeldahl nitrogen (TKN). However, sites E, F, and G show higher median conductivity, nitrate and nitrite (NO<sub>3</sub> and NO<sub>2</sub>), and total phosphorus (TP) than site B. A comparison of conductivity and nutrient concentrations in Neuse River WWTP effluent (discussed in Section 3), to the concentrations observed at site B upstream of the effluent discharge, suggests that the slightly higher mean concentrations observed at sites E and F are likely a result of the plant effluent; however, other sources such as agricultural runoff may also contribute.

There were no DO exceedances (DO concentration of less than 4 mg/L) at these sites during 2008 through 2012. There were, however, a number of fecal coliform exceedances (fecal coliform concentrations of more than 400 cfu/100 mL) during this period at each site.

There have been occasional spikes of TSS and turbidity at all three sites, with the highest spikes in concentrations at site F. These short-term increases in turbidity and TSS are likely a result of sedimentation and erosion producing high suspended solids in runoff during heavy, localized rain events. Likewise, there have been occasional high ammonia and total Kjeldahl nitrogen spikes at all three sites. Nitrate and nitrite levels were relatively stable at all three sites, with the lowest levels at site B. Over the past five years, there have been occasional spikes in total phosphorous concentrations at sites E, F, and G up to 0.9 mg/L, while site B remained at relatively stable concentrations, generally lower than 0.1 mg/L, which implies lower impact from WWTP effluent and agricultural fertilizer runoff. A review of the Neuse River WWTP effluent water quality data suggests that some of these spikes may be associated with elevated concentrations in the effluent. For example, the ammonia spikes at sites E and F in March 2008 correspond to an ammonia spike in WWTP effluent of 4 mg/l (effluent total Kjeldahl nitrogen is typically around 0.9 mg/l).

## 2.3 Trace chemical constituents in the Neuse River and Region

There are now at least a thousand research articles documenting the presence of trace chemical constituents in aquatic ecosystems around the world that are impacted by human populations (Wells et al, 2008; Wells et al, 2009; Wells et al, 2010; Bell et al, 2011; da Silva et al, 2012; and da Silva et al, 2013). Detected concentrations of trace chemical constituents are generally on the order of tens of ng/L to hundreds of µg/L in environmental samples. Some researchers have demonstrated ecological impacts of trace chemical constituents present in WWTP outfalls on local aquatic organisms, where other researchers have found in laboratory studies that much higher concentrations are necessary to result in acute impacts. The ecological impacts due to chronic exposure to trace chemical constituents and due to mixtures of these compounds are still unknown because of the difficulty in designing studies that control for all of the complex set of variables occurring in aquatic ecosystems impacted by human activity. This issue is gaining attention in the popular press. For example, a recent National Public Radio (NPR) print and radio story highlighted findings of PPCPs found in Lake Michigan at concentrations high enough to cause ecological impact at a distance two miles away from Milwaukee's

WWTP outfalls, suggesting that the impact of dilution in the lake is far less than previously assumed (Quirnbach, 2013; Blair et al, 2013).

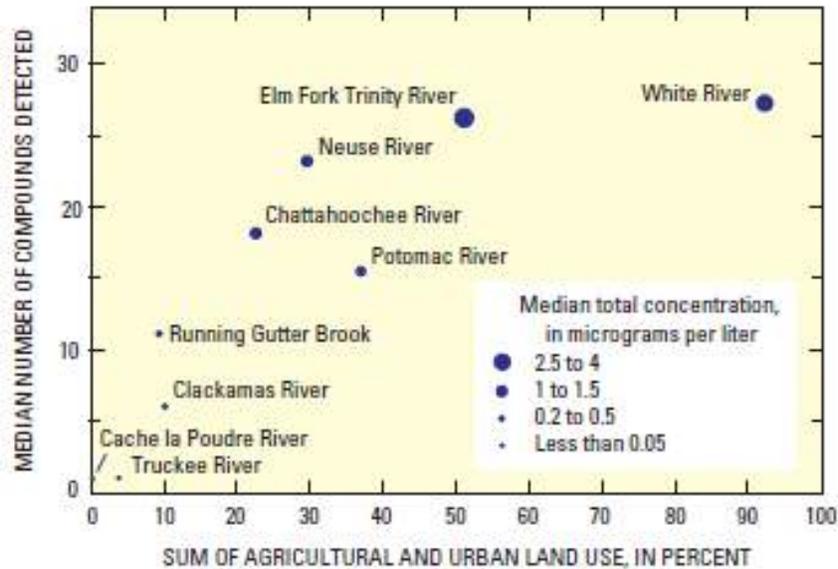
Trace chemical constituents have also been detected in drinking water at very low concentrations (generally on the order of a few ng/L) in numerous water supplies in the nation (Donn et al, 2008). Improvements in analytical methods have resulted in the ability to detect constituents at extremely sensitive levels – 3 to 6 orders of magnitude lower than other chemicals typically found in drinking water. In general, researchers conclude these concentrations are likely too low to have human health impact, even with long-term exposure. For example, researcher Shane Snyder noted in a Congressional hearing on the subject, “The highest concentration of any pharmaceutical compound in U.S. drinking waters is approximately 5 million times lower than the therapeutic dose and that ...one could safely consume more than 50,000 8-ounce glasses of this water per day without any health effects.” (Snyder, 2008). Nonetheless, the effect of long term exposure of combinations of chemicals and their degradation products at extremely low levels is unknown and is an area of public concern.

The following sections summarize research on trace chemical constituents detected in the Neuse River (Section 2.3.1) and in North Carolina water treatment plants (WTPs) (Section 2.3.2). **Appendix C** summarizes the compounds that were detected in each of these studies, along with the detection limits in each study.

### 2.3.1 Trace chemical constituents in the Neuse River

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program was launched in 1991 to develop long-term data on streams, rivers, ground water, and aquatic systems in the nation. The Neuse River is studied as part of an ongoing NAWQA investigation of community water systems across the United States. A range of compounds were studied (277 total), including disinfection byproducts (DBPs) (4), commercial and industrial chemicals (70), agricultural chemicals (140), pavement and combustion-related compounds (32), PPCPs (26), and naturally occurring biochemicals (5). Compounds in each category were detected in the Neuse River, with 100 percent of the 17 Neuse River samples containing chloroform and herbicides simazine, metolachlor, and prometon (Kingsbury, 2008). These compounds were also commonly detected in the Potomac River in Maryland, the Elm Fork of Trinity River in Texas and the White River in Indiana, along with other herbicides. Other compounds that were frequently detected in the Neuse River in this study include fuel additive methyl tertiary butyl ether (MTBE) (76% of samples); herbicides and herbicide degradates including atrazine (76%), deethylatrazine (71%), and 3,4-Dichloroaniline (88%); and PPCPs HHCB (88%) and AHTN (82%), as shown in Appendix C. It is important to note that concentrations of compounds detected in this study generally were less than 1 µg/L, and annual mean concentrations of all compounds were less than available human-health benchmarks in source and finished water samples.

Urban land use is higher in the Neuse River watershed (14%) than any other watershed in this study (Kingsbury, 2008). When compared with eight other sites nationally, the Neuse River USGS monitoring site near Smithfield, North Carolina had a relatively higher number of compounds detected, with higher concentrations than other sites with less agricultural and urban land use in the watershed (**Figure 2-5**). Concomitantly, the site also had a relatively lower number of compounds detected, with lower concentrations than other sites with more agricultural land use in the watershed (i.e. the Elm Fork of Trinity River in Texas and the White River in Indiana, which have 54 and 86% of land use in agricultural production).



**Figure 2-5. The Median Number of Anthropogenic Organic Compounds (out of 277 compounds studied) and Median Total Concentration of all Compounds Detected in Source-Water Samples Collected during the First Phase of Sampling, October 2002–March 2004. (Reproduced from Kingsbury, 2008.)**

Figure 2-5 shows that, in general, the higher the sum of agricultural and urban land use in a watershed, the higher the median number of and median total concentration of anthropogenic organic compounds.

There has been one recent study in North Carolina on ecological impacts from a pharmaceutical detected near a WWTP outfall. In a study of Crabtree Creek, a tributary to the Neuse River near the Town of Cary, researchers detected concentrations of fluoxetine (Prozac®, Eli Lilly) at concentrations of 104–119 ng/L, citalopram (Celexa) at 4.5 ng/L, bupropion (Wellbutrin and other trade names) at 52.6 ng/L, metoprolol (Lopressor and Toprol-XL) at 108.4 ng/L, and trimethoprim (antibiotic) at 37.7 ng/L in the effluent channel of the Crabtree Creek WWTP (Bringolf et al, 2010). Fluoxetine, citalopram, metoprolol, and trimethoprim concentrations decreased in the river at 50 meters and 100 meters downstream. Bupropion concentrations were higher than the effluent 50 meters downstream (77.6 ng/L), but decreased 100 meters downstream (35.5 ng/L). These researchers also evaluated the concentration of fluoxetine that resulted in disruptive impacts on freshwater mussels in the lab. Freshwater mussels are in danger of extinction and are sensitive to selective serotonin reuptake inhibitors (SSRIs) such as fluoxetine. The researchers found that negative impacts in the mussels were observed at 300 µg/L and higher. Though the measured concentration in the river was orders of magnitude lower than the concentration that showed short-term effects in the lab, the researchers pointed out that additional tests are necessary to understand long-term exposure to environmentally relevant concentrations, particularly at critical life stages.

### 2.3.2 Drinking water

In a USGS study focused on the Town of Smithfield, North Carolina, monthly samples from the Neuse River (source water) and the town's public water supply system (finished water) were assessed for a range of 277 different constituents during 2002-2005 (Moorman, 2012). The same suite of compounds was studied in this study as in the Kingsbury et al, 2008 study. Fifty-two organic

compounds were detected in at least 20 percent of the samples in source and/or finished water, with 42 compounds detected at concentrations greater than 0.1 µg/L in each category of compound studied. A total of 113 compounds were detected in all, as shown in Appendix C. Human health benchmarks, the concentration above which there is a risk to humans, were established for only 18 of the compounds detected at a concentration of 0.1 µg/L or greater. Given the limitation in established benchmarks, the concentration of only one compound exceeded its benchmark (benzo[a]pyrene). Benzo(a)pyrene is a semivolatile petroleum hydrocarbon that is likely introduced into drinking water by leaching from the lining of water storage tanks and distribution lines rather than an environmental source. The study concluded that adverse effects to human health due to the presence of the detected constituents are negligible.

In a portion of the USGS NAWQA study that focused on the Research Triangle Area of North Carolina, eight drinking water source sites (6 reservoirs and 2 rivers) were sampled twice (during fall and spring months) and tested for wastewater-derived organic compounds (Giorgino et al, 2007). A total of 126 compounds were studied, including commercial and industrial compounds, agricultural compounds, sterols, and pharmaceuticals. In this study, 24 compounds were detected in at least one sample during the study, generally at concentrations of less than 0.5 µg/L, as shown in Appendix C. The most commonly detected compounds were AHTN (45%) and HHCB (62%) (both used in fragrances in cosmetics and household products), tri(2-chloroethyl) phosphate (62%) (used as an additive in polymers such as polyurethanes and polyester resins), and caffeine (48%). No concentrations exceeded Safe Drinking Water Act (SDWA) or water quality criteria established by the State of North Carolina, though such criteria are available for only a few of the compounds studied.

In a study of three unidentified WTPs that draw from surface water reservoirs in North Carolina that are downstream from WWTP discharge points, some antibiotics (erythromycin, tylosin, roxithromycin, sulfamethoxazole, oxolinic acid and flumequine) were detected in trace concentrations (< 10 ng/L) in the finished water from two of the three WTPs, indicating impact by WWTP effluents or animal feeding operations (Ye and Weinberg, 2007). Other antibiotics that were studied (including other quinolones, as well as all tetracycline analytes and all sulfonamides, except for sulfamethoxazole) were not detected. The researchers also detected some of the antibiotics in the source water at higher concentrations than detected in the finished water, indicating partial removal or transformation during treatment.

In general, researchers conclude that while the concentrations of trace chemical constituents that have been detected in drinking water sources and finished water are too low to have human health impacts, there are quite likely long-term ecological impacts of low concentrations of these constituents in the environment that are yet to be discovered. Thus, the water reuse practices may help avert some of these potential ecological impacts by eliminating direct WWTP effluent contributions of trace chemical constituents to aquatic ecosystems.

## 2.4 Summary

The Neuse River water quality is generally satisfactory for most designated uses, but there is evidence that the high fraction of urban and agricultural land use impacts the river water quality.

- The river has local areas of exceedances of low DO, elevated nutrient levels, elevated chlorophyll a concentrations, and evidence of historic PCB contamination. There are also localized areas of copper and zinc contamination, which is primarily attributed to urban stormwater runoff, though there could be some industrial sources.

- When compared with eight other sites nationally, the Neuse River USGS monitoring site near Smithfield, North Carolina had a relatively higher number of trace chemical constituents detected, with higher concentrations than other sites with less agricultural and urban land use in the watershed (Kingsbury, 2008). Concentrations of compounds detected in this study generally were less than 1 µg/L, and annual mean concentrations of all compounds were less than available human-health benchmarks in source and finished water samples.
- Crabtree Creek was found to have concentrations of fluoxetine at concentrations of 104–119 ng/L in the effluent channel of the Crabtree Creek WWTP (Bringolf et al, 2010).
- Trace chemical constituents were also detected in the source and finished drinking water in Smithfield (Moorman, 2012), and in the source water in the Research Triangle area at low concentrations (Giorgino et al, 2007). Both of these studies concluded that adverse human health effects are negligible, with the caveat that human health benchmarks have not been established for all of the compounds detected. In an additional study, antibiotics were detected at trace concentrations (< 10 ng/L) at two unidentified WTPs that draw from wastewater-impacted surface water reservoirs in North Carolina.

In general, concentrations of trace chemical constituents are generally on the order of tens of ng/L to hundreds of µg/L in environmental samples and on the order of a few ng/L in finished drinking water samples. There may be adverse ecological impacts due to chronic exposure to these constituents at these environmental concentrations; this is an area of ongoing research. Researchers have generally concluded that the concentration of these constituents in drinking water is likely too low to have human health impact, but this is likewise an area of ongoing scientific debate and an area of public concern. Very few of the studied trace chemical constituents have established water quality criteria or health benchmarks.

## Section 3

# Water Quality of the Neuse River WWTP Effluent

In order to understand how constituents present in WWTP effluent may be impacted by the river, it was important to look at the effluent quality entering the river. The Neuse River WWTP was the focus of this study, and is the largest WWTP discharging into the Neuse River. CDM Smith looked at historical compliance data for the Neuse River WWTP and conducted a literature review of regional effluent studies. This section outlines the findings, which were used in selecting the specific chemical constituents for sampling and analysis for this project.

### 3.1 Historical Compliance Data for Neuse River WWTP

The Neuse River WWTP is located approximately 12 miles southeast of Raleigh in Wake County and is the City's largest wastewater treatment facility, with a treatment capacity of 60 million gallons per day (mgd). The City is currently expanding the capacity to 75 mgd. The treatment process stream includes preliminary screening and grit removal, primary clarifiers, conventional activated sludge with biological nutrient removal through a 4-stage process with an internal nitrified recycle flow for nitrogen removal and capability of a 5-stage process mode for phosphorous removal, secondary clarifiers that are equipped with chemical feed for phosphorus removal, tertiary filters, and low pressure-high output UV (ultraviolet) disinfection. The effluent discharged to the Neuse River is subject to limitations and monitoring requirements as set forth in NPDES permit NC0029033. The Neuse River WWTP NPDES effluent limitations are summarized in **Table 3-1** along with weekly average effluent data from 2007 through 2013. The plant performance is exceptional as demonstrated by the effluent concentrations of parameters that were all substantially below their respective permit limits over the period of analysis.

Plant effluent data also includes testing for various metals, although the NPDES permit does not set regulatory limits for metals. **Table 3-2** presents the minimum, median, average, and maximum data for each metal for 2012 and 2013. The table also indicates the percentage of measurements that were above the method detection limit. Zinc is the only metal that is consistently detected in the Neuse River WWTP effluent, with an average concentration of 26 ug/L.

### 3.2 Trace Chemical Constituents in WWTPs

#### 3.2.1 Neuse River WWTP Effluent Trace Chemical Constituent Characterization (EPA Data)

In 2014, the EPA published the results of a study assessing the concentrations of 56 active pharmaceutical ingredients that were present in effluent from 50 large wastewater treatment plants (Kostich et al., 2014). The City of Raleigh's Neuse River WWTP, was one of the fifty plants selected for the study. National WWTPs were screened for study inclusion based several factors:

- Discharging to surface waters (excluding ocean discharge)
- Serving a population greater than 100 people and at least 75% of flow originating from the municipal users
- Reported per capita wastewater production between 50 and 1000 liters (L) per person per day.

**Table 3-1. Neuse River WWTP Historical Effluent Data**

Constituent	NPDES Permit Effluent Limitations <sup>1,2</sup>		Weekly Average 2007-2013 <sup>3</sup>			
	Monthly Average	Weekly Average	Min	Median	Average	Max
Flow (MGD)	75.0	-	37.6	41.4	42.2	55.8
pH (SU)	6.0<pH<9.0		6.2	6.8	6.7	7.1
Temperature (°C)	-	-	13.7	21.4	21.6	27.8
Dissolved Oxygen (mg/L)	-	-	5.8	7.0	7.1	9.7
Specific Conductance (µmhos/cm)	-	-	490	673	671	807
Turbidity (NTU)	-	-	0.5	1.7	1.6	4.2
Total Suspended Solids (mg/L)	30.0	45.0	0	0	0.1	3.0
BOD5 (Summer) <sup>4</sup> (mg/L)	5.0	7.5	0	0	0.1	1.4
BOD5 (Winter) <sup>4</sup> (mg/L)	10.0	15.0	0	0	0.2	3.1
Ammonia as N (Summer) <sup>4</sup> (mg/L)	2.0	6.0	0	0	0.1	0.8
Ammonia as N (Winter) <sup>4</sup> (mg/L)	4.0	12.0	0	0	0	0.9
Nitrate as N (mg/L)	-	-	0	1.1	1.2	5.7
Nitrate Nitrite as N (mg/L)	-	-	0.2	1.2	1.4	4.1
Total Kjeldahl Nitrogen (mg/L)	-	-	0	0.9	0.8	2.4
Total Nitrogen (mg/L)	-	-	0.4	2.0	2.1	7.3
Total Nitrogen Load (lb/yr)	682,483		263,446 <sup>5</sup>			
Total Phosphorus <sup>6</sup> (mg/L)	2.0		0.7	1.2	1.2	1.7
Fecal Coliform (MPN/100 mL)	200	400	0	2	7	233

**Notes:**

- 1) As set forth in NPDES Permit NC0029033
- 2) Cells marked with “-“ signify permit does not state effluent limitations
- 3) Unless noted otherwise, values are based on weekly averages from 2007-2013. Values below the method detection limit are given as ‘0’ and included in the average as 0.
- 4) Summer: April 1 – October 31; Winter: November 1 – March 31
- 5) Average of yearly totals from 2007-2013
- 6) Values based on quarterly averages

**Table 3-2. Neuse River WWTP Effluent Metals Data**

Metal <sup>1</sup>	2012-2013 <sup>2</sup>				
	Min	Median	Average	Max	% Above Detection Limit <sup>3</sup>
Arsenic (µg/L)	0	0	0	0	None
Barium (µg/L)	0	0	0	0	None
Cadmium (µg/L)	0	0	0.2	3.8	6%
Chromium (µg/L)	0	0	0	0	None
Copper (µg/L)	0	0	0	0	None
Lead (µg/L)	0	0	1.2	28.3	8%
Mercury (ng/L)	0	0.9	1.2	5.4	86%
Molybdenum (µg/L)	0	0	0	0	None
Nickel (µg/L)	0	0	1.5	9.2	24%
Selenium (µg/L)	0	0	0.4	6.8	7%
Silver (µg/L)	0	0	0	0	None
Zinc (µg/L)	14.1	25.7	25.7	44.0	100%

**Notes:**

- 1) Only metals with measurements above detection limits presented
- 2) Table presents summarized data for 2012 and 2013
- 3) Percentage of readings above detection limits divided by total number of readings

The largest 50 plants (based on daily flow rate) that met the criteria, were selected for sampling. Together, the plants are generally representative of US WWTPs. Plants were included from 20 different states and their combined flow is about 17% of all municipal wastewater effluent produced in the US.

Effluent samples were collected as a 24-hour composite between January 11<sup>th</sup> and April 5<sup>th</sup> of 2011. Samples were intended to capture a representative daily effluent composition, because instantaneous concentrations can vary based on normal drug dosing schedules. Because samples were collected in winter months, the results may be skewed towards detecting pharmaceutical drugs used more frequently in the winter. For example, some drugs are more prescribed during the cold and flu seasons, where drugs such as antihistamines are more frequently used in warm months.

Of the 56 pharmaceuticals and 7 metabolites reported, 15 pharmaceuticals and three hormones were detected in the Neuse River WWTP effluent. **Table 3-3** shows the results of the Neuse River WWTP effluent analytes, along with the national mean, and national maximum for the same parameters. Analytes that were detected in the Raleigh samples are highlighted in light blue. This data was previously summarized in a review memorandum prepared for the City of Raleigh, posted on the City's public website (Stanford, 2013). Concentrations reported by Stanford included duplicate detection of the same analyte by multiple analytical methods, and estimated values not published in the final Kostich report (these values are flagged in Table 3.3). Enalapril, progesterone, sufamethoxazole, testosterone, and trimethoprim were analyzed by two analytical methods with differing detection limits and detailed in Section 2.3 of the Kostich report.

**Table 3.3. EPA Analytes and Results<sup>1</sup>**

Analyte <sup>2</sup>	CAS Number	No. of samples	Percent of samples with detections	National Mean <sup>3</sup> (ng/L)	National Max <sup>3</sup> (ng/L)	Raleigh (ng/L)
10-hydroxy-amitriptyline	64520-05-4	50	12%	<RL	<RL	ND
acetaminophen	103-90-2	50	14%	79 (300)	1500 (4500)	ND
albuterol	18559-94-9	50	54%	14	35	ND
alprazolam	28981-97-7	50	30%	10	31	ND
amitriptyline	549-18-8	50	40%	11	110	ND
amlodipine	111470-99-6	50	22%	6.9	18	ND
amphetamine	51-63-8	50	10%	3.5	40	ND
atenolol	29122-68-7	50	96%	940	3000	360.7
atorvastatin	134523-00-5	48	8%	<RL	<RL	ND
benztropine	86-13-5	50	0%	ND	ND	ND
carbamazepine	298-46-4	50	96%	97 (140)	240 (460)	ND
ciprofloxacin	85721-33-1	49	61%	67 (72)	260 (320)	ND
clonidine	4205-91-8	50	0%	ND	ND	ND
desmethylsertraline	79902-63-9	50	18%	9.9 (10)	24	ND
diltiazem	33286-22-5	49	84%	85	340	92.8
diltiazem-desmethyl	130606-60-9	50	68%	24	100	ND
enalapril	76095-16-4	50	18%	4.6	38	ND
enalapril	76095-16-4	49	27%	13	32	ND
enalaprilat	76420-72-9	49	10%	14 (18)	150	ND
florfenicol	73231-34-2	49	0%	ND	ND	ND
fluocinonide	356-12-7	50	0%	ND	ND	ND
fluoxetine	59333-67-4	48	38%	8.7	31	21.5
fluticasone	57-83-0	50	0%	ND	ND	ND
furosemide	54-31-9	50	90%	280 (350)	810 (2100)	255.3
gemfibrozil	25812-30-0	50	76%	420 (480)	2300	140.9
hydrochlorothiazide	58-93-5	50	100%	1100 (1200)	2800	1466
hydrocodone	143-71-5	50	44%	22 (24)	92 (100)	ND
hydrocortisone	50-23-7	50	0%	ND	ND	ND
ibuprofen	15687-27-1	50	46%	460 (690)	4200 (4600)	ND
lincomycin	859-18-7	49	0%	ND	ND	ND
lisinopril	83915-83-7	49	47%	180 (1700)	3300 (13000)	ND
melengestrol acetate	2919-66-6	49	0%	ND	ND	ND
methylprednisolone	83-43-2	50	0%	ND	ND	ND
metoprolol	56392-17-7	50	98%	410 (450)	660 (1200)	572.4
norethindrone	68-22-4	50	0%	ND	ND	ND
norfluoxetine	83891-03-6	46	17%	7.7	15	ND
norverapamil	67814-42-4	48	52%	5.8	20	ND

Table 3.3. EPA Analytes and Results<sup>1</sup> (continued)

Analyte <sup>2</sup>	CAS Number	No. of samples	Percent of samples with detections	National Mean <sup>3</sup> (ng/L)	National Max <sup>3</sup> (ng/L)	Raleigh (ng/L)
ofloxacin	82419-36-1	49	90%	160	660	59.1
oxycodone	124-90-3	50	60%	53	310	39.9
paroxetine	110429-35-1	50	0%	ND	ND	ND
prednisolone	50-24-8	50	0%	ND	ND	ND
prednisone	53-03-2	50	0%	ND	ND	ND
progesterone	80474-14-2	50	4%	<RL	<RL	ND
progesterone	80474-14-2	49	0%	ND	ND	ND
promethazine	58-33-3	50	0%	ND	ND	ND
propoxyphene	1639-60-7	48	25%	17	34 (46)	ND
propranolol	318-98-9	50	88%	33	260	ND
ranitidine	66357-59-3	50	38%	120	1400	155.5
sertraline	79559-97-0	50	64%	21	71	23.5
simvastatin	79902-63-9	50	24%	<RL	<RL	ND
sulfadimethoxine	122-11-2	49	0%	ND	ND	ND
sulfamethazine	57-68-1	49	2%	12	87	ND
sulfamethoxazole	723-46-6	50	80%	910	2900	2190.6
sulfamethoxazole	723-46-6	49	90%	330	1000	942.4
testosterone	58-55-9	50	0%	ND	ND	ND
testosterone	58-55-9	49	0%	ND	ND	ND
theophylline	58-55-9	50	8%	<RL (88)	<RL (100)	ND
triamterene	396-01-0	50	70%	37	170	ND
trimethoprim	738-70-5	43	86%	170	370	367.4
trimethoprim	738-70-5	49	82%	90	210	146.8
valsartan	396-01-0	41	98%	1600 (1700)	5300 (8200)	1336.5
verapamil	137862-53-4	49	80%	26	97	16.7
warfarin	81-81-2	50	0%	ND	ND	ND
estrone <sup>4</sup>	53-16-7	50	96%	13 *	93 *	1.9 *
17- $\alpha$ -ethynylestradiol <sup>4</sup>	53-63-6	50	86%	1 *	4 *	0.4 *
androstenedione <sup>4</sup>	63-05-8	50	100%	3 *	10 *	1.5 *

**Notes:**

- 1) Adapted from Kostich et al., 2014
- 2) Analytes shown with multiple results were analyzed using more than one method
- 3) Numbers in parenthesis include estimated concentrations from samples that failed qualification criteria
- 4) Results marked with asterisk (\*) did not meet quality control requirements and should be flagged as estimates, these points were not published in Kostich et al., 2014.

Detection of analytes in the effluent suggest that these pharmaceuticals are not fully degraded in the Neuse River WWTP processes and may be introduced into the river. All of the detections in the Raleigh Neuse River WWTP were below the national maximum; in general the values were near or below the national average. Additionally, none of the compounds were detected only in the Raleigh effluent. It is important to note that WWTPs are not the only source of pharmaceuticals and hormones in surface waters. As such, non-detects in the Neuse River WWTP effluent are not necessarily indicative of an absence of these compounds at detectable concentrations in the river water. Agriculture, industry, storm water, and run-off are other potential sources of these compounds.

There is not data on the lowest concentration of observable human effects for most of the compounds tested (Kostich et al., 2014). However, Kostich et al. and Stanford (2013) evaluated the potential risk implications of the results. Stanford used the Australian Drinking Water Guidelines (ADWG) which are intended to establish safe values for lifetime exposures. Though these values are not recognized by the EPA, the Neuse River WWTP detections were one to five orders of magnitude lower than the available Australian guideline values (guideline values were not available for nine of the 18 compounds). Kostich et al. compared the maximum detected concentrations to the daily therapeutic dose. A daily consumption of 2 liters of water containing the maximum concentrations detected nationally in effluent waters equated to a potential of less than one daily dose equivalent every year to ten years, depending on the compound. However, it is important to keep in mind that this analysis represents concentrations in treated wastewater, not drinking water, and does not represent actual exposure. Concentrations in ambient surface waters and finished drinking waters are assumed to be lower due to dilution, degradation, and water treatment processes. Kostich et al. (2014) concluded that the risks to healthy human adults from the maximum detections was very low. As the Neuse River WWTP effluent values in this study were lower than the maximum values, it can be inferred that the risks from the treatment plant effluent are also extremely low.

### 3.2.2 Literature Survey of Trace Chemical Constituents in WWTPs in the Region

CDM Smith conducted a literature survey on trace chemical constituents detected in WWTPs in the region and found a limited set of articles on the subject. As described in Section 2, fluoxetine was detected in the effluent channel of the Crabtree Creek WWTP.

One additional study worth noting specifically evaluated concentrations of hormones in WWTP influents and effluents. A group of researchers based at the National Oceanic and Atmospheric Administration (NOAA) and the College of Charleston analyzed a range of hormones in WWTP influent and effluent as well as surface water samples in Charleston Harbor, South Carolina (Sapozhnikova et al, 2011). The researchers detected estriol, estrone and testosterone in WWTP influent samples (at concentrations on the order of 10 to 100 ng/L), whereas only estrone was detected in a single effluent sample, at a concentration of 24 ng/L. The same researchers likewise sampled two Charleston WWTPs and Charleston Harbor water monthly for a year to study PPCP concentrations in a separate study (Hedgespeth et al, 2012). All of the compounds studied (acetaminophen, caffeine, cotinine, estriol, estrone, fluoxetine, ibuprofen, norfluoxetine, testosterone, triclocarban, and triclosan) were detected in WWTP influent, and all but estriol and testosterone were detected in WWTP effluent. Effluent concentrations (at concentrations on the order of 10 to 100 ng/L) were generally lower than influent concentrations (on the order of 100 to 100,000 ng/L). Acetaminophen, caffeine, and cotinine were most frequently detected in surface water (at concentrations on the order of 10 ng/L). The study indicated that WWTP effluent is the most likely major point-source input of PPCPs into Charleston Harbor and found degradation in wastewater and surface water was slower in colder months.

## Section 4

# Study Design

To support the study objective of providing a baseline understanding of water quality in the Neuse River, CDM Smith and City staff collaborated to develop and implement a sampling and analysis plan (SAP) to conduct water quality sampling and analysis on the Neuse River during the fall of 2013. The SAP defined the following:

- The number and locations for sample collection
- The number and type of constituents for analysis, including analytical methods
- Targeted river flow and seasonal conditions for sampling
- Sampling frequency and duration
- Estimated costs to implement the recommended SAP

This section describes the selection of constituents for analysis, selection of sampling locations, and sampling frequency, duration, and targeted river flow for this study, as developed for the SAP.

### 4.1 Selection of Constituents for Analysis

A range of constituents that are important indicators of water quality with respect to public health were selected for analysis as part of this study. The focus of the study is on microbial indicators and trace chemical constituents that may be potentially present in wastewater sources. Therefore, the study includes six microbial indicators, nearly 100 chemical constituents, and one parameter that provides a measure of bulk genotoxicity. UV fluorescence excitation/emission matrix (EEM) spectroscopy was also used to provide gross characterization of organic matter in water samples to measure changes in surface water quality as a result of inputs from various sources into the Neuse River basin.

In addition, a suite of conventional parameters was analyzed to offer a picture of general water quality. It is important to note that the overarching selection criterion was to include parameters of relevance to public health. Ecological health was not a central focus in the selection of constituents. The following sections describe the selection of specific constituents for analysis.

#### 4.1.1 Conventional Parameters

The LBNA conducts ongoing river water quality sampling in the Neuse River basin in coordination with the North Carolina AMS program. A range of conventional water quality parameters that are already analyzed monthly within the Neuse River basin by the LNBA were also selected for this study. This data can be compared in order to establish whether samples taken under this baseline study are similar in water quality to historical samples. Conventional parameters measured as part of this study are listed in **Table 4-1**.

**Table 4-1. Conventional Parameters Analyzed in the Neuse River**

Category	Parameter
Field Measurements	Dissolved oxygen, specific conductance, pH, temperature, turbidity
Nutrients	Ammonia as N, nitrate-nitrite, total Kjeldahl Nitrogen, total phosphorus
Other	Total suspended solids (TSS), total organic carbon (TOC)

### 4.1.2 Microbial Indicators

Indicators of viruses, bacteria, and protozoa were monitored in the Neuse River basin in this baseline study, as described in the following sections. Research has shown that it is important to monitor a suite of indicator organisms in reclaimed water as no individual indicator is capable for fully predicting the presence of pathogens (Harwood et al., 2005).

#### 4.1.2.1 Viruses

Wastewater can contain a range of infectious enteric viruses. Since pathogenic viruses are difficult to detect and quantify, virus surrogates are used as an indicator of the fate and transport of enteric viruses. Male specific and somatic coliphages were chosen since they are easier to analyze than enteric viruses using proven methods and are present in raw wastewater in greater numbers. Literature has shown that coliphages are an acceptable indicator of pathogenic viruses, though correlations are inconsistent due to a variety of site-specific factors and differences in recovery methods from different studies (Keegan et al., 2009; Ashbolt et al., 2001). Determining the best indicator for pathogenic viruses is an ongoing area of research.

#### 4.1.2.2 Bacteria

Similar to enteric pathogenic viruses, enteric pathogenic bacteria (such as *Salmonella* spp.) are present in lower concentrations in wastewater than indicator species, such as coliform bacteria. *Escherichia coli*, *Enterococcus* spp., and fecal coliforms were selected to represent fecal bacteria. *Escheria coli* and enterococci were selected because they are recommended by the EPA as indicators of fecal pollution in freshwater recreational waters, since levels of these organisms were shown to be more accurate than fecal coliforms at predicting gastrointestinal illness (EPA, 2004; EPA 2012a). Fecal coliforms were also selected as a metric of comparison because LNBA includes fecal coliforms in routine monthly water quality testing.

#### 4.1.2.3 Protozoa

*Clostridium perfringens* was identified to represent protozoa such as *Giardia lamblia* and *Cryptosporidium parvum*. Although *C. perfringens* is a bacteria rather than protozoa, it is capable of forming spores which can act as surrogates for the cysts or oocysts of *Giardia* and *Cryptosporidium*, respectively. The methods to detect *Giardia* and *Cryptosporidium* are difficult, relying heavily upon laboratory sample preparations and technician skill, where the detection method for *C. perfringens* is more straightforward (though not yet EPA approved) and can distinguish between viable and non-viable spores. In Europe, *C. perfringens* has been used as an indicator of fecal contamination in water since the 1960s (NAS, 2004).

In addition, *C. perfringens* was recently added to the North Carolina regulations for Type 2 reclaimed water, which is the most restrictive category of water quality currently regulated for water reuse in the state. Type 2 reclaimed water can be used for indirect contact irrigation for crops that will not be

peeled, skinned, or thermally processed. (North Carolina does not currently have regulations governing DPR.) The rules for Type 2 reclaimed water specify effluent microbial concentrations and treatment performance requirements not only for *E. coli*, but also for coliphage and *C. perfringens*. To date, North Carolina is the only state in the country which uses *C. perfringens* as an indicator in its water reuse regulations.

As a summary, the microbial indicators that will be studied are presented in **Table 4-2**.

**Table 4-2. Microbial Indicators Analyzed in the Neuse River**

Category	Indicator
Virus	Male-specific coliphage, somatic coliphage
Bacteria	Fecal coliforms, <i>E. coli</i> , enterococci
Protozoa	<i>C. perfringens</i> <sup>1</sup>

Note:

1) *C. perfringens* is a type of bacteria but is used as an indicator for protozoa because it forms resistant spores.

### 4.1.3 Chemical Constituents

In addition to addressing acute risks associated with microbial contamination, it is important to gain an understanding of chemical constituents present at trace concentrations. As discussed in Section 2, CDM Smith conducted a search of data sources, including EPA, USGS, NCDENR, LNBA, nearby municipalities, and published scientific literature to determine what water quality data exists for the Neuse River related to pharmaceuticals and personal care products (PPCPs), endocrine disrupting compounds (EDCs), currently non-regulated disinfection by-products (DBPs) and other trace chemical constituents.

Trace chemical constituents selected for analysis in this study include those that have been previously measured at detectable levels in the Neuse River WWTP effluent, in the Neuse River, or in drinking water in the U.S. The primary literature sources consulted to create a focused list of trace chemical constituents for this study are summarized in **Table 4-3**. In certain cases, if multiple compounds of a similar class were detected, a single representative compound was selected for sampling to manage analytical costs. Input from City staff and local academic experts were also considered in selection of the final analysis list. A table of additional literature sources used in assembling the list of trace chemical constituents for this study is provided in **Appendix D**.

Metals were also analyzed in this study because several streams within the Neuse River basin are included on the North Carolina 303(d) List Category 5 as impaired for high levels of copper or zinc. There are portions of the Neuse River with historical degradation with respect to these metals, which were included in this study in order to capture contributions from legacy contamination sites. (Note that other metals which are captured in the same analytical method are also included, namely antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, selenium, and thallium.) Although several of the streams in the upper Neuse River basin are included on the North Carolina 303(d) List as impaired for high levels of PCBs, the source of this contamination is known (see Section 2) and is not of wastewater origin PCBs were not sampled in this study.

**Table 4-3. Primary Literature Sources for the List of Trace Chemical Constituents to be Studied**

Reference	Comment
EPA National Municipal Effluent Contaminants of Emerging Concern Survey (Kostich et al., 2014)	Constituents that were detected in the Neuse River WWTP effluent were included for study.
Organic Compounds Assessed in Neuse River Water Used for Public Supply near Smithfield, North Carolina (Moorman, 2012)	<p>This study focuses on the town of Smithfield and is part of the USGS NAWQA Program. Constituents that were either detected at concentrations of greater than 0.1 µg/L in source water or finished water, or that were commonly detected in source water or finished water (in at least 20% of samples) were included in this study, with the exception of the following:</p> <ul style="list-style-type: none"> <li>▪ Some VOCs, pesticides, herbicides and fungicides were omitted in lieu of other representative compounds.</li> <li>▪ Some fragrances were omitted because they are naturally occurring.</li> <li>▪ Some synthetic musks were omitted due to literature showing very minimal endocrine interruption.</li> </ul>
Occurrence of Organic Wastewater Compounds in Selected Surface-Water Supplies, Triangle Area of North Carolina (Giorgino et al, 2007)	<p>This study focuses on the Research Triangle area and is part of the USGS NAWQA Program. Constituents that were detected in the Neuse River were included in this study, with the exception of the following:</p> <ul style="list-style-type: none"> <li>▪ Some VOCs, herbicides, atrazine degradates, and antibiotic degradate were omitted in lieu of other representative compounds.</li> <li>▪ Some fragrances were omitted because they are naturally occurring.</li> <li>▪ Some synthetic musks were omitted due to literature showing very minimal endocrine interruption.</li> </ul>
Pharmaceuticals and Endocrine Disrupting Compounds in U.S. Drinking Water (Benotti et al, 2009)	This national study looked at trace chemical constituents in drinking water. The top 11 trace chemical constituents found in drinking water in the U.S were included in this study.

One tracer, sucralose, was also included for analysis as part of this study to aid in tracking wastewater derived compounds. Sucralose has been reported to be relatively non-degradable in the environment and can be used to serve as a conservative tracer for wastewater effluent (Anderson et al., 2010).

**Table 4-4** provides the complete list of chemical constituents that were analyzed as part of this baseline study. The selected subset of chemical constituents is representative of a wide range of chemical characteristics with respect to removal or degradation in the environment (e.g., photooxidation, sorption, catalysis, biodegradation, etc.).

**Table 4-4. Trace Chemical Constituents Analyzed in the Neuse River**

Category	Trace Chemical Constituent(s)
Pharmaceuticals	Acetaminophen, atenolol, caffeine, carbamazepine, cotinine, diltiazem, fluoxetine, furosemide, gemfibrozil, hydrochlorothiazide, ibuprofen, meprobamate, metoprolol, naproxen, ofloxacin, oxycodone, primidone, sertraline, sulfamethoxazole, trimethoprim, valsartan, verapamil
Sterols and Hormones	17- $\alpha$ -ethynylestradiol, 17- $\beta$ estradiol, androstenedione, $\beta$ -stigmastanol, $\beta$ -sitosterol, cholesterol, coprostanol, estrone
Flame retardants	Hexabromocyclododecane (HBCDD), tris[2-chloroethyl]phosphate (TCEP)
Perfluorinated compounds	Perfluorobutanoic acid (C4), perfluoropentanoic acid (C5), perfluorohexanoic acid (C6), perfluoroheptanoic acid (C7), perfluorooctanoic acid (C8, PFOA), perfluorononanoic acid (C9), perfluorodecanoic acid (C10), perfluorobutane sulfonate (PFBS), perfluorohexane sulfonate (PFHS), perfluorooctane sulfonate (PFOS)
Nonylphenols	Nonylphenol diethoxylate, nonylphenol monoethoxylate, para-tert-octylphenol, p-nonylphenol
Disinfection byproducts (DBPs)	Bromate, bromide, chlorate, chlorite, haloacetic acids (HAAs), <i>n</i> -nitrosodimethylamine (NDMA), trihalomethanes (THMs)
Volatile organic compounds (VOCs)	1,1,1,2-tetrachloroethane, 1,1,2,2-tetrachloroethane, 1,2,4-trimethylbenzene, 1,4-dioxane, acetone (2-propanone), benzene, carbon tetrachloride, ethylbenzene, isopropylbenzene, methyl tert-butyl ether (MTBE), m-xylene & p-Xylene, naphthalene, o-Xylene, tert-butyl alcohol, tetrachloroethene (perc), toluene
Metals	Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, selenium, thallium, zinc
Pesticides, herbicides, fungicides	2,4-D, atrazine, bentazon, benzo(a)pyrene, carbaryl, chlordane, N,N-diethyl-meta-toluamide (DEET), MCPA, metolachlor, pentachlorophenol (PCP), simazine
Consumer products and manufacturing additives	Anthraquinone, bisphenol-A (BPA), camphor, p-cresol, salicylic acid, triclosan, triphenylphosphate
Contrast media	Iopromide
Wastewater tracer	Sucralose

#### 4.1.4 Genotoxicity

Analysis of specific target compounds is complemented by the Ames bioassay, which provides a means to assess the bulk genotoxicity of samples due to the presence of a combination of compounds and their degradation products. It can also provide insight into the potential synergistic toxicity effects due to combinations of compounds present. Because it is impossible to analyze every possible compound that could be present in the samples collected for this study, the Ames test serves as a screening tool. The test results can aid in determining whether there are relative differences in the compounds or combinations of compounds that may be present in samples collected from different sites.

Mutagenesis is the introduction of a heritable change in an organism's genetics. Mutagens, both naturally occurring and anthropogenic, are common in the environment and may be present in source water stream. One means of testing for mutagenic activity uses specially constructed bacterial strains in what is known as the Ames test. This test examines the number of mutations to heterotrophy in one or more strains of *Salmonella typhimurium* induced by exposure of bacteria to source water samples.

The test is sensitive to a wide range of chemicals that can cause mutation directly or after conversion to genotoxic metabolite(s).

The test used in this study exposed *S. typhimurium* strain TA100 bacteria to sample water and did not include rat liver S9 activation. Strain TA100 shows a broad range of sensitivity to genotoxic chemicals and is the most useful strain for initial screening. Microsome from rat liver following induction of xenobiotic metabolizing enzymes can increase the range of sensitivity to chemicals that are not themselves mutagenic, but that can be metabolized to mutagenic chemicals by rat liver enzymes. Thus, for the test results presented, only direct acting mutagens, or chemicals that can be metabolized by bacterial enzymes to mutagenic products would be assessed by the Ames assay.

A positive test result is determined through comparison of the number of mutations induced by sample water and the natural background rate of mutation in a laboratory water control. Ames test strains of *S. typhimurium* require histidine in growth media. Mutations are observed when chemicals reverse this condition and allow mutated bacteria to grow without the presence of histidine. Results are presented as the statistical significance of the sample revertants to the number of natural (or wild type) revertants in the control, suggesting whether water samples have a mutagenic effect.

#### 4.1.5 Emission – Excitation Matrix (EEM)

It would be nearly impossible to completely characterize effluent and or natural organic matter at the molecular level with current technology due to the complexity of its origins and constituents. Thus, UV fluorescence EEM spectroscopy can be used to provide gross characterization of organic constituents in water samples. This analytical technique allows indirect measurement of changes in surface water quality as a result of inputs from various sources into the Neuse River basin. Spectra or “maps” are generated in which specific spectral signatures or “fingerprints” of organic matter can be localized.

EEM, or 3D fluorescence, can be used to characterize the organic matter present in waters from diverse sources. When organic matter present in wastewater is excited at a particular wavelength, only part of the organic matter emits light (fluorescence). Fluorescence occurs when a molecule absorbs energy in the form of electromagnetic radiation (ultraviolet and visible light) and re-emits that energy as light. Most molecules do not fluoresce but re-emit the light energy absorbed in the form of motion (kinetic energy) or heat (thermal energy). Therefore, the technique is limited to molecules containing fluorophores (sub-parts of molecules that have the ability to re-emit energy in the form of light). Many naturally-occurring organic compounds (humic and fulvic acids, amino acids, proteins, and microorganisms) and anthropogenic organic compounds fluoresce naturally.

The process of developing EEM maps involves the excitation of water samples at certain wavelengths (200–600 nm); the fluorescence intensity emitted from the samples is collected in a certain range (200–650 nm). The data are plotted as a three-dimensional map: an excitation, emission, and fluorescence-intensity matrix. By this representation, it is possible to localize fluorescence centers related to particular groups of fluorophores, also called fingerprints (i.e. Yan et al., 2000; Baker, 2001; Chen et al., 2003; Christensen et al., 2006; Stedmon and Markager 2000; Sierra et al. 2005). In a typical river water sample, discrete fingerprints have been identified: tryptophan ( $\lambda_{EX}$ , 275;  $\lambda_{EM}$ , 350 nm); fulvic-like compounds ( $\lambda_{EX}$ , 320–340 nm;  $\lambda_{EM}$ , 410–430 nm); and humic-like compounds ( $\lambda_{EX}$ , 370–390 nm;  $\lambda_{EM}$ , 460–480 nm) (Baker, 2001). In addition, it is possible to distinguish different sources such as sewage dominated by tryptophan-like proteins (Baker, 2002).

## 4.2 Selection of Sampling Locations

CDM Smith worked with City staff to identify eight locations which would allow characterization of the baseline water quality in the upper Neuse River between Falls Lake and Goldsboro. These sites represent locations on the Neuse River that are upstream, downstream, and at the Neuse River WWTP discharge. The selected sites are described in **Table 4-5** and shown in **Figure 4-1**.

All locations, except three sites, correspond to existing LNBA or AMS sampling sites to facilitate ease of access and provide for comparison with historical data. Sites C and D were selected for their proximity to the Neuse River WWTP discharge: Site C is in the river, directly at the effluent discharge and Site D is approximately 1.8 miles downstream of the effluent discharge. Site H is near a potential future drinking water intake site for Johnston County.

**Table 4-5. Sampling Locations**

Site ID	Latitude	Longitude	Drainage Area (sq mi)	Description	Monitoring Station
A	35.9408	-78.5801	770	Neuse River at SR 2000 - Falls Dam	AMS J189000
B	35.7266	-78.5139	1,090	Neuse River at SR 2555 Auburn Knightdale Rd	LNBA J4050000
C	35.7233	-78.4778	1,100	At Neuse River WWTP discharge	
D	35.7025	-78.4782	1,100	Neuse River at Mial Plantation Rd	
E	35.6473	-78.4056	1,150	Neuse River at NC42 Clayton	LNBA J4170000; USGS 02087500 (Real-time Streamflow)
F	35.6067	-78.3374	1,170	Neuse River at SR 1908 Fire Dept Wilsons Mills	LNBA J4190000
G	35.5128	-78.3499	1,210	Neuse River at US 70 Smithfield	AMS J4370000
H	35.3560	-78.1795	1,680	Kornegay Farms	

In addition to the Neuse River WWTP, which has a permitted discharge capacity of 75 mgd, two municipal WWTPs (with a combined permitted capacity of 18 mgd) discharge between sites A and B, and five municipal WWTPs (with a combined permitted capacity of 41.6 mgd) discharge between sites G and H. A more detailed map showing the eight sampling locations in relation to the LNBA and AMS sampling sites, permitted NPDES discharge locations and water treatment plant locations is included in Appendix A.

## 4.3 Sampling Frequency, Duration, and Targeted River Flow

Three separate sampling events were included in this study. For each event, all eight locations listed in Table 4-5 were sampled for all the constituents listed in Section 4.1. Sampling events were conducted to target conditions that reflect a worst-case water quality, that is, when concentrations of microbial indicators or trace chemical constituents are anticipated to be the highest. This is expected to occur during low flow conditions.

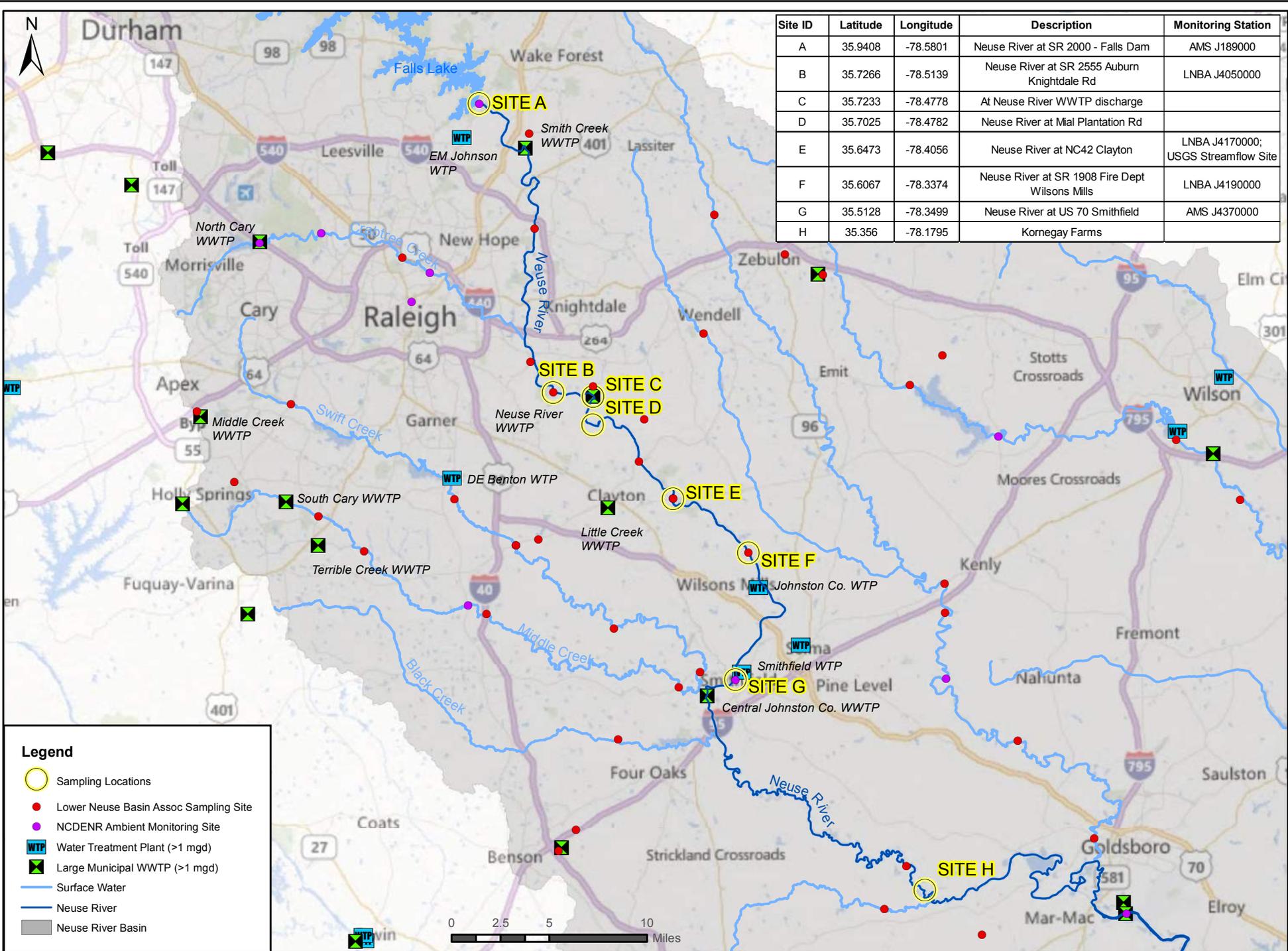


Figure 4-1. Sampling Locations on the Neuse River

Historically, July through mid-November is the lowest flow period in the upper Neuse River, based on data from the USGS stream gauge near Clayton (corresponding to sampling Site E). The 7Q10 (the lowest 7-day average flow that occurs on average once every 10 years) occurs, on average, between August 20th and October 21<sup>st</sup>. Rainfall totals through September 2013 were near historical average for the Raleigh area; therefore, actual 7Q10 conditions were not expected to occur during the sampling; however, the sampling was conducted as close to this period as possible.

Sampling events were conducted on three consecutive weeks in October 2013; sampling for each event required 2 days to complete, as shown in **Table 4-6**. Precipitation and stream flows during the sampling period are provided and discussed in Section 6.1.

**Table 4-6. Sampling Events and Dates in 2013**

	Sampling Event 1	Sampling Event 2	Sampling Event 3
Dates	October 14-15	October 21-22	October 28-29
Total Sites Sampled	8	8	8

## 4.4 Sample type

The portions of the samples that were analyzed for trace chemical constituents listed in Table 4-4 and EEM analysis were filtered prior to analysis, as required by their individual laboratory analysis methods (listed in Section 5). Therefore, particle-associated trace chemical constituents were not analyzed. In a potable reuse scenario, particle-associated compounds are likely to be removed from water by both conventional and advanced treatment systems.

## Section 5

# Neuse River Study Methods

This section covers the methods of sample collection, laboratory and field analysis, and statistical analysis of the results for this study.

### 5.1 Sample Collection

Surface water samples were collected from the Neuse River by CDM Smith and Environment 1, Inc. (Environment 1) located in Greenville, North Carolina. Environment 1 collects monthly samples on behalf of the LNBA from three of the sites (i.e. Sites B, E, and F) that were included as part of this water quality study. The surface water samples were collected on the upstream side of bridge crossings at all of the sites with the exception of Sites C and H. Samples were collected from the concrete effluent discharge outfall at Site C and from the southern bank of the Neuse River at Site H. A photo log showing the upstream view of each site or outfall discharge is provided in **Appendix E**.

Each surface water sample was collected by filling laboratory-sterilized 500 milliliter and 1 liter plastic bottles and transferring the contents to laboratory supplied sample bottles with the exception of water samples collected from Site H. The plastic bottles were placed in a metal bin tethered by rope



**Surface Water Sample Collection Method**

to a reel and lowered just below the river surface. Note that the samples were collected from the same depth that the monthly samples are collected from at the LNBA sites. The metal bin as shown in the picture to the left was specifically designed by Environment 1 for collecting surface water samples from bridge crossings. New plastic bottles were used for each sample location to prevent cross-contamination. Samples from Site H were collected just below the river surface using a plastic dip cup connected to an extension rod as shown in the picture below.



**Site H Sample Collection Method**

Upon collection, samples were immediately placed on ice with the exception of samples collected for the perfluorinated compound analysis. Samples collected for the perfluorinated compound analysis had an ambient temperature requirement. Prior to shipping, the samples were re-iced, secured in coolers, and custody seals were placed on each cooler to prevent tampering with the sample bottles. Standard chain-of-custody procedures were followed to document the handling of the samples. The samples were either shipped to the laboratories via Fed-Ex priority overnight, local courier, or delivered by CDM Smith.

Conventional water quality parameters including pH, temperature, specific conductance, dissolved oxygen, and turbidity were measured at each site using a YSI-556 multi-parameter meter and either a HACH 2100P or Hanna HI 98703 turbidity meter.

## 5.2 Methods by Analyte

**Table 5-1** outlines the project analytes, methods, laboratories, and the standard method detection limits (MDLs) provided by the laboratories. Individual MDLs may vary by sample, depending on dilution, extraction volume, and/or the individual equipment used. For example, a laboratory with more than one mass spectrometer will have an instrument specific MDL for each machine. Individual MDLs are included in results (Section 6) charts.

**Table 5-1. Analytical Methods and standard laboratory MDLs**

Analyte	Analyte Category	Method	Method Detection Limit
1,1,1,2-Tetrachloroethane	VOCs	8260B	0.33 µg/L
1,1,2,2-Tetrachloroethane	VOCs	8260B	0.18 µg/L
1,2,4-Trimethylbenzene	VOCs	8260B	0.33 µg/L
1,4-Dioxane	VOCs	8260B	50 µg/L
17 α-Ethinyl-Estradiol	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	0.9 ng/L
17 beta-Estradiol	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	0.7 ng/L
2,4-D	Pesticides/Herbicides/Fungicides	515.1	0.036 µg/L
Acetaminophen	Pharmaceuticals	1694	20 ng/L
Acetone	VOCs	8260B	5 µg/L
α-Chlordane	Pesticides/Herbicides/Fungicides	525.2	0.040 µg/L
α-HBCDD	Flame retardants	AXYS METHOD MLA-070 Rev 02	1.5 ng/L
Ames Test	Genotoxicity	Muta-Chromo Plate	N/A
Ammonia as N	Conventional	350.1	0.026 mg/L
Androstenedione	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	9.4 ng/L
Anthraquinone	Consumer Products	8270C	5 µg/L
Antimony	Metals	6010C	5.3 µg/L
Arsenic	Metals	6010C	4.6 µg/L
Atenolol	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	1.1 ng/L
Atrazine	Pesticides/Herbicides/Fungicides	525.2	0.021 µg/L
Barium	Metals	6010C	10 µg/L
Bentazon	Pesticides/Herbicides/Fungicides	515.1	0.096 µg/L
Benzene	VOCs	8260B	0.25 µg/L

**Table 5-1. Analytical Methods and standard laboratory MDLs (continued)**

Analyte	Analyte Category	Method	Method Detection Limit
Benzo[a]pyrene	Pesticides/Herbicides/Fungicides	525.2	0.028 µg/L
Beryllium	Metals	6010C	0.2 µg/L
β Stigmastanol	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	18.4 ng/L
β-HBCDD	Flame retardants	AXYS METHOD MLA-070 Rev 02	1.0 ng/L
β-Sitosterol	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	23.3 ng/L
Bisphenol-A	Consumer Products	1694	150 ng/L
Bromate	DBPs	300.1B	2.5 µg/L
Bromide	DBPs	300.1B	4.7 µg/L
Bromodichloromethane	DBPs	524.2	0.1 µg/L
Bromoform	DBPs	524.2	0.39 µg/L
Cadmium	Metals	6010C	2.0 µg/L
Caffeine	Pharmaceuticals	1694	51 ng/L
Camphor	Consumer Products	624	2.8 µg/L
Carbamazepine	Pharmaceuticals	1694	10 ng/L
Carbaryl	Pesticides/Herbicides/Fungicides	531.1	0.31 µg/L
Carbon tetrachloride	VOCs	8260B	0.50 µg/L
Chlorate	DBPs	300.1B	2.1 µg/L
Chlorite	DBPs	300.1B	3.7 µg/L
Chloroform	DBPs	524.2	0.29 µg/L
Cholesterol	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	159 ng/L
Chromium	Metals	6010C	1.2 µg/L
<i>C. perfringens</i>	Microbial Indicator	Membrane Filtration with CCP Agar	1 CFU/100mL
Coliphages, Total	Microbial Indicator	EPA 1602	1 PFU/100mL
Copper	Metals	6010C	1.9 µg/L
Coprostanol	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	19.7 ng/L
Cotinine	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	1.4 ng/L
DEET	Pesticides/Herbicides/Fungicides	1694	25 ng/L

**Table 5-1. Analytical Methods and standard laboratory MDLs (continued)**

Analyte	Analyte Category	Method	Method Detection Limit
Dibromoacetic acid	DBPs	552.2	0.38 µg/L
Dibromochloromethane	DBPs	524.2	0.43 µg/L
Dichloroacetic acid	DBPs	552.2	0.98 µg/L
<i>E. coli</i>	Microbial Indicator	Colilert	1 MPN/100mL
Emission-Excitation Matrix (EEM)	EEM	UV & fluorescent spectroscopy	N/A
Enterococci	Microbial Indicator	Enterolert	1 MPN/100mL
Estrone	Sterols and hormones	AXYS METHOD MLA-068 Rev 03	4.0 ng/L
Ethylbenzene	VOCs	8260B	0.11 µg/L
Fecal coliforms	Microbial Indicator	Colilert	1 MPN/100mL
Field pH	Conventional	YSI 556	N/A
Field Temperature	Conventional	YSI 556	0 °C
Fluoxetine	Pharmaceuticals	1694	25 ng/L
Furosemide	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	42.1 ng/L
γ-Chlordane	Pesticides/Herbicides/Fungicides	525.2	0.043 µg/L
γ-HBCDD	Flame retardants	AXYS METHOD MLA-070 Rev 02	1.4 ng/L
Gemfibrozil	Pharmaceuticals	1694	25 ng/L
Hydrochlorothiazide	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	41.5 ng/L
Ibuprofen	Pharmaceuticals	1694	25 ng/L
Iopromide	Contrast media	1694	51 ng/L
Isopropylbenzene	VOCs	8260B	0.10 µg/L
Lead	Metals	6010C	4.0 µg/L
MCPA	Pesticides/Herbicides/Fungicides	515.1	8.3 µg/L
Meprobamate	Pharmaceuticals	1694	10 ng/L
Methyl tert-butyl ether	VOCs	8260B	0.20 µg/L
Metolachlor	Pesticides/Herbicides/Fungicides	525.2	0.019 µg/L
Metoprolol	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	3.5 ng/L
Monobromoacetic acid	DBPs	552.2	0.75 µg/L
Monochloroacetic acid	DBPs	552.2	0.40 µg/L

**Table 5-1. Analytical Methods and standard laboratory MDLs (continued)**

Analyte	Analyte Category	Method	Method Detection Limit
m-Xylene & p-Xylene	VOCs	8260B	0.20 µg/L
Naphthalene	VOCs	8260B	1.00 µg/L
Naproxen	Pharmaceuticals	1694	52 ng/L
Nitrate Nitrite as N	Conventional	353.2	0.01 mg/L
Nitrogen, Kjeldahl	Conventional	351.2	0.15 mg/L
N-Nitrosodimethylamine	DBPs	GCMSMS_NDMA	0.37 ng/L
Nonylphenol diethoxylate (Technical mixture)	Nonylphenols	WS-MS-0010	1.9 µg/L
Nonylphenol monoethoxylate (Technical mixture)	Nonylphenols	WS-MS-0010	3.0 µg/L
Ofloxacin	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	2 ng/L
Oxycodone	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	1.2 ng/L
Oxygen, Dissolved	Conventional	YSI 556	0.01 mg/L
o-Xylene	VOCs	8260B	0.25 µg/L
para-tert-Octylphenol	Nonylphenols	WS-MS-0010	0.3 µg/L
p-Cresol	Consumer Products	8270C	0.36 µg/L
Pentachlorophenol	Pesticides/Herbicides/Fungicides	515.1	0.037 µg/L
Perfluorobutane sulfonate (PFBS)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluorobutanoic acid (C4)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluorodecanoic acid (C10)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluoroheptanoic acid (C7)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluorohexane sulfonate (PFHS)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluorohexanoic acid (C6)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluorononanoic acid (C9, PFNA)	Perfluorinated Compounds	LC-MS/MS	10 ng/L

**Table 5-1. Analytical Methods and standard laboratory MDLs (continued)**

Analyte	Analyte Category	Method	Method Detection Limit
Perfluorooctane sulfonate (PFOS)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluorooctanoic acid (C8, PFOA)	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Perfluoropentanoic acid	Perfluorinated Compounds	LC-MS/MS	10 ng/L
Phosphorus	Conventional	365.4	0.041 mg/L
p-Nonylphenol (Technical mixture)	Nonylphenols	WS-MS-0010	1.5 µg/L
Primidone	Pharmaceuticals	1694	260 ng/L
River flow, mean	Conventional	Flowmeter	N/A
Salicylic Acid	Consumer Products	1694	50 ng/L
Selenium	Metals	6010C	6.4 µg/L
Sertraline	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	0.6 ng/L
Simazine	Pesticides/Herbicides/Fungicides	525.2	0.034 µg/L
Specific Conductance	Conventional	YSI 556	1 µmhos/cm
Sucralose	Wastewater tracer	1694	500 ng/L
Sulfamethoxazole	Pharmaceuticals	1694	10 ng/L
tert-Butyl alcohol	VOCs	8260B	2.60 µg/L
Tetrachloroethene	VOCs	8260B	0.15 µg/L
Thallium	Metals	6010C	8.8 µg/L
Toluene	VOCs	8260B	0.33 µg/L
Total Organic Carbon	Conventional	415.1	0.5 mg/L
Total Suspended Solids	Conventional	160.2	5 mg/L
Trichloroacetic acid	DBPs	552.2	0.38 µg/L
Triclosan	Consumer Products	1694	50 ng/L
Trimethoprim	Pharmaceuticals	1694	10 ng/L
Tris(2-chloroethyl)phosphate	Flame retardants	1694	50 ng/L
Turbidity	Conventional	Turbidity meter	0.1 NTU
Valsartan	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	4.5 ng/L
Verapamil	Pharmaceuticals	AXYS METHOD MLA-075 Rev 05	0.1 ng/L
Zinc	Metals	6010C	8.7 µg/L

## 5.3 Method Descriptions

The following provide a brief overview of some of the non-standard methods of analysis. Refer to EPA guidance documents and *Standard Methods for the Examination of Water & Wastewater* for details on methods not covered below.

### 5.3.1 Ames Test

Samples were evaluated for potential presence of mutagenic materials by the Muta-Chromo Plate™ Kit (EBPI, Ontario, Canada). The kit utilizes the principles of the AMES reverse mutation test but has the added advantages of being more sensitive due to the number of test wells and accommodating to larger test sample volume. The test was conducted utilizing Salmonella strain TA100 that is sensitive to base-pair substitution mutations, but not with the S9 activation enzyme.

### 5.3.2 *C. Perfringens*

*C. perfringens* bacteria were enumerated by a standard membrane filtration technique. Duplicate 10 ml and 100 ml sample aliquots were filtered, and the filters were placed in petri dishes containing CP ChromoSelect agar (Fluka). The dishes were incubated overnight in an anaerobic atmosphere at 44.5°C. Green colonies were counted as *C. perfringens*. Concentrations were calculated as colony-forming units (cfu) per 100 ml of water sample.

### 5.3.3 *E. Coli*, Fecal Coliforms, and Enterococci

The fecal coliform, *E. coli*, and enterococci enumeration assays were performed using the US EPA-approved IDEXX defined substrate Colilert and Enterolert Quanti-Tray system. Sample aliquots (100 ml) were poured into sterile sample bottles containing sodium thiosulfate to neutralize any residual chlorine. Either Colilert or Enterolert reagent was dissolved in the sample. The mixtures were poured into Quanti-Tray/2000 and sealed shut.

Sample trays containing Colilert reagent were incubated at 37°C for four hours to enhance recovery of injured coliform bacteria, then transferred to 44.5° for 20 hours. Yellow tray compartments were counted as positive for fecal coliform bacteria, and compartments which exhibited fluorescence when exposed to 365 nanometer ultra-violet light were counted as positive for *E. coli*.

Sample trays containing Enterolert reagent were incubated at 41.5°C for 24 hours. Tray compartments which exhibited fluorescence when exposed to 365 nm light were counted as positive for enterococci.

Concentrations of fecal coliforms, *E. coli* and enterococci were determined using the IDEXX Quanti-Tray/2000 Most Probable Number (MPN) table, which yields bacterial concentration estimates as MPN per 100 ml of water sample.

### 5.3.4 Emission Excitation Matrix (EEM)

Samples were analyzed by EnviroChem Services in conjunction with the Chemistry Department at Tennessee Technological University (TTU); TTU performed spectroscopic analyses. Samples were passed through 0.45µ filters with no additives. UV-visible and fluorescence spectra were obtained for each sample. Second-order Rayleigh scattering was removed instrumentally.

Data were analyzed by Dr. Martha J.M. Wells, Ph.D., EnviroChem Services. The analyses included correcting for the Raman spectrum of water and for primary and secondary inner filtering in the fluorescence spectra. Graphical interpretation of the fluorescence data were prepared in three formats: 1) Three-dimensional (3D) fluorescence spectra, also referred to as EEM spectra 2) two-dimensional (2D) spectra prepared at either constant excitation wavelength or constant emission wavelength; and 3) one-dimensional (1D) data derived from specific x,y data points represented by excitation/emission wavelength pairs. Statistical analysis of variance by the Duncan's Separation of Means test was performed using the Statistical Analysis System® (SAS).

### 5.3.5 HBCD

Axys Analytical Laboratories used internal method MLA-070 for the analysis of HBCDD. Samples were spiked with <sup>13</sup>C-labelled surrogate standards prior to extraction. Samples with greater than 1% suspended solids were centrifuged prior to solid and liquid phase extraction with dichloromethane. Samples with less than 1% suspended solids went through liquid-liquid extraction with dichloromethane. Sample analysis was completed with a high performance liquid chromatography (HPLC) reversed phase C18 column using a solvent gradient. The column is coupled to a triple quadrupole mass spectrometer run at unit mass resolution in the Multiple Reaction Monitoring (MRM) mode. Instrument calibration is performed using a series of calibration solutions (7 points) covering the concentrations (1 ng/mL - 300 ng/mL) specific for the individual compounds of interest.

### 5.3.6 N-Nitrosodimethylamine

Nitrosamines (NSAs) were determined by gas chromatography coupled with chemical ionization tandem mass spectrometric detection (GC/CI/MS/MS) by Test America. Matrix specific extraction procedures are applied in conjunction with isotope dilution for quantitation. Two deuterium-labeled NSAs representing key target analytes are added to each sample prior to extraction and carried through the entire extraction, extract clean-up, and analytical process. This application of the isotope dilution technique yields highly accurate and recovery corrected results for each corresponding NSA target analyte. NSA target analytes without a corresponding deuterium-labeled analog are quantitated using the internal standard technique. The recovery of the deuterium-labeled nitrosamines is also calculated and reported.

A one liter aliquot of aqueous sample is typically extracted with dichloromethane using a separatory funnel extraction (SFE), while a 10 gram aliquot of solid sample is typically extracted with dichloromethane using a sonication extraction procedure. After extraction, resulting extracts are concentrated and reduced to final volume of 500 ul.

A 20 ul aliquot of sample extract is injected into the GC/CI/MS/S instrument operated in chemical ionization precursor/product mass transition mode. The GCMS is calibrated with a 5 point calibration curve containing each of the two deuterium-labeled compounds and their corresponding native analogs, along with a recovery standard and 5 additional NSA analytes. Target analytes can be reported as positive results down to the established reporting limit, with 'J' flagged results reported as estimated down to the MDL value.

### 5.3.7 Nonylphenols

Nonylphenols (NPs), nonylphenol ethoxylates (NPEs), bisphenol-A (BPA) and octylphenols (OPs) are determined by gas chromatography with mass spectrometric detection utilizing selected ion monitoring (GC/MS-SIM), similar to determination of semivolatile compounds by SW846 Method 8270. These compounds are sometimes referred to collectively as alkylphenols (APs) and alkylphenol

ethoxylates (APEs). Matrix specific extraction procedures are applied in conjunction with quantitation by the internal standard technique. Two straight-chain AP/APEs not typically present in commercial mixtures or the environment are added to each sample prior to extraction as extraction surrogates. BPA can also be determined by liquid chromatography tandem mass spectrometry (LC-MS/MS) using the isotope dilution technique if additional sensitivity and/or selectivity are required (reference method ASTM D7475).

A one liter aliquot of aqueous sample is typically extracted with dichloromethane using separatory funnel extraction, while a 10 gram aliquot of solid sample is typically extracted with dichloromethane/acetone using a microwave assisted extraction procedure. After extraction, soil/sediment extracts are reconstituted in water and cleaned up using solid phase extraction (SPE) cartridges, then concentrated and reduced to final volume of 500 ul.

A 1 or 2 µl aliquot of sample extract is injected into the GC/MS instrument operated in selected ion monitoring (SIM) mode. The GC/MS is calibrated with a 5 point calibration curve containing each of the two straight-chain surrogate compounds, target analytes as technical mixtures, and internal standards. A total of 3 AP and 2 APE parameters are calibrated and reported. Note that AP and APE technical mixtures typically contain multiple isomeric species with a variety of branched alkyl moieties of the same carbon number (8 or 9) substituted on the phenolic ring. Target analytes can be reported as positive results down to the established reporting limit, with 'J' flagged results reported as estimated down to the MDL value.

### 5.3.8 Perfluorinated Compounds

Perfluorinated compounds (PFCs) were analyzed by Dr. Knappe's lab at the North Carolina State University. Concentrations of the PFCs listed were determined by LC-MS/MS. An Agilent 1100 Series LC pump and PE Sciex API 3000 LC-MS/MS system equipped with a FluoroFlash HPLC column (4.6 mm i.d. x 50 mm, Fluorous Technologies Inc.) was used for PFC separation. The gradient method was used to elute PFCs from the HPLC column. Mobile phase A was 2 mM ammonium acetate in deionized water with 5% methanol. Mobile Phase B was 2 mM ammonium acetate in methanol with 5% deionized water.

### 5.3.9 Pharmaceuticals & Personal Care Products<sup>1</sup>

Pharmaceutical and personal care products were analyzed by Test America and Axys Analytical Laboratories. PPCPs are determined by LC-MS/MS. Matrix specific extraction procedures are applied in conjunction with isotope dilution for quantitation. Up to forty-three C13- or H2-labeled compounds spanning the functional groups and chemical classes of environmentally significant PPCPs are added to each sample prior to extraction and carried through the entire extraction, extract clean-up, and analytical process. This application of the isotope dilution technique yields highly accurate and recovery corrected results for each corresponding PPCP target analyte. PPCP target analytes without a corresponding labeled analog are quantitated using the internal standard technique. The recovery of the labeled compounds is also calculated and reported.

A one liter aliquot of aqueous sample is typically extracted with a SPE procedure, while a 2 gram aliquot of solid sample is typically extracted with water/acetonitrile and additional solvents using a sequential microwave extraction procedure. After extraction, resulting extracts are centrifuged,

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<sup>1</sup> The method described here was also used for the wastewater tracer sucralose, the pesticide DEET, contrast media iopromide, flame retardant TCEP, and consumer products.

concentrated, solvent-exchanged, and reduced to final volume of 1 ml. Additional analytical fractions are prepared from the initial extract if an extended analyte list is required.

A 10  $\mu$ l aliquot of sample extract is injected into the LC-MS/MS instrument operated in parent/daughter transition mode. The LC-MS/MS is calibrated with a multi-point calibration curve containing each of the forty-three isotopically labeled compounds and their corresponding native analogs, along with several labeled recovery standards.

### 5.3.10 Sterols & Hormones

Axys Analytical Laboratories used internal method MLA-068 for analysis of sterols and hormones. Surface waters filtrate and solid phases are extracted separately and combined after extraction to result in a single analysis. Aqueous sample and the diluted extracts of the solids are cleaned up by solid phase extraction on hydrophilic lipophilic balanced cartridges, then dried using sodium sulphate, and derivitized with N,O-Bis(trimethylsilyl)trifluoroacetamide (BSTFA) prior to analysis. Instrumental analysis of the final derivitized extracts is performed by capillary gas chromatography and either low-resolution (LRMS) or high-resolution (HRMS) mass spectrometric detection. The extract is injected by split/splitless injection on a high-resolution gas chromatograph (HRGC) equipped with a Restek RTx-5 capillary column (30 m, 0.25 mm i.d., 0.25  $\mu$ m film thickness). The LRMS is operated at unit mass resolution in the EI mode using multiple ion detection (MID). The HRMS is operated at a static (ratio of 5000) mass resolution in the electron ionization (EI) mode using Voltage SIR detection. Two characteristic ions for each target analyte and surrogate standard are acquired. Initial calibration is performed using a multi-point series of derivitized calibration solutions that encompass the working concentration range. Calibration is verified at least once every twelve hours by analysis of a mid-level calibration solution.

## 5.4 Statistical Methods Used

Correlations and analysis of variance between parameters were calculated with MiniTAB statistical software, Version 16. Conventional and chemical results were analyzed for correlations with condition parameters such as time of travel, stream flow, sample event, and presence of wastewater, using sucralose as a tracer. Non-detects were included in all calculations at the sample MDL concentration. Absolute values of Pearson correlations greater than 0.60 with p-values of less than 0.10 were a preliminary screening tool. A strong correlation was defined as Pearson's correlation  $>0.90$  and a coefficient of determination ( $r^2$  value) of  $>0.8$ .

Analysis of variance (ANOVA) with Tukey's test was used for separation of means at a 95% confidence interval. This method compares all possible means based on the studentized range distribution (q). In essence, it tells whether there can be 95% confidence that two means are significantly different. Conventional and chemical results were analyzed for variance based on location and event. Results were not analyzed for variance by time of travel or stream flow since the values are not independent of the sample location. Non-detects were included in all calculations at the sample MDL concentration.

## 5.5 Considerations for Data Interpretation

The complex analytical methods and the very low concentrations that are being evaluated in this study present special issues for some analytes. There were a number of issues with data that should be considered during interpretation of the results are described below.

- **Diltiazam:** Diltiazam results were not received at the time this report was published. An addendum will be provided upon receipt of the laboratory results.
- **Sucralose:** Two extractions were completed with the water samples. The initial extraction had poor isotope dilution analysis recovery and a signal to noise ratio of less than 10:1. This indicates matrix interference from the water samples, and results from this run are considered estimates. The second extraction was a smaller volume to remove this effect, but the detection limit was raised to 10,000 ng/L, and the sample hold time was exceeded on some of the samples. Results from both runs are reported, and the retained values are noted in the results section.
- **Acetaminophen:** The isotope dilution analyte (IDA) recovery associated with acetaminophen was below the method recommended limit for all samples. Generally, data quality is not considered affected if the IDA signal-to-noise ratio is greater than 10:1, which is achieved for this IDA in the samples. All results were reported and retained.
- **Sulfamethoxazole:** The IDA recovery associated with sulfamethoxazole in the following samples is below the method recommended limit: Site C Event 1, Site D Event 1, Site A Event 2, Site B Event, Site D Event 2, Site E Event 2, Site G Event 2, Site H Event 2, Site A Event 3, Site D Event 3, Site F Event 3, Site G Event 3, and site H Event 3. Generally, data quality is not considered affected if the IDA signal-to-noise ratio is greater than 10:1, which is achieved for this IDA in the samples. All results were reported and retained.
- **Iopromide:** The IDA recovery associated with iopromide in the following samples is below the method recommended limit: Site C Event 2. Generally, data quality is not considered affected if the IDA signal-to-noise ratio is greater than 10:1, which is achieved for this IDA in the samples.
- **Method 515.1:** Sample from Site A Event 3 contained residual chlorine upon receipt. The sample was extracted and analyzed. 2,4-D, bentazon, MCPA, and pentachlorophenol results may be biased low.

## Section 6

# Neuse River Study Results and Discussion

This section presents a summary of the results obtained in this study as well as a discussion of the findings.

## 6.1 Presentation of results and discussion

### 6.1.1 Organization of results and discussion

Sections 6.2 through 6.19 present results of sample analysis as well as conditions of the Neuse River WWTP effluent during this study. In each section, the results are presented first in a “Results” subsection, followed by a discussion of those results in an “Interpretation” subsection. Where figures are presented, the letters A through H indicate the sampling site (corresponding to site locations given in Figure 4-1 and shown on a map in Appendix A) and numbers 1 through 3 indicate the sampling event (event 1 on October 14<sup>th</sup> -15<sup>th</sup>, event 2 on October 21<sup>st</sup> -22<sup>nd</sup>, and event 3 on October 28<sup>th</sup> -29<sup>th</sup>, 2013). **Table 6-8** at the end of this section presents the average values by parameter for each of the eight sample locations across the three sampling events, as well as the average and maximum values for across all locations and events samples for a given parameter. To calculate averages, if a sample was non-detect, the method detection limit was used in the calculation along with detected values. Detailed results in tabular and graphical format are provided in **Appendix F**.

The sampling results are presented following the order in **Table 6-1**.

### 6.1.2 Statistical Tests

As described in Section 5.4, conventional and chemical results were analyzed for correlations with parameters such as time of travel, stream flow, sample event, and presence of wastewater, using sucralose as a tracer. Absolute values of Pearson correlations greater than 0.60 with p-values of less than 0.10 were used as a preliminary screening tool. Strong correlations were defined as a Pearson’s value greater than 0.9 and coefficient of determination ( $r^2$ ) value greater than 0.8. To evaluate whether the averages between two parameters were different (for example, comparing site A to site B across all three events), Tukey’s method for analysis of variance (ANOVA) was used with a 95 percent confidence interval.

### 6.1.3 Data Quality

The fact that the reporting limits presented in this study are generally similar to (or lower than) the reporting limits published in the literature gives confidence in the present study that the methods used were capable of detecting compounds at extremely low concentrations. There were no significant quality issues with the data. Minor data quality issues are noted in the discussion of individual constituents.

### 6.1.4 Wastewater Tracer

In this study, sucralose was used as an indicator parameter to screen for correlations between the presence of wastewater and other parameters. Sucralose results are presented in Section 6.4.

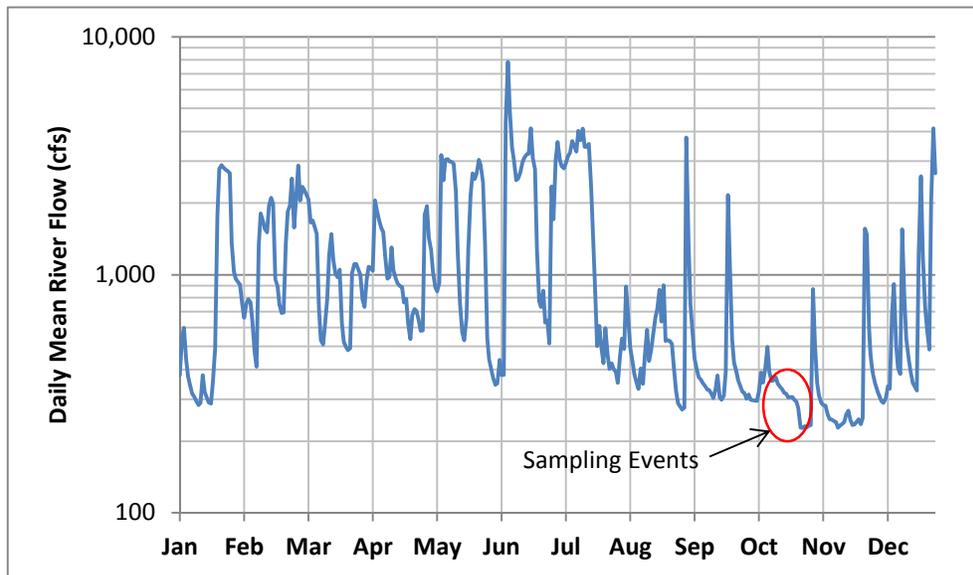
**Table 6-1. Results Presented and Discussed, by Section**

Section	Category	Constituent(s)	Analysis of	
			WWTP Effluent	Neuse River
6.2	General river conditions	River flow, precipitation, time of travel		X
6.3	General effluent water quality	Flow, pH, temperature, DO, specific conductance, turbidity, TSS, ammonia, nitrate-nitrite, TKN, fecal coliforms	X	
6.4	Wastewater tracer	Sucralose		X
6.5	Conventional parameters	DO, specific conductance, pH, temperature, turbidity, ammonia, nitrate-nitrite, TKN, phosphorus, TSS, TOC		X
6.6	Microbial indicators	<i>C. perfringens</i> , male-specific coliphage, somatic coliphage, <i>E. coli</i> , enterococci, fecal coliforms		X
6.7	Pharmaceuticals	Acetaminophen, atenolol, caffeine, carbamazepine, cotinine, diltiazem, fluoxetine, furosemide, gemfibrozil, hydrochlorothiazide, ibuprofen, meprobamate, metoprolol, naproxen, ofloxacin, oxycodone, primidone, sertraline, sulfamethoxazole, trimethoprim, valsartan, verapamil		X
6.8	Sterols and hormones	17- $\alpha$ -ethynylestradiol, 17- $\beta$ estradiol, androstenedione, $\beta$ -stigmastanol, $\beta$ -sitosterol, cholesterol, coprostanol, estrone		X
6.9	Flame retardants	HBCD, TCEP		X
6.10	Perfluorinated compounds	C4, C5, C6, C7, PFOA, C9, C10, PFBS, PFHS, PFOS		X
6.11	Nonylphenols	Nonylphenol diethoxylate, nonylphenol monoethoxylate, para-tert-octylphenol, p-nonylphenol		X
6.12	Disinfection byproducts (DBPs)	Bromate, bromide, chlorate, chlorite, HAAs, NDMA, THMs		X
6.13	Volatile organic compounds (VOCs)	1,1,1,2-tetrachloroethane, 1,1,2,2-tetrachloroethane, 1,2,4-trimethylbenzene, 1,4-dioxane, acetone, benzene, carbon tetrachloride, ethylbenzene, isopropylbenzene, MTBE, m-xylene & p-Xylene, naphthalene, o-Xylene, tert-butyl alcohol, tetrachloroethene (perc), toluene		X
6.14	Metals	Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, selenium, thallium, zinc		X
6.15	Pesticides, herbicides, fungicides	2,4-D, atrazine, bentazon, benzo(a)pyrene, carbaryl, chlordane, DEET, MCPA, metolachlor, PCP, simazine		X
6.16	Consumer products and manufacturing additives	Anthraquinone, BPA, camphor, p-cresol, salicylic acid, triclosan, triphenylphosphate		X
6.17	Contrast media	Iopromide		X
6.18	Genotoxicity	Ames Test		X
6.19	EEM	Bulk organic matter		X

## 6.2 River Flow, Precipitation, and Time of Travel

### 6.2.1 Results

This study targeted sampling during low flow river conditions because concentrations of microbial indicators or trace chemical constituents are anticipated to be the highest during low flows, when the Neuse River WWTP effluent contribution to the river flow is highest. In other words, low flow river condition represents a worst case scenario with respect to wastewater influence. **Figure 6-1** shows the daily mean river flow during 2013 at the USGS Station 02087500 (site E), which is located near the town of Clayton. The three sampling events in October occurred near the lowest flows during the year.



**Figure 6.1. Daily River Flow at USGS Station 02087500 (Site E) during 2013.**

**Figure 6-2** shows river flows at site E and precipitation at a nearby USGS station during October 2013. Some precipitation occurred during the week prior to the first sampling event. A total of 0.58 inches of rainfall occurred on October 10<sup>th</sup> and a small corresponding spike in river flow was observed. No significant precipitation was recorded prior to sampling events 2 or 3. Total precipitation for the month was 1.1 inches, which is below the historical average precipitation of 3.5 inches for October.

The OASIS model of the Neuse River basin was used to estimate the time of travel between sample sites and the respective river flows at each site for a given condition. **Figure 6-3** shows the model-predicted river flow and time of travel from site A (upstream) through site H (downstream) for 25<sup>th</sup> and 50<sup>th</sup> percentile flow conditions. The travel time for 10<sup>th</sup> percentile flow conditions is similar to that for the 25<sup>th</sup> percentile conditions. Total travel time from site A to site H is approximately 3 days under normal (50<sup>th</sup> percentile) flow conditions and approximately 4 days under low (10<sup>th</sup> percentile) flow conditions.

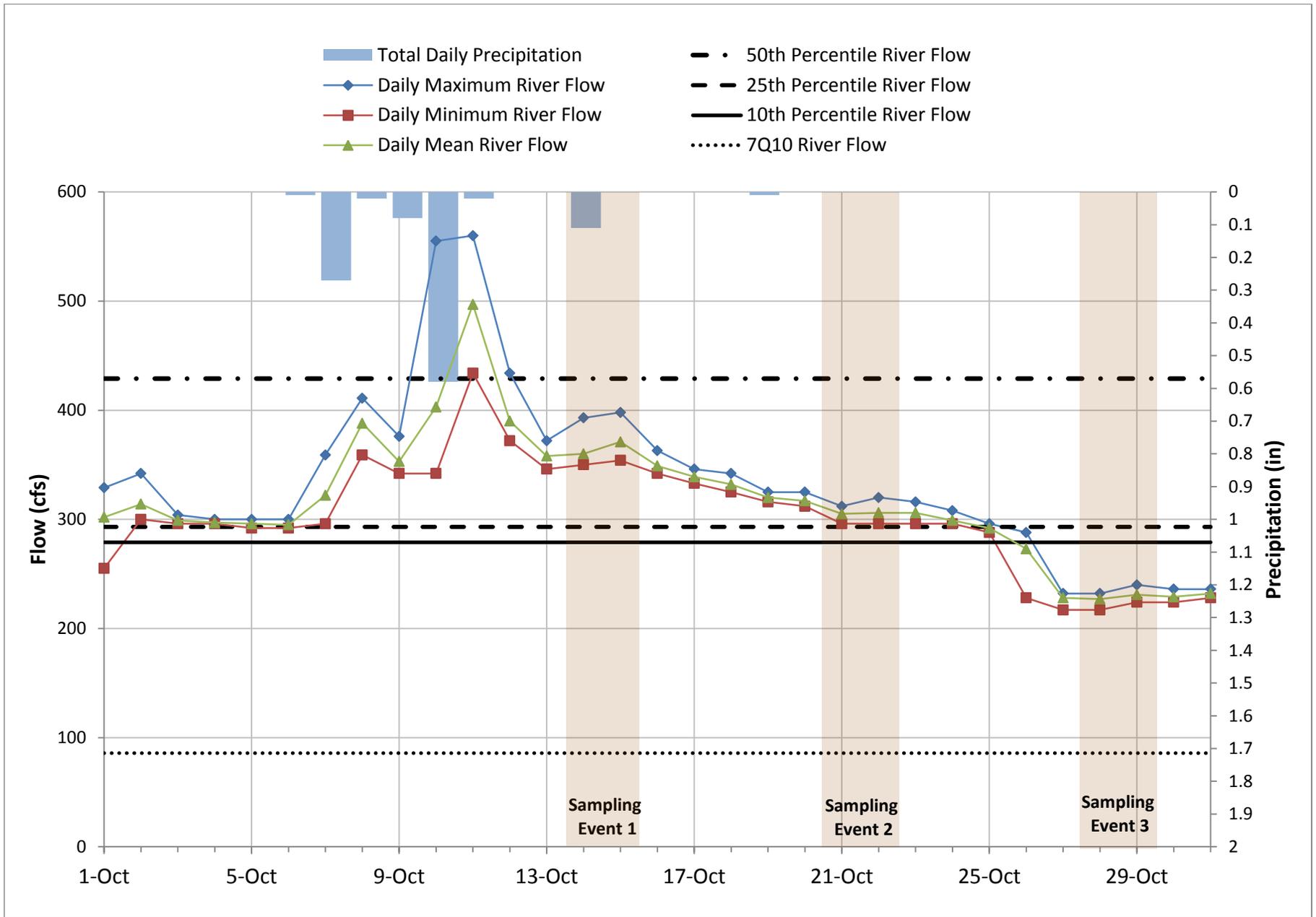


Figure 6-2. River Flow (USGS Station 02087500 at Site E) and Precipitation (USGS Station 02087359 on Walnut Creek) During Sampling Events

The Crabtree Creek tributary flow enters the river between sites A and B. Increase in flow between sites B and D is due to the discharge from the Neuse River WWTP. Several tributaries, including Swift Creek, Middle Creek, and Black Creek, enter the river between sites G and H, contributing to the significant flow increase between those two sites. There are two additional municipal WWTPs that discharge between sites A and B, and five municipal WWTPs that discharge between sites G and H. However, the combined permitted discharge flows for these facilities are less than two percent of the river flow (during low flow conditions) at the respective locations along the river. As a comparison, the Neuse River WWTP permitted discharge is approximately 40 percent of the river flow (during low flow conditions) at the discharge location.

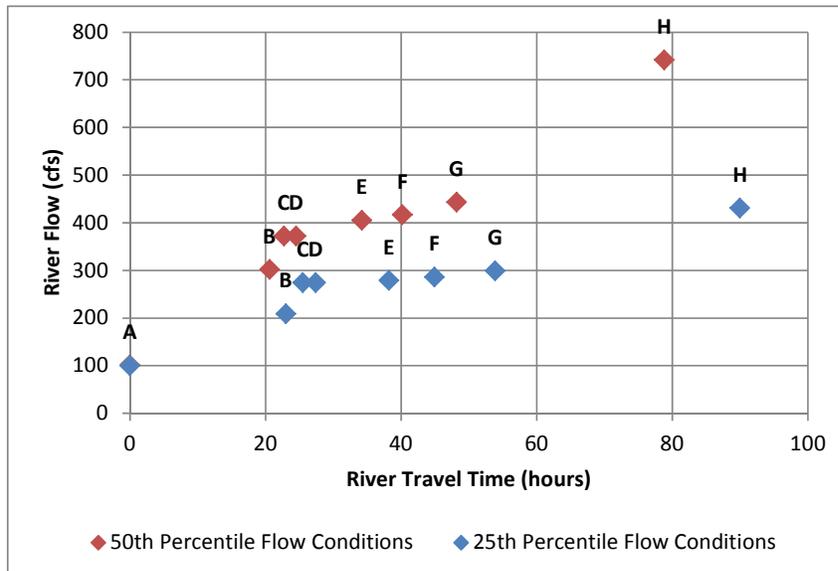


Figure 6.3. Modeled Time of Travel and River Flow at Sampling Sites.

### 6.2.2 Interpretation

For the first sampling event, river flow at the USGS station at site E was between the 25<sup>th</sup> and 50<sup>th</sup> percentile of historical flow (Figure 6-2). River flow was near the 25<sup>th</sup> percentile for the second sampling event, and at below the 10<sup>th</sup> percentile for the third sampling event. The third sampling event occurred during the lowest river flows of the year. Sampling results represent below normal flow conditions in the Neuse River.

The river travel time between the Neuse River WWTP discharge (site C) and site H was in the range of 2.5 to 3 days during the sampling events. The distance between these two sites is approximately 53 river miles. The samples from all eight sites were collected over a two-day period for each sampling event. While each event represents roughly the same ambient conditions in the river, the sampling did not attempt to match the river travel time to follow a single 'slug' of water from site A through site H.

## 6.3 Water Quality of the Neuse River WWTP Effluent During Sampling

### 6.3.1 Results

The effluent flow from the Neuse River WWTP was fairly consistent over the three sampling events. **Table 6-2** lists average flow and other constituents measured in the WWTP effluent, as reported in the plant's discharge monitoring reports (DMRs). The values reported in the table are an average of daily samples over the two days of each sampling event. It should be noted that all of the samples collected for this study are grab samples. Therefore, samples at site C (river sample located at the effluent discharge) may not directly correspond with the average effluent measurements in Table 6-2 because effluent discharge may fluctuate over the course of the day.

**Table 6-2. Neuse River WWTP Average Effluent Characteristics During Sampling Events**

Constituent	NPDES Permit Effluent Limitations		WWTP Effluent Characteristics During Present Study		
	Monthly Average	Weekly Average	Event 1 Oct 14/15	Event 2 Oct 21/22	Event 3 Oct 28/29
Flow (mgd)	75	-	43	39	40
Flow (cfs)	116	-	66	61	61
pH (SU)	6.0<pH<9.0		7.0	7.0	7.0
Temperature (°C)	-	-	24.2	23.0	22.5
Oxygen, Dissolved (mg/L)	-	-	6.3	6.3	6.7
Specific Conductance (µmhos/cm)	-	-	667	638	493
Turbidity (NTU)	-	-	0.8	0.7	0.7
Total Suspended Solids (mg/L)	30.0	45.0	ND (2.5)	ND (2.5)	ND (2.5)
Ammonia as N (mg/L) (summer)	2.0	6.0	ND (0.10)	0.11	ND (0.10)
Nitrate Nitrite as N (mg/L)	-	-	4.27	0.93	0.79
Nitrogen, Kjeldahl (mg/L)	-	-	1.13	0.92	0.63
Fecal coliforms (MPN/100 mL)	200	400	12	3	4

**Notes:**

ND = non-detect; method reporting limit shown in parenthesis

### 6.3.2 Interpretation

The WWTP effluent characteristics for permitted parameters (flow, pH, TSS, ammonia, and fecal coliforms) were lower than or within appropriate ranges specified by the NPDES limits (monthly or weekly averages).

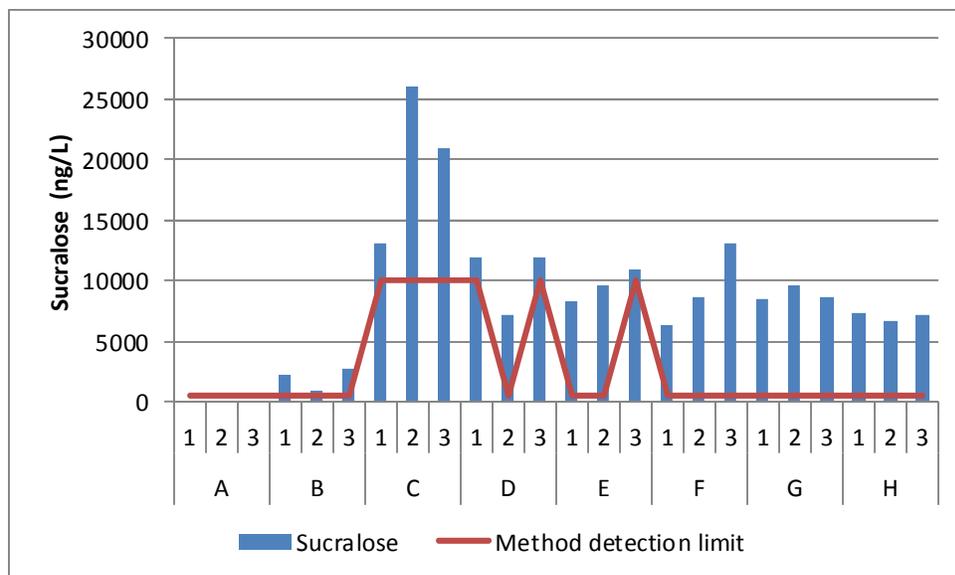
## 6.4 Wastewater Tracer Sucralose

### 6.4.1 Results

Sucralose is introduced into the waste stream by ingestion and excretion of artificial sweeteners. Because the compound is not naturally occurring or removed by most wastewater treatment plants, it

is frequently used as an indicator of wastewater in surface waters. The detected concentrations of sucralose are presented in **Figure 6-4**.

As noted in Section 5.5, there was a data quality issue with sucralose extraction. The initial extraction of sucralose had poor recovery of the spiked isotope during dilution analysis and an instrument signal to noise ratio of less than 10:1. This indicates matrix interference from the water samples, and results from this run are considered estimates. Therefore, a second extraction was conducted, which was done past the designated hold time for the method for the samples taken during events 1 and 2, but within the hold time for samples taken during event 3. The second extraction was conducted with a smaller volume to remove the matrix interference, which resulted in a method detection limit that was twenty times higher. Because the compound is relatively stable, we elected to retain some of the exceeded sample results. Retained data points are bolded in **Table 6-3**. Estimated results under the detection limit of the second extraction and detects in the second extraction were retained.



**Figure 6-4. Sucralose Concentrations in Neuse River Samples. (MDL varies based on the volume of extraction.)**

## 6.4.2 Interpretation

Site A was the only sample location with no detections of sucralose. The highest levels were observed at site C, as expected. Mean results of all three samples at site C were significantly higher than any other location.

## 6.5 Conventional Parameters (Neuse River Samples)

### 6.5.1 Results

The observed pH, temperature, conductivity, turbidity, TSS, ammonia, nitrate and nitrite, TKN, and phosphorus of river samples are presented in **Figures 6-5** through **6-15**, respectively. The North Carolina surface water quality standards (NC SWS) for pH, turbidity, and dissolved oxygen are indicated on the appropriate graphs.

**Table 6-3. Wastewater Tracer Results**

Analyte	Site A						Site B					
	Event 1		Event 2		Event 3		Event 1		Event 2		Event 3	
Sucralose*	<b>520</b>	ND	<b>500</b>	ND	<b>510</b>	ND	<b>2200</b>	E	<b>920</b>		<b>2800</b>	E
Sucralose	10000	ND, H	10000	ND, H	10000	ND	10000	ND, H	10000	ND, H	10000	ND
Analyte	Site C						Site D					
	Event 1		Event 2		Event 3		Event 1		Event 2		Event 3	
Sucralose*	16000	E	27000	E	16000	E	7300	E	<b>7200</b>	E	10000	E
Sucralose	<b>13000</b>	H	<b>26000</b>	H	<b>21000</b>		<b>12000</b>	H	10000	ND, H	<b>12000</b>	
Analyte	Site E						Site F					
	Event 1		Event 2		Event 3		Event 1		Event 2		Event 3	
Sucralose*	<b>8400</b>	E	<b>9700</b>	E	13000	E	<b>6300</b>	E	<b>8600</b>	E	<b>13000</b>	E
Sucralose	10000	ND, H	10000	ND, H	<b>11000</b>		10000	ND, H	10000	ND, H	10000	ND
Analyte	Site G						Site H					
	Event 1		Event 2		Event 3		Event 1		Event 2		Event 3	
Sucralose*	<b>8500</b>	E	<b>9600</b>	E	<b>8700</b>	E	<b>7400</b>	E	<b>6700</b>	E	<b>7200</b>	E
Sucralose	10000	ND H	10000	ND H	10000	ND	10000	ND H	10000	ND, H	10000	ND

**Notes:**

All values in bold retained for calculations

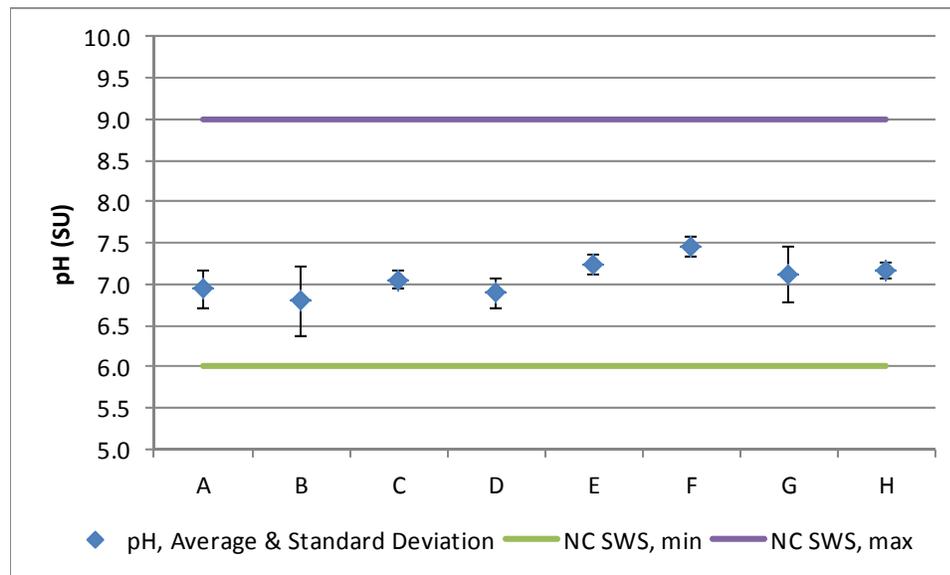
All results in ng/L

E = Result higher than calibrated range

H = Hold time exceeded

ND = Non-detect

\* = Samples had poor isotope dilution analysis recovery and signal to noise ratio less than 10:1, results are estimated



**Figure 6-5. Average pH of Neuse River Samples**

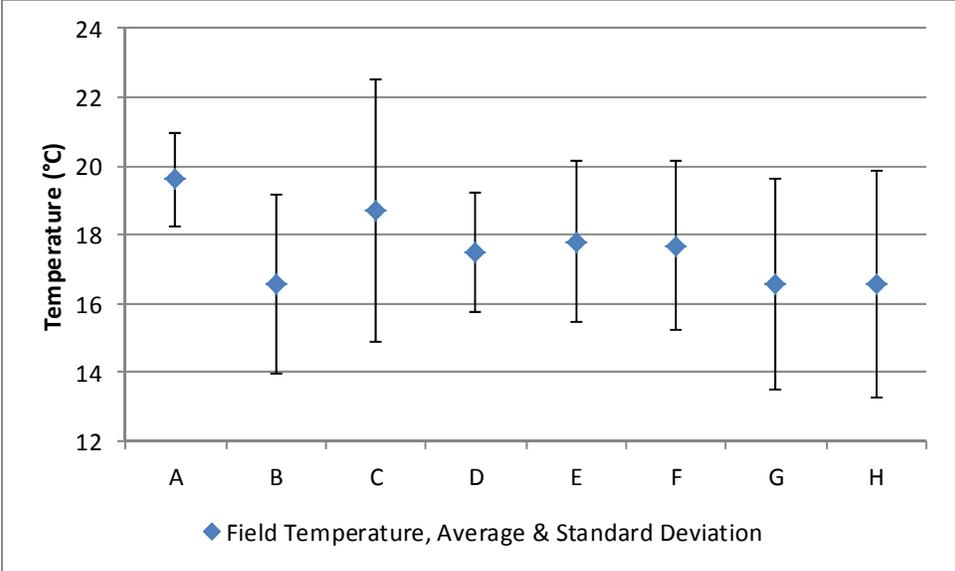


Figure 6-6a. Average Temperature of Neuse River Samples

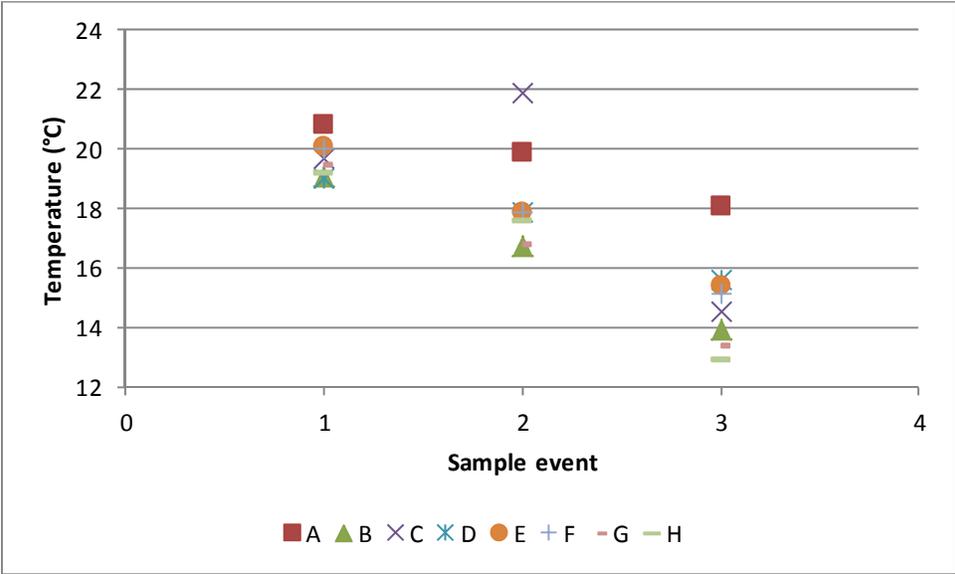


Figure 6-6b Temperature Fluctuation over the Sample Events

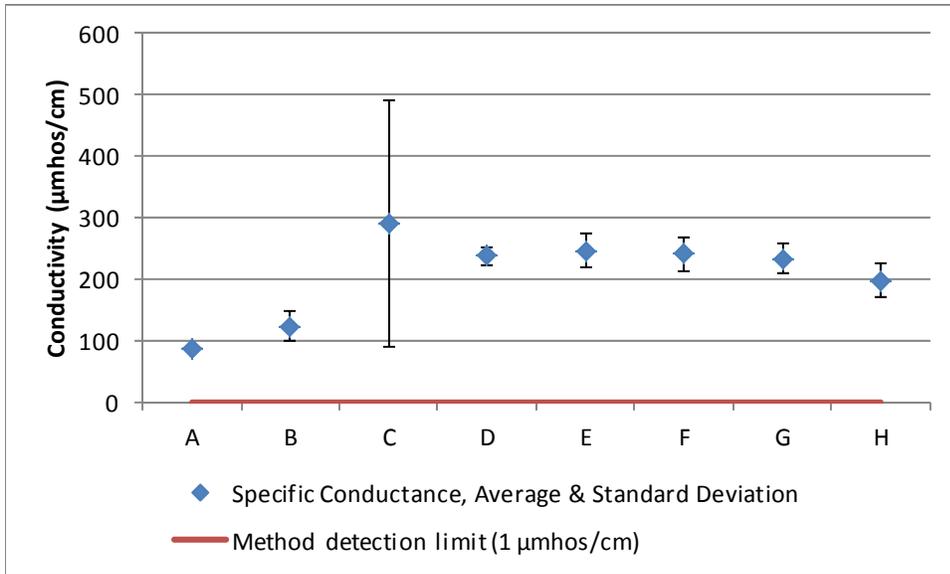


Figure 6-7. Average Conductivity of Neuse River Samples

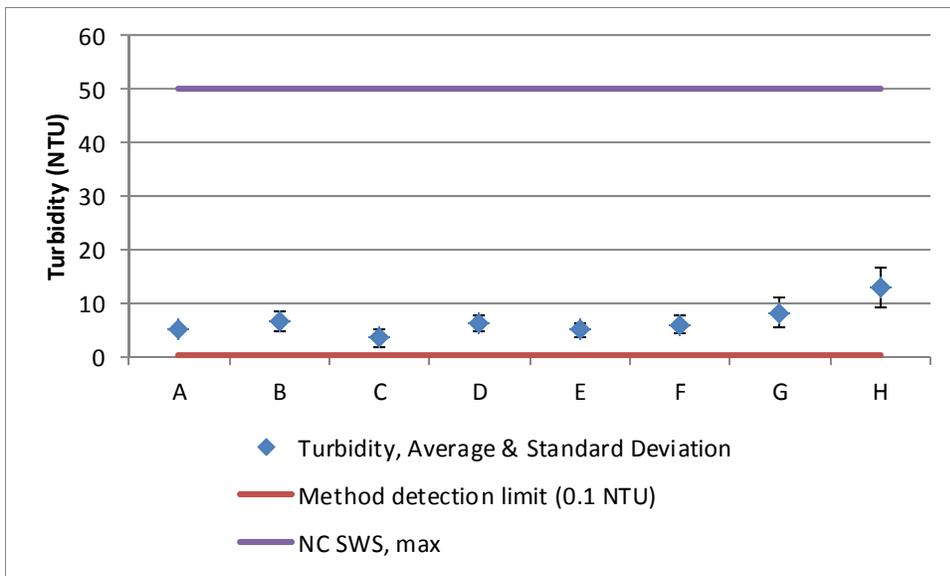


Figure 6-8a Average Turbidity of Neuse River Samples

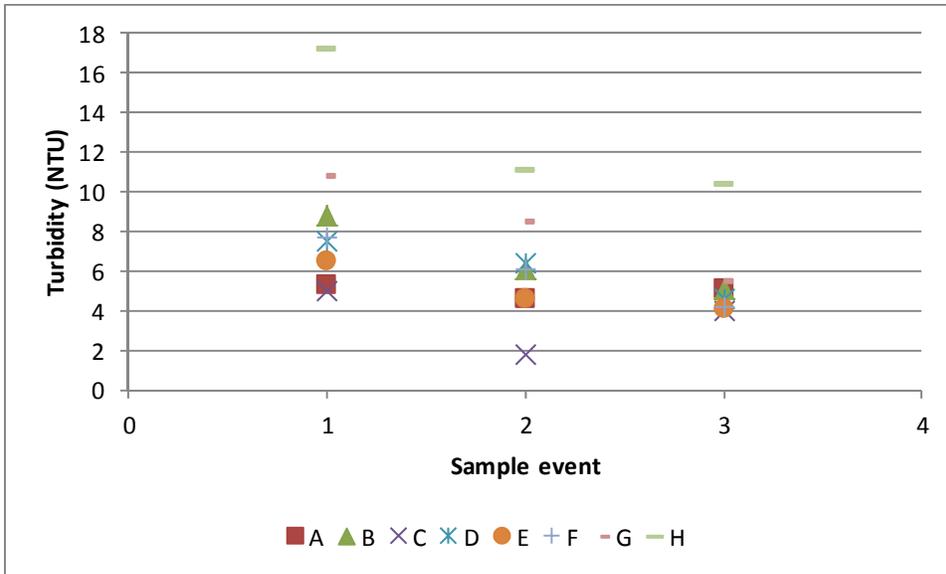


Figure 6-8b Turbidity Fluctuation over the Sample Events

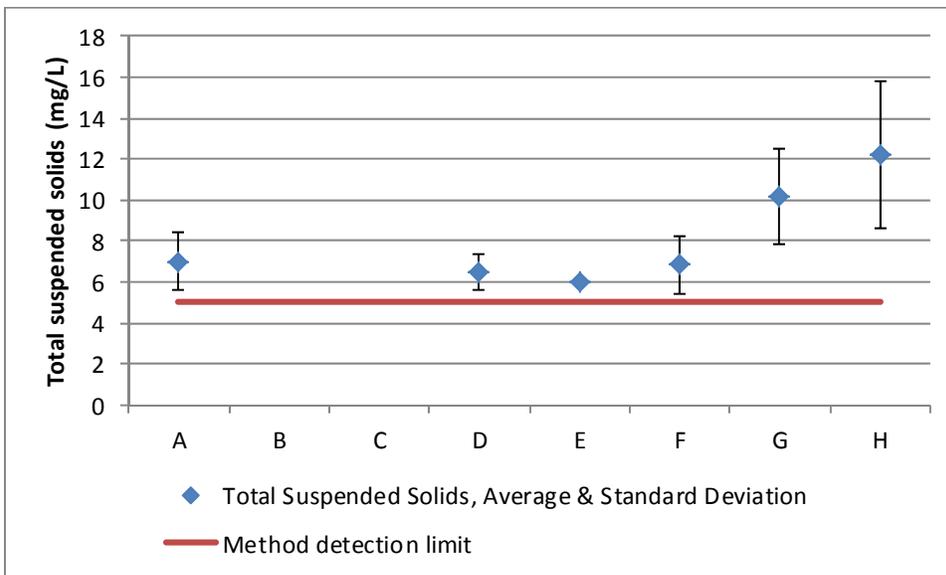


Figure 6-9. Average Total Suspended Solids Concentrations of Neuse River Samples

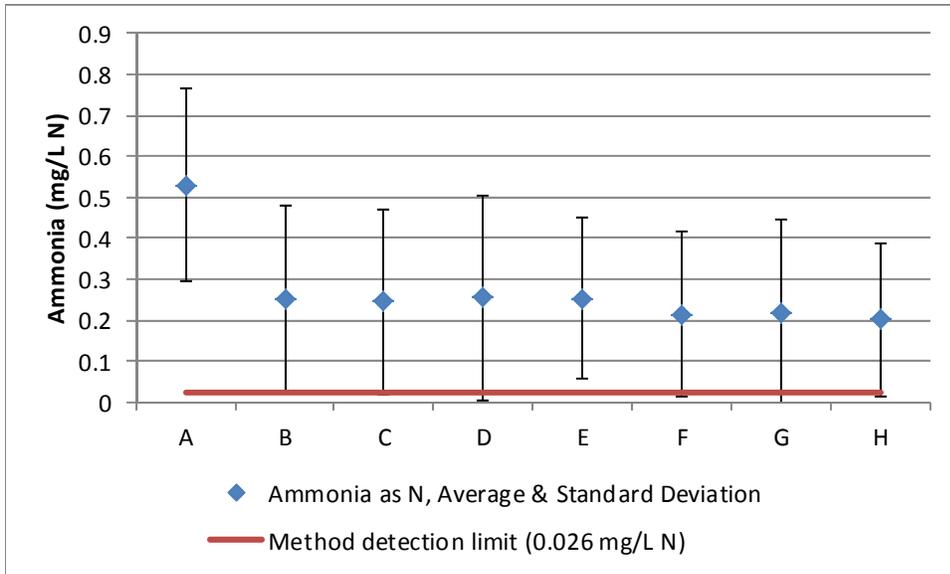


Figure 6-10. Average Ammonia Concentrations of Neuse River Samples

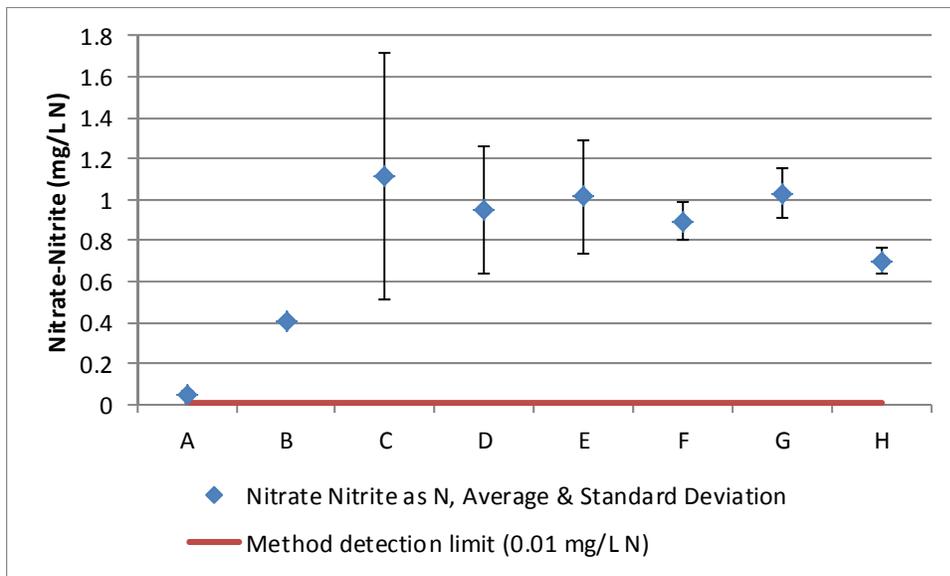


Figure 6-11. Average Nitrate and Nitrite (Combined) Concentrations of Neuse River Samples

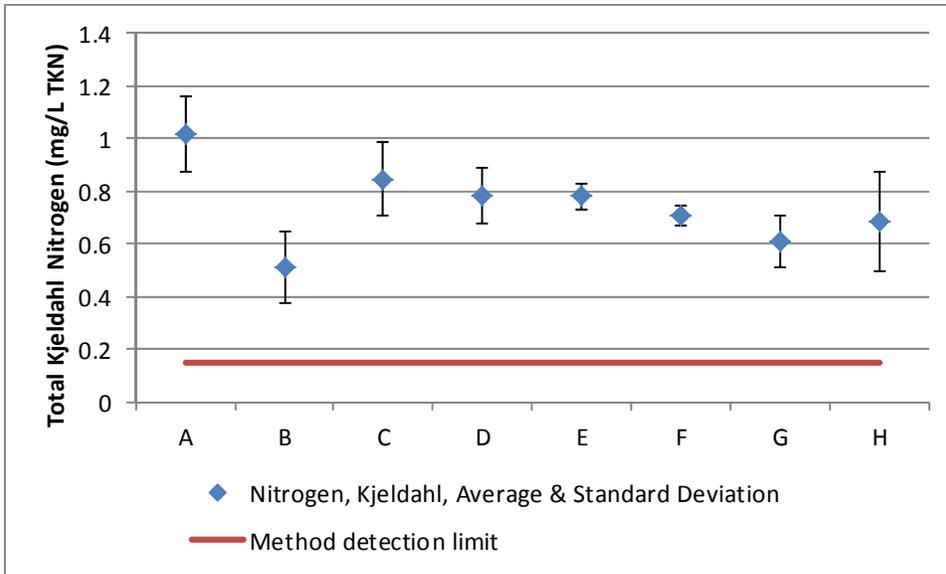


Figure 6-12. Average Total Kjeldahl Nitrogen Concentrations of Neuse River Samples

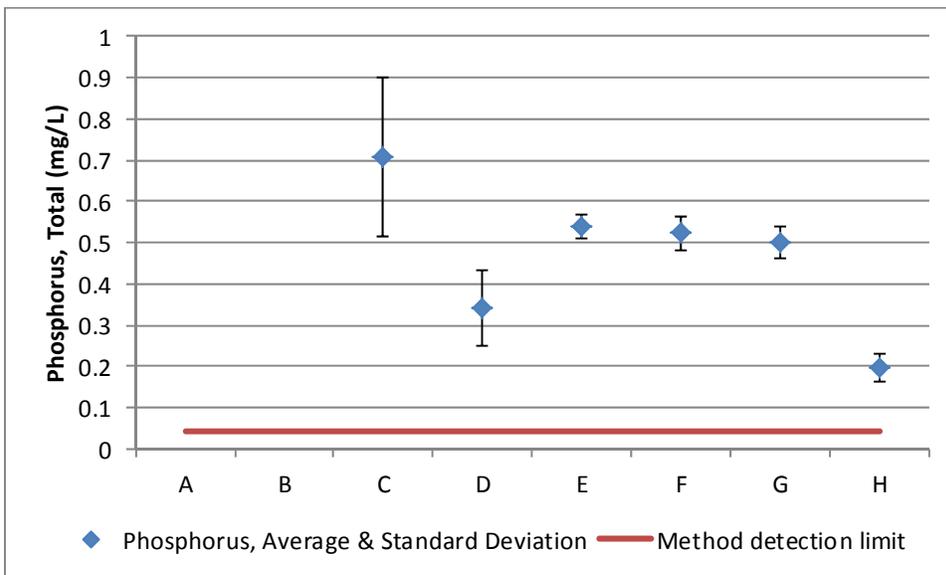


Figure 6-13. Average Phosphorus Concentrations of Neuse River Samples

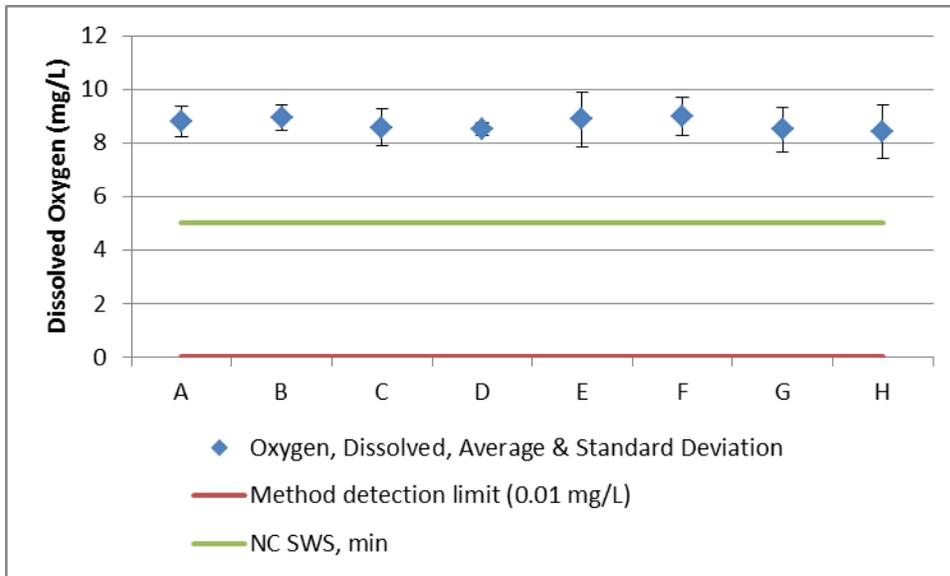


Figure 6-14. Average Dissolve Oxygen Concentrations of Neuse River Samples

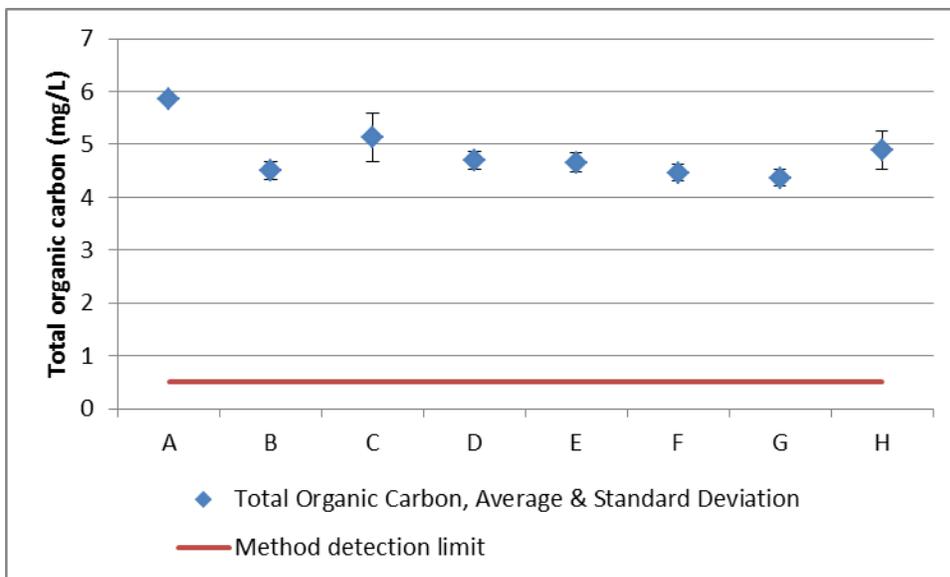


Figure 6-15. Average Total Organic Carbon Concentrations of Neuse River Samples

### 6.5.2 Interpretation

All of the samples collected in this study met North Carolina Surface Water Quality Standards for the designated uses at each stretch of the river studied, indicating good water quality. For reference the relevant North Carolina surface water quality standards and EPA standards are included in **Appendix H**.

The samples collected at sites A, B, D, E and F had temperature, pH, turbidity, conductivity, TSS, and fecal coliforms that were within the ranges observed over the past five Octobers (2008-2012) (presented as historical river data in Section 2.2; note that sites D and G do not have corresponding AMS or LNBA monitoring sites). This indicates that the samples collected during this study were generally representative of October flow conditions and samples did not show any anomalies with respect to conventional parameters. None of the conventional parameters correlated with river flow rates.

Water pH was relatively consistent for most of the sample sites (Figure 6-5) and well within the North Carolina surface water quality standards (Appendix H) of pH from 6.0 to 9.0. The observed pH values are consistent with the historical river values.

Water temperatures dropped over the sampling events (Figure 6-6), as expected due to seasonal patterns. Site C, at Neuse River WWTP effluent discharge, did not follow the same trend but this is expected; effluent water temperature will be a function of both the influent temperature as well as the local weather. While the water temperatures in the river dropped due to seasonal patterns, it is also of interest to note that the Falls Lake reservoir temperatures reflect that sampling was conducted immediately following a reservoir turnover event.

Specific conductance increased downstream of the Neuse River WWTP effluent discharge; this trend was seen over all three sample events (Figure 6-7). All sites except site C had consistent values over the three events. Conductivity was slightly higher at site C for event 2 (523  $\mu\text{mhos/cm}$ ) than at sites B and E historically (51-315  $\mu\text{mhos/cm}$ ), which may indicate higher TDS wastewater during event 2. This result nonetheless falls within the historical range of the average weekly conductivity values of WWTP effluent (488 -807  $\mu\text{mhos/cm}$ ) as described in Section 3.1.

The EPA Secondary Drinking Water Standard for TDS is 500 mg/L (corresponding to about 750  $\mu\text{mhos/cm}$ ), therefore the current Neuse River WWTP effluent is generally below this criterion. However, public perception problems could arise if a DPR system introduced higher conductivity water than is currently distributed. If treated wastewater effluent were used to augment the drinking water supply, there is potential to increase conductivity in the drinking water which could increase conductivity in the WWTP effluent. While the cycling of TDS can be a consideration in some potable reuse scenarios, additional investigation would be required to determine whether TDS control would be a beneficial as part of the treatment process design.

Turbidity and TSS were highest downstream at sites G and H (Figures 6-8 (a) and 6-9). Turbidity appears to decrease slightly over the sample events (Figure 6-8 (b)). Turbidity results were lower than the North Carolina surface water quality standards for all sites, and turbidity and TSS results were in line with the historical norms for the river. There was a weak correlation between turbidity and the time of travel (Pearson's 0.719, P-value 0.000, coefficient of determination 0.516). This suggests that turbidity varies based on sample location. Based on these results and the Neuse River WWTP's low historical turbidity and TSS, other runoff or river formations are the major source of water turbidity and suspended solids in this section of the Neuse River.

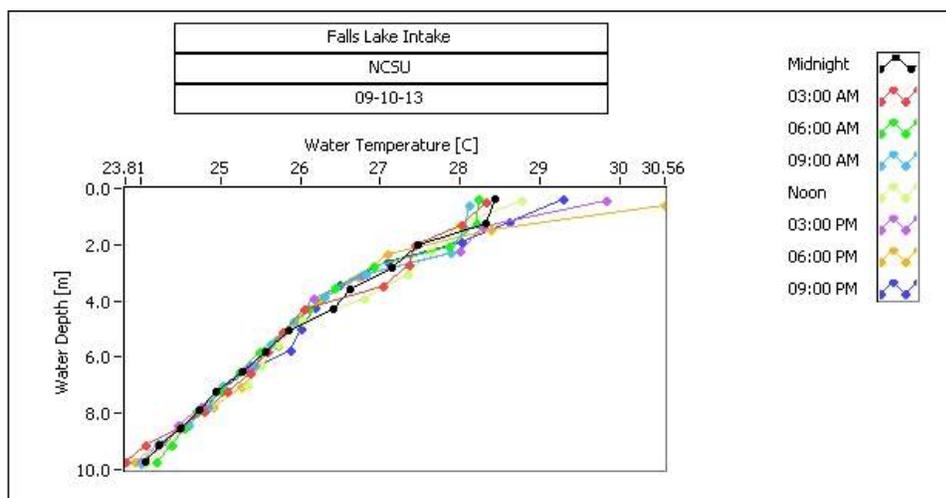
There was little fluctuation of the dissolved oxygen (Figure 6-14) and TOC (Figure 6-15) concentrations over the sample events or between the sites.

Nitrate-nitrite and phosphorus were highest at site C near the Neuse River WWTP effluent discharge, and values downstream are higher than upstream. However, there was not a statistical correlation between sucralose concentrations (as an indicator of the presence of wastewater) and nitrate-nitrate concentrations. TKN (Figure 6-12) was lower at site B than other locations. Generally, wastewater effluent containing less than 5 mg/L of TKN is considered to be fully nitrifying; if a WWTP is also fully denitrifying, the nitrate-nitrite concentrations will also be low (less than 2 to 3 mg/L). The low nitrogen concentrations (TKN and nitrate-nitrite) observed at site C, and historical effluent data suggests that the plant is typically effective at nitrification-denitrification.

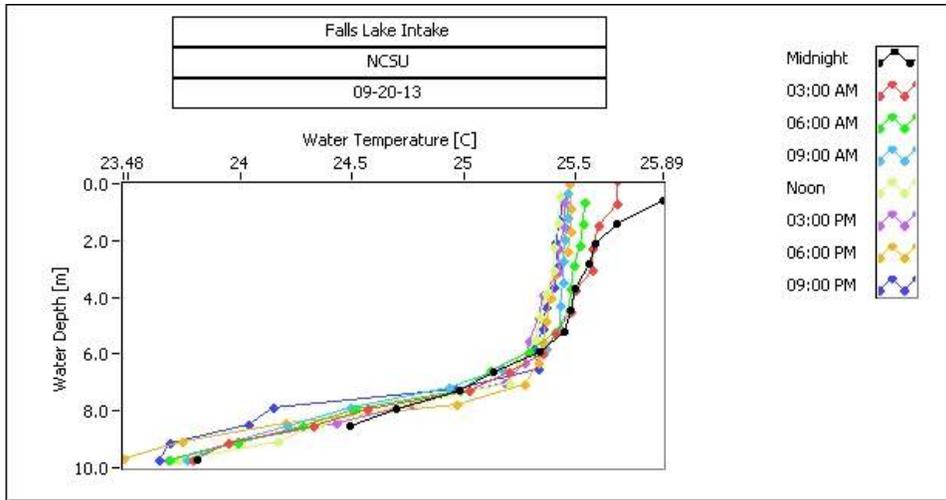
Ammonia concentrations were two to five times higher at sites A, B, E, and F than historical values (Figure 6-10 and Section 2.2). Nitrate-nitrate concentrations (Figure 6-11 and 6-13) were below the maximum concentrations historically observed on this stretch of the river (2.53 mg/L) but generally higher than the average concentration (0.7 mg/L) for the past five Octobers (Section 2.2). These higher than average values may be attributed to the time of year and conditions of Falls Lake with respect to lake turnover which appears to occurred sometime immediately prior to sample collection.

In the southeast, it is common that lakes and reservoirs become thermally stratified on an annual basis. This means that by the end of summer, cold water is found at the bottom of the lake/reservoir and, warm water is found at the top with a temperature gradient in between. Dead planktonic organisms, sediments, and other nutrients that have become abundant near the surface in the summer, sink to the bottom of the water body begin to decay in the lower, colder part of the waterbody, called the hypolimnion. As lower temperatures prevail and the sun is less intense during fall, the warmer surface waters (or epilimnion) begins to cool and becomes more dense. The cooler, dense water sinks past the thermocline to the bottom waters or the hypolimnion and causes mixing to achieve a uniform temperature throughout the water body. During this mixing process, decaying matter, including nutrients, are redistributed throughout the lake/reservoir.

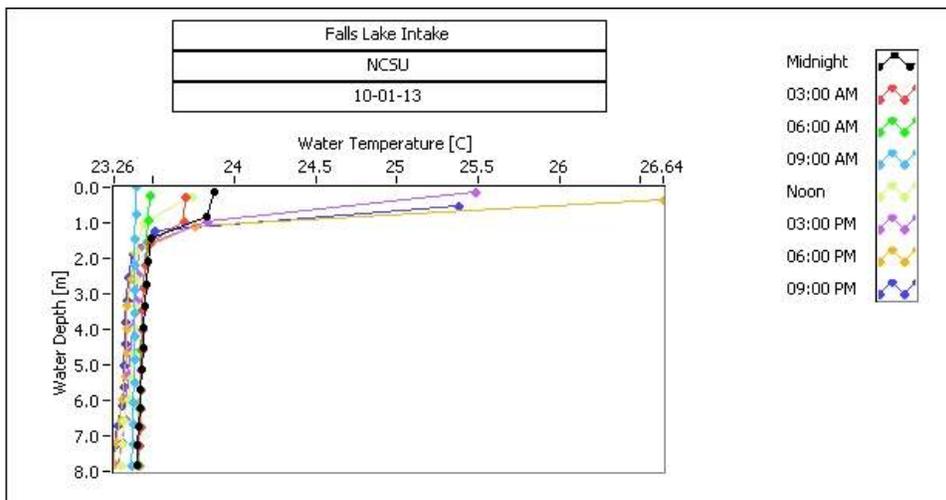
The samples collected for this study were taken immediately following a lake destratification event as shown in **Figures 16a through 16c**, which demonstrate that the Falls Lake was stratified as late as mid-September with the turnover event occurring around the first of October.



**Figure 6-16a. Temperature Profiles at the Falls Lake Intake 9/10/2013**  
(from North Carolina State University Center for Applied Aquatic Ecology)



**Figure 6-16b. Temperature Profiles at the Falls Lake Intake 9/20/2013**  
(from North Carolina State University Center for Applied Aquatic Ecology)



**Figure 6-16c. Temperature Profiles at the Falls Lake Intake 10/1/2013**  
(from North Carolina State University Center for Applied Aquatic Ecology)

This lake turnover event may also explain the changes in TKN and nitrate-nitrite concentration between Sites A and B. Considering that total nitrogen can be approximated by adding TKN and nitrate-nitrite, the total nitrogen is approximately the same at Sites A and B.

The observed phosphorus concentrations (Figure 6-13) were generally above the average historical total phosphorus concentrations, but well below the observed maximum for the past five October months on this stretch of the river (Section 2.2). There was some correlation between the wastewater indicator, sucralose, and phosphorus concentrations (**Figure 6-17**). This was the only conventional parameter with some correlation to sucralose. This correlation suggests that some of the phosphorus in the river may be coming from a WWTP along the river. It also indicates that there is little attenuation of phosphorus over this stretch of the river.

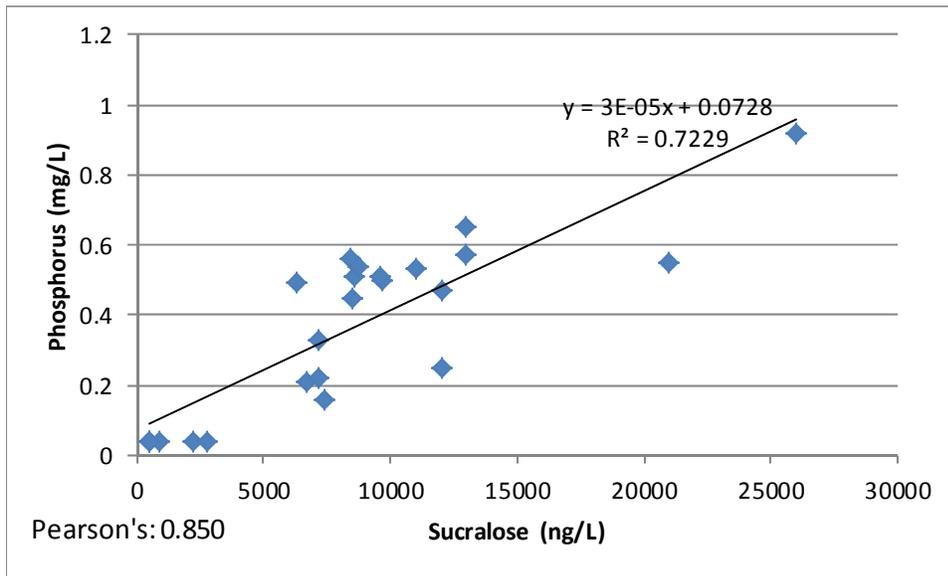


Figure 6-17. Correlation between Phosphorus and Sucralose Concentrations of Neuse River Samples

## 6.6 Microbial Indicators (Neuse River Samples)

### 6.6.1 Results

Concentrations of microbial indicators detected from samples averaged over the three sampling events are shown in **Figure 6-18**. The concentrations of fecal coliforms detected at each site for the three sampling events are presented in **Figure 6-19**. All microbial results are shown in tabular form in Appendix F.

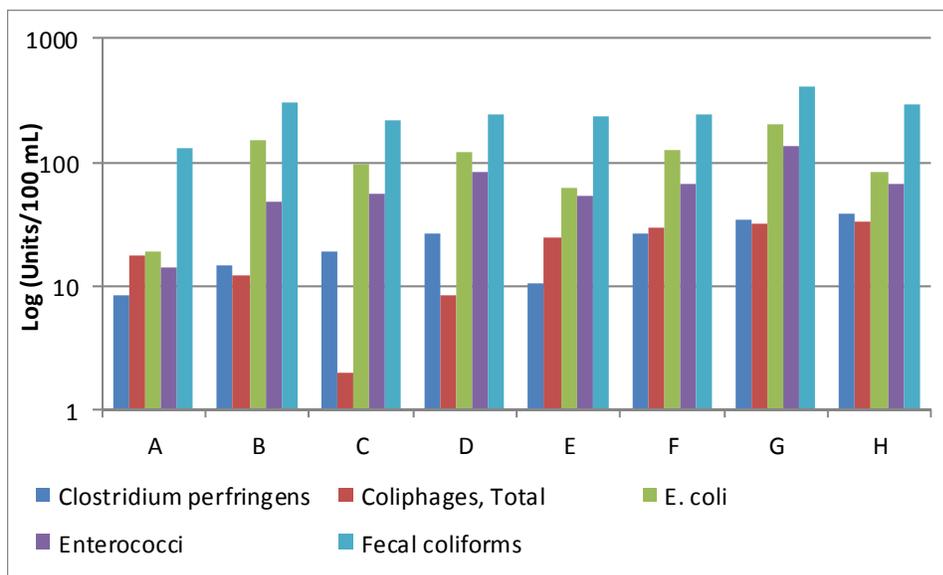


Figure 6-18. Average Microbial Indicator Concentrations of Neuse River Samples. (Detection limits: 1 CFU/100mL *C. perfringens*, 1 PFU/100mL fecal coliforms, and 1 MPN/100mL for total coliphages, enterococci and *E. coli*.)

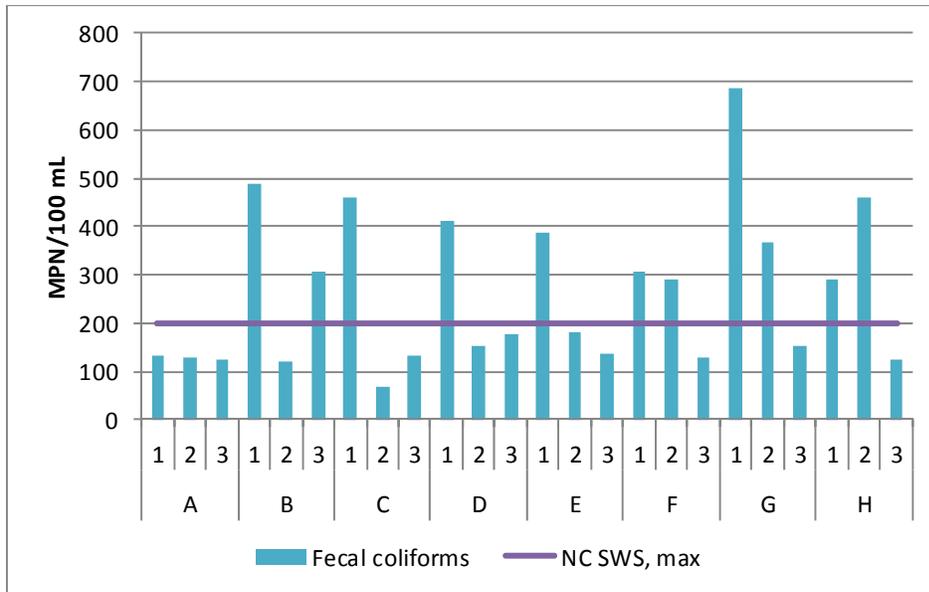


Figure 6-19. Fecal Coliform Concentrations of Neuse River Samples

### 6.6.2 Interpretation

Although there are three types of stream classifications from sites A through H (Class C, Water Supply IV, and Water Supply V), all classifications along this stretch of the river require fecal coliform levels to be below a geometric mean of 200 MPN/100 mL (based on at least five consecutive samples during any 30 day period), as indicated in Appendix H. There were eleven detections of fecal coliforms in the river that individually exceeded the North Carolina water quality standards, at sites B, C, D, E, F, and G (Figure 6-16). Note, however, that the water quality standards would consider five consecutive samples, rather than a single exceedance.

Fecal coliform concentrations observed at sites B, E, and F were in range of historical median and average values (refer to Section 2.2). The concentrations of fecal coliforms observed at site C during this study were likewise within the historical ranges observed at sites B and E. Results for site A were higher than the historical maximum of 77.0 CFU/100 mL, but still under the North Carolina surface water quality standards. Statistical analysis suggests that fecal coliform concentrations may increase at higher flow events, as is commonly observed. There was a weak correlation (Pearson's 0.602, P-value 0.002) between river flow rates and fecal coliforms. Additionally, there was rain prior to the first sampling event on October 10<sup>th</sup>, and the mean coliform results for event 1 were significantly higher than the means of the other two sample events.

The average levels of microorganisms at site C were not statistically different than averages at the other sites for all microorganisms studied. Thus, concentrations of microbial indicators near the WWTP effluent at site C represent background river levels. Further, in addition to the effluent concentrations from the Neuse River WWTP meeting NPDES requirements for fecal coliforms (as presented in Section 6.3.1), the effluent concentrations were also lower than the concentrations of site C samples, which implies that current disinfection is effective at the Neuse River WWTP.

There were no statistically significant differences between the average concentrations for each microbial indicator between the sites. In addition, there were no statistical correlations found between the microbial indicator species and the wastewater tracer sucralose. This suggests that the wastewater treatment plant is not a major source of microbial contamination in the river and that the microbial indicators were not appreciably attenuated along this stretch of the river. In other words, transport of water downstream does not appear to improve the microbiological quality. This is not surprising – based on the estimated travel time of three days under normal (50<sup>th</sup> percentile) flow conditions of the river between site A to site H (as described in Section 6.1), attenuation of microorganisms between sites A and H would not be expected. At UOSA in Fairfax, VA, a study by Rose et al. (2001) similarly demonstrated that reclaimed water quality is better than the ambient water in the reservoir with respect to microorganisms, thus indicating that the reclaimed water does not adversely affect the microbiological water quality for downstream users.

## 6.7 Pharmaceuticals (Neuse River Samples)

### 6.7.1 Results

Results were received for all pharmaceuticals with the exception of diltiazam. A separate addendum will be provided after the laboratory results are received.

Table 6-8 (at the end of Section 6) presents the average concentrations of detected pharmaceuticals for each of the eight sample locations, as well as the average and maximum values across all samples for a given parameter. To calculate averages, if a sample was non-detect, the method detection limit was used in the calculation along with detected concentrations. Detailed data is provided in Appendix F. Atenolol, caffeine, carbamazepine, cotinine, fluoxetine, furosemide, gemfibrozil, hydrochlorothiazide, ibuprofen, meprobamate, metoprolol, ofloxacin, oxycodone, sertraline, sulfamethoxazole, trimethoprim, valsartan, and verapamil were each detected in one or more samples. Cotinine, a metabolite of nicotine, was the only pharmaceutical detected at all sites. Sulfamethoxazole was the only compound detected at over 1 µg/L (**Figure 6-20**). One sample from site C, event 2 had 1.1 µg/L sulfamethoxazole. Acetaminophen, naproxen, and primidone were not detected in any of the samples.

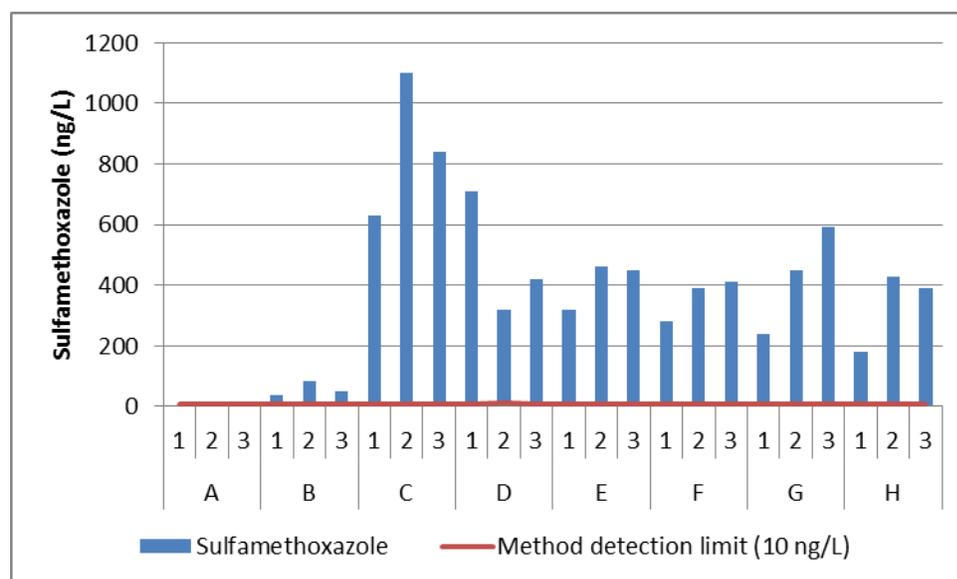
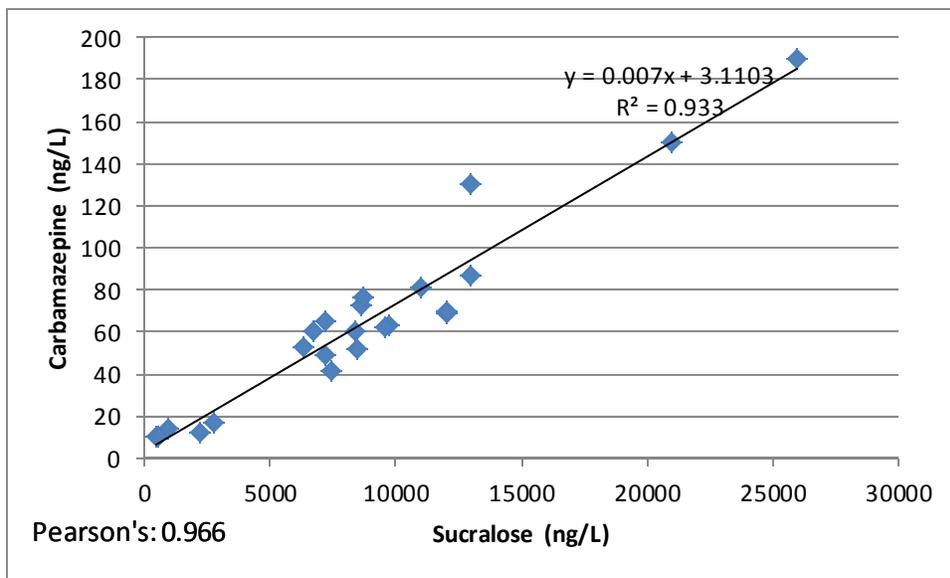


Figure 6-20. Sulfamethoxazole Concentrations of Neuse River Samples

### 6.7.2 Interpretation

Several pharmaceutical compounds correlated strongly (Pearson's coefficient > 0.9 and coefficient of determination > 0.8) with the wastewater tracer sucralose, including carbamazepine (**Figure 6-21**), meprobamate, trimethoprim, sulfamethoxazole, metoprolol, and oxycodone. This suggests that a WWTP is a likely source of these constituents and that they are not being degraded over the stretch of river included in this study. There was some correlation (Pearson's value > 0.8 and coefficient of determination > 0.7) between sucralose and atenolol and verapamil. **Table 6-4** presents the statistical parameters for pharmaceuticals with correlations to sucralose. There were no correlations between pharmaceutical concentrations and river flows or time of travel.



**Figure 6-21. Correlation between Carbamazepine and Sucralose Concentrations of Neuse River Samples**

**Table 6-4. Pharmaceuticals that Correlated with the Presence of Sucralose.**  
**(Strong correlations shaded in light blue)**

Analyte	Pearson's Correlation Factor	P-Value	Coefficient of Determination ( $r^2$ )
Atenolol	0.889	0.000	0.791
Carbamazepine	0.966	0.000	0.933
Meprobamate	0.947	0.000	0.897
Metoprolol	0.922	0.000	0.861
Oxycodone	0.926	0.000	0.857
Sulfamethoxazole	0.941	0.000	0.885
Trimethoprim	0.906	0.000	0.820
Verapamil	0.838	0.000	0.703

The correlation of carbamazepine, meprobamate, trimethoprim, sulfamethoxazole, metoprolol, and oxycodone to the wastewater tracer sucralose indicates that degradation or other transformation mechanisms are not occurring along the river for these compounds – just dilution. Each of these compounds mentioned were likewise detected in the Neuse River WWTP effluent in the EPA study with the exception of carbamazepine (Kostich et al., 2014). Carbamazepine, trimethoprim, sulfamethoxazole, atenolol, gemfibrozil, meprobamate, and naproxen are among the top 11 chemicals detected in drinking water and are known to be relatively recalcitrant in the environment and in wastewater treatment (Benotti et al., 2009). The maximum detections in the Neuse River were higher than the detections in a study of 19 US source waters for atenolol, carbamazepine, fluoxetine, gemfibrozil, mebroamate, sulfamethoxazole, and trimethoprim (Benotti et al., 2009). Mebroamate and sulfamethoxazole are also fairly recalcitrant in the environment and in wastewater treatment (Drewes et al., 2008). Metoprolol is generally well removed in wastewater treatment (Drewes et al., 2008).

In general, the concentrations of chemicals detected in the river samples in the present study are similar to the concentrations found in the 2011 national survey of wastewater effluents conducted by the EPA (Kostich et al., 2014). **Table 6-5** compares results for the analytes included in both studies. Fluoxetine, an antidepressant, was the only compound detected in the river water in this study at concentrations higher than the national mean and maximum concentrations in wastewater reported by Kostich et al. (2014) and Benotti et al. (2009). Literature results for fluoxetine in the Neuse River are contradictory. Fluoxetine has previously been detected in some studies the Neuse River water and plant effluent (Brigolf et al., 2010), but other studies did not detect it in the river water, even at a lower detection limit (Giorgino et al., 2007). Ibuprofen and carbamazepine were detected in this study but were not previously detected in the Neuse River WWTP effluent (Kostich et al., 2014). The ibuprofen and carbamazepine concentrations detected in this study in the Neuse River water were below the national means and maximums of wastewater concentrations (Kostich et al., 2014). Trimethoprim and sulfamethoxazole results were higher than the national mean for Method 2, which is most comparable the method used in our study. However, they were lower than the national maximums for Method 1. It is important to note that these values are for wastewater effluent and river water, and therefore can be expected to have higher concentrations than finished drinking water which has undergone further treatment.

**Table 6-5. Comparison of this Study Results with Published Data on Neuse River WWTP Effluent**

Analyte <sup>1</sup>	Neuse River WWTP effluent in 2011 <sup>2</sup> (Kostich et al. 2014 data)					2014 Neuse River <sup>2</sup> (present study)	
	No. of samples	Percent of samples with detections	National Mean <sup>3</sup> (ng/L)	National Max <sup>3</sup> (ng/L)	NRWWTP Effluent (ng/L)	Neuse River Mean <sup>4</sup> (ng/L)	Neuse River Max <sup>4</sup> (ng/L)
acetaminophen	50	14%	79 (300)	1500 (4500)	5 ND	21 ND	21 ND
atenolol	50	96%	940	3000	360.7	9.4	50.7
carbamazepine	50	96%	97 (140)	240 (460)	11 ND	62.7	190
diltiazem	49	84%	85	340	92.8	N/R	N/R
fluoxetine	48	38%	8.7	31	21.5	27	55
furosemide	50	90%	280 (350)	810 (2100)	255.3	61.1	254
gemfibrozil	50	76%	420 (480)	2300	140.9	26.5	43
hydrochlorothiazide	50	100%	1100 (1200)	2800	1466	78.5	378
ibuprofen	50	46%	460 (690)	4200 (4600)	12 ND	26.7	48
metoprolol	50	98%	410 (450)	660 (1200)	572.4	88.6	390
ofloxacin	49	90%	160	660	59.1	10.5	63.4
oxycodone	50	60%	53	310	39.9	14.0	58.4
sertraline	50	64%	21	71	23.5	4.5	25.6
Sulfamethoxazole <sup>5</sup>	50	80%	910	2900	2190.6	N/A	N/A
Sulfamethoxazole <sup>6</sup>	49	90%	330	1000	942.4	367.1	1100 E
Trimethoprim <sup>5</sup>	43	86%	170	370	367.4	N/A	N/A
Trimethoprim <sup>6</sup>	49	82%	90	210	146.8	46.0	210
valsartan	41	98%	1600 (1700)	5300 (8200)	1336.5	30.9	211
verapamil	49	80%	26	97	16.7	1.8	13.3
estrone	50	96%	(13)*	(93)*	(1.9)*	5.7 ND	5.7 ND
17- $\alpha$ -ethynylestradiol	50	86%	(1)*	(4)*	(0.4)*	3 ND	3 ND
androstenedione	50	100%	(3)*	(10)*	(1.5)*	7.4 ND	7.4 ND

**Notes:**

- 1) Analytes shown with multiple results were analyzed using more than one method
- 2) ND = Non-detect, shown with method detection limit; N/A = Not applicable for comparison with this method; N/R = Results not received at this time; E = Result is beyond the calibration range and estimated
- 3) Numbers in parenthesis include estimated concentrations from samples that failed qualification criteria. Asterisk (\*) indicates that results failed quality qualification requirements and were not published in Kostich, et al. (2014); values should be treated as estimates.
- 4) Results from the present study represent the mean and maximum concentrations of all sites for all locations.
- 5) Kostich et al. method 1 used for analysis.
- 6) Kostich et al. method 2 used for analysis. Method 2 is closer to EPA method 1694, used for analysis of the Neuse River samples.

The maximum sulfamethoxazole concentration observed in this study (from site C) was higher than sulfamethoxazole concentrations detected in previous studies of Neuse River effluent (Kostich et al., 2014), Neuse River water samples (Giorgino et al., 2007), and national source waters (Benotti et al., 2009). The maximum trimethoprim concentrations detected in this study were also higher than previous detections in effluent discharged to the Neuse River (Kostich et al., 2014; Ye and Weinberg, 2007; Bringolf et al., 2010), Neuse River water samples (Giorgino et al., 2007; Bringolf et al., 2010), and national source waters (Benotti et al., 2009). Carbamazepine was not detected in previous studies of Neuse River water (Giorgino et al., 2007). Metoprolol was previously detected in the Crabtree Creek WWTP effluent and downstream of the discharge at levels similar to the current study (Bringolf et al., 2010). To our knowledge there have been no previous studies of meprobamate in Neuse River water or plant effluent.

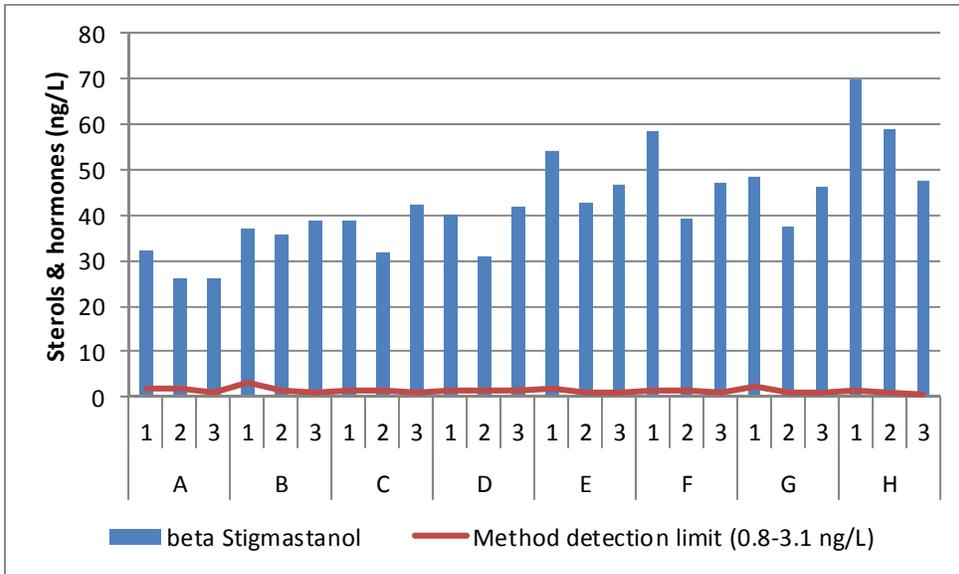
It is quite interesting that acetaminophen (along with naproxen and primidone) was not detected in any sample, since it is produced in the region. It is possible that industrial pretreatment is effective at removing acetaminophen from any waste streams such that the production facility is not a source. There is however also evidence from other utilities practicing UV disinfection that compounds such as acetaminophen might be degraded through nitrogen catalysis with UV treatment; however, these reports have been from facilities that use medium pressure UV disinfection (Keen et al., 2012 or 2013). In the EPA study (Kostich et al., 2014), acetaminophen and ibuprofen were likewise studied but not detected in the Neuse River WWTP effluent. Another study of Neuse River water (Giorgino et al., 2007) detected acetaminophen, but did not detect ibuprofen. In the present study, ibuprofen was detected in half of the samples with a detection limit of 26 ng/L. The reporting limits for ibuprofen in the EPA (12 ng/L) and Neuse River (42 ng/L) studies were similar. The acetaminophen reporting limit for the Neuse river study (5 ng/L, Giorgino et al.), was lower than this study but their average detection (79 ng/L) was higher than this studies' detection limit (21 ng/L). Previous studies of caffeine in the Neuse River were non-detect or below the reporting limit (Moorman et al., 2012, Giorgino et al., 2007).

Cotinine, a metabolite of nicotine, was the only pharmaceutical detected at all sites. A 2012 study, (Hedgespeth et al., 2012) assessing trace chemical constituents in Charleston, South Carolina wastewater treatment plants and surface waters reported cotinine as one of the three most frequently detected compounds in surface water. Another study, (Giorgino et al., 2007) detected cotinine in 42.9 percent of samples collected from the Neuse River and Triangle Research Area.

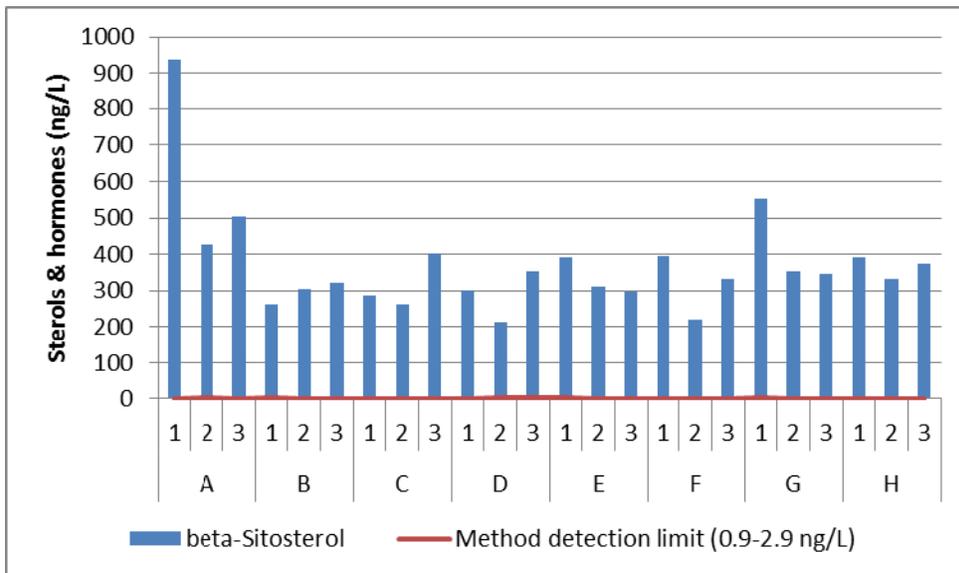
## 6.8 Sterols and Hormones (Neuse River Samples)

### 6.8.1 Results

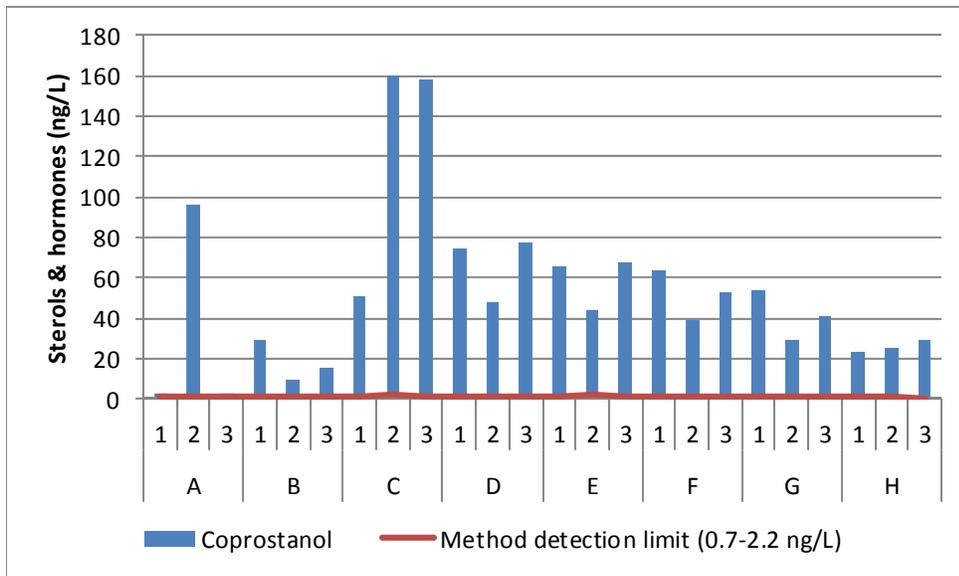
There were detections of,  $\beta$ -stigmastanol,  $\beta$ -sitosterol, coprostanol, and cholesterol at all sites (**Figures 6-22a to d**). 17- $\beta$ -estradiol had low level detections at sites B and C in event 1 (**Figure 23**). Table 6-8 (at the end of Section 6) presents the average concentrations of the detected sterols and hormones for each of the eight sample locations, as well as the average and maximum values for all samples. Detailed data is provided in Appendix F. Estrone, 17- $\alpha$ -ethinylestradiol, and androstenedione were not detected in any of the samples.



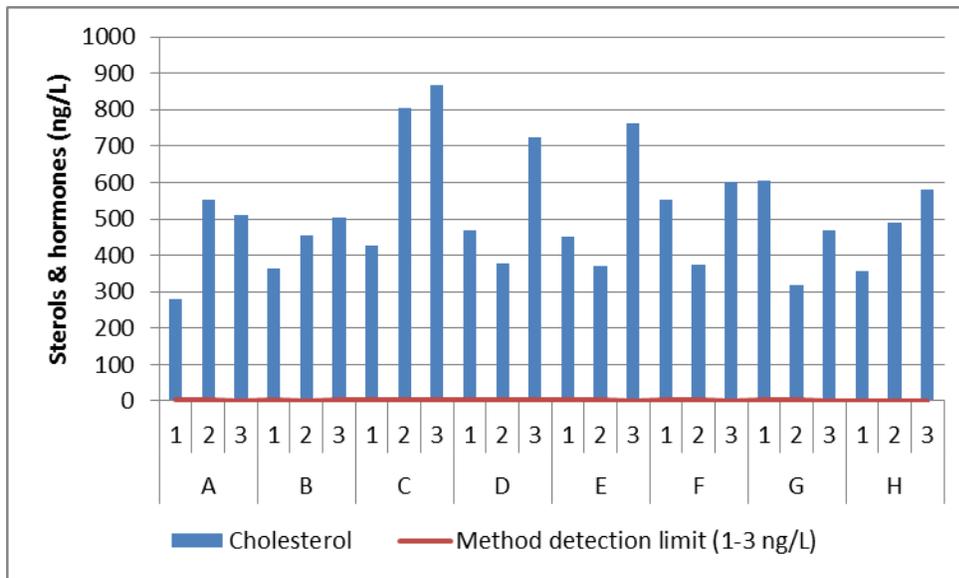
Figures 6-22a.  $\beta$ -Stigmastanol Concentrations of Neuse River Samples



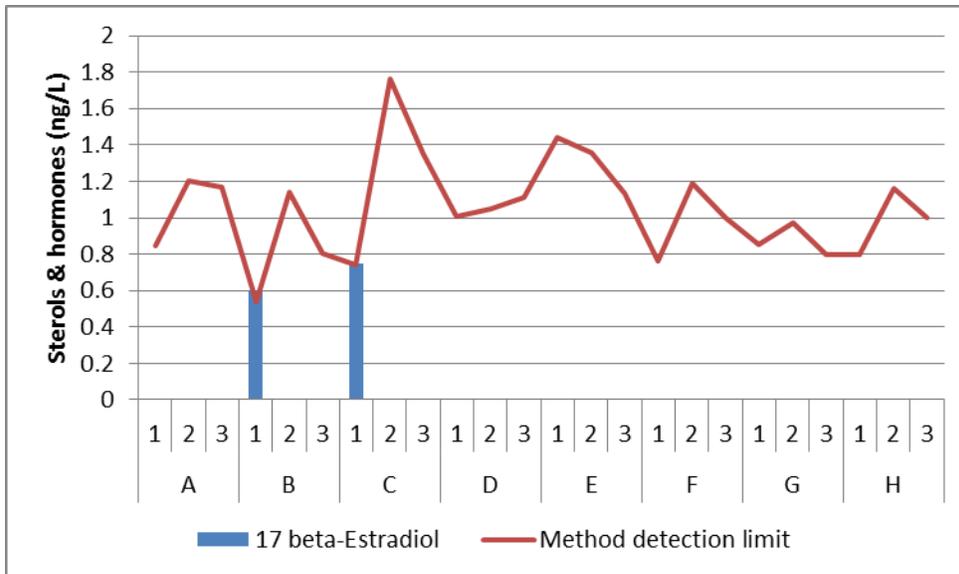
Figures 6-22b.  $\beta$ -Sitosterol Concentrations of Neuse River Samples



Figures 6-22c. Coprostanol Concentrations of Neuse River Samples



Figures 22d. Cholesterol Concentrations of Neuse River Samples



Figures 6-23.  $\beta$ -estradiol Concentrations of Neuse River Samples

## 6.8.2 Interpretation

None of the concentrations of sterols and hormones detected had a strong correlation with the concentration of wastewater tracer sucralose, time of travel, or river flow. Cholesterol and  $\beta$ -stigmastanol levels were generally consistent at all sites, indicating it is pervasive throughout the river. The highest detection of  $\beta$ -sitosterol was at site A in event 1 (937 ng/L), however the site A mean was not significantly higher than other locations. While coprostanol concentrations had no correlation with sucralose concentrations due to the detection of coprostanol at site A, the mean concentration of coprostanol for site C was significantly higher than sites A, B, and H which indicates a WWTP is a potential source of the compound.

Of the sterols and hormones studied, there was some detection of 17- $\beta$ -estradiol,  $\beta$ -stigmastanol,  $\beta$ -sitosterol, cholesterol, and coprostanol. These compounds include several fecal sterols which can be used to evaluate the source of various wastewater sources. For example,  $\beta$ -stigmastanol is an herbivore fecal indicator because it derives from digestion of sitosterol, which is a plant sterol; whereas, coprostanol is a carnivore fecal indicator. Cholesterol is less specific but is often used as a fecal indicator; it is also a plant sterol. 17- $\beta$ -estradiol is a common natural estrogen hormone that is sometimes used alone or if other estrogenic compounds are measured, serves as the standard for comparison for estrogenic response. In the case where multiple estrogenic compounds are measured, the concentrations are often converted to an estrogenic equivalent (EEQ) to reflect complex mixture of chemicals in a water sample. These compounds did not show a correlation to sucralose; likely because, with the exception of coprostanol, these are natural compounds that are generally degraded by any number of treatment processes. Only coprostanol appears to have a higher concentration at site C, so it is likely that the source of this compound is the WWTP effluent; the lack of correlation with sucralose may indicate additional removal in the river because it is a hydrophobic compound and it may associate with solids in the river.

17- $\alpha$ -ethynylestradiol, androstenedione, and estrone were not detected at any of the sampling locations for any of the sampling events in this study. These three hormones were detected previously in the Neuse River WWTP effluent in the EPA study at extremely low levels but were not published in Kostich et al. (2014) due to failure to meet data quality control criteria. The detections were reported in Stanford (2013). Estrone is one of the top 11 chemicals detected in drinking water (Benotti et al., 2009).  $\beta$ -sitosterol,  $\beta$ -stigmastanol, and cholesterol were previously detected at estimated concentrations (under the reporting limit) in samples from the Neuse River and Smithfield finished drinking water (Moorman et al., 2012). Results

## 6.9 Flame retardants (Neuse River Samples)

### 6.9.1 Results

TCEP was detected in several samples (**Figure 6-24**). There were no detections of the other flame retardants studied ( $\alpha$ -HBCDD,  $\beta$ -HBCDD, and  $\gamma$ -HBCDD).

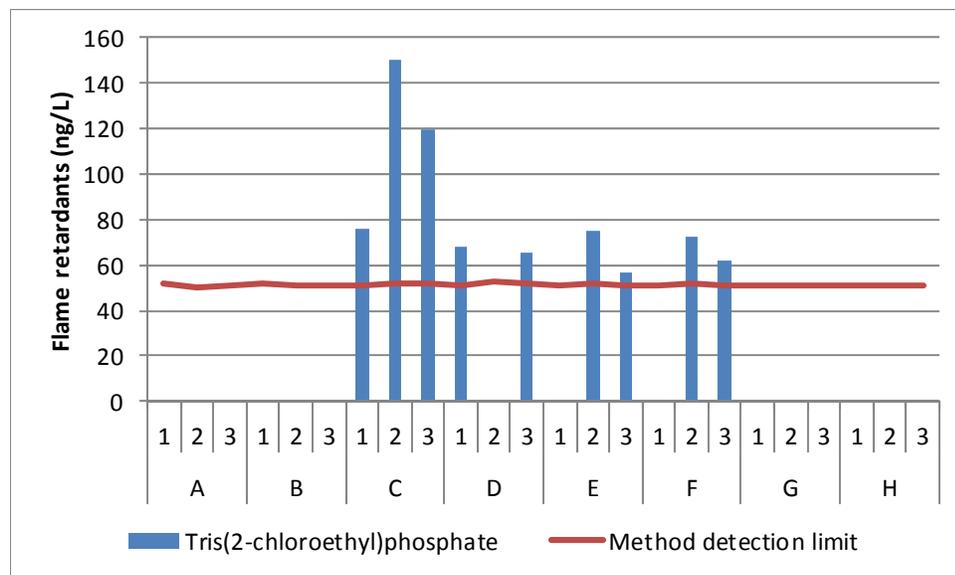


Figure 6-24. TCEP Concentrations of Neuse River Samples

### 6.9.2 Interpretation

There was some correlation of TCEP with the wastewater indicator sucralose (Pearson's 0.852, coefficient of determination 0.725), and the mean for site C was significantly higher than other sites, indicating that a WWTP is a potential source of the compound.

TCEP was previously detected in Smithfield drinking water at estimated concentrations (below the reporting limit) (Moorman et al., 2012) and in the Neuse River in the Research Triangle area (Giorgino et al., 2007). The TCEP reporting limit for this study was ten times lower than the reporting limits in Moorman et al. or Giorgino et al. TCEP is a suspected endocrine disruptor that is frequently detected in the environment, and can be transported in water as well as urban dust (Giorgino et al., 2007). EPA has not set an maximum contaminant level (MCL) for TCEP. To our knowledge there have been no previous studies of HBCDD in the Neuse River.

TCEP is one of the most recalcitrant compounds studied, along with carbamazepine. This factor, combined with their ubiquitous presence in the environment help explain why both TCEP and carbamazepine are among the top 11 chemicals detected in drinking water (Benotti et al., 2009). The maximum detection of TCEP in the Neuse River (15 ng/L), was lower than the maximum detection in the Benotti et al. (2009) survey of 19 US source waters. TCEP is one of the chemicals that may need to be carefully monitored in potable reuse scenarios, as it is poorly removed by membrane bioreactor, ozone, UV-hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) advanced oxidation process (AOP), chlorination, chloramination, granular activated carbon, and UV treatments. It is removed moderately by powdered activated carbon and removed well by nanofiltration and reverse osmosis (RO) (Drewes et al., 2008).

## 6.10 PFCs (Neuse River Samples)

### 6.10.1 Results

There were a few, low level detections of four PFCs: perfluorobutanoic acid (C4), perfluoropentanoic acid, perfluorobutane sulfonate (PFBS), and perfluorooctane sulfonate (PFOS) (**Figure 6-25**). The following PFCs were not detected at any of the sampling locations for any of the sampling events: perfluorohexanoic acid (C6), perfluoroheptanoic acid (C7), perfluorooctanoic acid (C8, PFOA), perfluorononanoic acid (C9), perfluorodecanoic acid (C10), and perfluorohexane sulfonate (PFHS).

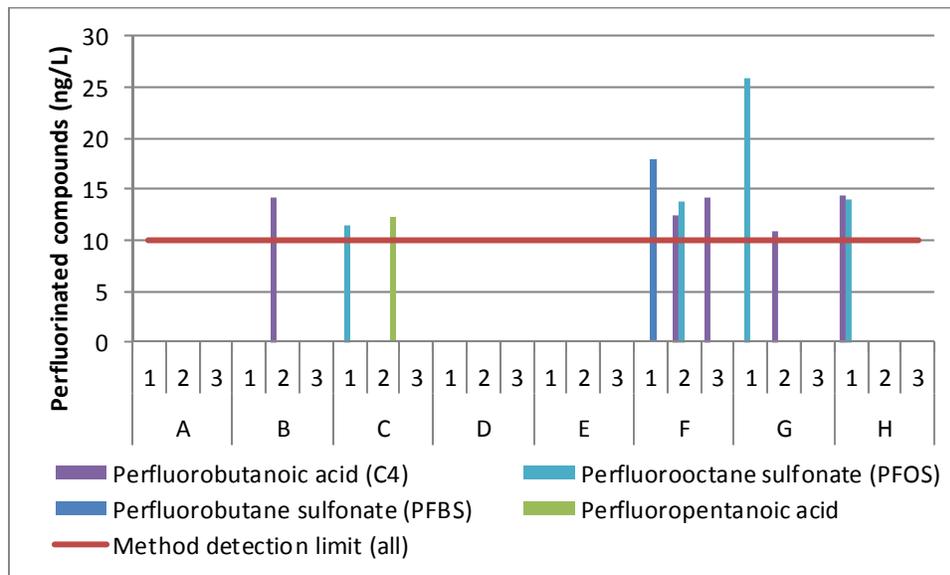


Figure 6-25. Perfluorinated Compound Concentrations of Neuse River Samples

### 6.10.2 Interpretation

PFCs are industrial compounds that are sometimes found in municipal WWTP effluent. As described in Section 6.2.1, WWTP effluent enters the river between sites A and B, C, and between sites G and H, so some of the detected concentrations of PFCs along the Neuse River may originate from wastewater. PFCs can also originate from industrial discharges to the river. All of the PFCs included in this study were detected previously in the Neuse River WWTP effluent in an EPA study at extremely low levels, many near the MDL of this study, as reported in Stanford (2013a). The findings of a few low level detections in this study are consistent with the EPA study results and do not indicate major sources of PFCs in the Neuse River study area.

## 6.11 Nonylphenols (Neuse River Samples)

### 6.11.1 Results

None of the nonylphenols studied (nonylphenol diethoxylate, nonylphenol monoethoxylate, para-tert-octylphenol, and p-nonylphenol) were detected at any of the sampling locations for any of the sampling events.

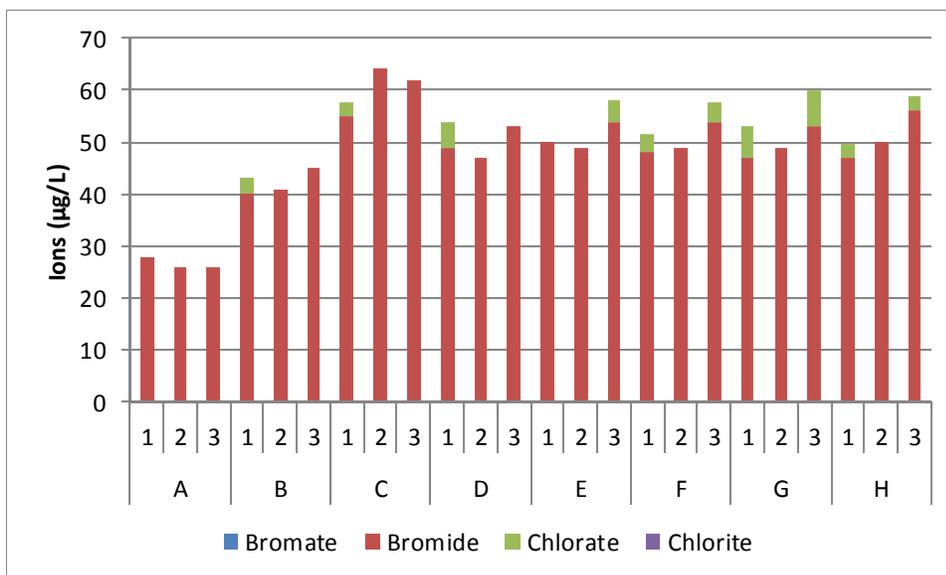
### 6.11.2 Interpretation

Previous studies of nonylphenols in Neuse River water (Moorman et al., 2012, Giorgino et al., 2007) reported low detected concentrations (4.3 µg/L nonylphenol diethoxylate) or non-detect (nonylphenol diethoxylate, para-tert-octylphenol, and para-nonylphenol). The reporting limits for this study were similar for the nonylphenols to those reported previously by Moorman et al. (2012) and Giorgino et al. (2007). Nonylphenols were not detected in the Neuse River WWTP in the EPA study (unpublished data), so the results in this study are consistent with previous findings.

## 6.12 DBPs (Neuse River Samples)

### 6.12.1 Results

Bromide was detected in each of the samples (**Figure 6-26**). Chlorate was detected in a few of the samples. There were a few low level detections of NDMA at sites C and E, and one detection of the HAA monochloroacetic acid at site B, which is located upstream of the Neuse WWTP. For these results, refer to Appendix F for complete data sets or Table 6-8 at the end of this section for summary information. The following DBPs were not detected at any of the sampling locations for any of the sampling events: bromate, chlorite, bromodichloromethane, bromoform, chloroform, dibromochloromethane, dibromoacetic acid, dichloroacetic acid, monobromoacetic acid, and trichloroacetic acid.



**Figure 6-26. Inorganic DBP Concentrations of Neuse River Samples.**  
(MDLs: 2.5 µg/L bromate, 4.7 µg/L bromide, 2.1 µg/L chlorate, and 3.7 µg/L chlorite)

## 6.12.2 Interpretation

There were no correlations between the detected DBPs (bromide and chlorate) and the wastewater tracer sucralose.

Chlorate is formed by ozonation, chlorine, chlorine dioxide, and chloramination. The Neuse River WWTP and upstream North Cary WWTP both use UV disinfection for microbial inactivation and are not anticipated to discharge significant quantities of these DBPs in the effluent.

The presence of bromide in each of the samples (at concentrations of 28 to 64 µg/L), likely naturally occurring, could be a source of the DBP bromate if ozonation is selected as part of the treatment process. However, these bromide levels are considered to be in the low (< 50 µg/L) to moderate (50 to 100 µg/L) range and may not require mitigation of bromate formation depending upon the ozone doses required to achieve treatment goals. If meeting the drinking water MCL of 10 µg/L proves to be challenging, there are several mitigation strategies that can be evaluated that often have a synergistic effect with the ozonation process. These bromate mitigation strategies include the following treatment options prior to ozonation: pH suppression, chlorine followed by ammonia addition, chlorine dioxide, or hydrogen peroxide. In many cases, the addition of these oxidants upstream of ozone treatment reduces the ozone dose, offsetting the additional cost of the bromide mitigation chemical.

THMs and HAAs are formed when chlorine is added to water that contains naturally occurring organic matter such as humic and fulvic acids; if ammonia is present in the water, NDMA can also form. NDMA was detected only three times (at sites C and E), at concentrations close to or below the 10<sup>-6</sup> lifetime cancer risk level of 0.7 ng/L (NRC, 2012). Similar to bromate, chlorate and chlorite, the Neuse River WWTP is not anticipated to contribute THMs, HAAs or NDMA because the facility uses UV disinfection for microbial inactivation. There were no detections of THMs in any of the sample events.

## 6.13 VOCs (Neuse River Samples)

### 6.13.1 Results

None of the VOCs studied (methyl tert-butyl ether (MTBE), m- & p-xylene, o-xylene, 1,2,4-trimethylbenzene, naphthalene, isopropylbenzene, benzene, ethylbenzene, carbon tetrachloride, toluene, 1,4-dioxane, tert-butyl alcohol, acetone (2-propanone), tetrachloroethene (perc), 1,1,1,2-tetrachloroethane, and 1,1,2,2-tetrachloroethane) were detected at any of the sampling locations for any of the sampling events.

### 6.13.2 Interpretation

Several VOCs studied in the present study were previously assessed by Moorman et al. (2012) in Smithfield source and drinking water, including 1,2,4-trimethylbenzene, acetone, benzene, carbon tetrachloride, ethylbenzene, isopropylbenzene, m- & p-xylene, MTBE, naphthalene, o-xylene, tert-butyl alcohol, tetrachloroethene, and toluene. In general, Moorman's reporting limits were lower than this study with the exception of acetone. 1,2,4-trimethylbenzene, benzene, m- & p-xylene, o-xylene, and toluene were detected at concentrations lower than our detection limit. MTBE and tert-butyl alcohol were detected at low concentrations under the reporting limit in previous study. MTBE was detected in 63 percent of the samples, but at very low (maximum of 0.3 µg/L) concentrations (Moorman et al., 2012). One analyte, 1,4-dioxane, that was not evaluated in the Moorman et al. (2012) study, was evaluated here, however it was analyzed at a relatively high detection limit.

## 6.14 Metals (Neuse River Samples)

### 6.14.1 Results

Zinc was detected at sites C, D, E, and F and barium was detected in each water sample (Figures 6-27 and 6-28). None of the other metals analyzed (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, selenium, and thallium) were detected in any of the sampling locations for any of the sampling events.

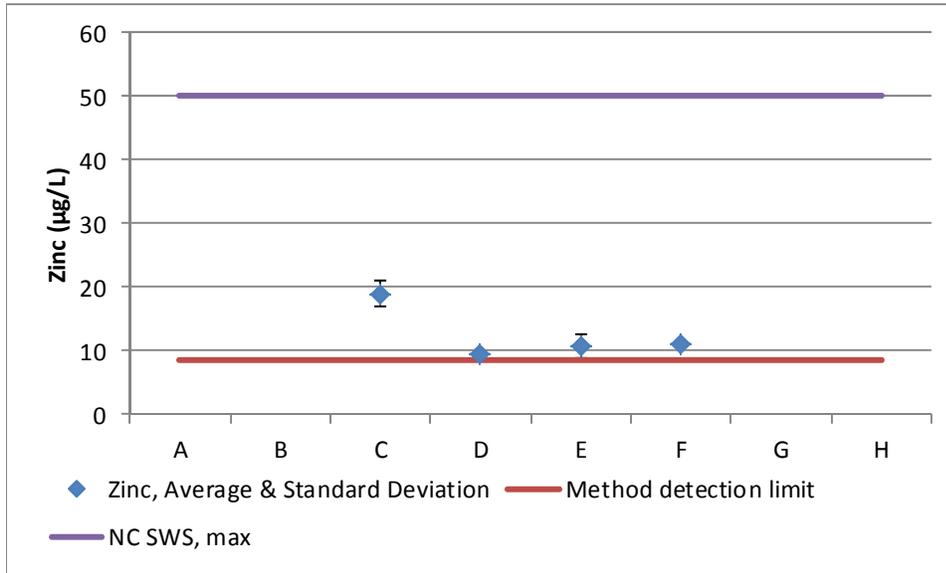


Figure 6-27. Average Zinc Concentrations of Neuse River Samples

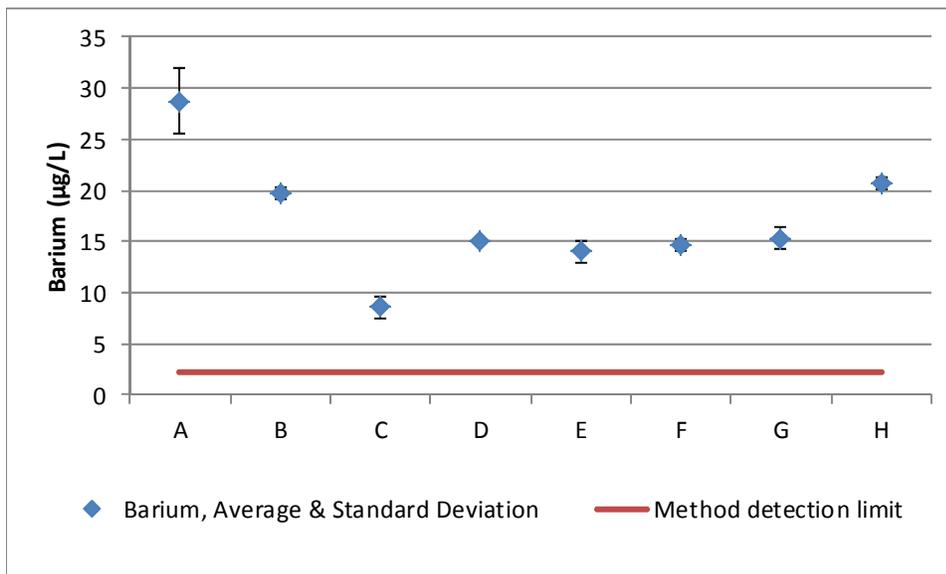


Figure 6-28. Average Barium Concentrations of Neuse River Samples  
 Note: Surface water standards for sites A, E, F, G, and H are 1000 µg/L (not shown), there are no standards for Barium at sites B, C, and D

### 6.14.2 Interpretation

The presence of low concentrations of zinc (10 to 21 µg/L) at sites C, D, E, and F is likely not a cause for concern and should not present any particular treatment requirements or controls. (The North Carolina surface water quality standard for zinc is 50 µg/L for the designated uses between sites A through H.) Zinc is commonly found in industrial/manufacturing wastewater. Zinc orthophosphate is not used as a corrosion inhibitor at the City's drinking water treatment plants. The Neuse River WWTP effluent historically has a zinc concentration averaging 41 µg/L (Section 2.2). All of the concentrations observed in the Neuse River samples were lower than the North Carolina surface water quality standards of 50 µg/L.

Barium, detected in each water sample, is likely naturally occurring in the source waters. Average concentrations for barium were lower than the North Carolina surface water quality standards for sites A, E, F, G, and H. (There are no surface water quality standard for barium at sites B, C, or D because of their designated uses, which are listed in Appendix H.) There was a negative correlation with the presence of sucralose (Pearson's  $-0.829$ , P-value 0.000), further indicating a geologic source. The mean concentration at site A was significantly higher than other sites, while the mean concentration at site C was significantly lower than all other sites. There were no detections of barium in the WWTP effluent in the historical data provided, but there was an average of 37.8 µg/L in the influent, indicating that the compound is removed in the treatment process.

The lack of detection of other metals at all of the sampling locations is an indication of good water quality.

## 6.15 Pesticides, Herbicides, Fungicides (Neuse River Samples)

### 6.15.1 Results

DEET was detected in each of the samples for sites A & B, and one sample for sites D and H (**Figure 6-29**). There was one detection of 2,4-D at site A (0.09 ng/L), however it was six orders of magnitude lower than the North Carolina Surface Water Standard for that location. Atrazine,  $\alpha$ -chlordane, bentazon, benzo(a)pyrene, carbaryl,  $\gamma$ -chlordane, MCPA, metolachlor, pentachlorophenol, and simazine were not detected in any of the samples.

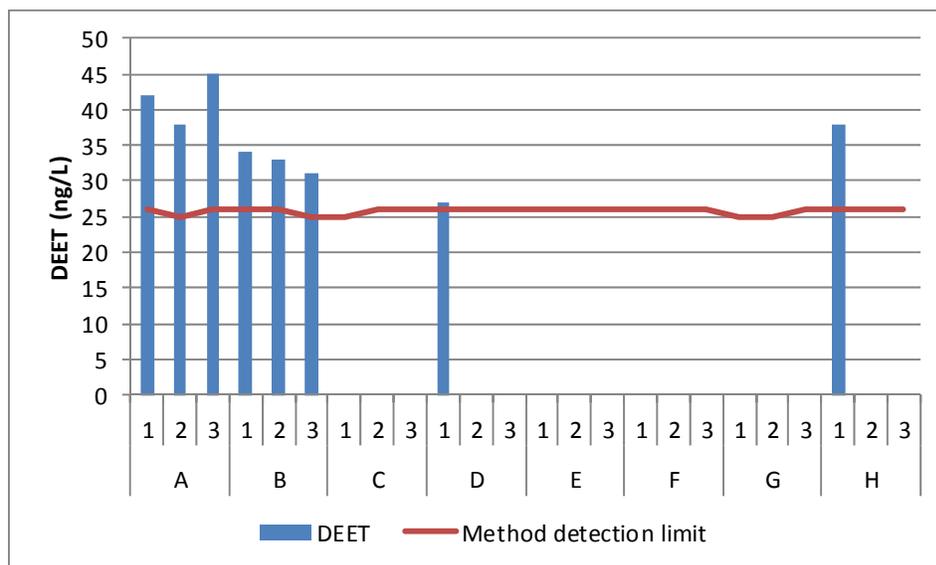


Figure 6-29. DEET Concentrations of Neuse River Samples

### 6.15.2 Interpretation

There were no correlations between the concentrations of DEET or 2,4-D with the concentrations of wastewater tracer sucralose. DEET is the active ingredient in many insect repellent products used to repel biting pests such as mosquitoes and ticks, including ticks that may carry Lyme disease. Except for veterinary uses, DEET is registered for use by consumers, and it is not used on food. The maximum DEET detection in the Neuse River (45 ng/L) is lower than the maximum detection in a study of 19 US source waters (Benotti et al., 2009), 2,4-D is a common systemic herbicide used in the control of broadleaf weeds. It is one of the most widely used herbicides in the world, and is the third most commonly used herbicide in North America being used for both residential and agricultural applications.

Within this grouping of compounds, atrazine, 2,4-D, metolachlor, pentachlorophenol, and simazine were previously detected in Smithfield source or drinking water, at concentrations below their respective MCLs (Moorman et al., 2012). Only benzo(a)pyrene was previously detected in drinking water in Smithfield at a concentration slightly higher than the MCL. Benzo(a)pyrene is a semivolatile petroleum hydrocarbon that is likely introduced into drinking water by leaching from the lining of water storage tanks and distribution lines rather than an environmental source.

It is notable that atrazine was not detected in the current study since it is one of the top 11 chemicals detected in drinking water (Benotti et al., 2009). Indeed, in a review of 2012 water quality reports in the region, atrazine was detected in 2012 in Johnston County in samples taken in January and July at concentrations of 180 and 130 ng/L, respectively (Johnston County Public Utilities, 2013). Atrazine was not detected in Smithfield or Raleigh in 2012 (City of Raleigh, 2013; Town of Smithfield, 2013). The presence of agricultural chemicals in the river could vary seasonally and may be higher during spring and summer months. The samples in the USGS study (Moorman et al., 2012) were collected in both winter and summer months. In general, the reporting limits for the Moorman et al. (2012) study for agricultural, consumer, and industrial compounds were similar or higher than the reporting limits in this study, with the exception of simazine<sup>1</sup>.

## 6.16 Consumer Products and Manufacturing additives (Neuse River Samples)

### 6.16.1 Results

There was one detection of salicylic acid, the primary component of the drug aspirin and used in a number of consumer skincare products. Bisphenol-A, or BPA, was detected at sites C, D, E, F, and G (Figure 6-30). BPA is used in plastic and epoxy manufacturing. Anthraquinone, camphor, p-cresol, triclosan, and triphenylphosphate were not detected in any of the samples.

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<sup>1</sup> The reporting limit for simazine in the Moorman et al. study was 0.01 µg/L, whereas for this study, it was slightly higher at 0.034 µg/L.

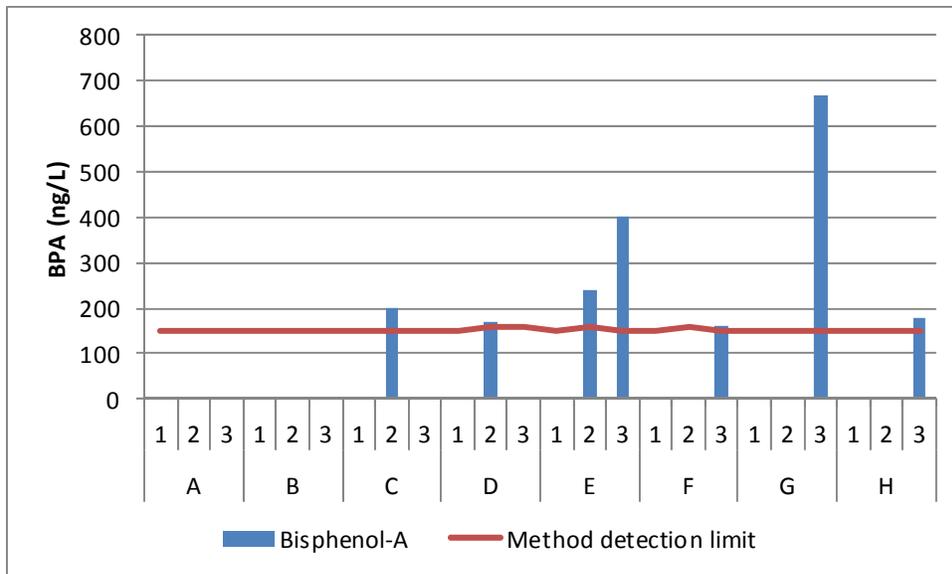


Figure 6-30. Bisphenol-A Concentrations of Neuse River Samples

### 6.16.2 Interpretation

There were no correlations between the concentrations of salicylic acid or BPA and the wastewater tracer, time of travel, or river flow.

Salicylic acid was detected once at site C and BPA was detected a handful of times at sites C, D, E, F, and G. BPA was studied in the Neuse River previously but the results failed method performance criteria and were not reported (Giorgino et al., 2007). The maximum BPA detection in the Neuse River was higher than the concentrations seen in a study of 19 national source waters (Benotti, et al., 2009). To our knowledge, salicylic acid was not previously studied in the Neuse River. Both salicylic acid and BPA are well removed by ozonation, UV-H<sub>2</sub>O<sub>2</sub> AOP, granular activated carbon, and RO, but are not removed as well by chlorination, chloramination, UV, nanofiltration, and powdered activated carbon. In Raleigh, a treatment system could be developed that would remove these compounds to non-detect levels. Anthraquinone, p-cresol, triphenyl phosphate, camphor, and triclosan have been previously studied (Giorgino et al., 2007, Moorman et al., 2012), but all of the results were estimated (below the reporting limit) or non-detect. None of these compounds were detected in this study.

## 6.17 Contrast Media (Neuse River Samples)

### 6.17.1 Results

The contrast media iopromide were not detected in any of the sample events.

### 6.17.2 Interpretation

To our knowledge, iopromide has not been previously studied in the Neuse River.

## 6.18 Genotoxicity (Neuse River Samples)

### 6.18.1 Results

Six of the samples taken from sites A, B, C, G, and H demonstrated mutagenic effects (95 percent or greater probability of a positive mutagenic effect when compared with reagent water), as shown in **Table 6-6**. Sites D, E, and F did not have any samples showing mutagenic effects. The results from event 3 had a high number of wild-type revertants in the two control sample (>30 of the 96 wells). Such a high background diminishes the sensitivity of the test and negative results reported in this event should be interpreted with caution.

**Table 6-6. Samples that Demonstrated Mutagenic Effects (95% or greater probability of a Positive Mutagenic Effect when Compared with Reagent Water)**

Site	Event 1	Event 2	Event 3 <sup>1</sup>
A	Yes	-	-
B	-	-	Yes
C	Yes	Yes	-
D	-	-	-
E	-	-	-
F	-	-	-
G	Yes	-	-
H	Yes	-	-

**Note:**

1) The control plate for event 3 had a high number of revertant colonies (>30 of the 96 wells) which diminishes the sensitivity of the test.

### 6.18.2 Interpretation

As presented in Section 6.6, six of the samples from sites A, B, C, G, and H demonstrated genotoxic effects when compared with reagent water. The results for event 3 samples must be interpreted with caution because the control sample had a high number of wild-type revertants. This high level of wild-type revertants diminishes the sensitivity of the test and negative results reported in this event should be interpreted with caution.

A positive result indicates that some chemical or combination of chemicals in water samples have mutagenic potential, but the assay cannot give an indication of which types of compounds might be present. The assay also cannot account for all of the physiological toxicological and biochemical factors that would affect whether mutagenic chemical(s) pose a threat to human health. Thus, these results are not directly applicable to general ecological or human health risk. Positive results do not indicate that water samples are mutagenic to humans.

The purpose for including the Ames test in this study was to capture the potential effect of compounds that were not specifically targeted. Of the analytes that were included in this study, some of the VOCs, DPBs, agricultural chemicals, and metals might contribute to genotoxicity, but of the chemicals in these categories that are possible mutagens, only NDMA and 2,4-D were detected. Flame retardants, perfluorinated compounds, sterols and hormones, and most pharmaceuticals are generally not thought to contribute to genotoxicity. Thus, it is possible that the compounds present in the samples that contributed to genotoxicity were compounds not targeted for individual analysis in this study, as

well as potentially NDMA or 2,4-D. Other studies in the US have shown river water impacted by urban and agricultural sources to have mutagenic effects (Whitehead et al., 2004; Monarca et al., 2002).

It is difficult to conjecture as to why site A showed some genotoxicity for event 1 because it is upstream of urban impacts. Evidence of genotoxicity at sites B, C, G, and H could be influenced by nonpoint source pollution (sites B, C, G, and H) as well as wastewater effluent (sites C, G, and H). There are ten small industrial sites between sites F and G that hold 'minor' discharge industrial NPDES permits for an oil/gas storage terminal in Selma, NC. The higher turbidity and TSS concentrations at sites G and H could be evidence of nonpoint pollution at these sites.

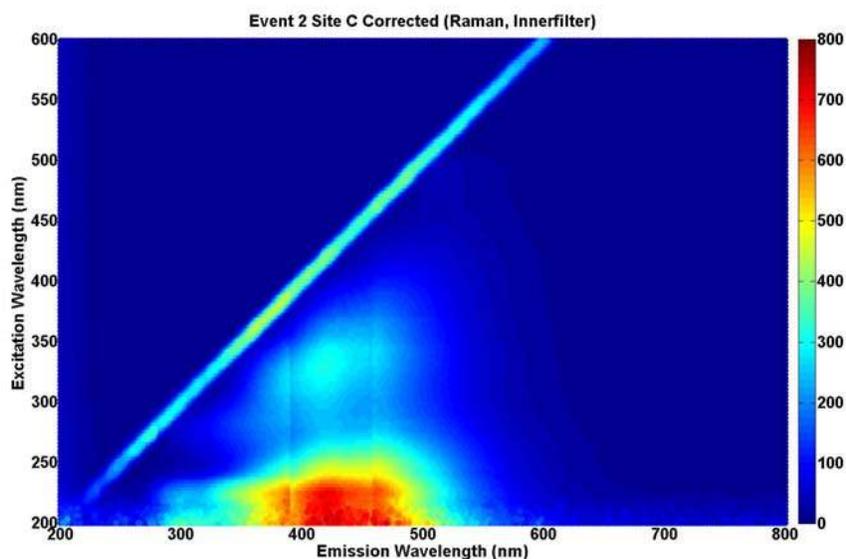
In the future, further study could be conducted to determine which chemicals in the river contribute to genotoxicity and whether these derive from point or non-point sources (such as agriculture). In a potable reuse scenario, further study using Ames tests would be warranted in order to demonstrate that any mutagenic effects can be removed by whatever treatment train would ultimately be selected using multiple, redundant unit processes – the same design criteria as needed for removing pathogens or trace chemical constituents.

## 6.19 EEM (Neuse River Samples)

### 6.19.1 How EEM data are presented

As described in Section 4.1.5, spectra representing spectral signatures or “fingerprints” of organic matter can be localized on three-dimensional (3-D) EEM data matrices that include an excitation, emission, and fluorescence intensity. One-, 2-, and 3-D EEM fluorescence spectroscopy can be used to evaluate the quality of different types of water, i.e., drinking water, surface waters, industrial and treated wastewater effluents, and to monitor drinking water and wastewater treatment trains (Bell et al., 2012, Wells et al., 2004).

Visualizing a 3D EEM map is similar to looking down on elevations of a mountain in a topographic map. A 3D EEM spectrum can be represented as a contour map just as many topographic maps are, but in these data the height of the elevations (intensity of fluorescence) is denoted by variations in color (**Figure 6-31**).



**Figure 6-31. Example of a 3D EEM Map Obtained for Event 2 Sampling at Site C. (Colors indicate corrected fluorescence intensity.)**

In the 3D EEM maps presented in this report, the x-axis represents the emission wavelengths, the y-axis represents the excitation wavelengths and the z-axis (represented by the color bar, and coming out of the plane of the page toward the viewer) indicates the intensity of the corrected fluorescence at a specific excitation-emission wavelength pair (x,y data point). The intensely colored diagonal stripe in the 3D maps, located where the excitation wavelength (EX) is equal to the emission wavelength (EM), is not due to fluorescence but results from scattering of light (by atoms, molecules, particles) and is referred to as first-order Rayleigh scattering. The 3D EEM maps for all samples and blanks are depicted in **Appendix G**, which includes the full EEM Report.

Other useful graphical representations—2D plots—can be derived from the 3D EEM data matrix: (1) by collecting data points at constant excitation wavelength (**Figure 6-32a**) as the emission wavelength varies (parallel to the 3D x-axis, often depicting a path along the ridge of the fluorescent mountain), or conversely, (2) by collecting data points at constant emission wavelength (**Figure 6-32b**) as the excitation wavelength varies (parallel to the 3D y-axis, often depicting an uphill/downhill path at 90° to the ridge of the mountain). This allows investigation of specific groups of compounds. The wavelength pairs for target categories of organic compounds used in the analysis of this data are shown in **Table 6-7**. The exact spectrographic locations of these regions within a 3D map can vary between geographic locations.

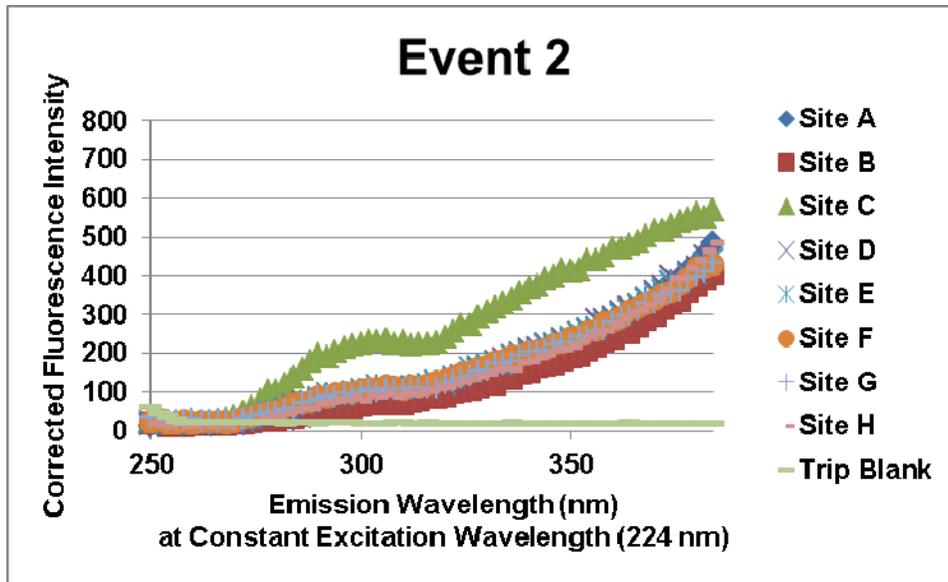


Figure 6-32a. Example of a 2D Fluorescence Spectrum for Event 2 Sampling of all Sites at a Constant Excitation Wavelength (224 nm) Indicating Presence/Absence of Anthropogenic Influence.

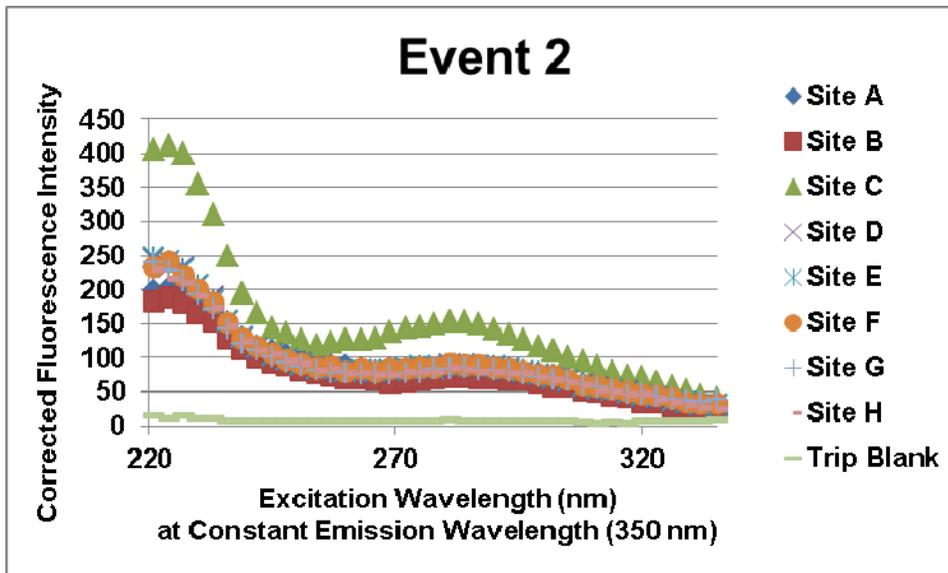


Figure 6-32b. Example of a 2D fluorescence spectrum for Event 2 sampling of all Sites at a constant emission wavelength (350 nm) indicating presence/absence of anthropogenic influence.

**Table 6-7. Wavelength pairs used to identify categories of organic compounds in this study**

Compound	Excitation wavelength (nm)	Emission wavelength (nm)
General anthropogenic influence	224	300-350
Fulvic-like substances (ubiquitous in natural waters)	224	424
Humic-like substances (ubiquitous in natural waters)	224	474

When the peak maxima at specific wavelength pairs are compared (1D data from the 3D EEM matrix), the relative influence of various types of compounds can be compared for various samples, as presented in the following sections.

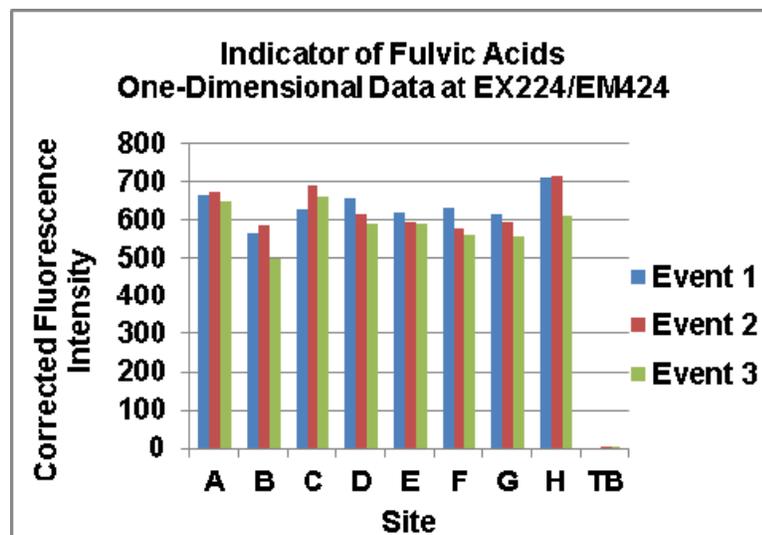
### 6.19.2 Results

All the EEM fluorescence spectral results are presented in Appendix G. Trip blank samples were included with each sampling event. The trip blanks were composed of distilled water shipped in sample containers identical to those used to collect actual samples. The trip blank samples for each of the three sampling events indicated no background interferences in the UV-visible or the fluorescence spectra, which is a necessary data quality condition.

### 6.19.3 Interpretation

#### 6.19.3.1 Evidence of fulvic and humic acids

Investigation of the fluorescence of the wavelength pairs listed in Table 6-7 indicates that samples from sites A through H contained fulvic acids and humic acids as expected. **Figure 6-33a and b** present 1D single point fluorescence data comparing all events and all sites for the wavelength pairs indicating the presence/absence of fulvic and humic acids. Statistical analysis indicated that sites D, E, F, and G are considered to be intermediary in fulvic acid influence, with sites A, C, and H having more fulvic acid influence and Site B having less fulvic acid influence. (Refer to Appendix G for statistical analysis.) With respect to humic acid influence, sites A, C, D, E, F, and G had intermediary influence, between sites H (more humic acid influence) and site B (less humic acid influence). Taken together, site B had the lowest influence of fulvic and humic acids.



**Figure 6-33a. Presence/Absence of Fulvic Acids – Corrected fluorescence intensity for wavelength pair EX224/EM424 for all sites and events (TB = trip blank)**

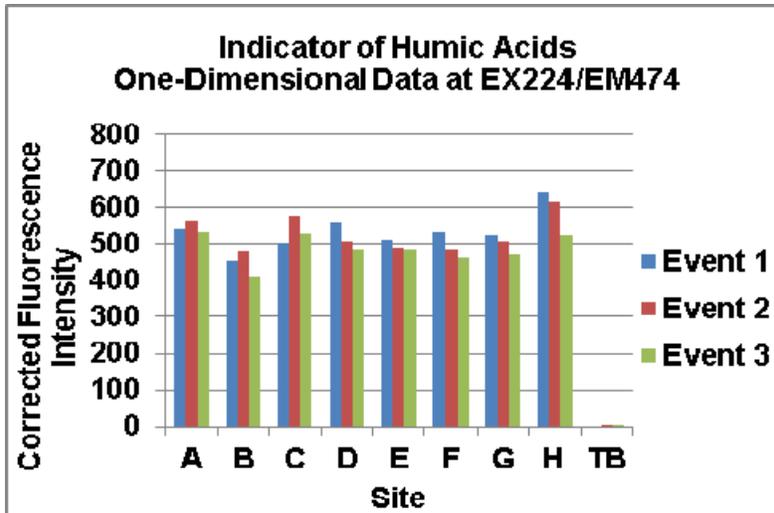


Figure 6-33b. Presence/Absence of Humic Acids – Corrected fluorescence intensity for wavelength pair EX224/EM474 for all sites and events (TB = trip blank)

### 6.19.3.2 Evidence of anthropogenic influence

Investigation of the fluorescence at the wavelength pairs EX224/EM300 and EX224/EM350 indicates that samples from selected Sites exhibited anthropogenic influence (**Figure 6-34a and b**). The character/concentration of the anthropogenic influence at EX224/EM300 cannot be assumed to be equivalent to the character/concentration of anthropogenic influence at EX224/EM350 (Henderson et al., 2009). Tyrosine and tryptophan are the only amino acids in proteins that fluoresce naturally. The wavelength pair at EX224/EM300 is attributed to tyrosine-like compounds, and the wavelength pair at EX224/EM350 is attributed to tryptophan-like compounds (Henderson et al., 2009).

At either wavelength pair, the majority of the fluorescence at sites A or B resulted from background fulvic acid and not from anthropogenic influence; any excess fluorescence exhibited at the other Sites relative to sites A or B at these wavelength pairs represents anthropogenic influence. The greatest degree of excess fluorescence indicating anthropogenic influence was observed at site C. The intensity of the fluorescence at site C varied in the order: event 2 > event 3 > event 1. The anthropogenic influence at site C varied most among sampling events compared to the other sites. Statistical analyses (presented in detail in Appendix G) shows that sites D, E, F, and G are considered to be intermediary in anthropogenic influence between site C (more) and sites A, B, and H (less) when considering the wavelength pair EX224/EM300. When considering the wavelength pair EX224/EM350, sites D and E are considered to be intermediary in anthropogenic influence between site C (more) and sites A, B, F, G, and H (less). Taken together, sites A, B, and H appear to have the lowest anthropogenic influence.

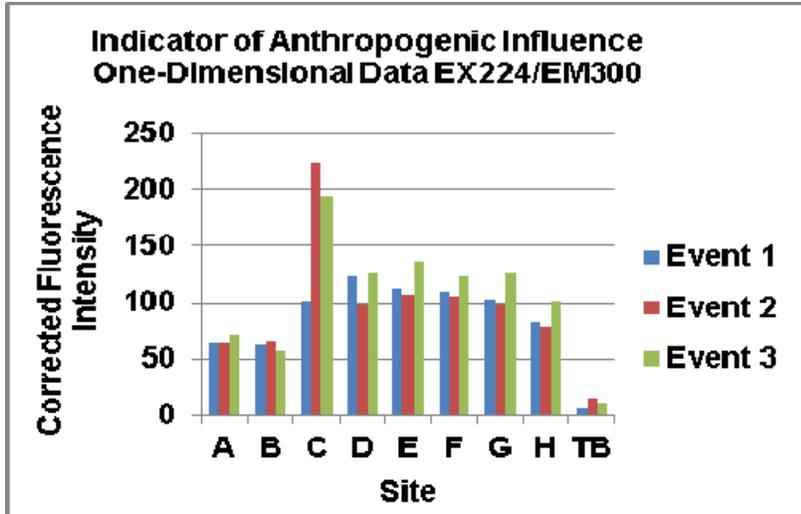


Figure 6-34a. Presence/Absence of Anthropogenic influence – Corrected fluorescence intensity for wavelength pair EX224/EM300 for all sites and events (TB = trip blank)

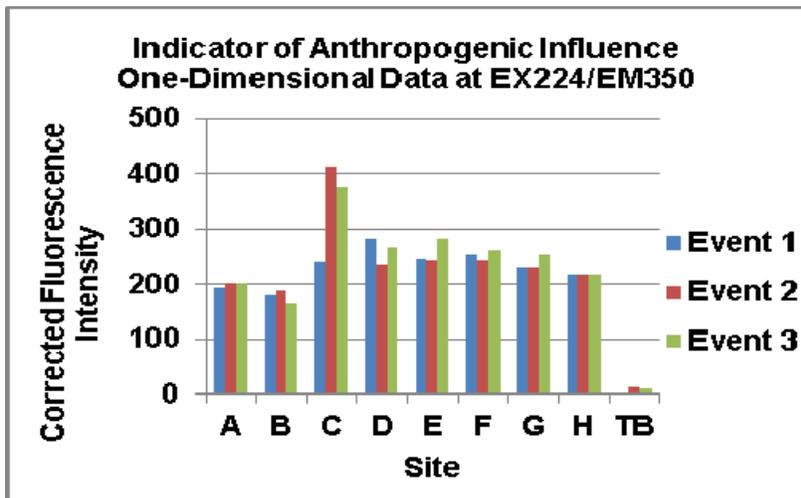


Figure 6-34b. Presence/Absence of Anthropogenic Influence – Corrected fluorescence intensity for wavelength pair EX224/EM350 for all sites and events (TB = trip blank)

**Table 6-8. Summary of Detected Data in Neuse River Samples**

Category	Analyte	Maximum, all sites and events		Average (over the three sampling events) <sup>2</sup>								
		Value <sup>1</sup>	Site	All sites	A	B	C	D	E	F	G	H
Wastewater Tracer <sup>3</sup>	Sucralose (ng/L)	26000 H	C	8490	<520	1973	20000	10400	9700	9300	8933	7100
Conventional	Ammonia as N (mg/L)	0.80	A	0.27	0.53	0.25	0.24	0.25	0.25	0.21	0.22	0.20
	Field pH (SU)	7.6	F	7.1	6.9	6.8	7.1	6.9	7.2	7.5	7.1	7.2
	Field Temperature (°C)	21.9	C	17.6	19.6	16.6	18.7	17.5	17.8	17.7	16.6	16.6
	Nitrate Nitrite as N (mg/L)	1.80	C	0.77	0.05	0.41	1.12	0.95	1.01	0.89	1.03	0.70
	Nitrogen, Kjeldahl (mg/L)	1.10	A	0.74	1.02	0.51	0.85	0.78	0.78	0.71	0.61	0.69
	Oxygen, Dissolved (mg/L)	9.59	E	8.70	8.79	8.95	8.57	8.52	8.88	8.98	8.50	8.42
	Phosphorus (mg/L)	0.92	C	0.37	0.04	0.04	0.71	0.34	0.54	0.52	0.50	0.20
	Specific Conductance (µmhos/cm)	523	C	207	87	123	291	237	247	241	234	198
	Total Organic Carbon (mg/L)	5.9	A	4.81	5.87	4.50	5.13	4.70	4.66	4.47	4.37	4.90
	Total Suspended Solids (mg/L)	15.0	H	7.2	6.3	<5.0	<5.0	6.1	5.3	6.4	8.9	12.2
Turbidity (NTU)	17.2	H	6.7	5.0	6.7	3.6	6.2	5.1	6.0	8.3	12.9	
Microbial Indicator	<i>C. perfringens</i> (CFU/100mL)	48	H	22	8	15	19	26	10	26	35	38
	Coliphages, Total (PFU/100mL)	73	H	20	17	12	2	8	25	30	32	34
	<i>E. coli</i> (MPN/100mL)	411	G	107	19	152	96	122	61	126	199	82
	Enterococci (MPN/100mL)	261	G	65	14	47	56	82	53	67	136	66
	Fecal coliforms (MPN/100mL)	687	G	259	128	306	220	247	234	243	402	293
Disinfection byproducts <sup>4</sup>	Bromide (µg/L)	64	C	48	27	42	60	50	51	50	50	51
	Chlorate(µg/L)	6.9 J	G	2.9	<2.1	2.4	2.3	3.0	2.7	3.2	5.1	2.5
	Monochloroacetic acid (µg/L)	7.4	B	0.7	<0.4	2.7	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
	N-Nitrosodimethylamine (NDMA) (ng/L)	1.50 J	C	0.44	<0.37	<0.37	0.83	<0.37	0.49	<0.37	<0.37	<0.37
Metals <sup>5</sup>	Barium (µg/L)	31.0	A	17.1	28.7	19.7	8.6	15.0	14.0	14.7	15.3	20.7
	Zinc (µg/L)	21.0	H	10.4	<8.7	<8.7	19.0	9.3	10.8	9.5	<8.7	<8.7
Pharmaceuticals <sup>6</sup>	Atenolol (ng/L)	50.7	C	9.4	<0.6	1.7	29.1	14.3	10.6	8.7	7.0	3.5
	Caffeine (ng/L)	93.0	D	55.8	<52.0	<52.0	61.7	65.7	59.3	51.7	54.7	<51.0
	Carbamazepine (ng/L)	190.0	C	62.7	<10.0	14.3	156.7	62.7	68.0	71.0	63.3	55.3
	Cotinine (ng/L)	16.8	C	10.0	9.8	8.1	14.3	10.7	9.9	9.6	9.0	8.9
	Fluoxetine (ng/L)	55.0	D	27.0	<26.0	<26.0	<26.0	35.7	<26.0	<26.0	<26.0	<26.0
	Furosemide (ng/L)	254.0	C	61.1	45.8	<41.7	174.5	66.6	41.0	<40.4	<41.4	<41.4
	Gemfibrozil (ng/L)	43.0	C	26.5	<26.0	<26.0	31.3	<26.0	<26.0	<26.0	<26.0	<26.0
	Hydrochlorothiazide (ng/L)	378.0	C	78.5	<20.9	<20.8	207.2	115.8	74.9	81.4	54.9	52.8
	Ibuprofen (ng/L)	48	C	26.7	<26	<26	33	<26	<26	<26	<26	<26
	Meprobamate (ng/L)	160.0	C	42.2	<10.0	<10.0	114.3	44.7	49.0	41.7	39.7	28.3
	Metoprolol (ng/L)	390.0	C	88.6	<12.2	9.7	245.6	115.0	103.6	96.9	77.5	51.8
	Ofloxacin (ng/L)	63.4	C	10.5	<2.7	<5.0	38.7	13.1	10.6	6.0	<3.7	<15.0
	Oxycodone (ng/L)	58.4	C	14.0	1.7	1.3	36.1	17.5	17.2	16.5	14.8	6.5
Sertraline (ng/L)	25.6	C	4.5	<0.4	0.5	17.6	6.4	4.1	3.5	2.3	0.8	

**Table 6-8. Summary of Detected Data in Neuse River Samples (continued)**

Category	Analyte	Maximum, all sites and events		Average (over the three sampling events) <sup>2</sup>								
		Value <sup>1</sup>	Site	All sites	A	B	C	D	E	F	G	H
Pharmaceuticals <sup>6</sup>	Sulfamethoxazole (ng/L)	1100.0 E	C	367.1	<10.0	<b>57.0</b>	<b>856.7</b>	<b>483.3</b>	<b>410.0</b>	<b>360.0</b>	<b>426.7</b>	<b>333.3</b>
	Trimethoprim (ng/L)	210.0	C	46.0	<10.0	<10.0	<b>156.7</b>	<b>60.0</b>	<b>52.0</b>	<b>41.3</b>	<b>28.3</b>	<10.0
	Valsartan (ng/L)	211.0	C	30.9	<4.1	<b>7.4</b>	<b>97.5</b>	<b>45.8</b>	<b>32.0</b>	<b>25.9</b>	<b>20.4</b>	<b>14.5</b>
	Verapamil (ng/L)	13.30	C	1.78	<0.17	<0.16	<b>8.49</b>	<b>2.50</b>	<b>1.40</b>	<b>1.03</b>	<b>0.38</b>	<0.16
Sterols & Hormones <sup>7</sup>	17-β-Estradiol (ng/L)	0.75 J	C	1.05	<1.20	<b>0.85</b>	<b>1.29</b>	<1.11	<1.44	<1.19	<0.97	<1.16
	β-Stigmastanol (ng/L)	70.0	H	42.5	<b>28.2</b>	<b>37.1</b>	<b>37.7</b>	<b>37.6</b>	<b>47.8</b>	<b>48.2</b>	<b>44.1</b>	<b>58.9</b>
	β-Sitosterol (ng/L)	937.0	A	369.5	<b>621.3</b>	<b>296.0</b>	<b>316.0</b>	<b>289.7</b>	<b>334.3</b>	<b>315.3</b>	<b>417.7</b>	<b>365.7</b>
	Cholesterol (ng/L)	866.0	C	511.3	<b>448.3</b>	<b>440.0</b>	<b>699.3</b>	<b>523.3</b>	<b>528.3</b>	<b>510.0</b>	<b>464.7</b>	<b>476.0</b>
	Coprostanol (ng/L)	160.0	C	52.5	<b>34.0</b>	<b>18.0</b>	<b>123.1</b>	<b>66.5</b>	<b>59.0</b>	<b>52.3</b>	<b>41.3</b>	<b>26.0</b>
Flame retardants <sup>8</sup>	Tris(2-chloroethyl)phosphate (ng/L)	150.0	C	63.0	<52.0	<52.0	<b>115.3</b>	<b>62.0</b>	<b>61.0</b>	<b>61.7</b>	<51.0	<51.0
Perfluorinated compounds <sup>9</sup>	Perfluorobutanoic acid (C4) (ng/L)	14.3	H	10.7	<10.0	<b>11.4</b>	<10.0	<10.0	<10.0	<b>12.2</b>	<b>10.3</b>	<b>11.4</b>
	Perfluoropentanoic acid (ng/L)	12.3	C	10.1	<10.0	<10.0	<b>10.8</b>	<10.0	<10.0	<10.0	<10.0	<10.0
	Perfluorobutane sulfonate (PFBS) (ng/L)	17.9	F	10.3	<10.0	<10.0	<10.0	<10.0	<10.0	<b>12.6</b>	<10.0	<10.0
	Perfluorooctane sulfonate (PFOS) (ng/L)	25.8	G	11.0	<10.0	<10.0	<b>10.5</b>	<10.0	<10.0	<b>11.3</b>	<b>15.3</b>	<b>11.3</b>
Pesticides, herbicides, and fungicides <sup>10</sup>	2,4-D (μg/L)	0.09 J	A	0.038	<b>0.054</b>	<0.037	<0.036	<0.036	<0.036	<0.036	<0.036	<0.036
	DEET (ng/L)	45	A	29.2	<b>41.7</b>	<b>32.7</b>	<26.0	<b>26.3</b>	<26.0	<26.0	<26.0	<b>30.0</b>
Consumer products and manufacturing additives <sup>11</sup>	Bisphenol-A (ng/L)	670	G	191	<150	<150	<b>167</b>	<b>160</b>	<b>263</b>	<b>157</b>	<b>323</b>	<b>160</b>
	Salicylic Acid (ng/L)	81	C	53	<52	<52	<b>61</b>	<53	<52	<52	<51	<51

Notes:

- 1) Data values are flagged as follows, where applicable: E - Sample exceeded the calibration range; H - Sample exceeded the method hold time; J - Result is under the method reporting limit
- 2) The columns labeled A through H represent the average values of all three sampling events for the given site. Non-detects were included in average calculations as the MDL.  
The site with the highest maximum average value is highlighted in blue. The site(s) with the lowest average value is/are highlighted in green, based on the value and/or MDL. (MDLs may vary from sample to sample.)  
Sites with at least one detect shown in bold, sites with three non-detect values are shown as less than (<) the MDL.
- 3) Average and maximum of retained results only. Refer to section 6.4 for additional details.
- 4) The following disinfection byproducts were not detected at any of the sampling locations for any of the sampling events: Bromate, chlorite, bromodichloromethane, bromoform, chloroform, dibromochloromethane, dibromoacetic acid, dichloroacetic acid, donobromoacetic acid, trichloroacetic acid
- 5) The following metals were not detected at any of the sampling locations for any of the sampling events: Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, selenium, thallium
- 6) The following pharmaceuticals were not detected at any of the sampling locations for any of the sampling events: acetaminophen, naproxen, primidone
- 7) The following hormones and sterols were not detected at any of the sampling locations for any of the sampling events: 17-α-ethinylestradiol, androstenedione, estrone
- 8) The following flame retardants were not detected at any of the sampling locations for any of the sampling events: α-HBCDD, β-HBCDD, γ-HBCDD
- 9) The following perfluorinated compounds were not detected at any of the sampling locations for any of the sampling events: Perfluorohexanoic acid (C6), perfluoroheptanoic acid (C7), perfluorooctanoic acid (C8, PFOA), perfluorononanoic acid (C9, PFNA), perfluorodecanoic acid (C10), perfluorohexane sulfonate (PFHS)
- 10) The following pesticides, herbicides, or fungicides were not detected at any of the sampling locations for any of the sampling events: α-chlordane, atrazine, bentazon, benzo[a]pyrene, carbaryl, γ-chlordane, MCPA, metolachlor, pentachlorophenol, simazine
- 11) The following consumer products or manufacturing additives were not detected at any of the sampling locations for any of the sampling events: Anthraquinone, camphor, p-cresol, triclosan, triphenylphosphate
- 12) None of the volatile organic compounds tested (Methyl tert-butyl ether (MTBE), m- & p-xylene, o-xylene, 1,2,4-trimethylbenzene, naphthalene, isopropylbenzene, benzene, ethylbenzene, carbon tetrachloride, toluene, 1,4-dioxane, tert-butyl alcohol, acetone (2-propanone), tetrachloroethene (perc), 1,1,1,2-tetrachloroethane, and 1,1,2,2-tetrachloroethane) were detected at any of the sampling locations for any of the sampling events  
None of the nonylphenol compounds tested (Nonylphenol Diethoxylate, Nonylphenol Monoethoxylate, para-tert-Octylphenol, p-Nonylphenol) were detected at any of the sample locations for any of the sample events.  
The contrast media iopromide was not detected at any of the sample locations for any of the sampling events.

## Section 7

# Potable Reuse Overview

This section provides an introduction to potable reuse (Section 7.1), estimates of *de facto* potable reuse in the US (Section 7.2), a discussion of the extent of IPR and DPR in the US (Section 7.3), an overview of regulatory frameworks for potable reuse in the US (Section 7.4) and in North Carolina (Section 7.5), and examples of current operations and their monitoring requirements (Section 7.6). Treatment technologies appropriate for meeting potable reuse requirements are presented in Section 7.7 and summarized in Section 7.8, and a brief discussion of some of the additional factors that need to be considered when planning a reuse scheme are summarized in Section 7.9.

## 7.1 Introduction to Potable Reuse

Reclaimed water can be reused for a range of potable and nonpotable applications, as listed and defined in **Table 7-1**. Treatment technologies are available such that any level of water quality can be achieved depending upon the use of the reclaimed water, as illustrated conceptually in **Figure 7-1**.



**Figure 7-1 Treatment Technologies are Available to Achieve any Desired Level of Water Quality (taken from EPA, 2012b)**

Augmenting potable water supplies with reclaimed water has significant potential to help meet future needs. The following definitions for potable water reuse terms are important for setting the scene for this discussion (EPA, 2012b):

- **Indirect potable reuse (IPR):** Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes drinking water treatment.
- **Direct potable reuse (DPR):** The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a drinking water treatment plant, either collocated or remote from the advanced wastewater treatment system.
- ***De facto* reuse:** A situation where reuse of treated wastewater is, in fact, practiced but is not officially recognized (e.g., a drinking water supply intake located downstream from a WWTP discharge point).

**Figures 7-2 and 7-3** provide graphical representations of IPR and DPR, respectively, with some examples.

**Table 7-1. Number of US States or Territories with Rules, Regulations, or Guidelines Addressing Various Categories of Water Reuse (EPA, 2012b)**

Category of Reuse		Description	Number of States or Territories with Rules, Regulations, or Guidelines Addressing Reuse Category	Addressed in North Carolina Regulations
Urban Reuse	Unrestricted	The use of reclaimed water for nonpotable applications in municipal settings where public access is not restricted	32	✓
	Restricted	The use of reclaimed water for nonpotable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction	40	✓
Agricultural Reuse	Food Crops	The use of reclaimed water to irrigate food crops that are intended for human consumption	27	✓
	Processed Food Crops and Non-food Crops	The use of reclaimed water to irrigate crops that are either processed before human consumption or not consumed by humans	43	✓
Impoundments	Unrestricted	The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities (some states categorize snowmaking in this category)	13	
	Restricted	The use of reclaimed water in an impoundment where body contact is restricted (some states include fishing and boating in this category)	17	
Environmental Reuse		The use of reclaimed water to create, enhance, sustain, or augment water bodies, including wetlands, aquatic habitats, or stream flow	17	✓
Industrial Reuse		The use of reclaimed water in industrial applications and facilities, power production, and extraction of fossil fuels	31	✓
Groundwater Recharge – Nonpotable Reuse		The use of reclaimed water to recharge aquifers that are not used as a potable water source	16	
Potable Reuse	IPR	Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes normal drinking water treatment	9	
	DPR	The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a water treatment plant, either collocated or remote from the advanced wastewater treatment system	0	

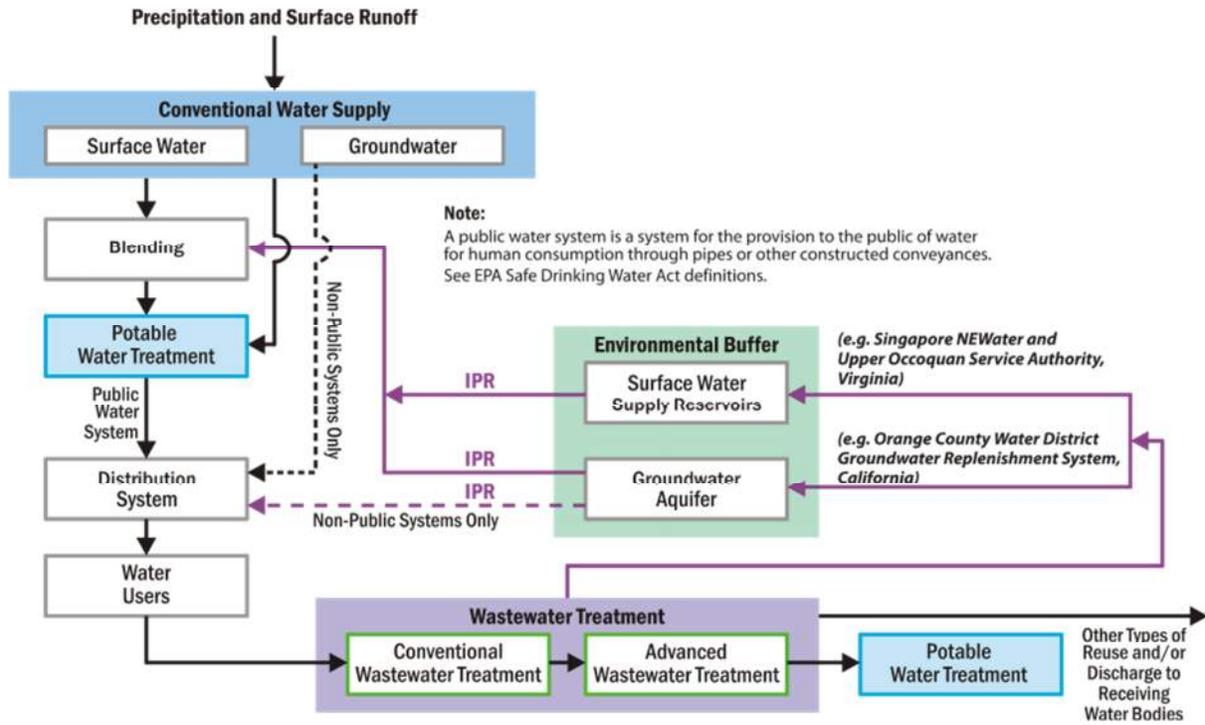


Figure 7-2. Planned IPR Scenarios and Examples (from EPA, 2012b)

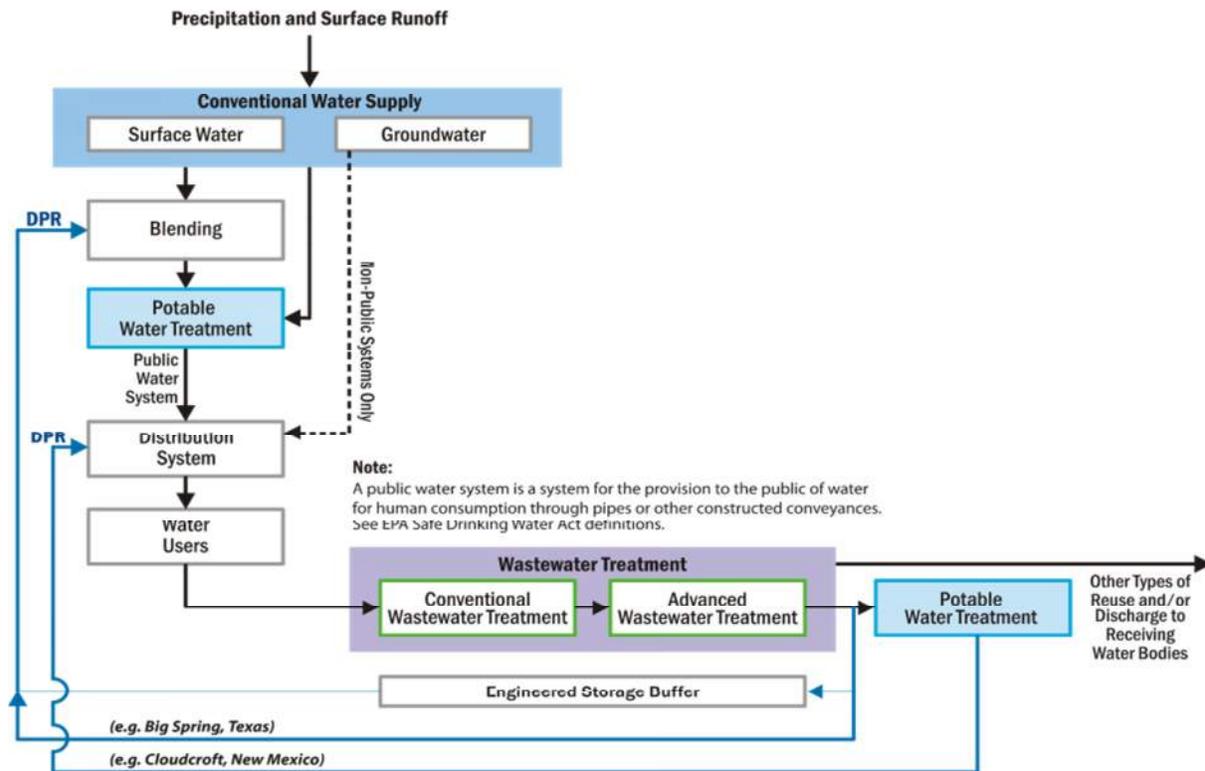


Figure 7-3 Planned DPR and Specific Examples of Implementation (from EPA, 2012b)

Comparing Figures 7-2 and 7-3 it is evident that the key difference between IPR and DPR is the presence of an environmental buffer, which can provide additional treatment, reaction time in case of process upsets, and storage. At the same time, the environmental buffer can also reduce the water quality of the reclaimed water, depending on the conditions. This is one of the factors that have prompted the water reuse industry to consider DPR, because an engineered buffer might, in theory, provide some of the benefits of an environmental buffer, but with greater control over water quality.

As shown in Figure 7-3, DPR is the introduction of purified water, derived from municipal wastewater after extensive treatment and monitoring, directly into a municipal water system. This can be done after storage in an engineered storage buffer or more directly in pipe-to-pipe blending back into the distribution system for delivery to water users. These scenarios take advantage of utilizing existing water distribution infrastructure, rather than the new purple pipe infrastructure often required for new non-potable reuse applications.

It is appropriate to evaluate IPR and DPR in water management planning to help meet urban water supply requirements, as they may be less energy intensive or more favorable ecologically than alternative solutions, while providing at least equivalent water quality that is protective of public health. Further, this is consistent with the engineering practice of selecting the highest quality source water available for drinking water production. However, even where DPR is selected as an appropriate component of water supply, DPR cannot be a stand-alone water supply. Other local water sources must be combined with DPR to ensure a reliable, robust, and sustainable water supply.

## 7.2 Extent of *de facto* Reuse in the US

As previously mentioned, *de facto* potable reuse is a significant portion of the nation's water supply, though the extent of its contribution is difficult to estimate. The 13 percent that is used for groundwater recharge as shown in Figure 7-2 may be considered to be part of the nation's *de facto* reuse, but this represents only a fraction of the portion of *de facto* reuse occurring from groundwater sources. The most recent study on the contribution of wastewater effluent to WTPs drawing from surface water sources was done by the EPA in 1980 (EPA, 1980). This study identified the top 25 WTPs most impacted by upstream WWTPs. Upon reexamining the 25 most impacted WTPs, it was determined that currently between 2 to 16 percent of the flow at these WTPs is derived from upstream WWTPs under average streamflow conditions and 7 to 100 percent under low streamflow conditions (Rice, 2013). The full extent of *de facto* reuse in the US is likely much higher because of population growth (resulting in construction of new WWTPs over what was present in 1980) and incorporation of populations into centralized sewer systems. In many locations, the treated municipal wastewater discharges provide a steady supply of streamflow for downstream human and ecological uses.

Large cities such as Philadelphia, Nashville, Cincinnati, and New Orleans draw their drinking water from the Delaware, Cumberland, Ohio, and Mississippi Rivers, respectively, and can be counted among the populations served by *de facto* reuse. The potable water in these locations meets current drinking water regulations resulting from the drinking water treatment technologies used.

In 2012 the National Research Council (NRC) issued a report titled "Water Reuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater" that discusses the importance of *de facto* reuse in the US. Through numerous examples and comparative risk discussions, NAS finds that:

*"... with recent advances in technology and design, treating municipal wastewater and reusing it for drinking water, irrigation, industry, and other applications could significantly increase the nation's total available water resources, particularly in coastal areas facing water shortages. Moreover, new analyses suggest that the possible health risks of exposure to chemical contaminants and disease-causing microbes from wastewater reuse do not exceed, and in some cases may be significantly lower than, the risks of existing water supplies."*

Significant advances in treatment technology and monitoring methodology in the last decade and health effects data from IPR projects and DPR demonstration facilities have bolstered confidence in IPR and DPR. This, combined with the reality of ubiquitous *de facto* reuse suggests that IPR and DPR scenarios may be reasonable options to consider when future water needs are assessed by communities. The technology, monitoring and controls are available to apply technology to reuse water sources under a utility's control in a more cost-effective management approach.

Further, as regulations on WWTP discharge water quality become more stringent and the water quality required of a plant discharge meets or exceeds the water quality of the receiving stream based on all regulated parameters, many utilities are reconsidering the value of enhanced wastewater treatment. The cost of enhanced wastewater treatment must be compared to reuse of the reclaimed water at its current quality (or with minor improvements) and some equitable value placed on the offset in demand on the potable water system.

### 7.3 Extent of IPR and DPR in the US

The US produces 32 billion gallons of municipal wastewater effluent per day, of which 7 to 8 percent is reclaimed (EPA, 2012b). Currently planned IPR and DPR only account for a small fraction of the volume of water being reused. However, if *de facto* reuse is considered, potable reuse is a significant portion of the nation's water supply. The only currently operating DPR system in the US is located in Big Spring, Texas (2.5 mgd). A second system in Wichita Falls, Texas (15 mgd) is under construction and is anticipated to come online in 2014. There are no current IPR or DPR installations in North Carolina.

The reuse master planning effort being conducted by the City is consistent with national trends where there is a growing interest in providing sustainable water supply solutions that leverage advances in the science and engineering of water treatment such that broader application of potable reuse practices can be applied. There are several places in the US that are planning or currently utilizing IPR or evaluating future DPR, which are described further in Section 7.3. While the implementation of DPR may still be considered an emerging practice, the 2012 EPA *Guidelines for Water Reuse* stated "...it [DPR] should be evaluated in water management planning, particularly for alternative solutions to meet urban water supply requirements that are energy intensive and ecologically unfavorable."

Research over the past decade at full-scale advanced water treatment facilities producing water for IPR has demonstrated that engineered systems can perform equally well or better than the natural processes that occur in environmental buffers at attenuating contaminants. Quality assurance in IPR and DPR is approached through the proper monitoring of indicators and surrogates. A number of these planned IPR projects have been in use for many years, demonstrating successful operation and treatment. For example, the water quality and treatment performance data generated at Water Factory 21/Orange County Groundwater Replenishment Project in California and the Occoquan Reservoir in Virginia help to show that the advanced wastewater treatment processes in place in these IPR projects achieved the required purification level.

Building on the successful track record of many IPR installations, DPR has been recently implemented in Big Spring, Texas and is being implanted in Wichita Falls, Texas this year. Brownwood, Texas is also evaluating DPR because of severe drought. A DPR project in Cloudcroft, New Mexico has recently been built, but is currently not in operation due to construction problems. These DPR installations are truly cutting-edge – the only other implementation of DPR worldwide is in Windhoek, Namibia, which was the first city to implement long-term DPR without the use of an environmental buffer. Windhoek’s experimental DPR project began in 1969 and was expanded in 2002 to 5.6 mgd. It now supplies about 50 percent of the city’s potable water demand. Several examples of planned IPR and DPR projects are shown in a map of the US (**Figure 7-4**).



**Figure 7-4. Planned IPR Projects (blue dots) and DPR Projects (orange dots) in the US (not intended to be an exhaustive survey)**

## 7.4 Regulating Potable Reuse in the US

Quality assurance in IPR and DPR is approached through the proper monitoring of indicators and surrogates. Water reuse guidance is issued at the federal level in the EPA *Guidelines for Water Reuse*, but each state regulates water reuse separately (EPA, 2012b). The 2012 EPA guidelines provide guidance for IPR but not DPR. The EPA has not yet begun a process to develop DPR guidance, but this is under consideration as of 2014. As shown at the bottom of **Table 7-1**, as of 2012 only 9 states address IPR in their rules, regulations, or guidelines. Neither IPR nor DPR applications are addressed in NC rules, regulations, or guidelines.

To date, no state yet has developed requirements for DPR. The process to develop such guidance is slow, because regulators can be reluctant to commit to maximum or minimum water quality levels for IPR, let alone DPR, due to a lack of definitive information related to public health risks. For example, California has recently published draft IPR regulations for groundwater recharge, a process that has been underway since the 1990s. California now has begun investigating the feasibility of developing regulatory criteria for DPR with an independent panel. Per Senate Bill 918, the California Department of Public Health (CDPH) is to provide a final report on this investigation to the Legislature by the end of 2016.

In the state of Georgia, the Environmental Protection Division and volunteers from the Georgia Association of Water Professionals are in the process of developing guidance documents for both IPR and DPR. The goal is to provide utilities, engineers and the public with resource documents that describe the drivers, history, public health considerations, treatment technologies, stakeholder education and outreach, and process for local governments to propose IPR or DPR. The IPR guidance document is scheduled to be issued by mid-2014 along with public information sessions on IPR. The DPR guidance document will follow the draft IPR document and is anticipated for issue in the third or fourth quarter of 2014.

Texas is likewise considering DPR regulations or guidance. The Texas Water Development Board, with support from a number of Texas utilities and WateReuse Texas, recently initiated a project that will develop a resource document by 2015 to help guide entities in Texas wishing to pursue DPR. In addition, the Texas Water Conservation Association is leading a coordinated effort involving key stakeholders, agencies, and professional organizations to advance potable reuse in the state. This association's water reuse committee has developed a white paper and recommendations related to potable reuse.

In addition, a WateReuse Research Foundation (WRRF) guidelines committee is currently discussing the potential need for national guidelines related to DPR. **Table 7-2** provides a summary of US states with potable reuse regulatory frameworks.

Australia was the first country to develop national guidelines for potable reuse with the 2008 release of Phase 2 of the Australian Guidelines for Water Recycling (AGWR): Augmentation of Drinking Water Supplies (EPA, 2012b). The AGWR provides non-mandatory concentration-based numeric guidelines for at least 86 pharmaceuticals in reclaimed water which are based on application of a safety factor of 1,000 to 10,000 relative to a single therapeutic dose – far higher than concentrations generally found in drinking water or reclaimed water.

**Table 7-2. US States with Potable Reuse Regulatory Frameworks**

State	IPR regulatory framework	DPR regulatory framework
Arizona	IPR is regulated on a case-by-case basis under the Aquifer Protection Permit program.	Under development.
California	Reuse regulations are found in section 60320, Title 22, of California's Code of Regulations as set by the California Department of Public Health. The local Regional Water Quality Control Boards are charged with issuing individual WWTP and advanced water treatment facility permits, so state regulations are interpreted on a case-by-case basis. Draft regulations for groundwater recharge IPR have been published and are expected to be finalized in 2014.  Regulatory guidance for IPR through surface water augmentation is being developed.	Regulatory guidance is being considered.
Florida	IPR (via aquifer recharge by injection) regulations are found in Part V of Chapter 62-610 of the Florida Administrative Code.	While the IPR regulations are not specific to DPR, they allow for other types of reuse activities not specified in the rule to be permitted on a case-by-case basis.
Hawaii	Hawaii has guidance on IPR. IPR projects would be reviewed on a case-by-case basis.	None.
Georgia	IPR proposals are reviewed on a case-by-case basis by an <i>ad hoc</i> committee of State regulators. Regulatory guidance for IPR is currently under development. Guidance that is currently under development would provide a structured process to review applications for either IPR or DPR.	Regulatory guidance for DPR is currently under development.
Massachusetts	IPR is permitted by Massachusetts water reuse regulations under Category A reclaimed water. IPR projects would be reviewed on a case-by-case basis.	None.
Pennsylvania	Pennsylvania has guidance on IPR. IPR projects would be reviewed on a case-by-case basis.	None.
Texas	IPR projects are reviewed on a case-by-case basis.	DPR projects are reviewed on a case-by-case basis. The two DPR facilities in Texas were permitted in this manner. The state is considering developing DPR regulatory guidance.
Virginia	IPR regulations are found in the Water Reclamation and Reuse Regulation (9VAC25-740). Virginia allows IPR that is defined as "a discharge of reclaimed water to a receiving surface water for the purpose of intentionally augmenting a water supply source, with subsequent withdrawal after mixing with the ambient surface water and transport to the withdrawal location, followed by treatment and distribution for drinking water and other potable water purposes." This definition does not include aquifer recharge where groundwater is used as a water supply source.	None.

## 7.5 North Carolina Water Reuse Regulations

### 7.5.1. North Carolina Overall Water Reuse Policy

In 2008, the legislature established a new policy under General Statute (GS) § 143-355.5 and 143-215.1(d2) stating that use of reclaimed water is critical to North Carolina meeting its future water supply needs and finding that properly permitted and operated systems can meet many beneficial demands while being environmentally acceptable and protective of public health. Recent changes in the North Carolina Reclaimed Water Regulations in response to the new direction (15A NCAC 02U-effective June 18, 2011) treat reclaimed water more as a resource though there continues to be references to “wastewater origin” and use area limitations akin to land application of raw or partially treated wastewater. The new regulations allow for additional beneficial uses of reclaimed water including wetlands augmentation and irrigation of food crops intended for human consumption. The rules establish two tiers of water quality/treatment standards, as given in **Table 7-3**.

Type 2 reclaimed water treatment facilities are required to provide dual disinfection systems containing UV disinfection or equivalent and chlorination or equivalent to provide pathogen control and must be capable of the following pathogen reduction:

- log 6 or greater reduction of *E. coli*;
- log 5 or greater reduction of Coliphage; and
- log 4 or greater reduction of *C. perfringens*.

**Table 7-3. Type 1 and Type 2 Reclaimed Water Standards**

Parameter	Type 1		Type 2	
	Daily Maximum	Maximum Monthly Average	Daily Maximum	Maximum Monthly Average
Turbidity (ntu)	10	--	5	--
BOD <sub>5</sub> (mg/L)	15	10	10	5
TSS (mg/L)	10	5	10	5
NH <sub>3</sub> (mg/L)	6	4	2	1
<i>E. coli</i> /Fecal Coliform (#/100 mL)	25	14	25	3
Coliphage (#/100 mL)	--	--	25	5
<i>C. perfringens</i> (#/100 mL)	--	--	25	5

Reclaimed water systems are classified in North Carolina as either conjunctive or non-conjunctive systems. A conjunctive reclaimed water system refers to a system where beneficial use of reclaimed water is an option and reuse is not necessary to meet the wastewater disposal needs of the facility. In this case, other wastewater utilization or disposal methods (i.e., NPDES permit) are available to the facility at all times. A non-conjunctive reclaimed water system evolved from land disposal system permits and refers to a system where the reclaimed water utilization option is required (or dedicated)

to meet the wastewater disposal needs of the facility and no other disposal or utilization options are available. Of the 117 active reclaimed water permits in North Carolina, 56 permits (48 percent) are for conjunctive use systems with 36 of those issued to municipalities.

Changes in the 15A NCAC 02U regulations now allow more flexibility for utilities to expand use beyond dedicated land disposal. The 2011 reclaimed water regulations allow many uses of reclaimed water by regulation, and increase the potential to use reclaimed water in agricultural applications, especially with Type 2 reclaimed water. This higher quality reclaimed water has few agricultural restrictions (one being a 24-hour waiting period following application of reclaimed water prior to harvest). These new rules allow utilities to now consider wholesale supply of reclaimed water to agricultural interest, assuming the value of this water to both parties can be agreed upon. Some example uses allowed for Type 1 and Type 2 reclaimed water are given in **Table 7-4**. The City's production of higher quality reclaimed water, even if not tested and approved at the Type 2 quality, improves the acceptance and continued use of the reclaimed water and could be perceived as a higher value product.

**Table 7-4. Example Type 1 and Type 2 Reclaimed Water Uses**

Use	Type 1	Type 2
Landscape irrigation	✓	✓
Irrigation of food crops		✓
Peeled, cooked or thermally processed	✓	✓
Not peeled, cooked or thermally processed <sup>1</sup>		✓
Dust control for street sweeping	✓	✓
Vehicle washing	✓	✓
General construction purposes	✓	✓
Industrial/commercial uses	✓	✓
Cooling towers	✓	✓
Urinal and toilet flushing (industrial/commercial only)	✓	✓
Fire protection (industrial/commercial only)	✓	✓
Wetlands augmentation	✓	✓

**Note:**

<sup>1</sup> Only allowed for indirect contact with reclaimed water (no direct contact)

Section 15A NCAC 02U.0113 (a) defines ten uses for reclaimed water that are permitted by rule as long as the use does not create a violation of surface or groundwater standards. These ten uses are:

- (1) Discharges to land surface from flushing and hydrostatic testing;
- (2) Overflow from elevated reclaimed water storage facilities;

Any *de minimus* runoff of reclaimed water from Division approved uses;

- (1) Incidental discharge to a municipal separate storm sewer system (MS4) from Division approved uses;
- (2) Rehabilitation, repair, or replacement of reclaimed water lines in kind;
- (3) Flushing (including air release valve discharge) and hydrostatic testing water discharges associated with reclaimed water distribution systems;
- (4) Utilization of reclaimed water received from a permitted reclaimed water bulk distribution program;
- (5) Irrigation of residential lots or commercial (non-residential) application areas less than one acre in size that are supplied with reclaimed water as part of a conjunctive use reclaimed water system;
- (6) Irrigation of agricultural crops supplied with reclaimed water as part of a permitted conjunctive use reclaimed water system;
- (7) Drip irrigation sites supplied with onsite reclaimed water as part of a Department permitted conjunctive use reclaimed water system under 18A.1900.

There are several provisions in current GS and the NCAC that would require modification or clarification in order to facilitate DPR or IPR in North Carolina.

Changes to NCGS § 143-355.5, Water reuse; policy; rule making, would be required to clarify that reclaimed water may be used as a supplement to raw water supplies for drinking water under certain conditions. Provisions restricting when and how this may be done would likely be required in order to get sufficient legislative support. Legislators would potentially want to limit the scope and circumstances under which this would be considered by requiring water conservation and water efficiency measures to be in place and demonstrated as effective prior to consideration of DPR or IPR. Maximum percentages of mixing would also likely be required to limit the potential for the accumulation of contaminants that are difficult to remove through treatment processes in a partially closed-loop water system.

The NCAC Section 15A, which deals with Environment and Natural Resources, would require amendments to address watershed classification issues and reclaimed water usage issues that would be barriers to DPR or IPR. Specifically, 15A NCAC 02B, which deals with the state's watershed classification rules, would require modifications to allow reclaimed water to be discharged within the critical area of a water supply watershed of the classification required by a proposed DPR or IPR system. In addition, 15A NCAC 02U .0501 (e) would require amendment to allow reclaimed water to be considered for direct reuse as a raw water supply under the conditions as specified under the required modifications outlined to NCGS § 143-355.5 in the previous paragraph. Lastly, 15A NCAC 18C .0202, which is in the Environmental Health section of the code, may require modification to clarify that reclaimed water could be used as a raw water supply supplement or source and still meet the sanitary survey requirements of this code.

### 7.5.2. North Carolina Potable Water Reuse Policy

NCDENR has established a policy preferring use of reclaimed water to support non-potable uses and has stated they would not support a new wastewater discharge permit if the treated effluent were proposed to be discharged to a drinking water source reservoir. This opinion was provided to City staff in response to a September 9, 2011 letter to Ms. Jessica C. Godreau, Chief of North Carolina Public Water Supply Section, NCDENR, as reported in an October 5, 2011 report “A Review and Evaluation of Reclaimed Water Utilization by the City of Raleigh.” This position is not new. In an April 10, 1996 presentation “Strategic Management Implications of Water Reclamation And Reuse on Water Resources” to the North Carolina American Water Works Association and the North Carolina Water Environment Association (NC AWWA-WEA) Reclaimed Water Conference, NCDENR staff indicated reclaimed water is a “new” source of water that can offset potable water uses and extend the capability of existing potable water systems while deferring new capital improvements. While NCDENR recognized advances in treatment processes leading to water augmentation projects and coastal aquifer barrier projects, they also cautioned about negative impacts to receiving streams if reclamation projects reduced historical stream flows, and cautioned that institutional challenges would require new public health protection measures.

In addition to the NCDENR opinions, nutrient limits and limitations on new wastewater discharge permits for discharge to local reservoirs currently used for raw water supply limit further discussions of IPR or supply augmentation in the immediate Raleigh area, unless regulatory philosophy is shifted and regulatory changes are made as outlined under the previous section.

## 7.6 Examples of IPR and DPR in the US

Examples of seven representative IPR and DPR projects from four states in the US (California, Georgia, Texas, and Virginia) are summarized in **Table 7-5 and Figure 7-5**, along with the monitoring requirements at these facilities. These monitoring requirements were each achieved through a case-by-case approval process at the state level, and as such, they differ widely from location to location. These facilities are individually presented in this section, along with a brief discussion of how each of the four states has addressed IPR and DPR monitoring requirements.

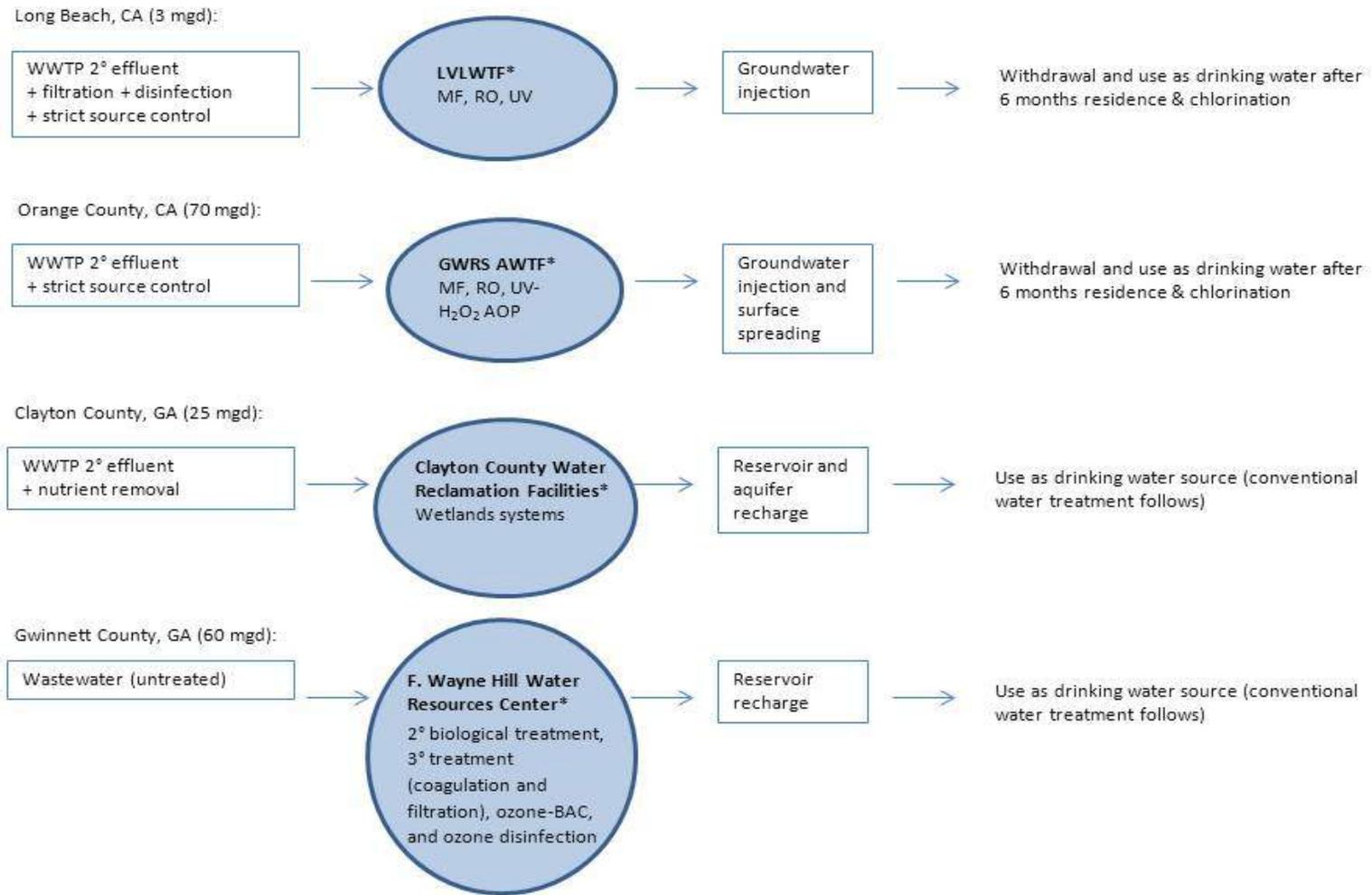
### 7.6.1 California

In California the CDPH, the California State Water Resources Control Board (SWRCB), and the nine Regional Water Quality Control Boards (RWQCBs) are involved in the oversight of water recycling. The SWRCB and RWQCBs are part of the California Environmental Protection Agency (Cal/EPA). The nine semi-autonomous RWQCBs are divided by regional boundaries based on major watersheds and make water quality planning and regulatory decisions for their region. The SWRCB sets statewide water quality policy while the CDPH protects public health. Protection of public health includes the regulation of public water systems (drinking water purveyors) and the development and adoption of water recycling criteria. For more information, refer to the case study titled “California State Regulations” in the EPA *Guidelines for Water Reuse* (EPA, 2012b). As mentioned in Section 7.4, California does not yet have regulations that govern IPR or DPR. IPR is regulated using a series of Draft IPR regulations that have been released by CDPH over the years, with the latest draft being released in June 2013. The IPR regulations specifically govern groundwater the water quality and blending requirements for surface and subsurface recharge. The IPR regulations are to be finalized in 2014.

**Table 7-5. Overview of Representative IPR and DPR Facilities in the U.S. (not intended to be a complete survey)**

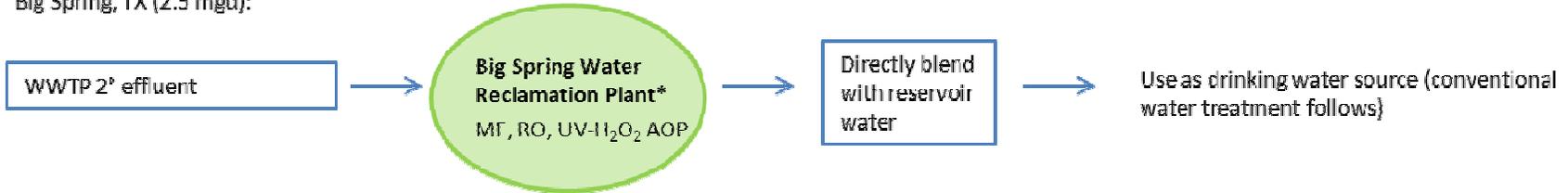
Project Size (mgd)	Installation Year (Upgrade)	Type of Reuse	Reuse Method	Process <sup>1</sup>	Upgrade from Existing WWTP?	Sampling requirements <sup>2</sup>
<b>Long Beach, CA</b> – Leo J. Vander Lans Advanced Water Treatment Facility (LVLWTF) <sup>3</sup>						
3 (8)	2005 (2013)	IPR	Groundwater recharge	MF, RO, UV (advanced oxidation is being added)	New facility, currently being expanded	Conventional wastewater parameters (1/D, 1/Q, or 1/Y depending on constituent), total coliform (1/D), disinfection byproducts (1/Q), priority pollutants (1/Q), all primary and secondary drinking water contaminants under the SDWA (1/Q), other chemicals with notification levels under CDPH rules for drinking water (1/Q or 1/Y, depending on constituent), several trace chemical compounds (1/Y: 17β-estradiol, caffeine, triclosan, DEET, sucralose, TCEP, and gemfibrozil), and NDMA (1/Q).
<b>Orange County, CA</b> – Orange County Groundwater Replenishment System (GWRS) / Advanced Water Treatment Facility (AWTF) <sup>3,4</sup>						
70 (100)	2008 (2014)	IPR	Groundwater recharge	MF, RO, UV- H <sub>2</sub> O <sub>2</sub> AOP	New facility built at an existing site. Old Water Factory 21 reuse plant was demolished to construct new GWRS facility.	Conventional wastewater parameters (1/D, 1/Q, or 1/Y depending on constituent), total coliform (1/D), disinfection byproducts (1/Q), priority pollutants (1/Q), all primary and secondary drinking water contaminants under the SDWA (1/Q), and several unregulated chemicals (1/Q: boron, chromium-6, perchlorate, vanadium, dichlorodifluoromethane, ethyl tertiary butyl ether, tertiary amyl methyl ether, tertiary butyl alcohol, 1,2,3-trichloropropane, NDMA, 1,4-dioxane, and pharmaceuticals and endocrine disrupting chemicals specified by CDPH).
<b>Clayton County, GA</b> <sup>3,5</sup>						
1. W.B. Casey Water Reclamation Facility → E.L. Huie Constructed Wetlands						
2. Shoal Creek Water Reclamation Facility → Panhandle Road Constructed Wetlands						
1. 24 2. 4.4	1. 2004 2. 1982 (2002)	IPR	Wetlands system recharges drinking water reservoir and underlying aquifer	Wetlands multi-cell treatment trains (nine and three respectively)	New systems	BOD <sub>5</sub> , (5D/W), TSS (5D/W), NH <sub>3</sub> -N (5D/W), TP (5D/W), Fecal coliform (3D/W), 120-day BOD (once during permit duration), chronic whole effluent toxicity (WET) (1/Y)
<b>Gwinnett County, GA</b> – F. Wayne Hill Water Resources Center						
60	2001 (2006)	IPR	Drinking water reservoir supply recharge	Two parallel trains: A) Coagulation + sand filter B) Coagulation, flocculation and clarification + UF Then 2 streams are combined and treated with ozone-BAC and final ozonation for disinfection.	New facility	Monitoring required for <sup>6</sup> : Ammonia, phosphorus, COD, TSS, turbidity, DO, pH, fecal coliform Additional goals include <sup>7</sup> : <ul style="list-style-type: none"> <li>▪ Meet chronic and acute bioassay toxicity standards</li> <li>▪ Meet National Primary Drinking Water Standards for TN and TDS</li> <li>▪ &lt; 15 platinum cobalt units (PCU) color</li> <li>▪ Aggressive pathogen removal (and establish CT credits for <i>Giardia</i>)</li> </ul>
<b>Big Springs, TX</b> – Big Spring Regional Water Reclamation Plant (Colorado River Municipal Water District) <sup>3,8</sup>						
2.5	2012	DPR	Direct blend to potable supply	MF, RO, UV-H <sub>2</sub> O <sub>2</sub> AOP	New facility	Nitrate (1/D), nitrite (1/D), <i>Giardia</i> (1/M for 2 yr), <i>Cryptosporidium</i> (1/M for 2 yr), <i>E. coli</i> (1/7D for 2 yr.), TOC, conductivity (continuous), TDS, UVT (continuous)
<b>Wichita Falls, TX</b> – River Road WWTP Cypress Water Treatment Plant (Emergency Reuse Scenario)						
15	2013	DPR	Direct blend to drinking water supply reservoir	RO, HF, MF, and UF membranes	New facility <sup>9</sup>	The draft list of parameters to be monitored (at multiple locations in the treatment train and at various frequencies) includes <sup>10</sup> : <ul style="list-style-type: none"> <li>▪ <i>E. coli</i>, <i>Giardia</i>, and <i>Cryptosporidium</i></li> <li>▪ A range of conventional parameters</li> <li>▪ Full metal scan</li> <li>▪ Algae counts</li> <li>▪ Inorganic, organic, radioactive, and secondary chemicals specified under Texas drinking water codes</li> <li>▪ Disinfection byproducts</li> </ul> In addition, the facility must meet the requirements of the SDWA.
<b>Fairfax, VA</b> – Upper Occoquan Service Authority – Millard H. Robbins, Jr Water Reclamation Plant <sup>3,11</sup>						
54	1978 (2005)	IPR	Drinking water reservoir recharge	Lime precipitation, two stage recarbonation with intermediate settling, multimedia filtration, GAC, chlorination and dechlorination	New facility, has undergone several expansions	pH (1/D), COD (5D/W), TSS (5D/W), TKN (5D/W), anionic surfactants (using Methylene Blue Activated Substances method) (1/M), DO (1/D), turbidity (1/D), total residual chlorine (1/D), <i>E. coli</i> (Geomean, 1/D), total phosphorus (5D/W), chronic toxicity (using <i>C. dubia</i> and <i>P. promelas</i> methods) (1/Y) <sup>12</sup>

1) Process Abbreviations: MF – Microfiltration; RO – Reverse Osmosis; UV – Ultraviolet; GAC – Granular Activated Carbon; HF – Hollow Fiber, UF – Ultrafiltration; AOP – advanced oxidation process  
 2) Codes: 1/D = Once every day; 1/M = Once every month; 1/Q = Once every quarter; 1/Y = Once every year; 3D/W = Three days every week; 5D/W = Five days every week; 7D/W = Seven days every week; 3G/24H = Three grabs per 24 hr period  
 3) EPA, 2012  
 4) Orange County Groundwater Replenishment System Website. Accessed November 24, 2013 at <http://www.gwrssystem.com/about-gwrssystem.html>  
 5) Clayton County Water Authority Website. Accessed November 24, 2013 at <http://www.ccwa.us/water-reclamation-facilities>  
 6) Per Mark Turner, Gwinnett County  
 7) Oneby et al, 2010  
 8) Per TCEQ approval letter (Appendix I)  
 9) City of Wichita Falls 2013 Drinking Water Quality Report. Accessed November 24, 2013 at [http://www.wichitafallstx.gov/documents/2/89/110/2013%20REPORT%20-%20WATER%20DEPARTMENT\\_201306241610204508.pdf](http://www.wichitafallstx.gov/documents/2/89/110/2013%20REPORT%20-%20WATER%20DEPARTMENT_201306241610204508.pdf)  
 10) See Appendix J for the draft list of constituents to be tested, the locations for testing, and the frequency of testing.  
 11) Upper Occoquan Service Authority Website. Accessed November 22, 2013 at <http://www.uosa.org/>  
 12) Virginia Pollutant Discharge Elimination System VPDES Permit. Accessed November 22, 2013 at <http://uosa.org/DisplayContentUOSA.asp?ID=654>

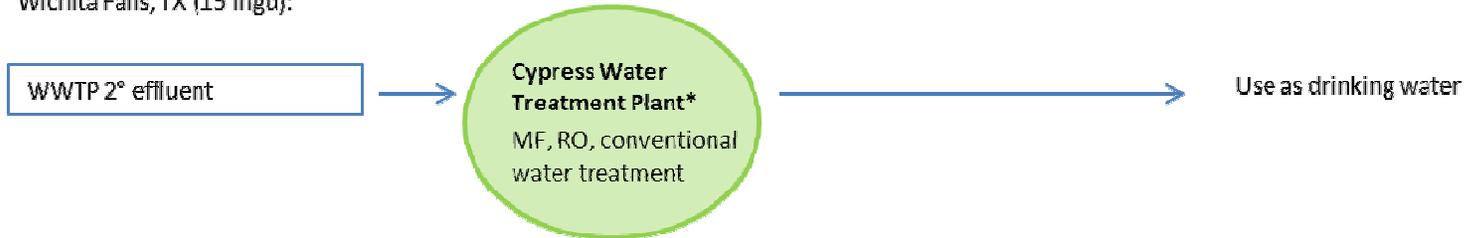


**Figure 7-5a. Treatment Schematics of Representative IPR and DPR Facilities in the US (not intended to be a complete survey). Blue circles are IPR facilities; green are DPR facilities.**

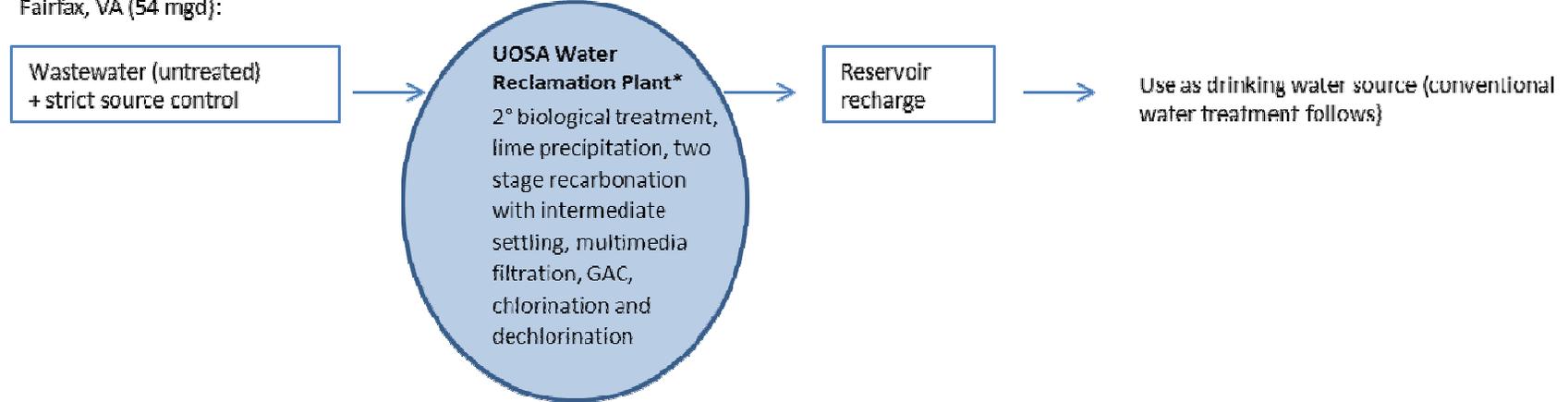
Big Spring, TX (2.5 mgd):



Wichita Falls, TX (15 mgd):



Fairfax, VA (54 mgd):



\* Entity responsible for specific reclaimed water monitoring requirements.

Figure 7-5b. Treatment Schematics of Representative IPR and DPR Facilities in the US (not intended to be a complete survey). Blue circles are IPR facilities; green are DPR facilities.

CDPH is currently investigating the feasibility of developing regulatory criteria for DPR. In 2009, the SWRCB adopted a Recycled Water Policy which included the establishment of a Science Advisory Panel to provide guidance for future monitoring trace chemical constituents in IPR. In 2010, the Science Advisory Panel produced a report which provided a conceptual framework for assessing potential targets for monitoring and used the framework to identify a list of chemicals and surrogates that should be monitored currently, including caffeine, 17 $\beta$ -estradiol, NDMA, triclosan, gemfibrozil, n,n-diethyl-meta-toluamide (DEET), iopromide, NDMA, sucralose, turbidity, dissolved organic carbon (DOC), and conductivity (EPA, 2012b). For IPR projects, CDPH requires quarterly monitoring of boron; chlorate; 1,4- dioxane; nitrosamines (NDMA, NDEA, and NDPA); 1,2,3-trichloropropane; naphthalene; vanadium; chromium-6; diazinon; and nitrosamines NPYR and N-nitrosodiphyllamine, with initial quarterly testing that could be reduced to annual testing if the chemicals are not detected (EPA, 2012b). CDPH also recommends annual monitoring of BPA, carbamazepine, and TCEP. Monitoring requirements are ultimately negotiated with the RWQCBs and specified in operating permits.

Two southern California IPR facilities, the Leo J. Vander Lans Advanced Water Treatment Facility (LVLWTF) in Long Beach and Orange County Groundwater Replenishment System (GWRS) Advanced Water Treatment Facility (AWTF) in Orange County, are described in the subsections that follow and in Table 7-5 as representative examples of how the CDPH recommendations and SWRCB policy are adapted for specific locations.

#### 7.6.1.1 Long Beach, CA

The LVLWTF was constructed in 2005 by the Water Replenishment District of Southern California (WRD) with a capacity of 3 mgd and is now being expanded to 8 mgd. Treated water from the existing plant is mixed with imported potable water prior to injection into the Alamitos Seawater Intrusion Barrier. The LVLWTF expansion will provide the entire supply to the barrier; therefore, eliminating the need for imported water.

The LVLWTF currently receives tertiary treated (Title 22) recycled water from the adjacent Los Angeles County Sanitation District's (LACSD) Long Beach Water Reclamation Plant (LBWRP). LACSD is responsible for the secondary treatment while the Long Beach Water Department owns and operates the Title 22 water system; Title 22 recycled water implies that secondary treated wastewater has then been filtered and disinfected. In the future, the LVLWTF will also use tertiary effluent from LACSD's Los Coyotes Water Reclamation Plant (LCWRP). The LVLWTF further treats the water using microfiltration (MF), reverse osmosis (RO), and UV and sends the water for injection to the Alamitos Barrier. The Alamitos Barrier pipeline and well facilities are owned and operated by the Los Angeles Department of Public Works (LADPW). The LVLWTF holds the recycled water permit for the project and is therefore responsible for all of the water quality testing and maintaining a contingency plan. The drinking water facilities that withdraw water do not have any special monitoring requirements beyond what is required for any drinking water facility in California.

Both LBWRP and LCWRP monitor for trace chemical constituents. The LVLWTF monitors for a suite of conventional parameters, disinfection byproducts, priority pollutants, all primary and secondary drinking water contaminants under the Safe Drinking Water Act (SDWA), other chemicals with notification levels under CDPH rules for drinking water and several trace chemical compounds. According to Section 13 of the LVLWTF 2012 engineering report for the facility expansion, WRD proposes to monitor the following trace chemical compounds on an ongoing basis, either quarterly or annually: 17 $\beta$ -estradiol, caffeine, NDMA, triclosan, DEET, sucralose, TCEP, and gemfibrozil. The LVLWTF has also monitored for 4-nonylphenol, acetaminophen, BPA, carbamazepine, estrone, 17 $\alpha$ -

ethinyl estradiol, ibuprofen, and iopromide but has not recommended ongoing monitoring because of lack of significant detection of these compounds. The WRD also proposes continuous monitoring of performance surrogates (TOC and electrical conductivity). The recent trace chemical constituent data is available in the Appendix of Amended Title 22 Engineering Report for the Leo J. Vander Lans Water Treatment Facility Expansion: Alamitos Barrier Recycled Water Project (available upon request).

The LVLWTF will be issued a new permit in February based on the June 2013 draft of the California IPR regulations due to the current expansion project. These new IPR regulations include a requirement to meet the following microbial removal/inactivation rates by having process redundancy:

- Enteric virus: 12-log
- *Giardia* cysts: 10-log
- *Cryptosporidium* oocysts: 10-log

### 7.6.1.2 Orange County, CA

The Orange County GWRS AWTF system was built to replace the aging Water Factory 21, which was built in 1976 as the first AWTF for groundwater IPR plant in the US. An aerial photo of the GWR system is shown in **Figure 7-6**. It has become known in the water industry as the “California Model” or “full advanced treatment” (FAT) system for IPR. The GWRS receives secondary treated water (80 percent activated sludge effluent and up to 20 percent trickling filter effluent) from the Orange County Sanitation District (OCS D) and further treats it using MF, RO, UV-hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) advanced oxidation process (AOP). The Orange County Water District owns the GWRS plant and the injection wells and therefore is responsible for all treatment plant and groundwater monitoring. The OCS D wastewater treatment plant and the GWRS facility are located adjacent to each other. The OCS D is required to have a strict source control program.

The GWRS system is currently the largest AWTF facility in the US for IPR at 70 mgd. This project is currently being expanded to 100 mgd and can ultimately be expanded to 130 mgd. Up to 46 mgd of the water is available for direct recharge into the groundwater through injection wells to prevent seawater intrusion at the Talbert Gap. The remaining flow is recharged via percolation at spreading grounds about 14 miles from the plant. The initial blend for both injection and spreading was 75 percent recycled water to 25 percent non wastewater to start. The GWRS has approval to inject or percolate 100 percent recycled water. The 36 injection well sites are located within zero to three miles of the GWRS facility. Extraction water wells, operated by various cities and water districts within the Santa Ana River basin, are located at a distance equivalent to at least six months travel time from the injection wells and spreading basins. The extracted groundwater is only chlorinated prior to use as drinking water. The GWRS system allowed the Orange County Sanitation District to avoid construction of a new outfall.

Although LVLWTF (Los Angeles Board) and GWRS (Santa Ana) fall under different regional boards, the monitoring requirements for the GWRS system are similar to those for the LVLWTF. The GWRS monitors for a suite of conventional parameters, disinfection byproducts, priority pollutants, all primary and secondary drinking water contaminants under the SDWA, and several unregulated chemicals. The unregulated chemicals specified for monitoring in the LVLWTF permit include boron, chromium-6, perchlorate, vanadium, dichlorodifluoromethane, ethyl tertiary butyl ether, tertiary amyl methyl ether, tertiary butyl alcohol, 1,2,3-trichloropropane, NDMA, 1,4-dioxane, and pharmaceuticals and endocrine disrupting chemicals specified by CDPH.



Figure 7-6. GWR System in Orange County, CA

## 7.6.2 Georgia

Georgia has guidelines governing urban and agricultural reuse under the Environmental Protection Division of the Georgia Department of Natural Resources. Georgia is currently developing guidelines for IPR and DPR which are scheduled to be issued this year. At present, potable reuse facilities are regulated under the NPDES permit program.

### 7.6.2.1 Clayton County, GA

Clayton County Water Authority (CCWA), located south of Atlanta, GA began reuse in the 1970s with two land applications systems (the W.B. Casey Water Reclamation Facility which includes the E.L. Huie Constructed Wetlands and the Shoal Creek Water Reclamation Facility which includes the Panhandle Road Constructed Wetlands). As the county population grew and water demands increased, CCWA converted to two constructed wetland systems with a combined capacity of 21.8 mgd to support the county water supply through percolation to the groundwater and supply to two surface reservoirs. The wetland systems polish highly treated effluent from primary and secondary wastewater treatment facilities that include nutrient removal followed by disinfection.

### 7.6.2.2 Gwinnett County, GA

Lake Lanier is the direct potable water supply for Gwinnett County and several other surrounding communities. The lake is an Army Corps of Engineers impoundment on the Chattahoochee River which is the potable water supply source for most of metropolitan Atlanta. The treated effluent from the F. Wayne Hill Water Resources Center can be discharged to Lake Lanier or downstream to the Chattahoochee River.

The facility consists of primary and secondary biological treatment followed by two parallel trains of tertiary treatment. The original Phase 1 tertiary treatment train consists of solids contact clarifiers using ferric chloride chemical addition followed by granular media (sand) filters. The Phase 2 tertiary treatment train consists of coagulation, flocculation and clarification (also using ferric chloride) followed by ultrafiltration membranes. Flows from the two parallel tertiary treatment trains then combine and are treated with pre-ozone, granular activated carbon (GAC) and final ozone disinfection prior to discharge. The GAC filters have not been replaced, so they currently operate as biologically active filters, rather than as sorptive activated carbon filters.

During permitting, there were multiple administrative and legal challenges identified by stakeholders, mostly surrounding an interest to maintain lake water quality. For example, detailed lake modeling

resulted in a proposed total phosphorus limit of 0.13 mg/L, which was further reduced to 0.08 mg/L during negotiations, using anti-degradation regulations as the rationale.

The only parameters routinely monitored at the F. Wayne Hill Water Resources Center are conventional wastewater parameters (ammonia, phosphorus, COD, TSS, DO, pH, and fecal coliforms) and turbidity. Three NPDES permits govern the facility's discharges to Lake Lanier, Chattahoochee River, and combined. The lake is also monitored upstream and downstream of the discharge for conventional wastewater parameters. Several research studies have used samples from the Water Resources Center to examine EDCs, pharmaceuticals, and other trace chemical constituents.

### 7.6.3 Texas

There is currently no specific IPR or DPR regulatory guidance in Texas and potable reuse projects are reviewed on a case-by-case basis. Site-specific monitoring requirements for specific DPR or IPR facilities are negotiated with the Texas Commission on Environmental Quality (TCEQ). The two DPR facilities in Texas, located in Big Spring and Wichita Falls, are described in the subsections below and in Table 7-5.

#### 7.6.3.1 Big Spring, TX

The Colorado River Municipal Water District (CRMWD) set a goal to reuse 100 percent of wastewater 100 percent of the time in the face of an increasing population and long-term drought conditions in Big Spring. The Big Spring Regional Water Reclamation Plant captures filtered secondary effluent from the Big Spring WWTP, treats it to drinking water standards using a MF/RO/UV-A treatment scheme (California Model), and mixes it with surface water prior to retreatment at the WTPs in six communities, including Big Spring, Odessa, and Midland (**Figure 7-7**). The scheme is designed for the reclaimed water to be a 10 to 30 percent mix with E.V. Spence lake water. The WTPs retreat the reclaimed water using rapid mix, flocculation, sedimentation, media filtration and disinfection. A benefit of this DPR scheme is that the reclaimed water is lower in total dissolved solids (TDS) than the lake water, which improves the overall source water for drinking water supply.

The monitoring requirements for Big Spring are site-specific and were agreed upon in collaboration with TCEQ (Appendix I). This agreement was reached based on performance data collected in January 2013 on a range of regulated drinking water contaminants, secondary contaminants, unregulated radionuclides, and additional unregulated trace chemical constituents (Enclosure C within Appendix I). As part of its agreement with TCEQ, Big Spring is required to meet the following virus inactivation level for DPR via UV disinfection:

- Virus: 4 log

The UV reactor must be maintained at a specified performance (based on UVT) continuously, in order to achieve this virus inactivation log credit. Bacteria and protozoa inactivation or removal levels are not specified in the agreement letter. However, the mechanism of microbe inactivation by UV disinfection is a function of the disruption of the genetic material of the target organism; and it is well known that much smaller UV doses are required for similar inactivation rates for bacteria and protozoans than for viruses. Thus, if the virus inactivation is met, generally bacteria and protozoa are likewise inactivated.

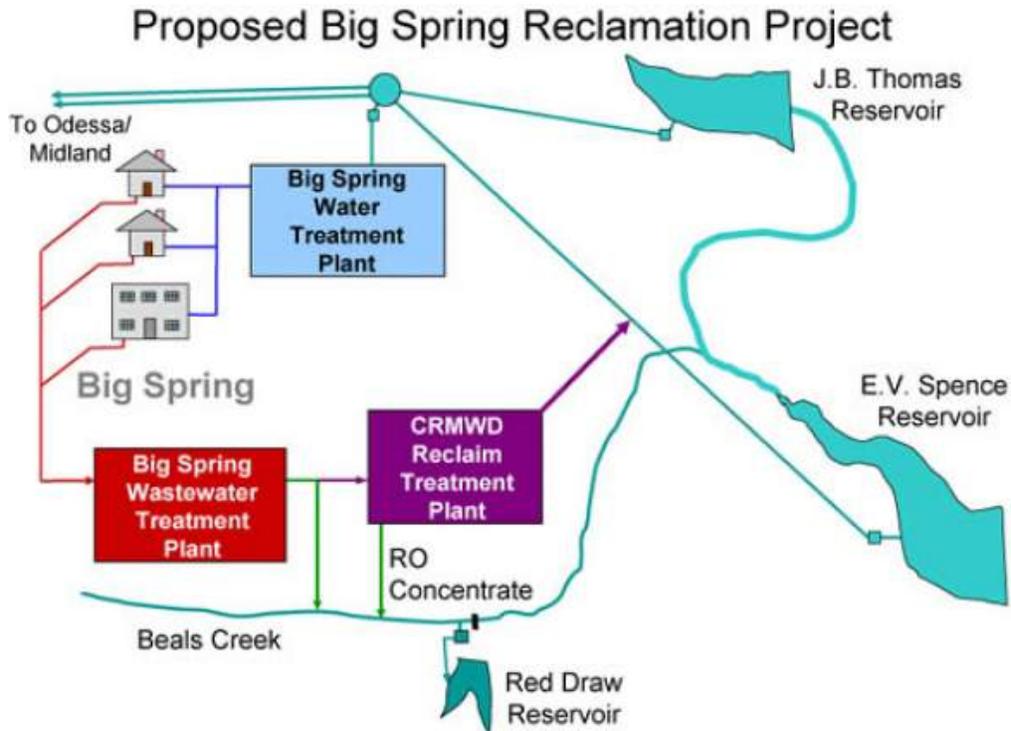


Figure 7-7. Layout of DPR Scenario in Big Spring, TX

In addition to the requirements specified in the facility's agreement letter, TCEQ has recommended (but does not yet require) monitoring a range of constituents including pathogens (viruses, protozoa, and bacteria), unregulated disinfection byproducts, and unregulated organic and inorganic chemicals. For a complete list, see Appendix I Enclosure D.

### 7.6.3.2 Wichita Falls, TX

Due to acute drought conditions, the City of Wichita Falls elected to temporarily take wastewater effluent from the River Road WWTP, and send it directly to the Cypress WTP where it is treated with MF/RO and then again with conventional treatment. This \$13 million temporary project adds around 5 mgd to the water supply. The system is currently under construction and is anticipated to come online in 2014. There is no special permit granted for DPR in Texas, but the process must go through a 45-day performance test prior to gaining regulatory approval for sending this water to the distribution system.

Water quality monitoring requirements are very similar to the current SDWA requirements dictated by EPA and include a range of chemical and microbial constituents. The list of these constituents, the locations to be sampled, and the frequency of monitoring are provided in a table in Appendix J. This list is a draft list as of Spring 2013 – the final monitoring requirements agreed upon with TCEQ may differ. TCEQ had previously recommended a longer list of chemical and microbial constituents. As part of its agreement with TCEQ, Wichita Falls is required to meet the following microbial removal/inactivation levels for DPR by having process redundancy:

- Virus: 9 log
- *Giardia*: 7 log
- *Cryptosporidium*: 5.5 log

TCEQ is not granting any log removal credit for the RO step in the treatment train, therefore other components must collectively meet these microbial removal/inactivation requirements. Per discussion with facility managers, two *Cryptosporidium* methods are required for ongoing monitoring – EPA method 1623 (every few weeks) and polymerase chain reaction (PCR) procedure (daily).

### 7.6.4 Virginia

In 2008, Virginia completed the process of creating a water reuse regulation, which governs a range of reuse applications including IPR. IPR projects may be permitted on a case-by-case basis but, direct potable reuse is prohibited (EPA, 2012b). One of the oldest IPR schemes in the country, located in Fairfax, Virginia, is described in the subsequent subsection and in Table 7-5.

#### 7.6.4.1 Fairfax, VA

The Upper Occoquan Service Authority (UOSA)'s discharge of reclaimed water into the Occoquan Reservoir is an often-cited example of IPR. Prior to 1971, the reservoir, which is the source of drinking water for a large portion of Northern Virginia, faced serious water quality issues due to the discharge of wastewater effluent from 11 small secondary WWTPs that totaled 2.9 mgd in flow in addition to agricultural and urban runoff (EPA, 2012b; Angelotti, 2011). Some of the issues included severe summer blooms of blue-green algae, frequent taste and odor problems in finished water, fish kills in the reservoir due to low DO, water treatment challenges due to very poor water quality, and detection of viruses in streams and in the reservoir. During low flow conditions, partially treated wastewater was a major part of the inflow into the reservoir. UOSA was formed in 1971 to address the water quality issue through investment in additional, more centralized wastewater treatment to recharge the reservoir, rather than exporting the wastewater effluent out of the water supply watershed. This effort both protected and augmented the water supply. The improvements were readily visible to the general public in the form of reduction in algal blooms, foul odors, and low DO for fish.

UOSA built a state-of-the-art water reclamation plant (which began operation in 1978) and reuse policy that had the following key quality assurance features:

- Standby treatment units
- Emergency holding basins
- Three independent electrical power sources
- Independent water quality monitoring program

The general layout of the UOSA IPR scenario is depicted in **Figure 7-8**.

The UOSA facility is currently permitted at a design flow of 54 mgd. The average and maximum water demands of the Fairfax Water potable WTP are 148 mgd and 240 mgd, respectively, which serves 1.8 million people. Under normal conditions, the UOSA contribution to raw water supply is 2 to 20 percent. Under extreme drought conditions, the raw water withdrawal at the Occoquan water treatment plant intake could be up to 60 percent of the UOSA flows (Angelotti, 2011).

UOSA's policy to deal with the potential presence of trace chemical constituents is built on four pillars: preparation, monitoring, research, and education (**Figure 7-9**).

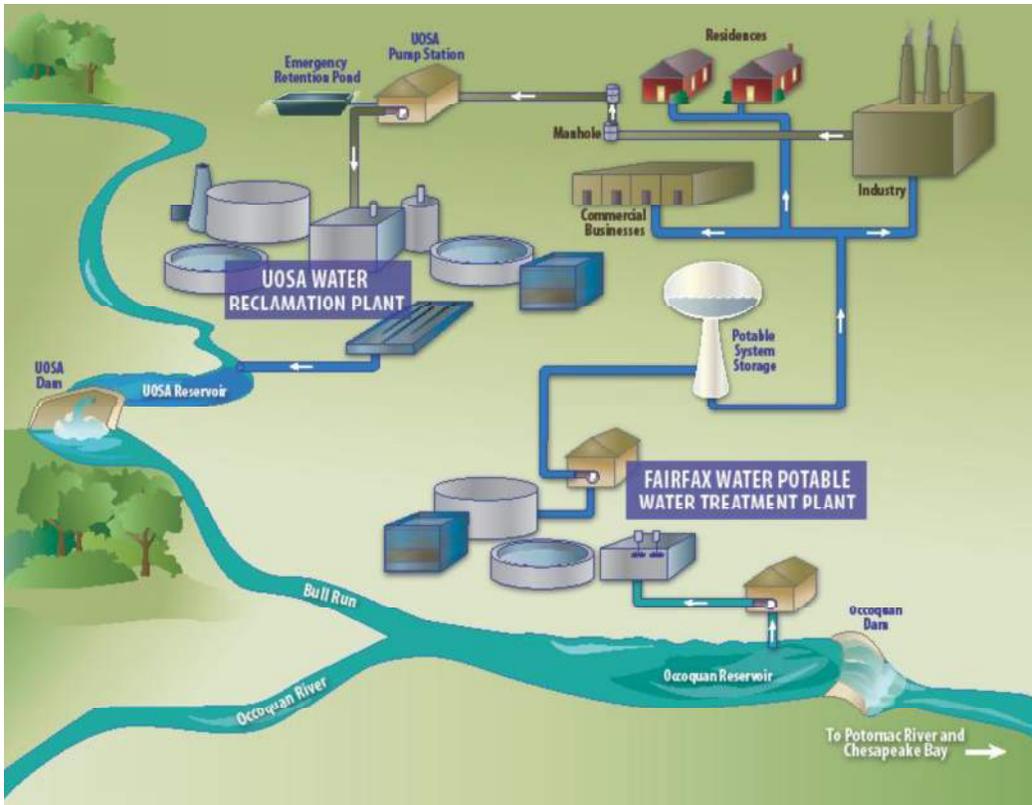


Figure 7-8. Layout of IPR Scenario in Fairfax, VA (EPA, 2012)

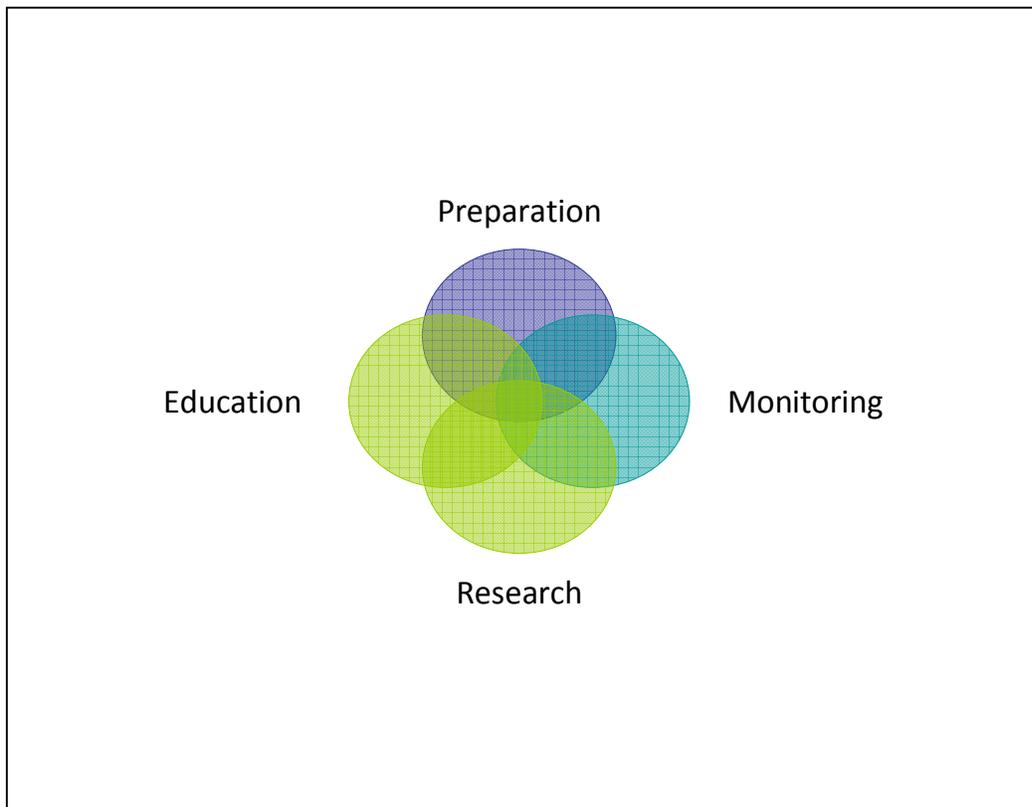


Figure 7-9. UOSA’s Policy to Deal with the Potential Presence of Trace Chemical Constituents is Built on Four Pillars

UOSA's preparation for removal of potential trace chemical constituents includes a multi-barrier approach both at the WWTP and WTP:

- Strict industrial pretreatment prior to the WWTP
- Biological degradation with high solids retention time (SRT) activated sludge in the WWTP
- Adsorption and partitioning to solids in the WWTP
- Volatilization in the WWTP
- High pH hydrolysis in the WWTP
- GAC adsorption at both the WTP and WWTP
- Ozone oxidation at the WTP
- Chlorine oxidation using free (WWTP) and combined chlorine (WTP)
- Further degradation via UV (sunlight), microbial degradation, and other possible decay mechanisms in natural system exposure (within the reservoir)

The independent monitoring program was mandated by the Virginia State Water Control Board Occoquan Policy in 1971 to provide unbiased water quality information to decision makers with the goal of protecting the reservoir for water supply and other beneficial uses. The monitoring program is operated by Virginia Tech's Department of Civil and Environmental Engineering. This unique feature of the Occoquan potable reuse scenario is viewed by UOSA staff to be a key to its years of success. A literature search conducted for this report did not identify any published studies in the literature regarding the presence of trace chemical constituents in the UOSA reclaimed water or the Occoquan reservoir.

UOSA has included a focus on public outreach and education at each stage of its history but has not required dedicated public relations staff or a formal public outreach and communication program. When formal IPR was first proposed, public hearings were conducted to share the proposed scheme and provide a venue for the public to express their views. In addition, over the past 30 years, UOSA has provided tours to local students, from grade school through college. These tours provide public outreach to the local population on the importance of UOSA's mission. In addition, UOSA maintains a public website with a great deal of in-depth information about UOSA's history, permits, and ongoing capital projects.

The UOSA system is a key example of an IPR system which does not employ RO in its treatment train. Another facility not described in detail here is the El Paso Water Utilities advanced treatment system in inland El Paso, Texas. The 12 mgd facility does not use membranes, instead selecting biological activated carbon (BAC), ozone and chlorine.

## 7.7 Overview of Relevant Treatment Technologies for Potable Reuse

This section presents the various options available for treating reclaimed water intended for potable reuse. Details include a description of the process, comparisons to other processes, effects on water quality, necessary pretreatment, and potential constraints. Some of the technologies discussed will result in better water quality and better value in terms of improvements in water quality relative to unit cost. This must be weighed with the potential for greater cost of operations and maintenance, and the potential for environmental impact caused by higher energy requirements, waste product disposal, and material usages.

Treatment systems for potable reuse require multiple unit processes as barriers to insure the removal or destruction of microbial and trace chemical constituents. By employing multiple barriers, the *robustness* of the system is expanded (by addressing multiple contaminants) and the system's *reliability* is improved (because multiple processes can be relied upon to remove a given contaminant).

Advanced treatment for potable reuse takes secondary effluent or tertiary treated water and brings it through multiple additional treatment processes. Water considered to have been treated to a tertiary standard has gone through primary (coarse) settling and secondary (biological) treatment prior to receiving tertiary filtration and disinfection.

Membrane filtration (either microfiltration (MF) or ultrafiltration (UF)), reverse osmosis (RO), and advanced oxidation processes (AOP) are currently the most common processes used to improve water quality for reclamation for planned potable reuse. However, alternative treatment systems incorporating granular activated carbon (GAC) or ozone with biologically activated carbon (BAC) are also viable options also being used or evaluated. Any treatment train also requires disinfection using methods such as UV disinfection, ozone, chlorination, or combinations of one or more methods. Alternative disinfection techniques that are still in the research stage for water reuse include peracetic acid (PAA), ferrate, and pasteurization. **Table 7-6** summarizes the treatment benefits of common unit processes used for potable reuse (note, that this table is meant to summarize general trends, but there are exceptions in each category; a limited number of exceptions are flagged as footnotes, with greater detail in the subsequent sections of text).

**Table 7-6. Treatment Benefits of Unit Processes (Green indicates significant impact, yellow indicates partial or limited impact, and red indicates no impact)**

Unit Process	Constituents that are physically removed (R) or degraded or destroyed (D)				
	TOC	TSS	TDS	Trace chemical constituents	Pathogens <sup>5</sup>
MF or UF	R (Partial)	R	-	-	R
RO or NF	R	R	R	R <sup>1</sup>	R
EDR	-	-	R	-	-
AOP (UV/H <sub>2</sub> O <sub>2</sub> , ozone/H <sub>2</sub> O <sub>2</sub> , ozone/UV, UV/TiO <sub>2</sub> , Fe/H <sub>2</sub> O <sub>2</sub> , Fe/ozone, Fe/H <sub>2</sub> O <sub>2</sub> /UV)	D <sup>2</sup>	-	-	D <sup>2</sup>	D
Cl <sub>2</sub>	D (Partial)	-	-	D (Partial)	D
UV	-	-	-	-	D
Ozone	D (Partial)	-	-	D <sup>2</sup>	D
PAA	D (Partial)	-	-	D (Partial)	D
Ferrate	D	R (Partial)	-	D (Partial)	D
Pasteurization	-	-	-	D (Partial)	D
GAC	R	R	-	R <sup>3</sup> (Partial)	R (Limited)
BAC	R, D (Partial)	R	-	R, D <sup>3,4</sup> (Partial)	R, D (Limited)

**Notes:**

- <sup>1</sup> Certain chemical constituents, including NDMA, 1,4-dioxane, and flame retardants may have removals less than 90% with RO or NF. RO, with tighter membrane skin, will typically offer greater removal than NF.
- <sup>2</sup> Certain compounds are resistant to oxidants, such as flame retardants tris-1-chloro-2-propylphosphate (TCPP) and tris-2-chloroethylphosphate (TCEP).
- <sup>3</sup> TOC removal (a surrogate parameter to reflect bulk trace chemical constituent removal) is typically between 40 and 60% for GAC and BAC, compared with greater than 98% for RO and NF.
- <sup>4</sup> While BAC removes trace chemical constituents, regrowth of microorganisms may result in higher TOC in effluent if a disinfectant residual is absent.
- <sup>5</sup> The actual removal or destruction of pathogens varies for each unit process depending on the type (i.e., virus, bacteria, or protozoa), or even species, of pathogen. Furthermore, the dose and contact time (for chemical oxidants) and optimization of the process has a large impact on pathogen removal. Indicative ranges of microbial log reductions reported in the literature for different treatment processes are presented in Table 6-3 of the EPA *Guidelines for Water Reuse* (EPA, 2012b). Because of the various strengths and weaknesses of different treatment types, multiple treatment barriers are necessary for potable reuse schemes to ensure redundancy and complete removal or inactivation.

Combinations of these processes and treatment of part or all of the flow can be used to achieve the water quality required for potable reuse. The California model of “full advanced treatment” (FAT) for potable reuse includes MF or UF filtration as pretreatment followed by RO and AOP. The only AOP process used in California to date is UV and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>); with UV-AOP, disinfection occurs simultaneously with the AOP. While additional chlorination at the end of the plant may or may not be required, it is important to consider its impacts if it is part of the process. Final chlorination of water containing ammonia can impact the NDMA concentrations in the finished product water. None of the currently permitted plants have engineered storage at the end of the treatment process, with the water being discharge directly to injection wells or percolation ponds. Recycled water storage is typically provided in the groundwater basin, though engineered storage is being considered for DPR as a means to provide time to respond to any treatment upset. For treatment processes other than FAT, disinfection could be required. For sidestream treatment of disinfected tertiary effluent, additional disinfection may not be required.

**FAT treatment for potable reuse (also known as the “California model”):**

MF/UF – RO – AOP – (Cl<sub>2</sub>) – Storage

In this model, RO may, in theory be replaced with nanofiltration (NF) or electrodialysis reversal (EDR), as discussed below. The major drawbacks of the FAT model are high capital costs, relatively high ongoing operating costs due to energy consumption, and concentrate disposal, which is a particular challenge in inland communities that cannot consider an ocean outfall for disposal. An alternative “non-FAT” treatment train that also may be appropriate for potable reuse is chemical oxidation (e.g., ozone) followed by BAC or GAC, which is then disinfected using UV or by chlorine residual addition before discharge:

**“Non-FAT” treatment for potable reuse:**

O<sub>3</sub> – BAC – UV – (Cl<sub>2</sub>) – Engineered Storage

This treatment train is designed to destroy and remove pathogens and chemical contaminants but does not offer TDS removal, so in areas with high TDS effluent and low TDS basin standards, non-FAT treatment may need to be combined with treatment of a portion of the flow by RO, NF, or EDR for blending to achieve desired TDS levels. Each of these processes is described in the subsequent sections.

An example of a system that uses the “non-FAT” system is the Windhoek DPR facility. The Goreangab WRP uses multiple barriers to treat the water, including powdered activated carbon (PAC), pre-ozonation, coagulation/flocculation, dissolved air flotation, media filtration, ozonation, BAC, GAC, UF, chlorine disinfection and stabilization. The city also requires that industrial discharges be collected separately from domestic sewer wastewater.

### 7.7.1 Membrane Filtration

In water reuse applications where the FAT model is applied, membrane filtration traditionally serves as a pretreatment process for the RO to mitigate potential “fouling” or plugging of the membranes that results in higher operating costs, more frequent chemical cleaning, and more rapid membrane replacement. Typically, RO pretreatment is achieved by a MF or UF system. MF membranes have a nominal pore size typically between 0.1 and 0.2 μm, whereas UF membranes have a nominal pore size typically between 0.01 and 0.08 μm. Membrane filtration systems come in two alternative

configurations: submerged or pressurized. Historically, submerged systems were used in larger plant (like the GWR system) while pressure configurations were used in smaller facilities (like the LVLWTF). Today, pressure systems seem to be the most economical configuration to about 15-20 mgd.

The goal for a membrane filtration system is to physically remove solids and pathogens prior to feeding the RO system. For both UF and MF systems, the membrane geometry is typically of hollow fiber membranes, where several hollow membrane fibers are wrapped in a tubular formation, with filtration occurring through the walls of the fibers. Membrane filtration systems most commonly use an outside-in operation, where the influent water on the outside passes through the membrane into the inside of small hollow fibers, where it is transported to downstream processes. The suspended solids and pathogens remain on the outside of the membrane where they are backwashed to waste. There are a few inside-out membrane filtration systems as well, including the membranes used at the world's largest membrane based reuse facility in Kuwait, but these systems have been less common in the US market.

In submerged systems, membranes are suspended in a basin and the feed water is at atmospheric pressure. A pump is used to provide vacuum pressure on the filtrate side of the membrane. Pressurized systems typically use pumps to apply a trans-membrane pressure to the feed, while the filtrate (treated) water is at roughly atmospheric pressure. In both instances, the pressure difference generated across the membranes drives the filtration process and the removal of suspended solids and pathogens.

#### 7.7.1.1 MF and UF

MF and UF systems can be obtained from numerous different suppliers, such as the Pall Corporation, Toray, GE, Memcor, Pentair, and others. It is also possible today to purchase semi-universal skids from third party equipment suppliers that are compatible with multiple different UF membranes. Semi universal skids would be skids that are compatible with some manufacturers products but not necessarily all membranes from all manufacturers. Photos of some different membrane filtration systems are shown in **Figure 7-10**.



**Figure 7-10. Typical MF/UF Systems from Pall Corporation, Memcor, and a Universal Skid with Toray Membranes**

For both MF and UF systems, a backwash system, coupled with a clean-in-place (CIP) system, needs to be provided for cleaning the membranes to remove foulants. The CIP systems typically clean the membranes about once a month if the influent water is relative clean. However, some reuse facilities have had to utilize chemical cleanings on a more frequent basis.

CIP periods are impacted by the water quality and will be higher for waters with high organic content, high microbial presence, or high coagulant doses, but less frequent for higher quality source waters, such as wastewaters where full nitrification is used. The GWR System for OCWD has a typical cleaning interval of 14-21 days when treating secondary effluent with only partial nitrification. Pilot testing at Los Angeles and San Diego treating tertiary effluent or very clean secondary effluent have extended cleaning intervals to more than 40 days. The CIPs systems generally apply a combination of acid and sodium hypochlorite to the membranes, coupled with an air scour as necessary and occasionally proprietary detergents. Sodium hydroxide is also used as a CIP chemical with some manufacturers.

MF and UF systems operate at similar pressures, removal rates, and fouling rates and produce a filtrate with similar water qualities; however, UF membranes generally achieve higher removal of viruses and occasionally a higher TOC reduction. Some in the industry advocate that UF systems offer better pretreatment than MF systems (though most of the membranes now supplied are UF membranes), but there isn't a lot of evidence to suggest that there is a significant difference in pretreatment capabilities and the two types of membrane systems continue to be used interchangeably in FAT plants in California.

The feedwater to MF and UF systems also requires conditioning to prevent damage to the membranes. Particles with diameters greater than 0.1 to 2-mm (depending on the system) are typically removed from the influent flow using automatically backwashing strainers. A chloramine residual is typically added to the feedwater to prevent biofouling or biological growth on the membranes (both MF and RO). A free chlorine residual is not recommended because of the potential to damage to the downstream RO membranes. For inside-out membranes, ferric chloride is often added as a coagulant to settle out suspended solids prior to treatment by the MF or UF systems.

Water quality improvements expected of MF or UF systems include:

- High removal rates of TSS
- High removal rates of bacteria, protozoa, and algae from the water
- Little to no TDS removal
- Virus removal varies widely depending on the membrane selected and the level of fouling, but is typically greater than 50 percent. Virus removal greater than 4-log has been demonstrated for some UF systems; however, typical integrity monitoring methods are generally not reliable at monitoring these high levels of removal.

#### **7.7.1.2 RO**

While RO is most commonly used for desalination of brackish and ocean water, it has also been employed in potable reuse since the mid-1970's, when California's Water Factory 21 first incorporated the technology. RO therefore, has a long history of being effectively utilized in wastewater treatment processes for removal of a wide array of dissolved constituents. For example, RO has been proven to be effective at removing synthetic organic compounds (SOCs), VOCs, PPCPs, pesticides, herbicides, and other industrial products and byproducts. RO is often recognized as a best available technology for reducing TDS and most trace organic constituents in wastewater effluent intended for groundwater replenishment, removing more than 99 percent of most dissolved constituents.

RO is a physical separation process that forces water through a membrane composed of a thin film composite, support layer, and membrane skin by pressurizing the influent water. There are two effluent streams from an RO process, the water which permeates through the membrane, or reverse osmosis permeate, and the portion of the flow containing all the materials that do not pass through the membrane, the reverse osmosis concentrate, or reject. RO typically requires influent water be conditioned via the application of a scale inhibitor and filtered with a cartridge filter upstream of the unit. Sulfuric acid is also commonly used to reduce the potential for scaling at increasing salt concentrations.

Standard installations for typical RO systems from the GWR System in Fountain Valley and the LVLWTF are shown in **Figure 7-11**.



**Figure 7-11. Typical RO Systems from the GWR System (OCWD) and the LVLWTF (WRD) (Photos courtesy of Bruce Chalmers.)**

Typically for reclaimed water applications, 70-85 percent of the influent flow will be RO permeate. The ratio of the RO permeate flow to the RO feed water flow is called the recovery rate. High recovery RO systems can have a recovery rate above 90 percent, but require either additional chemical conditioning and/or more frequent chemical cleaning of the membranes. Water quality improvements expected of RO technologies include:

- TDS reduction to <50 mg/l, including up to 2-log (99 percent) desalination
- TOC reduction to less than 0.25 mg/l, with reduction greater than 99 percent
- Removal of nearly all pharmaceuticals (greater than 99 percent)
- Greater than 2-log (99 percent) reduction of Giardia, Cryptosporidium, and viruses; credit as high as 3-log has been granted in Australia, however, integrity testing methods to reliably confirm these higher level removals have limited the credits that can be granted
- Removal of 40 to 90 percent of nitrosamines (such as NDMA), 1,4-dioxane, trihalomethanes, and other low molecular weight, volatile compounds

The remaining 15 to 30 percent of the flow is in the RO concentrate, which is the waste stream. The RO concentrate will contain dissolved solids and other constituents removed by the membranes, and will therefore have concentrations 3 to 7 times higher than the feed water for these parameters. The amount of concentration depends on the recovery rate employed and the level of rejection by the RO membranes for each constituent.

Because of the potentially high concentration of TDS, concentrate disposal can be challenging. An influent stream with a TDS of 700 mg/l will result in a concentrate over 4,600 mg/L, when operated with a recovery of 85 percent. Disposal of this concentrate is often a key challenge with use of the RO process. In addition, because of the nearly complete removal of stabilizing hardness and alkalinity from the RO permeate, it is also almost always necessary to stabilize the water by reintroducing calcium and alkalinity to the water to prevent corrosion of the transmission piping and storage reservoirs.

### 7.7.1.3 Nanofiltration (NF)

Nanofiltration is a potential alternative to RO. NF membranes are similar to RO membranes. NF membranes are manufactured by the same processes, made from the same materials, and configured in identical pressure vessel arrangements. Because there is no clear line of distinction between RO and NF membranes, it can be difficult to distinguish between the two in some cases, with membranes demonstrating similar rejection referred to alternatively as brackish RO or NF by different manufacturers. Generally NF membranes have a higher passage of monovalent ions, such as sodium and chloride, while retaining high rejection of more highly charged inorganic and organic constituents. Some NF membranes have also been tailored to pass higher levels of divalent ions (calcium and magnesium), while retaining high removal of organic constituents.

The primary benefit of the looser NF membranes is a significantly lower feed pressure required to produce permeate through the membranes. In general, the tighter the NF membrane, the more salts and organics it removes, until there is little or no pressure/cost savings for the NF system relative to RO system for membrane treatment. An in-depth, application-specific analysis of capital and operation costs and resultant water quality would need to be conducted to judge the worthiness of NF for a specific application.

The NF treatment train is essentially the same process flow diagram as required for FAT, including MF or UF treatment ahead of the NF and AOP or some other type of disinfection after. **Figure 7-12** shows a typical NF treatment train. Because the product water is not demineralized, it is possible that the post-treatment stabilization processes could be reduced or eliminated.

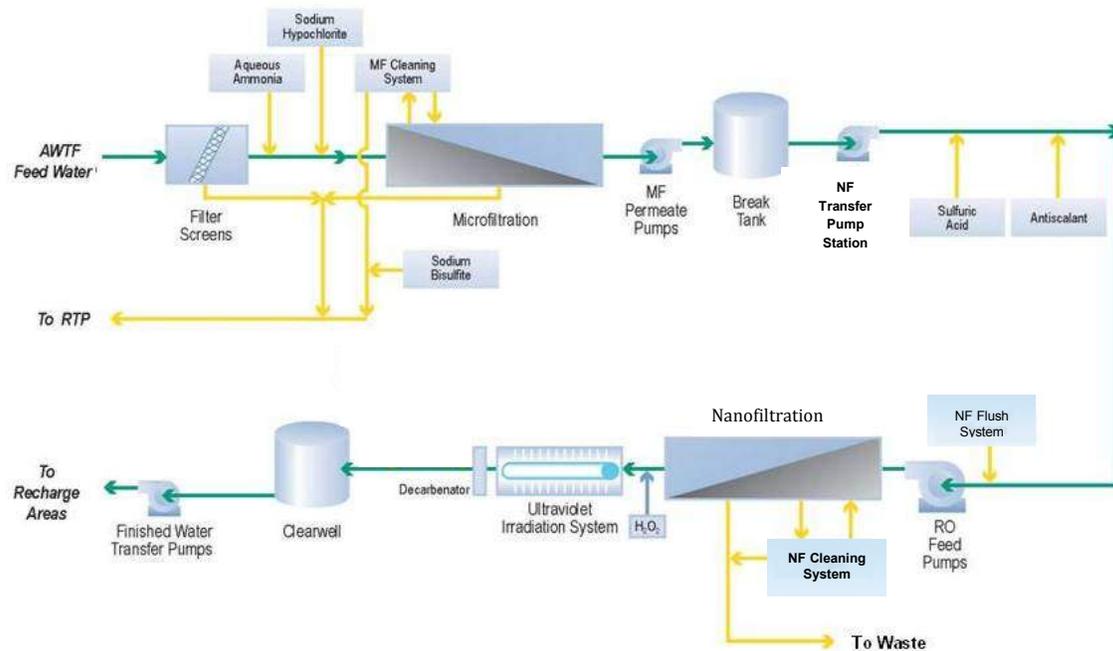


Figure 7-12. Typical NF Flow Diagram

The advantages of NF are its potential to provide water quality similar to RO at a lower price, due to its lower operating pressure. It is unclear from recent pilot testing whether the lower operating pressure is a temporary condition or a long term operational advantage because the pressures for the NF system tend to rise as the membranes become dirty and fouled. NF membranes are effective at pathogen, turbidity, color, DOC, hardness, and chloride removal. Recovery rates are 75 to 85 percent recovery as product water, similar to RO. In situations in which removal of high amounts of TDS are not required, such as in hardness removal for water softening applications, NF would be more desirable than RO.

The main disadvantage for NF systems is that NF membranes provide less TDS removal. The TOC levels in NF product water are also slightly higher than the TOC in RO product water, but TOC rejection by NF membranes is generally above 90 percent and can exceed 98 percent in tighter NF membranes. An additional and important disadvantage identified for using NF in reclaimed water is the poor rejection of nitrate, if high nitrates are present in the wastewater. For this reason, any NF process designed for potable reuse may need to be paired with another process that can effectively remove nitrogen, including potential denitrification at the wastewater plant, ion exchange, or sidestream RO.

NF treatment has the same conditioning, disinfection, concentrate disposal, and chemical membrane treatment requirements as RO. There are currently no approved NF installations for IPR in California or elsewhere in the world; however, NF has been tested by a number of different utilities and is being considered for future membrane replacement for installations where TDS or TN reduction is not critical. In addition, new hollow fiber, backwashable NF membranes have been introduced to the market recently, providing a potential opportunity to reduce fouling rates and demonstrate higher pathogen reduction than can be demonstrated with the traditional, spiral wound elements.

**Table 7-7** summarizes the advantages and disadvantages for the NF process when used in potable reuse treatment.

**Table 7-7. Summary of NF Advantages and Disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ Potential lower power cost than RO</li> <li>▪ Removes TOC nearly as well as RO</li> <li>▪ Newly introduced backwashable hollow fiber design may demonstrate higher pathogen reduction</li> </ul>	<ul style="list-style-type: none"> <li>▪ Power savings may be temporary</li> <li>▪ Less TDS removal than RO</li> <li>▪ No reduction of concentrate compared to RO</li> <li>▪ Poor removal of inorganic nitrogen</li> <li>▪ No existing NF facilities for potable reuse</li> <li>▪ Hollow fiber NF has not yet been tested in a potable reuse application</li> </ul>

### 7.7.2 Electrodialysis Reversal (EDR)

EDR has the potential to replace the MF/RO treatment train; however, it is a proprietary system and does not provide any reduction of suspended solids or pathogens. It is being discussed here for its potential to lower TDS, reduce system pressures, and decrease concentrate volumes.

In EDR, water is fed through a membrane “stack” with a cathode on one end, and an anode at the other end. The stack is filled with flat sheet membranes, half of which are made of a cation resin, and half of which are made of an anion resin. As the water flows through the stack, an electrical potential pulls charged ions through the membranes toward either towards the cathode or the anode. EDR operates under a different removal mechanism than NF and RO membranes. In NF and RO systems, pressure is applied to force the water to pass through the membrane, leaving water with a higher concentration of contaminants behind. In EDR, the charged ions pass through the membrane, leaving de-ionized water behind. As such, while it reduces TDS, it is not a barrier for TSS or pathogens. These constituents remain in the product rather than in the concentrate as with RO. In addition, neutral chemical compounds, like NDMA and many pharmaceuticals, are not removed. A general schematic of a system employing EDR is shown in **Figure 7-13**.

EDR has not become standardized for potable reuse applications, but is quite common in various industries, such as in applications drawing table salt from seawater for human consumption or removing industrial additives from water for mineral reclamation. EDR can also be used to reduce the volume of RO concentrate in inland desalter installations to minimize concentrate disposal costs.

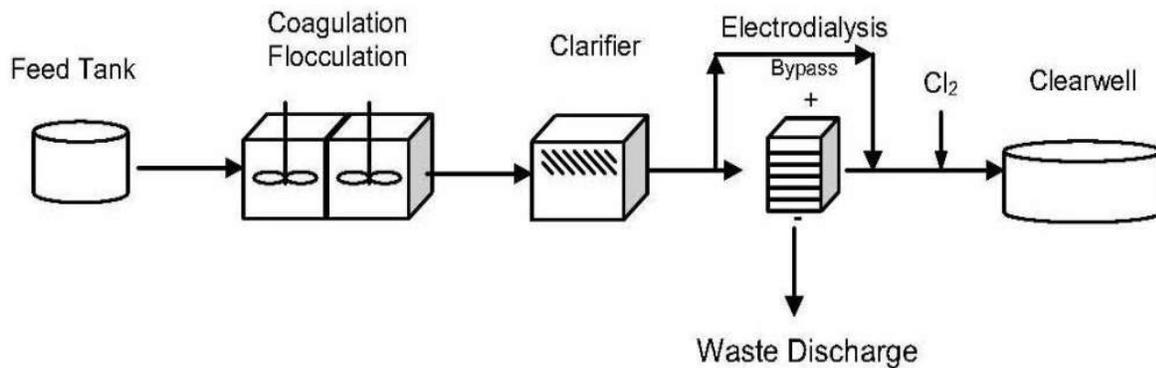


Figure 7-13. Typical EDR Process Flow Diagram

Because EDR is not a barrier to TSS, pathogens, or uncharged chemical compounds, EDR's usage would only be considered as part of a treatment train consisting of other processes which would be able to effectively remove these constituents. Similar to RO, EDR also requires influent water conditioning via the application of a scale inhibitor and filtering with a cartridge filter upstream of the unit. Regardless of conditioning, EDR membranes must be occasionally removed and manually cleaned. This cleaning is a time consuming and expensive process, and differs significantly from the CIP process of RO and NF membranes.

The advantage of EDR is that, although it can only remove TDS, it is very effective at doing so, and is capable of a higher recovery rate (ratio of product water to feedwater) than MF/RO. EDR can provide this treatment at the same (or slightly lower) unit cost as compared to MF/RO systems. Because the water isn't pushed through the electro dialysis membranes, the systems can be operated at lower pressures. The cost for the lower water pressure is offset, however, by the energy required to power the anodes and cathodes. EDR also has the potential to reduce total nitrogen (TN). Further, the EDR membranes, if maintained properly, are very durable, and may last up to fifteen years. In a situation in where the only further change to water quality necessary is reduction of TDS, a side-stream EDR unit may be suitable.

An alternative process just called electro dialysis (ED) exists that is identical to EDR, with one significant difference. In EDR, the polarity of the anode and cathode are periodically reversed. This changes the direction of the ion movement, preventing the buildup of contaminants on electrodes. In ED, there is no change in the polarity and the ions move in one direction only.

There is an existing municipal EDR facility used for wastewater treatment. This EDR system, located in San Diego at the City's North City Wastewater Plant, is used only for TDS reduction and is not used as part of an IPR program. Advantages and disadvantages for using EDR for an IPR project are summarized in **Table 7-8**.

**Table 7-8. EDR Advantages and Disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ Slightly higher recovery than FAT at 85+ percent</li> <li>▪ Can reduce TDS and TN</li> <li>▪ Can be used as part of “zero liquid discharge” (ZLD) treatment for concentrate management</li> </ul>	<ul style="list-style-type: none"> <li>▪ Not a barrier process</li> <li>▪ No TOC, TSS, or trace chemical constituent reduction</li> <li>▪ Few full size installations with no CA-permitted IPR facilities</li> <li>▪ Time-consuming manual membrane maintenance</li> <li>▪ Potential electrical and leakage problems</li> </ul>

### 7.7.3 Disinfection and Chemical Oxidation

A range of technologies are available to provide disinfection of pathogens, including UV, chlorination, ozone, ferrate, PAA, and pasteurization. Several of these technologies also provide break down of chemical constituents via oxidation and other degradation mechanisms. Each of these technologies is discussed further in this section

#### 7.7.3.1 UV

UV light inactivation of microorganisms is a physical or biophysical process with the germicidal wavelengths occurring in the UV-B and UV-C regions. Electromagnetic radiation in this range alters cellular proteins and nucleic acids (i.e., DNA and RNA) through dimerization of the thymine nucleic acids of DNA molecules. Because UV light inactivates pathogens by destroying their genetic material, in order to predict the number of pathogens destroyed by a particular UV system, the dose of required UV radiation must be calculated. The dose is a function of the UV radiation intensity and the exposure time that wastewater is retained in the UV reactor. The equation used to calculate UV dose is shown below:

$$\text{UV Dose} = I \times t$$

Where:  $I$  = UV intensity, in milliwatts per square centimeter ( $\text{mW}/\text{cm}^2$ )

$t$  = exposure time, in seconds (s)

UV Dose, in  $\text{mW}\cdot\text{s}/\text{cm}^2$  or millijoules per square centimeter ( $\text{mJ}/\text{cm}^2$ )

The actual UV intensity and exposure time are complex functions of the UV system, operating parameters and water quality. For example, in order to reach pathogens, the UV radiation must travel through the quartz sleeve, water and particles (if the microbes are embedded in particles). The exposure time is ideally the average hydraulic retention time within the UV reactor (or the reactor volume divided by the flow rate). However, actual exposure times for each target microorganism are a function of reactor volume, flow rate, mixing conditions within the reactor and extent of hydraulic short-circuiting. Other factors that can impact the amount of UV exposure include the distances between centers of the lamps, because even without absorption loss, UV intensity decreases with increasing distance from the lamp. Overall, the UV dose also depends on a range of water quality and lamp condition factors. Discussion of these factors is provided in the following sections.

Water quality affects the performance of a UV system by altering the UV intensity within the reactor and consequently, the UV dose received by the organisms within the wastewater. The most important

water quality parameters are the UV transmittance (UVT) of the water and the TSS concentration and particle size. In addition, dissolved solids may foul the quartz sleeves surrounding the lamps and decrease the effective UV output. Therefore, an understanding of the water hardness, iron and other dissolved organics in the wastewater is important to designing and evaluating the feasibility of a UV disinfection system.

UVT is defined as the percentage of UV light, at the 254 nm wavelength, not absorbed after passing through a 1-centimeter water sample. The UVT is one of the critical water quality parameters determining the UV intensity that will act on the microorganisms. As UV radiation travels through wastewater, its intensity is attenuated because the substances in wastewater absorb some of the UV light. The relationship between intensity and transmittance is directly proportional, i.e., the higher the transmittance the higher the intensity available.

TSS will absorb and scatter UV light thus lowering the UVT. Consequently, the higher the TSS concentration the higher the UV dose required. Additionally, the size of these solids highly affects the disinfection process — large suspended solids have the capability of screening or shading the target microbes preventing them from receiving their required UV dose. Although preferable, effluent filters are not a requirement for the effective application of UV disinfection at WWTPs.

Other water quality parameters, such as dissolved organics and inorganics, can absorb UV light and affect UV intensity. Increased concentrations of these constituents, as well as high chlorine residuals, can decrease UV intensity and the effectiveness of a UV disinfection system. High concentrations of dissolved compounds have also been shown to inhibit UV efficacy. A summary of some of these compounds is presented in **Table 7-9**. In addition to absorbing UV light, inorganic compound concentrations can affect the performance of UV disinfection systems by precipitating on the UV lamps, thus promoting lamp fouling.

**Table 7-9. UV Absorbing Compounds (from Bell et al., 2012)**

Inorganics	Organics	Conjugated Rings
Bromine	Coloring agents	Anisole
Chromium	Organic dyes	Benzene
Cobalt	Extract of leaves	Chlorobenzene
Copper	Humic acids	o,m,p-cresol
Iodides	Lignin sulfonates	Cyanoanthracene
Iron	Phenolic compounds	o-cyclohexyl phenol
Manganese	Tea	Cyclohexyl phenyl ketone
Nickel	Coffee	1-methyl-3,4-dihydronaphthalene
Sulfates		o-methylstyrene
Stannous chloride		Phenyl propene
		Phenol
		Toluene

Similar to other disinfection methods, site-specific testing must be conducted to determine the required dose that would allow consistent disinfection system process control.

### 7.7.3.2 Chlorine

Chlorine disinfection can be accomplished using chlorine gas or liquid hypochlorination, which have identical mechanisms of disinfection. When sodium hypochlorite is added to water, hypochlorous acid forms which can directly inactivate pathogens. Disinfection using chlorine gas is the least expensive chlorination method but presents safety concerns in handling and storage. Sizing a chlorine disinfection system requires confirmation of the residual chlorine concentration ( $C_R$ ) that yields sufficient bacterial inactivation for a given contact time ( $T$ ). Guidelines from the literature help to provide estimates of the  $C_R T$  value that will likely provide the required inactivation of *E. coli*. Once a design dose for chlorine has been confirmed experimentally, for a given contact time, sizing the components of a hypochlorination system is straightforward. Bulk liquid hypochlorite systems consist primarily of a tank farm with bulk storage tanks and secondary containment, suction and discharge piping, chemical metering pumps and control, chlorine residual analyzers, a softening system to prevent scaling, and injection points into the water system. Operation of a bulk hypochlorite system is comparable to other liquid chemicals fed at treatment plants. Sodium hypochlorite solution can be added directly to the water from storage tanks with chemical feed pumps. Mixing is most desirable at the point of chemical addition to achieve desired residual disinfection concentration-contact time ( $C_R T$ ) and, can be accomplished with a chemical induction system.

### 7.7.3.3 Ozone

Ozone is a strong oxidant utilized in potable water, wastewater, reclaimed water, and industrial water treatment applications. Ozone is a more powerful oxidant than chlorine or  $H_2O_2$  and is effective at oxidizing a wide range of organic and inorganic constituents. Ozone is used for:

- Disinfection (inactivation of viruses, bacteria, and protozoa, including *Giardia* and *Cryptosporidium*);
- Contaminant oxidation (iron and manganese removal, BOD/COD removal, taste and odor control, groundwater remediation, and removal of TOC-contributing compounds including trace chemical constituents; and
- Micro-flocculation/coagulation.

As a result, ozone processes can potentially replace MF/RO/UV- $H_2O_2$  AOP for removing or destroying trace chemical constituents and pathogens (with or without BAC). In addition, ozone processes can be added on to MF/RO systems to provide benefits including:

- Use as a pretreatment process ahead of the MF to optimize MF cleaning, and
- Increase productivity and energy efficiency of MF/RO/UV/ $H_2O_2$  AOP systems.

It should be noted that ozone does not generally remove TOC, but rather breaks large molecular weight organic compounds into smaller, more easily biodegradable compounds. As a result, it is common to couple ozone with BAC to remove the low molecular weight compounds and reduce the TOC. Further description of some of the benefits of using ozone in compound processes is included in Section 7.7.5.

Ozonation is a mature disinfection technology that is not fraught with the challenges of other technologies for a complex wastewater effluent, even though only a few WWTPs in the US currently use ozone. Historically, ozone has been used as a drinking water treatment technology more than a wastewater treatment technology. Early ozone technologies were adopted by a number of municipal facilities in the 1980s, but cost, both capital and operation and maintenance (O&M), resulted in many facilities abandoning their ozone systems. Ozone generation and application technologies have improved significantly since that time, and the technology is now being reevaluated for its applicability to municipal wastewater disinfection, primarily because it is the only mature disinfection alternative capable of treating color and partially or completely oxidizing complex, non-degradable trace organic compounds (e.g., pharmaceuticals, hormones, and precursors for DBPs) at typical disinfection doses.

There is a long history of ozone disinfection in wastewater and as a result, the mechanisms of ozone disinfection are well understood with inactivation of bacteria by ozone being attributed to the oxidation of cell membrane components and disruption of bacterial enzymatic activity. Currently eight WWTP facilities in the US are using ozone, as shown in **Table 7-10**. However, recent advances in ozone generation and dissolution technology, spurred by developments in the drinking water industry, have made ozone more economical and operationally robust. Improved economics along with consideration of secondary benefits of ozone are resulting in increasing interest in its application at WWTPs. Several new facilities are currently under design or construction in the US.

**Table 7-10. US Wastewater Facilities Utilizing Ozone**

Location	Average Flow (mgd)	Ozone Dose (mg/L)	Ozone Production (lb/d)	Treatment Objective
Mahoning County, OH	8	4	500	Disinfection
Springfield, MO	30	3	2,400	Disinfection
Frankfort, KY	40	4 – 8	1,000	Disinfection
El Paso, TX Fred Hervey Water Reclamation Plant	10	5	900	Disinfection for reuse
Trion, GA	8.0	27	1,800	Color removal, Disinfection
Gwinnett County, GA F. Wayne Hill Water Resources Center WWTP	50	4	4,700	Disinfection for reuse
Las Vegas, NV - Clarke County WRP	60	8	4,000	Disinfection for reuse

While there are varying approaches to determination of the application point and method of ozone application, all facilities that use ozone will have some variation of four major component systems: feed gas system, ozone generation units, ozone contacting system, and off-gas destruction system. Ancillary systems include supplemental nitrogen gas, cooling water systems, ozone residual quenching systems, monitoring, and safety systems. Early ozone systems used air as a feed gas with complex feed gas preparation systems involving compressors, refrigerant and desiccant dryers, and filters. However, most installations today use truck-delivered liquid oxygen (LOX) systems, because it is more economical and reduces O&M costs. Additionally, advances in ozone vent gas recovery and reuse in the biological process could reduce power demands on the aerations process.

Contrary to chlorination, increasing the ozone contact time (while maintaining ozone residual) from 30 seconds to 120 seconds does not appear to substantially boost disinfection performance as it appears that the effect of ozone in disinfection is very rapid. Design doses for ozone must be determined through pilot testing.

Ozonation also leaves byproducts, such as bromate and NDMA, which can complicate the efficacy of removing other contaminants, and need to be removed. In some tests, ozone has been shown to create NDMA in influent water that has not undergone nutrient removal at the wastewater plant. It is thought that the nitrifying/denitrifying processes remove precursors that create NDMA when oxidized by ozone.

#### 7.7.3.4 Peroxyacetic Acid (PAA)

PAA has historically been used as a bactericide, virucide, fungicide, and sporicide agent. Other uses include decoloring and disinfection in textile, pulp and paper industries; disinfection of ion exchangers and cooling towers; pathogen reduction in biosolids; sludge debulking; and reduction of biosolid odors. It has been applied in the food, beverage, medical and pharmaceutical industries, and its use has recently expanded to include wastewater treatment plants, particularly in Europe. Currently, no major WWTPs in the US use this technology for disinfection, although the EPA has approved PAA for use as a disinfectant to treat wastewater. Additionally, St. Augustine, Florida has piloted PAA to prove that the process can reduce the formation of DBPs that have strict limits included in their NPDES permit.

The disinfection efficacy of PAA depends on water quality. As a result, there can be wide variations in disinfection efficacy, depending on conditions. PAA disinfection is pH-dependent, with disinfection efficacy generally increasing when the pH is below 7. As with chlorination, high COD and suspended solids concentrations may scavenge PAA, thereby increasing PAA consumption. The mechanism of inactivation of pathogens has been reported to be similar for hypochlorite and PAA; however, PAA is more effective than hypochlorite in water with high organic content as organics tend to scavenge more hypochlorite than PAA. The effectiveness of PAA against various pathogens is generally thought to be greatest for bacteria, and incrementally decreases in effectiveness for viruses, bacteria spores, and protozoan cysts.

For *E. coli* in a secondary effluent, a dose of approximately 0.5 to 4 mg/L has been observed to be effective in providing a log reduction of up to 4.5 with a contact time of 8 to 38 minutes (WERF, 2008). However, because PAA has not been widely used in the US for full-scale disinfection applications, it would be necessary to conduct bench and pilot scale testing to assess the suitability of PAA for a given application. Equipment sizing is similar to that for bulk liquid hypochlorite systems; however, because PAA can react with some metal impurities, specific construction materials may be required for this application, e.g., stainless steel piping for delivery of chemical to the injection point.

### 7.7.3.5 Ferrate

Ferrate was explored in the 1970's as a replacement chemical for chlorine, but prior synthesis methods made its utilization cost prohibitive. With recent advances in new on-site production methods of ferrate, it has the potential to be applied as an alternative to other widely practiced oxidation and disinfection processes. Research has demonstrated that ferrate can be an extremely competitive oxidizing agent for disinfection processes with the key benefit of minimizing byproduct formation. There are many reports on the use of ferrate in wastewater disinfection (Jiang 2005; Jiang 2006a; Jiang 2006b; Jiang 2007). However, these studies have not optimized a disinfection process for full-scale implementation. The first full-scale installation of ferrate will be implemented at the 100 MGD East Bank WWTP in New Orleans, with start-up pending.

This technology could have advantages over other technologies due to the fact that it can provide oxidation and disinfection in the same application, similar to ozone, addressing trace chemical constituents as well as color. Ferrate chemistry results from the formation of iron in the plus 6 oxidation state, or  $Fe^{+6}$ . The process does not create halogenated DBPs and can be used to treat highly refractory compounds that other oxidants cannot transform because of the high reduction-oxidation (redox) potential of the compound.

Ferrate has been extensively studied for its oxidizing power in water and it is one of the most powerful oxidants, depending upon the pH of the solution. As pH will dictate the stability and reactivity of ferrate in solution (Lee et al., 2004), testing is required to determine the conditions under which ferrate disinfection is feasible.

The components of a ferrate disinfection system are similar to that of a liquid hypochlorination system with the exception of the addition of the on-site generation system, provided by the equipment manufacturer. Storage for raw materials required for on-site generation of ferrate includes provisions for bulk caustic, bulk ferric chloride and bulk liquid sodium hypochlorite solutions. Because additional solids are produced in ferrate disinfection, solids handling would be an additional component of a ferrate disinfection system.

### 7.7.3.6 Pasteurization

A novel disinfection approach that has been demonstrated for water reuse in California is pasteurization (EPA, 2012b). The technology was tested at the city of Santa Rosa's Laguna Wastewater Reclamation Plant, where validation testing was conducted for Title 22 approval. The California Department of Public Health approved pasteurization to meet the stringent "tertiary recycled water criteria" for specific minimum contact times and temperature based on this pilot study. A demonstration system has been installed in Ventura, California (**Figure 7-14**) and is in continuous operation. Pasteurization is economically favorable when waste heat can be captured and transferred for disinfection. In these scenarios, pasteurization can save utilities millions of dollars in lifecycle costs compared to UV disinfection (EPA, 2012b).



Figure 7-14. Pasteurization demonstration system in Ventura, Calif. (EPA, 2012b)

### 7.7.4 Advanced Oxidation Processes (AOP)

UV and ozone provide chemical oxidation and disinfection and, when combined with a chemical oxidant like  $H_2O_2$ , advanced oxidation of chemical and microbial constituents. In addition to UV/ $H_2O_2$  AOP and ozone/ $H_2O_2$  AOP, other AOP alternatives that can be added to the end of a treatment train include ozone/UV, UV/ $TiO_2$  (titanium dioxide), and a variety of Fenton reactions (Fe/ $H_2O_2$ , Fe/ozone, Fe/ $H_2O_2$ /UV) (Asano et al., 2007; Stasinakis, 2008; Munter, 2001). A simpler UV/chlorine process has recently been tested in Cincinnati for taste and odor reduction (Rosenfeldt, 2013), and is being evaluated for potable reuse at the Terminal Island plant in Los Angeles. These technologies have a broad range of applications, including reducing toxicity of industrial wastewater and finishing water for high-tech industries (Munter, 2001; WRRF, 2012b). To date, the only AOP that has been permitted at a full-scale advanced water purification facility is UV/ $H_2O_2$ .

What is common about the suite of AOP alternatives is that they are designed to generate highly reactive, nonspecific intermediate species (such as hydroxyl radicals and superoxide radicals) (Glaze et al., 1987). The hydroxyl radicals work along with the primary disinfectant to break down organic compounds. AOP is similar to ozone in that it generally does not remove TOC, but simply reduces large molecular weight compounds into smaller, more biodegradable compounds.

AOP is considered a best available technology to destroy trace chemical constituents that pass through RO membranes due to their low molecular weight and low ionic charge, notably 1,4-dioxane and flame retardants. In addition, light sensitive compounds, such as NDMA, will see enhanced removal when UV is used for the AOP. The optimum AOP system therefore depends on the target compound – UV/ $H_2O_2$

is the lowest-cost treatment for NDMA destruction, whereas ozone/H<sub>2</sub>O<sub>2</sub> or ozone treatments are the lowest-cost technologies for many other organic compounds (EPA, 2012b). It is essential that the transformation of target compounds be studied in actual wastewater samples during piloting, because transformation percentages can be lower than anticipated in bench studies because wastewater contains compounds that can scavenge hydroxyl radicals (Baeza and Knappe, 2011).

#### 7.7.4.1 UV/H<sub>2</sub>O<sub>2</sub> AOP

UV/H<sub>2</sub>O<sub>2</sub> destroys trace chemical constituents through two simultaneous mechanisms:

- The first mechanism is through UV photolysis (exposure to UV light) where UV photons are able to break the bonds of certain chemicals if the bond's energy is less than the photon energy, or if other photolytic processes occur.
- The second mechanism is through UV light reacting with H<sub>2</sub>O<sub>2</sub> to generate hydroxyl radicals. The H<sub>2</sub>O<sub>2</sub> is added upstream of the UV process.

The UV/H<sub>2</sub>O<sub>2</sub> AOP process is effective in oxidizing (or destroying) very small compounds that may remain in RO permeate, including trace chemical constituents. UV/H<sub>2</sub>O<sub>2</sub> AOP has been employed in the US for IPR at Orange County Water District's GWRS, at the El Segundo Water Reclamation Plant owned by West Basin, and in Scottsdale, Arizona. The Water Replenishment District's LVLWTF is installing AOP with its current expansion. In each case, the water is used for direct injection into the aquifer or for surface spreading. MF/RO/UV/H<sub>2</sub>O<sub>2</sub> AOP has also been used for DPR in the US in Big Spring, Texas, and Cloudcroft, New Mexico (constructed but not currently operating). Typical UV Systems from Trojan and Calgon are shown in **Figure 7-15**.



**Figure 7-15. Typical UV systems from the GWR System (OCWD) and Calgon pilot unit (Miami-Dade) (Photos courtesy of Bruce Chalmers.)**

#### 7.7.4.2 Ozone/H<sub>2</sub>O<sub>2</sub> AOP

Ozone/H<sub>2</sub>O<sub>2</sub> is being discussed in the reclaimed water industry as a potential alternative to UV/H<sub>2</sub>O<sub>2</sub>. Ozone/H<sub>2</sub>O<sub>2</sub> achieves greater than 2-log reductions of total coliforms and greater than 3-log reductions of fecal coliforms after oxidation (Gerrity, et al., 2011). Ozone/H<sub>2</sub>O<sub>2</sub> has been shown to achieve minimal inactivation of *Bacillus* spore inactivation/reduction, but consistently achieved high viral inactivation/reduction rates. Ozone/H<sub>2</sub>O<sub>2</sub> could have operational advantages over UV/H<sub>2</sub>O<sub>2</sub>, such as lower power costs and higher removal efficiencies for some trace chemical constituents, but the process does not remove NDMA as well as UV/H<sub>2</sub>O<sub>2</sub> because compounds such as NDMA. The addition

of H<sub>2</sub>O<sub>2</sub> to ozone in wastewater may reduce bromate formation, though there are conflicting reports in the literature (Ishida et. al., 2008, EPA, 2012b). Other AOP processes, including ozone/UV, UV/TiO<sub>2</sub>, Fe/H<sub>2</sub>O<sub>2</sub>, Fe/ozone, and Fe/H<sub>2</sub>O<sub>2</sub>/UV are currently still in the research stage as well.

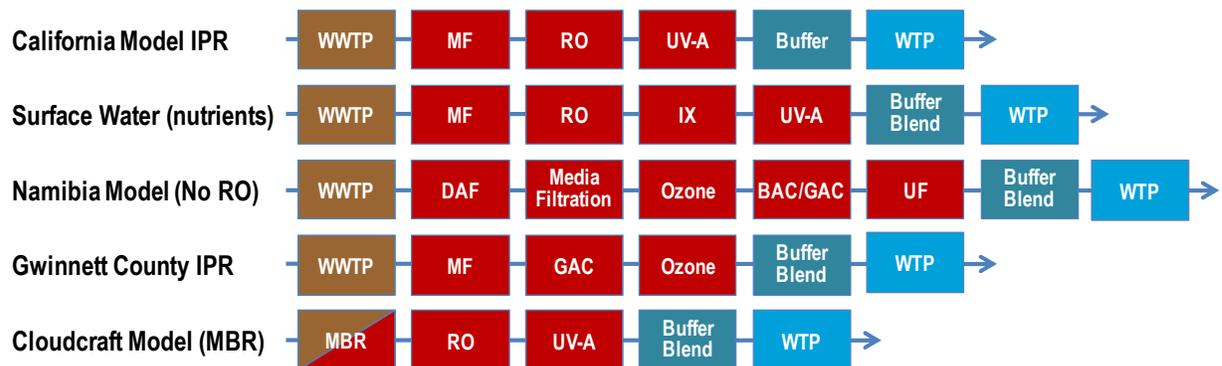
### 7.7.4.3 UV/Cl<sub>2</sub> AOP

UV/Cl<sub>2</sub> functions in a similar manner to UV/H<sub>2</sub>O<sub>2</sub>, destroying microconstituents through both UV photolysis and the formation of hydroxyl radicals. The efficiency of UV/Cl<sub>2</sub> is highly sensitive to pH, as the hypochlorite ions present at neutral and higher pH act as strong scavengers to the hydroxyl radicals, reducing the oxidizing efficiency of the process at these higher pH conditions. In contrast, the UV/Cl<sub>2</sub> process can be considerably more efficient than UV/H<sub>2</sub>O<sub>2</sub> when the pH is below 6 standard units and the majority of the chlorine is in the hypochlorous acid form. Benefits of the UV/Cl<sub>2</sub> process are that it reduces the number of different chemicals needed in the treatment process, it can be less costly than UV/H<sub>2</sub>O<sub>2</sub> when used to treat low pH RO permeate, and the remaining residual is in the form of traditional free chlorine rather than a hydrogen peroxide residual which may require quenching.

The primary drawbacks of UV/Cl<sub>2</sub> are that it is only effective with free chlorine, requiring breakpoint chlorination and potentially high chlorine doses, its efficiency will vary considerably with changes in the pH, and it may be challenging to permit, due to the relative novelty of the technology. At this time, UV/Cl<sub>2</sub> is not used in any full-scale drinking water or potable reuse installations; however, it has been successfully tested at a drinking water facility in Cincinnati, and is being evaluated at potable reuse facilities in San Pedro and Long Beach, California.

## 7.7.5 Putting it Together: Complete Treatment Trains for Potable Reuse

Alternative treatment processes that have or could be implemented for DPR are illustrated in **Figure 7-16**.



**Figure 7-16. Alternative Treatment Processes that Have or Could Be Implemented for DPR.**

Some of the combinations of treatment trains are described in the subsequent subsections.

### 7.7.5.1 Full Advanced Treatment (FAT) or the “California Model”

As described above, FAT consists of MF or UF followed by RO and AOP. FAT achieves the following water quality:

- TDS reduction to <50 mg/l, including 2-log desalination

- TOC reduction to less than 0.25 mg/l
- At least 12-log reduction of Giardia, Cryptosporidium, and enteric bacteria
- At least 6-log reduction of viruses
- Near complete removal or destruction of trace chemical constituents including pharmaceuticals, NDMA, 1,4 dioxane, and flame retardants.

FAT is being successfully utilized in California at the Terminal Island (Los Angeles Bureau of Sanitation), the Orange County GWRS (Orange County Water District), the Edward C. Little Plant in El Segundo (West Basin), and the LVLWTF (Water Replenishment System).

The disadvantage of FAT is that it has very high capital costs due to the MF/RO/AOP equipment requirements and high operating costs due to the energy requirements of the RO and UV processes. As mentioned above, concentrate management is also a major challenge. A summary of advantages and disadvantages of using FAT for potable reuse is provided in **Table 7-11**.

**Table 7-11. FAT Advantages and Disadvantages**

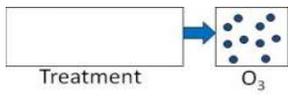
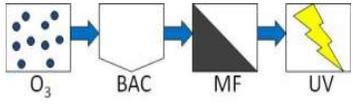
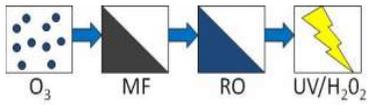
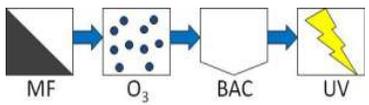
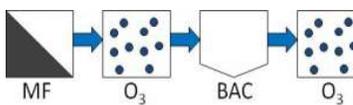
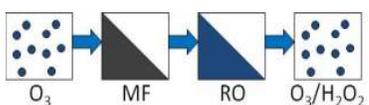
Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ Numerous existing permitted facilities</li> <li>▪ Can treat secondary effluent or media filtered tertiary effluent</li> <li>▪ Produces reliable, highest-quality water</li> <li>▪ Removes &gt;98% of TOC, TDS, TN &amp; trace chemical constituents</li> <li>▪ Accepted by the public in many locations for potable reuse</li> </ul>	<ul style="list-style-type: none"> <li>▪ Expensive to construct</li> <li>▪ MF and UV systems are proprietary that may require a specialized procurement program to pre-select, pre-purchase, or sole source the equipment</li> <li>▪ High O&amp;M cost for power and chemicals</li> <li>▪ Concentrate management required</li> </ul>

In California, tertiary treatment and FAT are the only treatment processes that are specifically named by draft groundwater recharge regulations as a potential treatment for IPR by groundwater replenishment. However, the CDPH will consider alternatives to tertiary treatment or FAT for surface spreading IPR projects. Use of alternative treatment techniques involves consideration from CDPH that requires the project sponsor to demonstrate the efficacy of the alternative treatment, which may involve pilot and/or demonstration testing, a public hearing, and independent reviews of the proposed treatment plan by technical committees.

**7.7.5.2 Overview of Treatment Trains Using Ozone**

Treatment applications using ozone, ozone with H<sub>2</sub>O<sub>2</sub>, or ozone with BAC filters are shown in **Table 7-12**.

Table 7-12. Ozone Treatment Applications

#	Process	Treatment Application (for O <sub>3</sub> and O <sub>3</sub> -BAC)				
		Contaminant Oxidation	Membrane Pretreatment	Increased UV Transmittance	Disinfection	Advanced Oxidation
1					X	
2		X	X	X		
3		X	X	X		
4		X		X		
5		X			X	
6		X	X			X

As illustrated in Table 7-12, for process Train 1, ozone alone is used at the end of the train for disinfection. In process Train 2, ozone and BAC are used in conjunction ahead of a membrane process for treatment of trace organics, with a membrane polishing process. This is similar to the process train used for potable reuse in Namibia. These treatment trains would not include BAC, but rely on RO and additional advanced oxidation to remove compounds oxidized, but not completely removed, by the initial ozone process as well as the byproducts of ozone oxidation. This process train was successfully tested on a pilot scale by the West Basin and was included in their Phase 5 expansion. The distinction between Trains 3 and 6 is that Train 3 uses UV/H<sub>2</sub>O<sub>2</sub> for AOP while Train 6 uses ozone-H<sub>2</sub>O<sub>2</sub> for AOP. Trains 4 and 5 are also similar, with Ozone/BAC being used as the main treatment process, with either UV or ozone used as the disinfection process. Lastly, Train 5 uses MF-Ozone/BAC as the main treatment processes for contaminant oxidation, as well as ozone again for disinfection.

### 7.7.5.3 Ozone/BAC

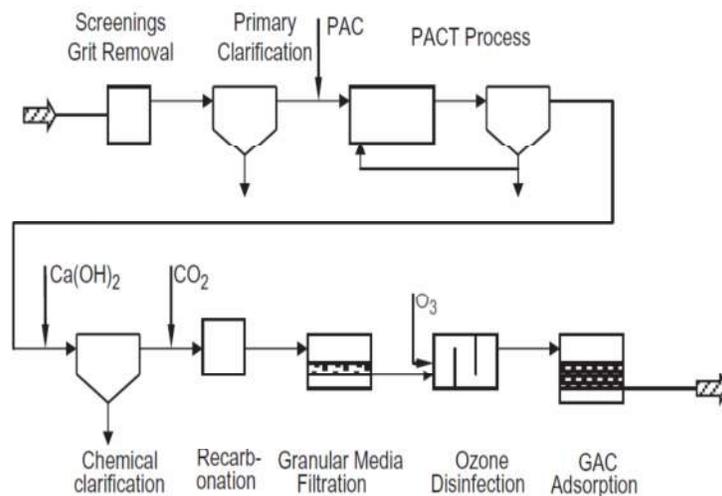
Ozone enhanced BAC filtration (ozone/BAC) is being investigated as an alternative to RO or membrane-based treatment trains. Ozone/BAC is an advanced filtration process which consists of a treatment train wherein water is first ozonated, and then filtered with BAC. BAC is GAC operated as a biological filter. Ozone first oxidizes bulk organics to produce lower molecular weight compounds, allowing the biological process in the BAC to degrade the low molecular weight compounds.

Remaining high molecular weight compounds are absorbed by GAC, resulting in breakthrough when the adsorptive capacity is exceeded (Levine et al., 2000).

Post-ozone biological filtration with sand or GAC has been shown to be an effective mitigation strategy for reducing unwanted oxidation byproducts (Gerrity, et al., 2011, Sundaram, 2011). It should be noted that the total removal of TOC in the ozone/BAC process is typically between 40 and 60 percent, which is considerably lower than the 99 percent reduction achieved by the FAT process. However, removal or destruction of high molecular weight chemical constituents typically exceeds 99 percent in both processes.

Ozone/BAC is a common technology in potable water treatment, and has been successfully employed in wastewater applications. For water reuse, ozone/BAC has not seen as widespread usage as MF/RO has, but it is a proven technology nonetheless and is currently used at a few facilities worldwide. The world's first municipal DPR facility, the Goreangab Water Treatment Plant in Windhoek, Namibia, has based their treatment train around ozone/BAC. There are pilot plants operating in the US which are testing the process as an alternative to membrane based FAT treatment trains.

The Fred Hervey Water Reclamation Plant (FHWRP) is a 10 mgd capacity plant in El Paso, Texas that treats wastewater to potable water quality using ozone/BAC. The treated effluent from FHWRP is used for irrigation and cooling water at the nearby Newman Power Plant, while the remaining effluent is injected into Hueco Bolson aquifer, at a depth of 800 ft (Oneby et al., 2010). The reclaimed water treatment processes includes pre-ozonation and GAC filtration as shown in **Figure 7-17**.



**Figure 7-17. FHWRP Process Flow Diagram (Oneby, Bromley, Borchardt, & Harrison, 2010)**

When ozone is used with BAC filtration, the combined treatment process controls taste and odor, reduces color, and removes unwanted trace organic compounds and DOC that can react with chemical disinfectants to form disinfection byproducts or cause membrane fouling, and can also disinfect.

As previously noted, the ozonation first breaks down high-molecular weight organic compounds to more biologically degradable organic matter, and GAC filtration removes matrix organic compounds from water by sorption. Further, when operated as a biological filter, microorganisms colonize the GAC surface (so the GAC filter becomes a BAC filter) and metabolize organic matter.

BAC has been shown to be effective at removing degraded organic molecules left after ozonation. BAC has the treatment capacity of GAC (i.e. removing matrix organic compounds), but due to the microorganisms which colonize the GAC, is also capable of metabolizing organic matter. There is some risk of the bacteria from the BAC re-entering and contaminating the effluent if not managed properly. Mitigation with an additional MF or UF system and/or chlorination are options to mitigate this issue.

Ozone/BAC will not reduce the TDS, so it may not be appropriate for projects where reducing the mineral content in the water is important. Ozone/BAC also does not achieve the same level of TOC reduction as FAT, which may impact regulatory requirements and require more blending water. As stated previously, TOC reduction in Ozone/BAC is typically between 40 and 60 percent, compared with 99 percent for the FAT process. Ozone/BAC also does not remove nitrogen compounds, but it can be used for installations where nutrient removal is performed at the wastewater plant.

The advantages of Ozone/BAC include:

- Nearly complete removal of trace chemical constituents
- Elimination of high salinity concentrate stream (when ozone/BAC is used in lieu of RO and UV/H<sub>2</sub>O<sub>2</sub> AOP)
- Reduced energy consumption and costs (when ozone/BAC is used in lieu of RO and UV/H<sub>2</sub>O<sub>2</sub> AOP)
- Potential for lower capital and/or operating costs, relative to alternatives utilizing MF and RO, although ancillary facility costs must be considered before a clear determination can be made, and no cost estimates were made for this evaluation.

The disadvantages of Ozone/BAC include:

- Ozone/BAC does not reduce TDS – if TDS removal is required, then additional treatment (like RO, NF, or EDR) may be necessary
- No removal of chloride – high chlorides could pose a problem for implementation of Ozone/BAC
- Less effective than UV at removing nitrosamines, such as NDMA
- No removal of nitrogen compounds – but if the WWTP effluent average TN concentration is less than 10 mg/L (the TN limit is 10 mg/L in California), additional nitrogen removal may not be required
- Loss of portions of the biological layer from BAC requires chlorine addition or MF/UF downstream. Maintenance of continuous residual downstream of filters to prevent bacterial regrowth in transmission piping

- Potential for creation of ozone byproducts, including bromate and NDMA – while these could be controlled through changes in the treatment process (pH adjustment), they could create complications for operators trying to balance removal of trace chemical constituents with formation of other hazardous byproducts
- Higher TOC in effluent as compared to RO as ozone/BAC removes only 40 to 60 percent of the TOC. This could result in higher blending requirements.

**Table 7-13** provides a summary of the advantages and disadvantages of using ozone/BAC for an IPR project.

**Table 7-13. Ozone/BAC Advantages and Disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ Removes some TOC</li> <li>▪ Effective at removing most trace chemical constituents</li> <li>▪ Elimination of high salinity concentrate stream</li> <li>▪ Potential for reduced energy requirements</li> </ul>	<ul style="list-style-type: none"> <li>▪ Does not reduce TDS or chlorides</li> <li>▪ Limited removal of nitrogen compounds</li> <li>▪ Less effective at removing NDMA</li> <li>▪ Does not remove as much TOC as FAT</li> <li>▪ Requires downstream chlorine residual to control microbial regrowth</li> <li>▪ Potential creation of ozone byproducts, including bromate and NDMA</li> </ul>

#### 7.7.5.4 Status of the Ozone/BAC Process

Ozone/BAC is already widely used in potable water plants, with about 400 installations in the US and about 3,000 installations worldwide (Oneby et al., 2010). Examples of wastewater and reclaimed water treatment applications using Ozone/BAC are summarized in **Table 7-14**.

Water produced by the Goreangab plant is blended with surface water and used by the City of Windhoek to meet potable demands. Note that for this facility TDS, TN, and chloride limits are not met without blending (or the future addition of RO). The FWHWRC plant discharges the treated water into the lake upstream of the inlet to the local water treatment plant. The FHWRP in Texas is similar to OCWD’s original Water Factory 21 in that lime clarification/ recarbonation is used ahead of granular media filtration. The ozone-GAC is used in place of the RO and chlorine disinfection.

#### 7.7.5.5 Combining Ozone/BAC with RO

For ozone/BAC processes, an option for lowering TDS, TOC and TN is to bring a portion of the flow through an MF/RO train (or NF or EDR) before further disinfecting the entire flow. The finished water would have lower TDS, TOC and TN, likely with lower unit cost (and water quality) than FAT. The TDS, TOC and TN concentrations will be dependent on the amount of flow that is treated through the MF/RO train; the more flow treated by MF/RO, the better the water quality. The lower the TOC concentration, the less diluent water is required. However, the improved water quality comes with increased treatment costs.

Table 7-14. Projects/Plants Using Ozone/BAC for Reuse

Facility Name	Location Year Installed (Upgraded)	Scale/ Capacity	Application	Processes	Comments/Source
Fred Hervey Water Reclamation Plant (FHWRP)	El Paso, Texas 1985 (2008)	Full-Scale 10 mgd	Reclaimed Water for Direct Reuse and Aquifer Recharge (IPR)	High – pH Lime → 2-stage Recarbonation → Sand Filtration → Pre-Ozonation/ Disinfection → GAC Filtration	<ul style="list-style-type: none"> <li>▪ (Oneby et al., 2010)</li> <li>▪ Ozone primary disinfection</li> <li>▪ GAC polishing filters for assimilable organic compound (AOC), synthetic organic compounds (SOC) and taste and odor removal</li> <li>▪ Taste and odor control</li> <li>▪ Reduces pesticides, synthetic organics, THMs &amp; precursors</li> </ul>
Denver Potable Water Demonstration Project	Denver, Colorado 1992	Pilot 70 gpm	Reclaimed Water for DPR	High-pH Lime → Sedimentation → Recarbonation → Filtration → UV → GAC Filtration → RO or UF → Air Stripping → Post-Ozonation → Chloramination	<ul style="list-style-type: none"> <li>▪ (van Leeuwen et al., 2003)</li> <li>▪ Evaluate feasibility for DPR</li> <li>▪ Met or exceeded drinking water standards</li> <li>▪ Removed organic compounds to non-detect in challenge study</li> </ul>
Lake Arrowhead Water Reclamation Pilot Plant (LAWRPP)	Lake Arrowhead, California 1995	Pilot 5.3 gpm	Reclaimed Water for Potable Reuse	Pre-Ozonation → BAC Filtration → UF → RO → Post-Ozonation	<ul style="list-style-type: none"> <li>▪ (Levine et al., 2000)</li> <li>▪ Treatment efficiency tested</li> <li>▪ Oxidized bulk organics to produce lower MW compounds</li> <li>▪ BAC degraded low MW compounds</li> </ul>
South Caboolture Water Reclamation Plant (SCWRP)	Queensland, Australia 1999	Full-Scale 2.6 mgd	Reclaimed Water for Reuse and River Discharge	BNR Denitrification (MBBR) → Pre-Ozonation → Coagulation → DAF → Sand Filtration → Ozonation → BAC Filtration → Post-Ozonation	<ul style="list-style-type: none"> <li>▪ (van Leeuwen et al., 2003)</li> <li>▪ Nutrient goals of &lt;1 mg/L TN and &lt;0.1 mg/L TP</li> <li>▪ 36% COD removal</li> <li>▪ Less effective against protozoa, bacteria and virus</li> <li>▪ Most of TN removal is at the BNR plant using a MBBR</li> <li>▪ Clear water contamination with Mn when ozone off</li> <li>▪ Chlorine residual required</li> </ul>

**Table 7-14. Projects/Plants Using Ozone/BAC for Reuse (continued)**

Facility Name	Location Year Installed (Upgraded)	Scale/ Capacity	Application	Processes	Comments/Source
Goreangab Reclamation Plant	Windhoek, Namibia 2002	Full-Scale 5.5 mgd	Reclaimed Water for DPR	PAC → Pre-Ozonation → Coag./Flocculation → DAF → Rapid Sand Filtration → Ozonation → BAC Filtration → GAC Filtration → UF → Chlorination/Stabilization	<ul style="list-style-type: none"> <li>▪ (Menge, no date)</li> <li>▪ Blended with 35% surface water</li> <li>▪ 1-1.5 mg ozone/ 1 mg DOC</li> <li>▪ Ct – 15 to 20 minutes</li> <li>▪ High MW compounds oxidized and removed by BAC</li> <li>▪ Filters – 30 minutes EBCT</li> <li>▪ Blending required for TDS, TN, and chlorides</li> </ul>
F. Wayne Hill Water Reclamation Center (FVHWRC)	Gwinnett County, Georgia 2003 (2006)	Full-Scale 40 mgd	Reclaimed Water for Lake Discharge (IPR)	Chemical Clarification → Pre-ozonation → Granular Media Filtration or MF → Pre-Ozonation → GAC Filtration → Post-Ozonation	<ul style="list-style-type: none"> <li>▪ (Oneby et al, 2010)</li> <li>▪ Used for IPR with discharge ahead of Lake Lanier and potable WTP.</li> </ul>
Reno-Stead Water Reclamation Facility (RSWRF)	Reno, Nevada 2010	Pilot 10.6 gpm	Reclaimed Water	Phase 1: UF → Ozone/H <sub>2</sub> O <sub>2</sub> → BAC Filtration → Phase 2: Sand Filtration → Ozone/H <sub>2</sub> O <sub>2</sub> → BAC Filtration	<ul style="list-style-type: none"> <li>▪ (Gerrity, et al., 2011)</li> <li>▪ Tested as alternative to FAT</li> <li>▪ Effectively reduced trace chemical constituents</li> <li>▪ Reduced estradiol and steroid hormones (except estrone) to below MRLs.</li> <li>▪ BAC reduced TCP and TCEP</li> <li>▪ BAC reduced TOC 33%</li> </ul>

A summary of the advantages and disadvantages of using a blend of reclaimed water and RO permeate for IPR is provided in **Table 7-15**.

**Table 7-15. Blend of Tertiary Recycled Water and RO Permeate Advantages and Disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Good water quality</li> <li>• Removes some TDS, TOC, TN &amp; trace chemical constituents</li> <li>• Implementation can be phased</li> <li>• AOP not required</li> <li>• May be less expensive than FAT</li> </ul>	<ul style="list-style-type: none"> <li>▪ Moderate O&amp;M cost for power and chemicals</li> <li>▪ Some concentrate management required</li> </ul>

## 7.8 Additional considerations

There are a number of other factors that need to be considered when planning a reuse scheme. Some of these factors are described briefly in this section.

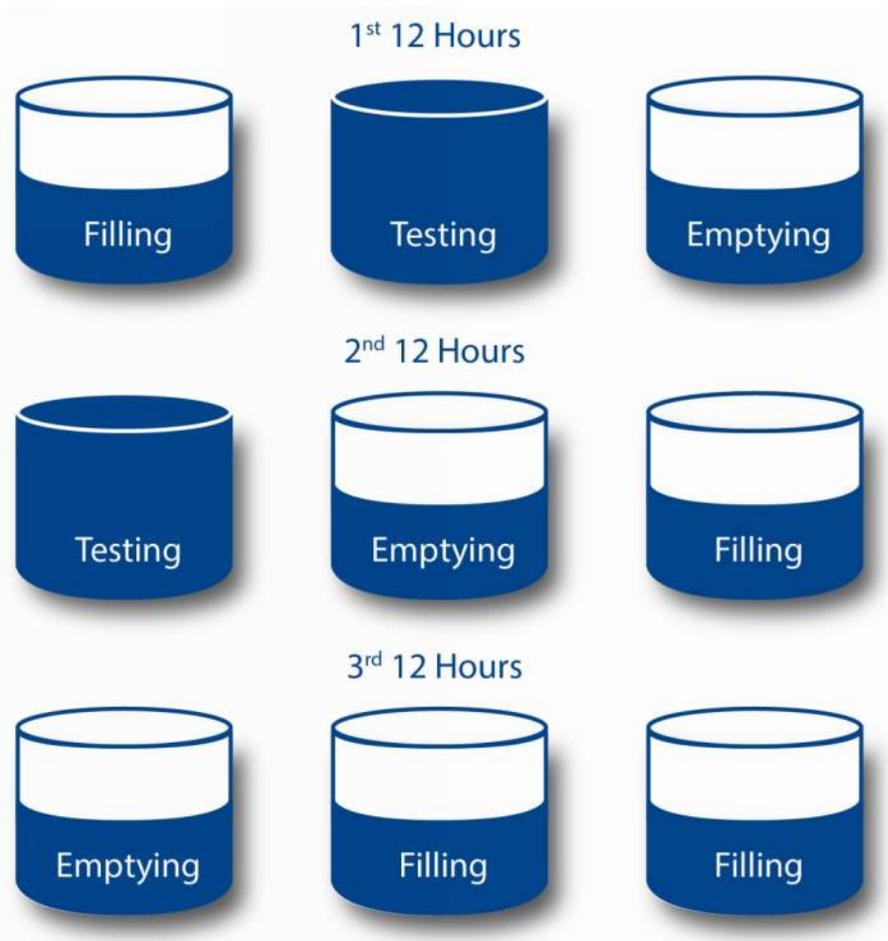
### 7.8.1 Source Control

An effective industrial source control program is a critical first barrier to preventing undesirable chemicals from entering a treatment system. The EPA has established technology-based numeric effluent guidelines for various industries and evaluates its effluent guidelines and pretreatment standards annually. The 2010 Effluent Guidelines Program Plan set out a strategy to develop best management practices for health care facilities to properly manage pharmaceutical disposal (EPA, 2012b). Utilities operating IPR facilities often conduct a pollutant prioritization process that includes chemical fate assessments for a broad range of chemicals; an outreach program for industries, businesses, and the public; and a toxics inventory (EPA, 2012b).

For example, the Orange County Sanitation District, which provides secondary effluent to the OCWD for the GWR project in southern California, was successful through its source control program to reduce the discharge of NDMA and 1,4-dioxane from industries into its wastewater management system (EPA, 2012b). The state of Oregon has passed rules that set trigger levels for over one hundred priority pollutants that do not have drinking water MCLs. The list of pollutants and the trigger levels were set by the Oregon Department of Environmental Quality in consultation with a Science Peer Review Panel. If these pollutants are detected in wastewater effluent above the established trigger levels, the facility must adopt a reduction plan for the pollutant (EPA, 2012b).

### 7.8.2 Storage

The essential difference between IPR and DPR is that DPR lacks the environmental buffer. Engineered buffers may be adopted instead, in order to provide some storage to allow response time during process upsets. An example scenario is shown in **Figure 7-18** (Salveson and Mackey, 2013). In this scenario, three storage tanks are used, which each have sufficient volume to allow for 12 hours of storage. During the first 12 hours, tank 1 is filling, while tank 2 is undergoing microbial water quality testing, and tank 3 is being used. Subsequently, during the second 12 hours, the tasks rotate, and tank 1 is being tested, tank 2 is being used, and tank 3 is filling. During the third 12-hour period, tank 1 is being used, tank 2 is filling, and tank 3 is being tested.



**Figure 7-18. Engineered Storage Scenario for DPR (adapted from Salveson and Mackey, 2013)**

The potential approaches to engineered storage are being investigated under WRRF project 11-10 (*Evaluation of Risk Reduction Principles for Direct Potable Reuse*, anticipated June 2014) and WRRF 12-06 (*Guidelines for Engineered Storage Systems*, anticipated June 2015).

### 7.8.3 Fail-Safe Operation

Because variability in influent quality, treatment process upsets, extreme events, or human error could affect treatment performance, it is essential to develop a system, operational practices, and response strategies to ensure system reliability. Furthermore, it is fundamental to incorporate appropriate monitoring strategies to ensure deviations in treatment performance are detected, triggering immediate and proportional response strategies.

Failure analysis is required of any system to make sure that process upsets and monitoring failures do not allow undertreated water to proceed. In failure analysis, the goal is to assess and be able to control potential failure points relative to their risk.

The fail-safe approach to DPR is an ongoing area of research under WRRF projects 11-10 (*Evaluation of Risk Reduction Principles for Direct Potable Reuse*, anticipated June 2014) and 13-3 (*CCP Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of DPR Scheme*, initiated in 2013). Researchers are looking to formal frameworks adopted by the airline, aerospace, and medical industries. An example approach is the hazard analysis and critical control point concept (HACCP) developed in 1959 by the National Aeronautics and Space Administration (NASA).

### 7.8.4 Monitoring

A critical area of ongoing research is focused on how to improve monitoring for DPR applications to ensure that there are no acute or long-term health impacts.

Pathogens present the most pressing concern with respect to acute health impacts. Current techniques to monitor pathogens such as those that detect microbial RNA or DNA (such as polymerase chain reaction (PCR)) or biosensors that are triggered by antibody or DNA recognition are too time-intensive and costly to implement on an ongoing basis. Researchers are evaluating online monitoring approaches such as fluorescence or the presence of adenosine triphosphate (ATP), a universal biological marker, in order to detect process upsets relatively rapidly (Salveson and Mackey, 2013).

In addition, each unit process in the treatment train can be monitored using indicator or surrogate chemicals to determine performance. Each unit process requires consideration of an indicator that will provide a conservative assessment of removal for that process. WRRF presents an approach to selection of such indicators in WRF-03-014 (Drewes et al, 2008).

Developing robust monitoring approaches for DPR is an area of research in WRRF projects 11-01 (*Monitoring for Reliability and Process Control of Potable Reuse Applications*, anticipated 2016), 11-10 (*Evaluation of Risk Reduction Principles for Direct Potable Reuse*, anticipated June 2014), 12-07 (*Standard Methods for Integrity Testing of NF and RO Membranes*, just launched in 2013), and 13-3 (*CCP Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of DPR Scheme*, initiated in 2013).

### 7.8.5 Non-cost factors

In addition to technical performance and cost, additional criteria can be important in assessing appropriate technologies. Some critical non-cost factors include:

- Public acceptance
- Constructability
- Maintenance of existing plant operations during construction and upgrades, including the complexity of construction sequencing to maintain plant compliance during construction, the risk of non-compliance during construction, and the relative level of interruption to operation during construction
- Operability, including the relative complexity of facility configuration and staff training requirements
- Traffic flow, for example, the relative number of added trucks per month for deliveries of chemicals

- Degree to which the system can be automated and remotely operated
- Demonstrated reliability and track record of prior performance
- Relative safety risk to operators
- Ability to meet potential future regulations

These factors can be evaluated and weighed along with technical and cost factors in order to holistically assess technology options.

## 7.9 Public Relations

Previous subsections have established how the technical issues of IPR and DPR can be addressed through advanced treatment. However, for a successful potable reuse program, an equally critical component is the development of a successful public education and outreach program to ensure stakeholder buy-in and acceptance (EPA, 2012b). Stakeholder involvement is critical from the beginning, including identifying those who will object to the project as well as those who will be supportive. Some of the actions that can be taken to develop a public participation program include (EPA, 2012b):

- Begin with an assessment of the community and of the utility itself, including the current political environment, economic, social, and environmental issues that might indirectly become part of the debate and communication platforms, public awareness and media coverage of water-related issues (particularly related to water quality and health), the history and reputation of the utility, who the potential supporters and opponents are, and the principal trusted conduits for information.
- Determine early the level of public involvement that will be sought, including a preliminary list of potential stakeholders. Meet with community officials and leaders early and then regularly.
- Develop and follow a comprehensive strategic communication plan that presents information clearly and anticipates long-term implications of reuse messages. Engage neutral, credentialed outside experts as potential spokespersons or evaluators while establishing the utility as the primary, credible source of information. Dialogue with the broader community of stakeholders through various means including active engagement of the media, including social media. Understand opposition and be proactive in responding.
- Involve employees and ensure they are informed with accurate, timely information.

Public acceptance can vary between regions or even projects. As described in Section 7.3, UOSA has conducted over 30 years of tours to involve the public but has not had to employ dedicated public relations staff. In California, much more involved public outreach was developed for San Diego and Orange County because previous IPR projects in San Diego and Los Angeles were halted due to public opposition (Chalmers, 2011). In San Diego, an intensive demonstration project was developed to evaluate and communicate IPR, with nearly half of the project funding being dedicated to the purpose of education and outreach (EPA, 2012b). The Orange County GWR Project has provided innumerable tours and hosted many national reporters.

Research shows that opinions about IPR and DPR can shift over time as a result of stakeholder engagement and growing public awareness of water reuse, as shown in **Figure 7-19**.

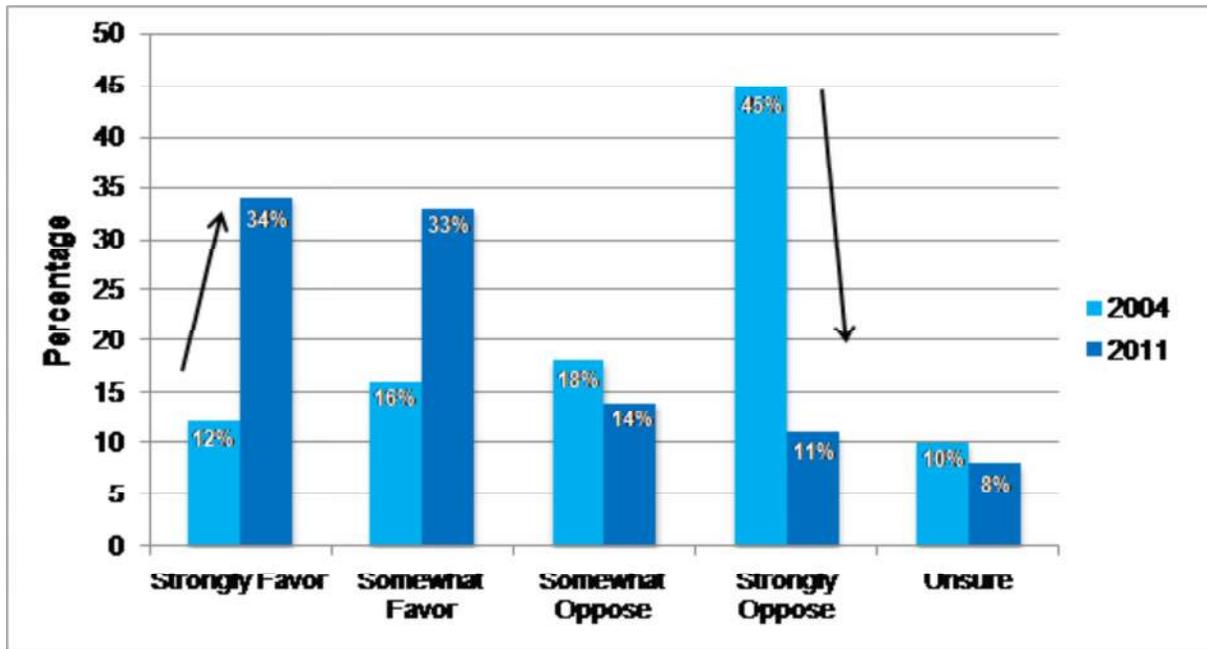


Figure 7-19. Survey results from San Diego: opinion about using advanced treated recycled water as an addition to drinking water supply (2004 and 2011) (EPA, 2012b)

Successful public engagement begins with clearly defining the problem and the potential benefits that the community can gain from each of the solutions. Once the options are fully explored — including status quo — it is then appropriate to discuss treatment and monitoring technologies that address potential risks associated with IPR and DPR. Research by the WaterReuse Association has shown that communication about IPR needs to be clear, consistent, and honest. The science surrounding IPR or DPR, as well as the analysis of alternative options, needs to be presented in a way that is understandable to the target audience and robust. The industry’s vocabulary can result in confusion, mistrust, or lack of public acceptance. **Figure 7-20** illustrates how the terms most often used by the water industry are least reassuring to the public (EPA, 2012). Therefore, positive terminology should be adopted that focuses on the monitoring and reliability of the safety and taste of drinking water.

Public involvement in IPR and DPR is an active area of research, including under WRRF 13-02 (Model Public Communication Plan for Advancing DPR Acceptance, just launched this year). Additional discussion of public involvement in water reuse is provided in Chapter 8 of the 2012 *EPA Guidelines for Water Reuse* (EPA, 2012b).

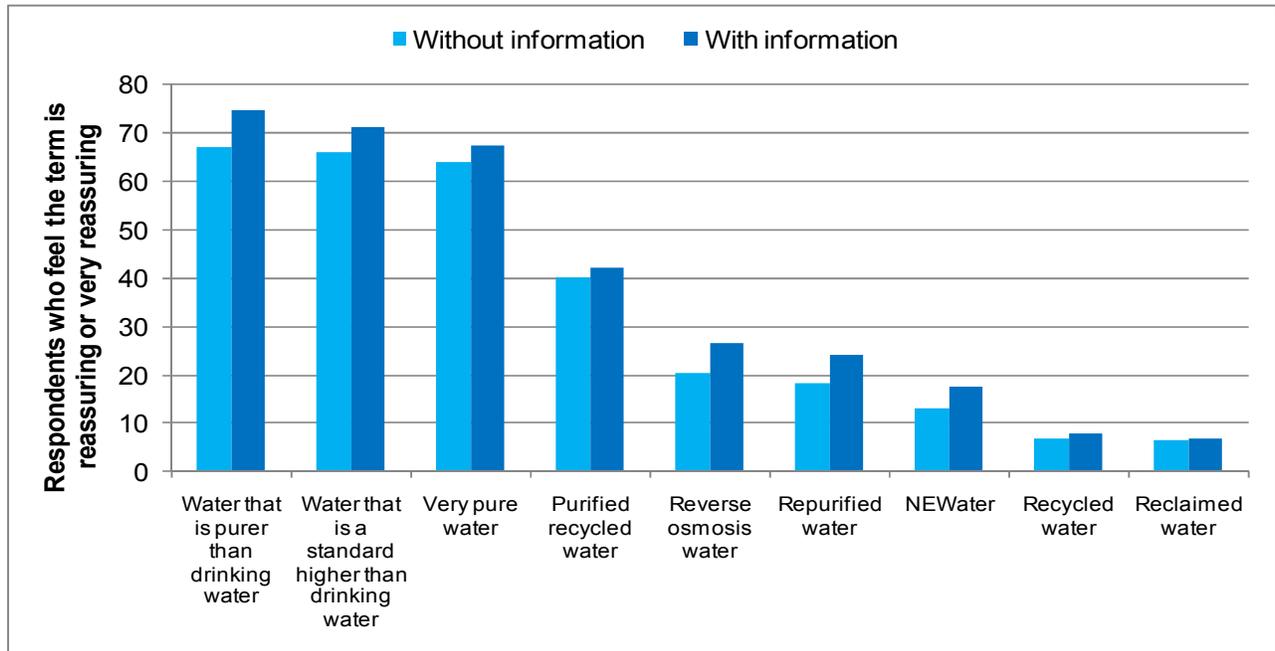


Figure 7-20. Water reclamation terms most used by the water industry are the least reassuring to the public. (EPA, 2012b)

## Section 8

# Conclusions and Recommendations

The objective of this study was to define the baseline water quality in the upper Neuse River by characterizing a selected list of constituents and evaluating the environmental fate and transport of these parameters. The study was conducted during a defined period that represents the highest contribution of treated effluent in the Neuse River between Falls Lake and Goldsboro. To support this objective, CDM Smith and City staff collaborated to develop and implement a sampling and analysis plan to conduct water quality sampling and analysis on the Neuse River during the fall of 2013. Eight sites labeled A through H were sampled along the Neuse River during three sampling events. In all, Neuse river water samples were analyzed for over 100 trace chemical constituents. The study design is described in Section 4. The results of this sampling and analysis has been presented and described herein. The data and evaluation support a number of important conclusions that are summarized below.

### 8.1 Summary of Key Results

The results from this study are presented and discussed in Section 6. This section presents a brief summary of the key findings.

- All of the parameters measured in samples collected in this study met North Carolina Surface Water Quality Standards for the designated uses at each individual stretch of the river studied, indicating **acceptable water quality**. Likewise, the samples that represented the Neuse River WWTP effluent met all NPDES requirements.
- The general water quality, as indicated by conventional parameters, was **similar to historical water quality** (which is presented in Section 2.2). This is an indication that the samples collected during this study were generally consistent with historical concentrations.
- **The Neuse River WWTP is not a significant source of microbial contamination** of the river. In general, the concentrations of microorganisms detected at all sites are typical values and the fecal coliform concentrations for all samples met the applicable North Carolina Surface Water Quality Standards on the Neuse River at each reach, indicating the river water is acceptable quality.
- The **river does not appear to be further improving the microbiological quality** downstream from site C. This may imply a lack of microbial attenuation as expected for the travel times along this stretch of the river and may also represent continued non-point source microbial pollution along the river.
- For trace chemical constituents studied, reporting limits presented in this study are generally similar to (or lower than) the reporting limits published in the literature. The methods used in the present study were **capable of detecting compounds at extremely low concentrations**.
- Site C, near the Neuse River WWTP discharge, had the greatest number of detections of trace chemical constituents (**Figure 8-1**), where 72% of the chemical compounds tested were detected in at least one sample. However, the mean of the cumulative number of detections per event for site C were not statistically different than those for sites D, E, and F.

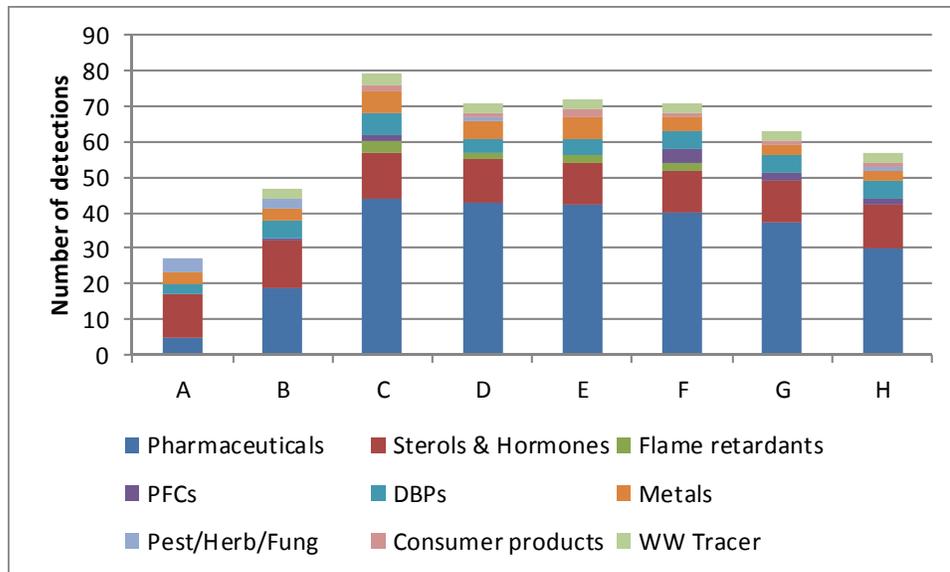


Figure 8-1. Chemical Detections by Site for all Three Events

- Bromide and barium were detected, likely occurring from natural sources. Zinc was also detected at concentrations that do not present a concern. The lack of detection of other metals at all of the sampling locations is an indication of good water quality.
- DBPs, perfluorinated compounds, and agricultural chemicals were minimally detected. NDMA was detected only three times. It is notable that atrazine was not detected in this study since it is one of the top 11 chemicals detected in drinking water (Benotti et al., 2009). However, the presence of agricultural chemicals in the river could vary seasonally and may be higher during spring and summer months.
- There were no detections of volatile organic compounds, nonylphenols, and iopromide. Nonylphenols were previously detected in Smithfield drinking water at concentrations below the reporting limit (Moorman et al., 2012).
- The **flame retardant** TCEP was detected in several samples; TCEP is a suspected endocrine disruptor that is frequently detected in the environment and is one of the top 11 chemicals detected in drinking water (Benotti et al., 2009). EPA has not set an MCL for TCEP. TCEP is one of the most recalcitrant compounds studied, along with carbamazepine. The other flame retardant studied HBCDD (including  $\alpha$ -HBCDD,  $\beta$ -HBCDD, and  $\gamma$ -HBCDD) was not detected at any location.
- Of the **consumer products** studied, only salicylic acid and BPA were detected. Various **pharmaceuticals** were detected (atenolol, caffeine, carbamazepine, cotinine, fluoxetine, furosemide, gemfibrozil, hydrochlorothiazide, ibuprofen, meprobamate, metoprolol, ofloxacin, oxycodone, sertraline, sulfamethoxazole, trimethoprim, valsartan, and verapamil), generally at concentrations similar to the concentrations found in the EPA's 2011 national survey of wastewater effluents (Kostich et al., 2014). Among these, carbamazepine, fluoxetine, gemfibrozil, ibuprofen, meprobamate, and sulfamethoxazole are considered to be recalcitrant in the environment and in many wastewater treatment steps (Drewes et al., 2008). Pharmaceuticals generally appeared at site C (with some compounds detected at sites A and B), with lower concentrations at points downstream from site C. Most, though not all, of the pharmaceuticals correlated well with the wastewater tracer sucralose.

- Acetaminophen, naproxen, and primidone were not detected in any samples.
- Of the **sterols and hormones** studied, there was some detection of 17- $\beta$ -estradiol,  $\beta$ -stigmastanol,  $\beta$ -sitosterol, cholesterol, and coprostanol. These are naturally occurring compounds that are degradable through a number of natural and WWTP treatment processes. As expected, unlike pharmaceuticals, these compounds did not correlate to sucralose and did not generally appear first at site C – there were detections at all sites without an upstream-downstream pattern in concentration. 17- $\alpha$ -ethinylestradiol, androstenedione, estrone were not detected in any of the samples, although estrone is one of the top 11 chemicals detected in drinking water (Benotti et al., 2009).  $\beta$ -sitosterol,  $\beta$ -stigmastanol, and cholesterol were previously detected in samples from the Neuse River and Smithfield finished drinking water (Moorman et al., 2012). Estrone, 17- $\alpha$ -ethinylestradiol, and androstenedione were detected previously in the Neuse River WWTP effluent in the EPA study (Stanford, 2013).
- In a review of 2012 public water quality reports in the region, with the exception of DBPs and atrazine (noted in section 6.15.2), no other trace chemical constituents sampled in the present study were detected in the finished drinking water in the region (Johnston County Public Utilities, 2013; City of Raleigh, 2013; Town of Smithfield, 2013).
- EEM data suggest that the **greatest degree of anthropogenic influence on the river was observed at Site C** as evidenced by the fluorescence at the wavelength pairs EX224/EM300 and EX224/EM350, which indicates that samples from selected sites exhibited anthropogenic influence from tyrosine and tryptophan-like compounds. Sites A, B, and H appear to have the lowest anthropogenic influence.
- Some of the samples (from sites A, B, C, G, and H) demonstrated **genotoxic effects** when compared with reagent water using the Ames test which employs a bacteria strain. While a positive result indicates that some chemical or combination of chemicals in water samples have some mutagenic potential, the assay cannot give an indication of the particular compounds present that account for the observed genotoxicity, nor whether the water samples would be mutagenic to humans. However, the results are useful in assessing whether there are gross changes in mutagenicity from one sample to another.

## 8.2 Implications

### 8.2.1 What does this data tell us about sources of chemical parameters in the river spatially and temporally?

The river water quality is generally very good and all samples met North Carolina Surface Water Quality Standards for the designated uses along this stretch of the river (outlined in Appendix H). The data collected in this study indicate that site C had the highest evidence of anthropogenic influences with respect to chemical constituents. On the other hand, site C had similar concentrations of microorganisms as other sites. There is evidence of nonpoint and or other point source pollution (as indicated by genotoxicity, the presence of some trace chemical constituents, and microbial indicators) at site A and at sites G and H (genotoxicity and elevated levels of turbidity and TSS).

### 8.2.2 What does this data tell us about attenuation/persistence of constituents in the river?

There is limited evidence of chemical attenuation between sites C and H. Because the Neuse River WWTP effluent quality is high with respect to microbial contamination, there is no evidence of microbial attenuation because the effluent concentrations of microbial constituents are not notably higher than the instream river concentrations.

The correlation of some detected pharmaceuticals to the wastewater tracer sucralose (carbamazepine, meprobamate, trimethoprim, sulfamethoxazole, metoprolol, and oxycodone) suggests that removal and degradation mechanisms are not prevalent along the river for these compounds. Detected pharmaceuticals that tended to appear around site C and have lower subsequent concentrations downstream which did not correlate to sucralose (atenolol, cotinine, furosemide, hydrochlorothiazide, ofloxacin, sertraline, valsartan, and verapamil) appear to have attenuated in the river. Of these chemicals that showed evidence of attenuation, only furosemide, hydrochlorothiazide, valsartan, and verapamil showed 1-log or greater removal or degradation between sites C and H.

### 8.2.3 How do we understand the relative risk of the observed results?

The National Research Council (NRC) published a 2012 report titled *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater*. The researchers authoring the study conducted a risk assessment of potable reuse and concluded that potable reuse could pose potential health hazards if populations were exposed to long-term, low-level exposure to trace chemical constituents in reclaimed water. However, the NRC panel concluded that the “occurrence of a contaminant at a detectable level does not necessarily pose a significant risk” and outlined risk assessment screening methods to develop a better understanding of potential future risks.

An important position taken by the NRC panel is the concept of the “risk exemplar” – that it is “appropriate to compare the risk associated with potable reuse projects with the risk associated with *de facto* reuse scenarios that are representative of [water] supplies that are widely experienced today.” Using this concept and risk assessment methods, the NRC panel compared *de facto* reuse where surface water supplies were made up of 5 percent wastewater effluent to IPR via groundwater recharge (both surface spreading and direct injection). The NRC panel studied a range of chemicals to 1) identify published contaminant occurrence data in reclaimed water and 2) compare against risk-based action levels (such as the EPA’s MCLs) to establish a margin of safety (MOS). An MOS of one indicates that the concentration is equal to the risk-based action level; higher MOSs indicate decreasing levels of relative risk. The NRC identified NDMA to have the lowest MOS (less than 1), followed by perfluorinated chemicals PFOA and PFOS (MOS of 4 to greater than 200). The other chemicals studied by the NRC, including pharmaceuticals, triclosan, and TCEP were all found to have margins of safety from 1,000 to 1,000,000 and found IPR to generally exceed the MOS for *de facto* reuse when the highest levels of treatment were applied.

An important assessment of the human health risks due to pharmaceuticals in drinking water was recently completed by the World Health Organization (WHO) (2012). The WHO studied the prevalence and risk of pharmaceuticals in finished drinking water and concluded that untreated or partially treated wastewater as well as wastewater effluent are a major source of pharmaceuticals found in surface waters and drinking water. However, in assessing the risk from pharmaceuticals detected in drinking water, the WHO concluded the following:

*Current observations suggest that it is very unlikely that exposure to very low levels of pharmaceuticals in drinking water would result in appreciable adverse risks to human health, as concentrations of pharmaceuticals detected in drinking water (typically in the nanogram per liter range) are several orders of magnitude (typically more, and often much more, than 1000-fold) lower than the minimum therapeutic dose. (WHO, 2012)*

Risk assessment was not within the scope of this study. However, in general, the concentrations of detected compounds in this study are consistent with previously published results such as the EPA national wastewater effluent survey, as discussed in Section 7.3 (Kostich et al., 2014). For illustration purposes, in the national survey, Kostich et al. (2014) conducted a risk assessment to illustrate how low the concentrations of detected pharmaceuticals are, even if the treated wastewater were consumed without additional treatment. These authors showed that of the detected pharmaceuticals in the national survey, it would take a person one to ten years of drinking two liters per day of wastewater effluent in order to consume one minimum daily dose.

Thus, while the present study was able to detect a range of trace chemical constituents, there is no current evidence that the concentrations detected pose any human health risk. A complete risk assessment following the guidance laid out by the NRC would be appropriate for evaluating the potential for potable reuse in Raleigh or in any location, including potential risks from pathogens, unknown chemicals, and known chemicals that currently lack toxicological data important to understanding low-level chronic and acute exposure impacts (NRC, 2012).

### 8.3 Recommendations for Future Work

The following components are recommended for ongoing assessment of potable reuse in Raleigh:

1. Conduct a risk assessment following the guidance laid out by the NRC, including potential risks from pathogens, unknown chemicals, and known chemicals that currently lack toxicological data important to understanding low-level chronic and acute exposure impacts (NRC, 2012). Such a risk assessment should compare the risks due to potable reuse against the risk associated with current *de facto* reuse experienced today along the Neuse River.
2. Assess the effectiveness of a potential industrial source control program to prevent undesirable chemicals from entering a treatment system.
3. Evaluation of storage options using environmental or engineered buffers.
4. Evaluation and development of a system, operational practices, and response strategies to ensure system reliability.
5. Develop appropriate monitoring strategies to ensure deviations in treatment performance are detected, triggering immediate and proportional response strategies. Pathogens present the most pressing concern with respect to acute health impacts. On the long-term chemical exposure side, NDMA, PFOA, PFOS, and TCEP are of importance. The formation of bromate would need to be monitored and potentially controlled if ozonation were included in a treatment process. In addition, each unit process in the treatment train can be monitored using indicator or surrogate chemicals to determine performance. Bulk measurements including EEM and the Ames genotoxicity bioassay would be helpful to use as well to show performance of individual treatment steps at removing unknown constituents. In addition, because ozonation of wastewater effluent can increase genotoxicity, particularly when

bromide is present, it would be important to monitor genotoxicity before and after each treatment step.

6. Weigh non-cost factors as described in section 8.9.5
7. Develop a successful public education and outreach program as described in section 8.9.6
8. Design and implement a pilot potable reuse system that involves multiple barriers to demonstrate the removal of trace chemical constituents and pathogens. This pilot could then be used to develop specific design criteria in support of a full-scale potable reuse project.

## Section 9

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# Section 10

## Acronyms

ADWG - Australian Drinking Water Guidelines

AGWR- Australian Guidelines for Water Recycling

AMS- Ambient Monitoring System

ANOVA – Analysis of Variance

AOP- Advanced Oxidation Processes

APEs- Alkylphenol Ethoxylates

APs- Alkylphenols

ATP- Adenosine Trphosphate

AWTF- Advanced Water Treatment Facility

BAC- Biological Activated Carbon

BOD- Biochemical Oxygen Demand

BPA- Bishpenol A

Cal/EPA- California Environmental Protection Agency

CCWA- Clayton County Water Authority

CDPH- California Department of Public Health

CECs- Contaminants of Emerging Concern

CFU- Colony- Forming Units

CIP- Clean-In-Place

City – City of Raleigh

COD- Chemical Oxygen Demand

CRMWD- Colorado River Municipal Water District

DO- Dissolved Oxygen

DBPs- Disinfection By-Products

DEET- N-Diethyl-Meta-Toluamide

DMR- Discharge Monitoring Report

DPR- Direct Potable Reuse

DWQ- Division of Water Quality

ED- Electro-Dialysis

EDCs- Endocrine Disrupting Compounds

EDR- Electrodialysis Reversal

EDs- Endocrine Disrupters

EEM- Excitation/Emission Matrix

EEQ- Estrogenic Equivalent

EI- Electron Ionization

EPA- U.S. Environmental Protection Agency

FAT- Full Advanced Treatment a.k.a. the California Model

FHWRP- Fred Hervey Water Reclamation Plant

FWHWRC- F. Wayne Hill Water Reclamation Center

GAC- Granular Activated Carbon

GC/CI/MS/MS- Gas Chromatography coupled with Chemical Ionization Tandem Mass Spectrometric Detection

GC/MS-SIM- Gas Chromatography with Mass Spectrometric Detection Utilizing Selected ION Monitoring

GS- General Statues

GWRS- Orange County Groundwater Replenishment System

H<sub>2</sub>O<sub>2</sub>- Hydrogen Peroxide

HAAs- Haloacetic Acids

HACCP- Hazard Analysis and Critical Control Point

HBCD- Hexabromocyclododecane

HPLC- High Performance Liquid Chromatography

HRGC- High-Resolution Gas Chromatograph

HRMS- High-Resolution Mass Spectrometric Dectection

IDA- Isotope Dilution Analyte

IPR- Indirect Potable Reuse

Kmoc- Sorption Coefficients

L- liters

LACSD- Los Angeles County Sanitation District

LAWRPP- Lake Arrowhead Water Reclamation Pilot Plant

LBWRP- Long Beach Water Reclamation Plan

LC-MS/MS- Liquid Chromatography Tandem Mass Spectrometry

LCWRP- Los Coyotes Water Reclamation Plan

LNBA- Lower Neuse Basin Association

LOX- Liquid Oxygen

LRMS- Low-Resolution Mass Spectrometric Detection

LVLWTF- Leo J. Vander Lans Advanced Water Treatment Facility

MCL- Maximum Contaminant Level

MDL- Method detection Limit

MF- Microfiltration

MFFCC- Membrane Filter Fecal Coliform Count

MGD- Million Gallons per Day

MID- Multiple Ion Detection

mL – Milliliter

MOS – Measure of Safety

MPN- Most Probable Number

MRM- Multiple Reaction Monitoring

MS4- Municipal Separate Storm Sewer System

MTBE- Methyl tertiary butyl ether

NASA- Nation Aeronautics and Space Administration

NAWQA- National Water-Quality Assessment

NC AWWA-WEA- North Carolina American Water Works Association and the North Carolina Water Environment Association

NCAC- North Carolina Administrative Code

NCDENR- North Carolina Department of Environment and Natural Resources

NCSWS- North Carolina Surface Water Quality Standards

NDMA- n-Nitrosodimethylamine

NF- Nanofiltration

ng/L- Nanograms per Liter

NH<sub>3</sub>- Ammonia

NO<sub>2</sub>- Nitrite

NO<sub>3</sub>- Nitrate

NOAA- National Oceanic and Atmospheric Administration

NPDES- National Pollutant Discharge Elimination System

NPEs- Nonylphenol Ethoxylates

NPR- National Public Radio

NPs- Nonylphenols

NRC- National Research Council

NSAs- Nitrosamines

O&M- Operation & Maintenance

OPs- Octylphenols

PAA- Peroxyacetic Acid

PAC- Powdered Activated Carbon

PARAFAC- Parallel Factor Analysis

PCB- Polychlorinated Biphenyl

PCP- Pentachlorophenol

PCR- Polymerase Chain Reaction

PFBS- Perfluorobutanesulfonic Acid

PFC- Perfluorinated compounds

PFHpA- Perfluoroheptanoic Acid

PFHxS- Perfluorohexanesulfonic Acid

PFNA- Perfluorononanoic Acid

PFOA- Perfluorooctanoic Acid

PFOS- Perfluorooctanesulfonic Acid

PPCPs- Pharmaceutical and Personal Care Products

Redox- Reduction-Oxidation

RO- Reverse Osmosis

RSWRF- Reno-Stead Water Reclamation Facility

RWQCBs- Regional Water Quality Control Boards

SAP- Sampling and Analysis Plan

SAS- Statistical Analysis System

SCWRP- South Caboolture Water Reclamation Plant

SDWA- Safe Drinking Water Act

SFE- Separatory Funnel Extraction

SIM- Selected Ion Monitoring

SOCs – Synthetic Organic Compounds

SPE- Solid Phase Extraction

SRT- Solids Retention Time

SSRIs- Selective Serotonin Reuptake Inhibitors

SWRCB- California State Water Resources Board

TCEP- Tris[2-chloroethyl]Phosphate

TCEQ- Texas Commission on Environmental Quality

TDS- Total Dissolved Solids

THMs- Trihalomethanes

TiO<sub>2</sub>- Titanium Dioxide

TKN- Kjeldahl Nitrogen

TMDL- Total Maximum Daily Load

TN- Total Nitrogen

TOC- Total Organic Carbon

TP- Total Phosphorus

TrOCs- Trace Organic Chemicals

TSS- Total Suspended Solids

TTU- Tennessee Technological Univeristy

µg/L- Micrograms per Liter

UF- Ultrafiltration

UOSA- Upper Occoquan Sewage Authority

USGS- U.S. Geological Survey

UV- Ultraviolet

UVT- UV Transmittance

VOCs- Volatile Organic Compounds

WERF- Water Environment Research Foundation

WET- Whole Effluent Toxicity

WHO- World Health Organization

WRD- Water Replenishment District of Southern California

WRF- Wastewater Reclamation Facility

WRRF- WateReuse Research Foundation

WTP- Water Treatment Plants

WWTP- Wastewater Treatment Plant