Biologically Active Filtration Media Properties: Practical and Mechanistic Implications

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Biologically active filtration [BAF] can be used to concurrently remove particles and natural organic matter during drinking water treatment. The selection of a given media type for use in BAF can impact filter performance, capital costs, and operating costs. BAF performance using different media types has been previously compared; however, no single media type has been found to provide the best performance across all studies. Notably, no comparisons of BAF with various media types have been reported where the same grain size distribution was used for all media types; therefore, observed differences in performance cannot be attributed solely to the media types, but may have been impacted by differences in grain size distribution. Furthermore, mechanisms affecting BAF performance are not well understood and mechanistic implications of media selection on BAF have not been fully elucidated.

In this study, the performance provided by different media types and media-associated mechanisms that impact BAF were investigated through two phases of experiments.

In Phase I, a procedure for matching the grain size distribution of different media types was developed. Pilot-scale biologically active filters [biofilters] were filled with coal-based granular activated carbon [GAC], anthracite, rough engineered ceramic media [REC], or wood-based GAC; the media grain size distributions were closely matched. The biofilters were fed water that was flocculated, settled, and ozonated at a full-scale water treatment plant. One extra filter containing coal-based GAC was operated in a declining-rate mode, whereas all other filters were operated in a constant-rate mode. The biofilters were operated continuously for 660 days. Dissolved organic carbon [DOC] removal, assimilable organic carbon [AOC] removal, trihalomethane formation potential [THMFP] removal, turbidity removal, headloss, and filter run time were monitored and compared. Prior to this study, REC had not been tested for use in BAF.

The GACs provided better DOC removal than either REC or anthracite. This improved removal was observed even though the coal-based GAC had been used for seven years in full scale filters prior to these experiments. The GACs were adsorptive media types whereas the REC and anthracite were nonadsorptive. It was demonstrated that the adsorptive property of GAC is critical for enhancing DOC removal during biofiltration relative to other media over the long-term, even for GAC that has been used for many years. The results also implied that mechanisms related to a medium's adsorptive properties (e.g. bioregeneration, adsorption of organic matter spikes) are significant to DOC removal during biofiltration in the long-term. It was also found that DOC removal improved when the filter was operated in declining-rate mode, as opposed to constant-rate mode. In some cases, operating a filter in declining

rate mode helped to offset differences in DOC removal provided by different media types. Differences in AOC and THMFP removal provided by the media types were observed during some sampling events; however, no media type consistently provided the best AOC or THMFP removal. Interestingly, dibromochloromethane formation potential increased slightly because of biofiltration, especially in GAC as compared to anthracite or REC filters.

Turbidity removal was assessed in two ways: (1) by comparing the stable effluent turbidity between ripening and breakthrough and (2) by comparing the ability of the biofilters to dampen influent turbidity spikes. A kaolin clay suspension was injected into the biofilter influent to cause the influent turbidity spikes. Rough media types (i.e. wood-based GAC, coal-based GAC, and REC) provided better turbidity removal and better turbidity dampening than smooth media (i.e. anthracite). It was concluded that media roughness generally enhances turbidity removal and turbidity dampening during BAF. REC and wood-based GAC provided the best turbidity removal of all the media types. The media type that provided the best performance, between REC vs. wood-based GAC and between coal-based GAC vs. anthracite, was seasonally dependent.

REC and anthracite generally provided slower headloss development than GAC media during biofiltration. The specific media type that provided better (i.e. slower) headloss development within adsorptive (coal-based vs. wood-based GAC) and non-adsorptive (REC vs. anthracite) media was seasonally dependent. It was found that there may be a trade-off between choosing a media type that provides the greatest DOC removal and choosing a media type that provides the best headloss performance.

Finally, the media types that provided the longest filter run time were seasonally dependent, but, in general, REC provided longer filter run times than wood-based GAC and anthracite provided longer filter run times than coal-based GAC.

In Phase II, spikes of an acetate (a nonadsorptive compound) and maltose (an adsorptive compound) were injected into the influent of a biofilter located at the University of Waterloo [UW] and biofilters located in Toronto, Ontario [Toronto]. The UW biofilter contained coal-based GAC that had previously been used in a full scale biofilter for 25 months. The UW biofilter was fed synthetic water containing sodium acetate and nutrients. Two sets of spikes, consisting of one acetate spike and one maltose spike, were introduced to the UW biofilter. The removal of total organic carbon and the production of inorganic carbon were monitored before, during, and after the spikes to assess the fate of organic carbon in the biofilter. The Toronto biofilters consisted of GAC and anthracite biofilters that had been continuously operated for

three years prior to the spike experiment. The biofilters were fed Lake Ontario water that was ozonated and flocculated. Two acetate spikes and one maltose spike were added to the filter influents.

The inorganic carbon produced by the UW biofilter exceeded the TOC removal in one of two spike experiments. This indicated that organic carbon adsorbed to the GAC or organic carbon present in the biomass was oxidized to CO_2. It was concluded that either bioregeneration of adsorbed organic matter and/or net decay of accumulated biomass can occur in drinking water biofilters containing GAC media after spikes of organic matter have been attenuated. Further research is needed to differentiate between these two mechanisms and to elucidate the scenarios under which each of these mechanisms occurs during drinking water treatment.

Maltose spikes were adsorbed onto GAC at both UW and Toronto. This work demonstrated that organic matter spikes can adsorb onto GAC even after the GAC has been used in biofiltration for extended periods of time. Adsorption of spikes of organic matter is one mechanism that may explain how GAC biofilters can provide better removal of organic matter than biofilters containing nonadsorptive media (i.e. anthracite and REC) over the long-term.

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List of Abbreviations

AOC	assimilable organic carbon
BAF	biologically active filtration
BDOC	biodegradable organic carbon
BOM	biodegradable organic matter
CFT	colloid filtration theory
DBP	disinfection by-product
DOC	dissolved organic carbon
EBCT	empty bed contact time
EPS	extracellular polymeric substances
"Floaters"	Low density filtration media that floats when placed in water
GAC	granular activated carbon
GSD	grain size distribution
IC	inorganic carbon
MIB	2-methylisoborneol
NOM	natural organic matter
NTU	nephelometric turbidity unit
REC	rough engineered ceramic filtration media
SUVA	specific UV absorbance
THMFP	trihalomethane formation potential
TOC	total organic carbon
UV_{254}	absorbance of light with a wavelength of 254nm
UW	University of Waterloo

Deo gratias

Chapter 1 Introduction

1.1 Research Context

Particle and organic matter removal are critical aspects of drinking water treatment. The presence and concentration of particles and organic matter affects finished water quality and can affect the design, operation, and feasibility of a variety of drinking water treatment processes. Biologically active filtration [BAF] is a process that has the potential to concurrently remove both particles and organic matter in a cost effective manner, thus allowing improved finished water quality. BAF provides many benefits, including "traditional" particle and turbidity removal, improved biological stability of finished water, removal of ozonation by-products, removal of disinfection by-product precursors, removal of taste and odour compounds, and decreased membrane fouling (LeChevallier et al., 1992; Emelko et al., 2006; Hallé et al., 2009; Elhadi et al., 2004); however, "design criteria and operational optimization [for biological treatment still] aren't well established" (Evans, 2010, p. 12) in North America despite the fact that "biological treatment [including BAF] of drinking water is used extensively to improve finished water quality in Europe, and to some extent in Canada and the United States" (Evans, 2010, p. 12).

BAF can be described in different ways (Nieminski, 2008); however, broadly speaking, it is a process wherein granular media filters are operated such that the removal of contaminants is caused or aided by the action or presence of indigenous microorganisms in the filters. BAF can occur unintentionally or by design. Unintentional BAF, also known as "passive" BAF, is when BAF occurs as an unintentional by-product of a design or operational decision, such as the removal of chlorination before filtration (Nieminski, 2008). Intentional BAF, also known as "active" BAF, is a process in which filters are specifically designed and operated to optimize microbial removal of contaminants; for example, by installing ozonation, which can degrade organics to a more biodegradable form (e.g., Carlson & Amy, 2001), prior to GAC filters to help promote biodegradation of the organic matter (also known as the "biological active carbon" process, or BAC; Rittmann & Huck, 1989) or by adding nutrients to the influent of a filter (e.g., Rahman et al., 2016; Azzeh et al., 2015; Wong, 2015; Ganger et al., 2014; Lauderdale et al., 2012; Sang et al., 2003; Yu et al., 2003).

Several contaminants can be removed by BAF during drinking water treatment and biologically active filters (also known as biofilters) can be can be configured in different ways to optimize their performance. Like conventional filtration, BAF can remove particles and turbidity; however, biologically active filters can also remove dissolved compounds, including various types of organic matter (i.e. natural organic matter [NOM], disinfection by-product [DBP] precursors, and taste and odour causing compounds),

pharmaceuticals, iron, manganese, nitrogen species, and perchlorate (e.g., Chaiket et al., 2002; Dussert & Tramposch, 1997; Elhadi et al., 2004; Hallé et al., 2015; LeChevallier et al., 1992; Nieminski, 2008; Urfer et al., 1997; Zearley & Summers 2012). The configuration of biologically active filters can be either multi-stage or single stage (Huck et al., 2000). Multi-stage BAF is where particle removal and microbial removal of dissolved contaminants occur in separate stages. Single stage BAF is where particle removal and microbial removal of dissolved contaminants occur in the same filter. The benefits of single stage BAF when compared to dual stage filtration include the relative ease of retrofitting existing rapid filtration plants, smaller footprints, and reduced infrastructure requirements. The focus of this research was on single stage active BAF for the purpose of concurrently removing particles and organic matter, because this form of biofiltration has the potential to be a cost-effective option for improving the removal of these materials in existing conventional drinking water treatment plants.

The optimization of particle removal by conventional, non-biological, filtration is an extensive area of research. Mechanistic theories of particle removal processes have been developed (e.g., Yao et al., 1971; Rajagopalan & Tien, 1976; Tufenkji & Elimelech, 2004; Long & Hilpert, 2009; Nelson & Ginn, 2011; Ma et al., 2013) and investigations have been conducted with the goal of optimizing different aspects of filter design and operation (Amirtharajah, 1993; Amburgy & Amirtharajah, 2005); however, current mechanistic theories of particle removal and current operational guidance for conventional filters may not be applicable to BAF given the presence of microorganisms in biofilters (e.g., Ahmed & Amirtharajah, 1998). Nonetheless, BAF has been shown to be able to provide good removal of particles and turbidity (Goldgrabe et al., 1993; Emelko et al., 2006); however, the applicability of advances in the understanding and optimization of particle removal to BAF needs to be investigated. Two such advances are the improved understanding of the impact of media roughness and the use of rough media for filtration. It has been shown that the roughness of a surface, including the surface of media grains, impacts the removal of particles (Jin et al., 2015a; Jin et al., 2015b; Scott, 2008). Rough engineered ceramic media [REC], in particular, can provide better removal of turbidity and particles than conventional dual-media (i.e. anthracite over sand) filters (Scott, 2008). Improved removal of turbidity by REC during BAF, however, has not been demonstrated. Furthermore, REC has not been tested for use in BAF and the performance of REC has not been compared to that of GAC.

The removal of organic matter by BAF, particularly over the long term, is primarily caused by heterotrophic bacteria, which oxidize the organic matter (Rittmann & Huck, 1989). There are several different factors that may affect the removal of organic matter by single stage BAF processes: for example, temperature, empty bed contact time [EBCT], backwash protocol, and type of filtration medium

(e.g., Urfer et al., 1997; Liu et al., 2001; Emelko et al., 2006). The type of filtration medium used is a design factor over which there is a large degree of control (Huck et al., 2000); it also can have significant cost implications. The impact of using different types of filtration media on the removal of organic matter from water has been widely investigated; however, conclusions from these studies are inconsistent. Some studies have shown that granular activated carbon (GAC, an adsorptive medium) can provide better removal of organic matter than non-adsorptive media (e.g. anthracite, expanded clay, and sand), while other studies have shown either no difference in organic matter removal or no difference in removal under specific operational conditions (e.g., Wang et al., 1995; Persson et al., 2007; Chaiket et al., 2002; Emelko et al., 2006). Notably, media grain sizes and/or grain size distributions have not been controlled in previously reported investigations of BAF with different media types. Therefore, there is no way to know whether differences in organic matter removal were attributable to the media types themselves, or to the differences in grain size distributions. This limitation makes it difficult to provide conclusive design guidance as to the type of filtration medium that should be used for BAF and precludes the elucidation of media-associated mechanistic insights into biofilter performance.

An understanding of the mechanisms and media properties that enable improved organic matter removal by granular activated carbon would help guide media selection and the development of design and operational guidance for BAF. It would also help elucidate why different conclusions regarding the effect of filtration medium type on the removal of organic matter have been drawn by different studies. Mechanisms that have been hypothesized to enable improved removal of organic matter by GAC include bioregeneration of the adsorptive capacity of GAC by microorganisms (AWWA, 1981); mechanisms related to the surface roughness of media (Dussert & Tramposch, 1997; Herzberg et al., 2005; Emelko et al., 2006); enhanced microbial attachment due to GAC surface chemistry (Dussert & Tramposch, 1997); and "chemical reduction of oxidants/disinfectants" by GAC (Dussert & Tramposch, 1997). Other mechanisms that also may result in improved removal of organic matter by GAC include adsorption of inhibitory substances (e.g. Choi et al., 2008), extension of the degradation time for slowly biodegradable substances through adsorption onto GAC (Çeçen & Aktaş, 2011), concentration of substrates on the surface of GAC (Çeçen & Aktaş, 2011), and adsorption of organic matter due to changes in influent concentration or composition. While some of these mechanisms have been studied, the exact role of these mechanisms in the removal of organic matter during drinking water treatment remains unknown.

Notably, all of the mechanisms that may contribute to organic matter removal during biofiltration listed above are related to filtration medium properties. Bioregeneration, adsorption of inhibitory substances, and adsorption of organic matter due to changes in influent concentration or composition are related to

media adsorptive properties. Enhanced microbial attachment and chemical reduction of oxidants/disinfectants are related to the chemical properties of the medium. Mechanisms related to media roughness also have been hypothesized to affect the removal of organic matter by shielding biofilm from shear forces. The relative importance of these properties in providing improved removal of organic matter is unknown.

Finally, operationally relevant performance metrics such as the rate of headloss development and filter run time affect the feasibility and cost-effectiveness of filtration processes. A limited number of peer-reviewed comparisons of headloss and run time (e.g. Najm et al., 2005; LeChevallier et al., 1992) have been conducted for biofilters containing different media types; however, the grain size distributions of the different media types used in these studies were not the same. Consequently, differences in performance observed in these studies cannot be attributed solely to the differences in media type. The impact of media type on headloss development and filter run time during BAF is currently unknown.

1.2 Research Objectives

The objectives of this research were to:

1. Develop a method that allows the grain size distributions of different media types to be closely matched.
2. Compare the performance of coal-based GAC, anthracite, REC, and wood-based GAC with matched grain size distributions when used for biologically active filtration during drinking water treatment.
3. Determine whether media roughness and/or its adsorptive properties provide long-term improvements in organic matter removal during biofiltration by GAC.
4. Investigate adsorption-related mechanisms that impact organic matter removal during biofiltration for drinking water treatment.
5. Evaluate filter media roughness impacts on turbidity removal during biofiltration.

The objectives of this research were addressed though two phases of experiments. Phase I consisted of large-scale pilot experiments comparing the performance of different media types. Phase II consisted of laboratory-scale and pilot-scale mechanistic experiments. Objectives 1, 2, 3 and 5 were investigated during Phase I. Objective 4 was investigated during Phase II.

1.3 Critical Notes on Terminology

The terms "**adsorptive media**", "**adsorptive media type**", and the "**adsorptive property**" of a media type are used throughout this document. In this thesis, the terms "adsorptive media" or an "adsorptive media type" are meant to indicate that the media can adsorb organic matter when the media is in its virgin state. Similarly, the term "adsorptive property" is meant to indicate that, in its virgin state, a media type has the property of being able to adsorb organic matter. These terms are not meant to imply that the media have a residual adsorptive capacity at a given point in time. An adsorptive media type may have residual adsorptive capacity or may be exhausted depending on how long it has been used in a process.

The term "**biomass**", in this thesis, is meant to include microorganisms and all particulate matter produced by the microorganisms, including extracellular polymeric substances and dead cells/cell debris. "**Active biomass**", however, refers to specifically live microorganisms that utilize substrate.

1.4 Thesis Structure

The remainder of the thesis is divided into seven chapters, a reference list, and a series of appendices. A brief description of the information provided in each chapter is provided below.

Chapter 2: Background

Background information related to the research goals is presented. The removal of particles and the removal of organic matter by rapid granular media filtration processes, and BAF specifically, are discussed. Factors and mechanisms affecting the removal of these contaminants are also discussed.

Chapter 3: Phase I Experiments

Phase I consisted of a large, multi-year pilot scale study. In Phase I, the performance of pilot-scale biofilters containing different media types with matched grain size distributions was compared. Media types that provided the best performance and media properties that impacted performance were identified.

Materials, methods, and results from Phase I experiments are presented.

Chapter 4: Phase II Experiments

Phase II consisted of select experiments into the mechanisms that impact the removal of organic matter by GAC biofilters. Bioregeneration and the adsorption of organic matter due to increases in influent concentration and composition were investigated.

Materials, methods, and results from Phase II experiments are presented.

Chapter 5: Conclusions and Implications

Overall conclusions and implications from Phase I and Phase II are summarized.

Chapter 6: Recommendations for Future Research

Recommendations for future research are provided.

Chapter 7: Contributions of the Research

The contributions of the proposed research and the relevance of the contributions to the practice and understanding of biologically active filtration processes for drinking water treatment are summarized.

Chapter 2 Background

Historically utilities have tried to prevent biological growth during water treatment because of concerns of increased pathogen occurrence as a result of microbial activity and potential for pathogen harbouring. Treatment improvements have focused on optimizing traditional aspects of process performance such as process run times prior to process cleaning/maintenance (e.g., backwashing of filters); however, increasingly stringent regulations for treated water quality require solutions for meeting the challenge of cost-effectively treating drinking water. Elimination of chlorine application prior to filtration allows biological growth within the filters to occur and enables biological treatment of drinking water.

Biologically active filtration [BAF] can remove both particles and organic matter (e.g. LeChevallier et al., 1992; Urfer et al., 1997; Emelko et al., 2006). It can be an effective pre-treatment for membrane technologies (e.g. Azzeh et al., 2015; Huck et al., 2011; Hallé et al., 2009) and by removing organic matter can reduce disinfection by-product formation (e.g. LeChevallier et al., 1992; Chaiket et al., 2002), remove taste and odour compounds (Elhadi et al., 2004), remove micropollutants such as pharmaceuticals and personal care products (e.g. Hallé et al., 2015; Zearley & Summers 2012), and improve the biological stability of water (e.g. LeChevallier et al., 1992). While benefits of BAF are predominantly linked to biological activity, the details of that activity and how it can be reliably "engineered" and optimized are not fully understood.

2.1 Evaluation of Filtration Performance

The performance of biological and non-biological rapid-rate filtration can be evaluated by determining the magnitude and reliability of particle and organic matter removal. Operational parameters such as headloss and filter run time can also be used to evaluate performance. A brief overview of these parameters and the various metrics associated with evaluating them is provided below.

2.1.1 Removal of Particles

The removal of particles by filtration can be assessed by the measurement of particle counts or the measurement of turbidity. Turbidity is an aggregate measure of the combined light scattering effect from suspended particles, generally using a nephelometer (Eaton et al., 2005). Particle counters, however, use a high-intensity light source (e.g., a laser) and sensitive detectors (e.g., photodetector) to count pulses of scattered light from particles. While it is generally believed that particle counts provide a more sensitive measure of filter performance relative to turbidity (Hargesheimer et al., 1992), drinking water regulations

(e.g., O.Reg. 170/03; National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule, Final Rule, 1998) are predominantly based on turbidity (Ontario Ministry of the Environment [MOE], 2010; National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment; Final Rule, 1998).

2.1.2 Removal of Organic Matter

The removal and character of organic matter has been evaluated using several techniques that are meaningful to drinking water treatment. General removal of organic carbon can be assessed by measuring the removal of aggregate parameters such as total organic carbon [TOC] or dissolved organic [DOC] (e.g. Hozalski, et al., 1995; Emelko et al., 2006; Chaiket et al., 2002). The removal of the biodegradable fraction of organic carbon can be assessed by measuring the removal of biodegradable dissolved organic carbon [BDOC] and assimilable organic carbon [AOC] (e.g. Chien et al., 2007; Chaiket et al., 2002; Wang, et al., 1995; Huck, 1990). The removal of disinfection by-product precursors can be assessed by measuring the change in (or removal of) the formation potential of the disinfection byproduct, for example trihalomethane formation potential [THMFP] (e.g. Chaiket et al., 2002). The removal of disinfection by-products and other specific compounds can be assessed by measuring the removal of those individual compounds, for example: carboxylic acids, ketones, aldehydes, ibuprofen, naproxen, atrazine, and bisphenol A (e.g. Hallé, 2015, Zearley & Summers, 2012; Liu et al., 2001; Carlson & Amy, 1998). Organic matter removal, in particular TOC and trihalomethane precursors, has also been correlated to changes in the absorbance of light with a wavelength of 254 nm [UV_{254}] (Edzwald et al., 1985). Finally, organic matter can be fractionated by liquid chromatography followed by organic carbon detection (Huber et al., 2011), adsorption to GAC (Nishijima et al., 1998), and adsorption to resins (e.g. Chow et al., 2004; Aiken et al., 1992; Malcolm & MacCarthy, 1992; Thurman & Malcolm, 1981; Leenheer, 1981).

While several different parameters can be used to evaluate the removal of organic matter, the information provided by each of these parameters is not necessarily the same nor is the magnitude of their removal during treatment. For example, TOC and DOC are related to chlorine demand and formation of disinfection by-products (LeChevallier et al., 1992). BDOC, by definition, can be used to assess the efficiency of biological treatment processes in removing dissolved organic matter through biodegradation. Reduction in BDOC is related to chlorine demand and disinfection by-product formation (Huck, 1990). AOC can be used to assess potential for microbial regrowth in the distribution system after treatment (Huck, 1990; van der Kooij, 1992). Measurement of individual compounds can provide information on the removal of those compounds but do not necessarily represent the total amount of either biodegradable organic matter or the organic matter that can be removed by a biological process (Carlson & Amy; 1997;

Carlson & Amy, 1998). Measurement of UV_{254} is related to the concentration of organic matter containing conjugated double bonds (Edzwald et al., 1985) and can be correlated to the removal of TOC and THMFP. Various fractions of organic carbon can be correlated with coagulant demand (Sharp et al., 2006); organic matter removal during coagulation and sedimentation (Chow et al., 2004); different stages of biofilter operations (e.g. Nishijima et al., 1998); and membrane fouling (e.g. Azzeh et al., 2015; Halle et al., 2009). The parameter used to characterize the organic matter removal by biofiltration, therefore, depends on the ultimate purpose for which it is collected.

2.1.3 Headloss and Filter Run Time

Headloss is a measure of the energy lost as water flows through a filter at a given flow rate. Practically, headloss is used to indicate the minimum pressure required to drive water through the filter. Filters that have lower headloss require less pressure, and thus less energy, to produce water at a given flow rate.

Filter run time is the length of time that a filter can be operated prior to cleaning (i.e. backwashing). Backwashing consists of pumping water upward through the filter to wash out debris removed from the water by the filters. Backwashing filters requires clean water and energy to run backwash pumps. The water normally used for backwashing is often that produced by the filter; therefore, frequent backwashing reduces the net production of water by the filters. Filters that have a longer run times generally can produce more water and require less energy for backwashing than filters with shorter run times.

2.2 Particle Removal by Filtration

Particle removal is a main goal of conventional filtration and single stage BAF. Many of the particles and colloidal matter that are not removed by coagulation, flocculation, and clarification are removed by filtration. As water flows through filter media, particles are predominantly removed by physico-chemical mechanisms. Physico-chemical filtration consists of transport of particles from fluid streamlines to the surfaces of collectors; particles may then attach to the surfaces of the filter media grains (also referred to as collectors). Attached particles collect on the surface of the media and can act as additional collectors for subsequent particles (O'Melia, 1985): this process can lead to improved particle removal in a phenomenon known as filter ripening (discussed later in this section). The process of the attachment and detachment of particles is discussed in Amirtharajah (1988). In brief, as attached particles collect on the surface of filter media, they can start to restrict the pores between filter media grains. Restriction of pores leads to increased headloss through the filters and to an increase in the pore velocity. Increases in pore velocity can cause an increase in shear forces acting on the attached particles and can cause attached particles to detach from surface of the filter media; the detached particles flow deeper into the filter bed

and may attach to filter media in a deeper layers. The process of transport, attachment and detachment is presented schematically in Figure 1.

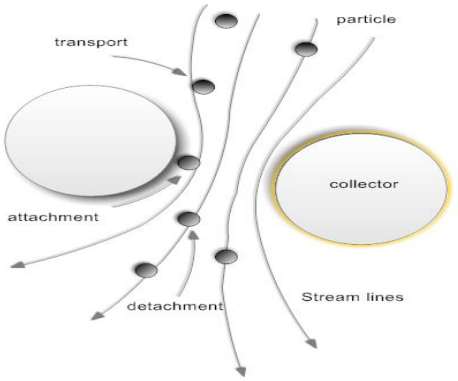


Figure 2-1: Particle attachment and detachment (Source: Jin, 2014 after Amirtharajah 1988, reproduced with permission)

Eventually, filter performance will begin to deteriorate. Detached particles and particles that do not attach to the collectors become present in significant concentrations in the filter effluent: this is referred to as particle breakthrough (or turbidity breakthrough, if turbidity measurements are used). When particle or turbidity breakthrough is reached, the filters no longer effectively remove particles. Alternatively, restriction of pores may cause headloss through the filter to increase to a point that the desired flow through the filter can no longer be maintained; this is referred to as terminal headloss. When either terminal headloss or particle/turbidity breakthrough is reached, the accumulated particles must be removed from the filters.

Accumulated particles are removed from filters through backwashing, wherein the flow through the filter is reversed and filtered water is directed upwards through the filter bed. The upward flow fluidizes the filter bed and is used to wash accumulated particles out of the filters. Fluidizing the filter bed and backwashing with water alone has been found to be a non-optimal method for removing particles from filters (Amirtharajah, 1978); therefore, additional protocols such as washing the surface of the filter with jets of water (surface wash) or by bubbling air through the filters to increase abrasion between filter media grains (air scour) have been used (Amirtharajah, 1978). Collapse pulsing, where air and water are simultaneously introduced to the filter at rates that cause air cavities to develop and then collapse, has also been shown to be particularly effective at causing abrasion between particles and removing attached particles within conventional filters (Amirtharajah, 1993). It should be noted that the attachment of microorganisms to filter media in biologically active filters is stronger than the attachment of inorganic particles such as clay (Ahmed & Amirtharajah, 1998). Therefore, the optimal backwash protocol required

for biologically active filters may differ from those used for conventional filters and longer or more vigorous backwash protocols may need to be used for biologically active filters (Ahmed & Amirtharajah, 1998).

After backwashing, normal flow of water through the filter is resumed and a period of impaired particle (or turbidity) removal called filter ripening may occur. Filter ripening, as described by Cranston and Amirtharajah (1987), is schematically represented in Figure 2.

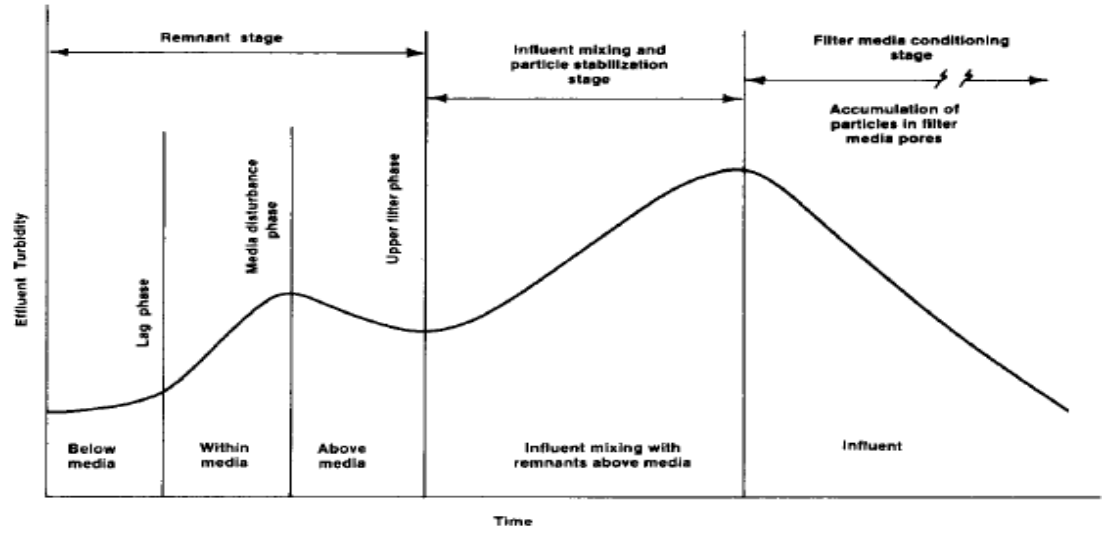


Figure 2-2: Filter ripening
(Reprinted with permission from Cranston, K.O. & Amirtharajah, A., 1987. Improving the initial effluent quality of a dual-media filter by coagulants in backwash. Journal AWWA, 79:12:50. http://www.awwa.org/publications/journal-awwa/abstract/articleid/11936.aspx. Copyright 1987, American Water Works Association.)

Figure 2-2 shows filter effluent turbidity with respect to time after a filter has been put back in service. During filter ripening, effluent turbidity may increase and peak when water and particles leftover from the backwash ("backwash remnants") flow through the filter (Amirtharajah & Wetstein, 1980; Cranston & Amirtharajah, 1987). Effluent turbidity can also peak a second time when the initial flow of influent water through the filter mixes with backwash water, reducing the effectiveness of influent coagulation ("influent mixing and particle stabilization stage") (Cranston & Amirtharajah, 1987). At the end of filter ripening ("filter media conditioning phase"), particles collect on the surface media and result in improved particle removal (Cranston & Amirtharajah, 1987).

The non-optimal removal of turbidity seen during filter ripening often can be reduced or eliminated by the use of an extended terminal subfluidization wash [ETSW] (Amburgy & Amirtharajah, 2005; Amburgy, 2005; Snider, 2011). In this process, the filter bed is washed at a subfluidization velocity until the entire volume of water present in the filter has been replaced; this procedure removes backwash remnants from the filter and can reduce turbidity peaks associated with the backwash remnants (Amburgy & Amirtharajah, 2005).

2.2.1 Particle Removal Mechanisms

As previously mentioned, physico-chemical filtration consists of the transport of particles from the bulk fluid to the surface of filter media grains; particles may then attach to the surface of the filter media grains. The primary mechanisms of particle transport to filter media grain surfaces in drinking water filters are diffusion, interception, and sedimentation (Yao et al., 1971). Interactions between particles and grain surfaces are traditionally described using the classical theory of colloidal stability developed by Derjaguin, Landau, Verwey, and Overbeek, collectively known as DLVO theory (Molnar et al., 2015). Particle attachment on filter media grains occurs via double layer compression, charge neutralization, and inter-particle bridging (Ryan & Elimelech, 1996). Several models have been developed to describe the transport and attachment of particles by these mechanisms (e.g. Yao et al., 1971; Rajagopalan & Tien, 1976; Tufenkji & Elimelech, 2004; Long & Hilpert, 2009; Nelson & Ginn, 2011; Ma et al., 2013). These models have greatly improved the understanding of particle removal in filtration.

While these mechanistic models can reasonably represent data from well controlled laboratory systems under conditions favourable for particle attachment, further research is needed to refine them (Molnar et al., 2015). Specifically, current mechanistic models do not yet fully represent (1) particle removal under unfavorable conditions for deposition (i.e. low-ionic strength), (2) the impact of media-associated chemical or physical heterogeneities on particle removal, or (3) realistic bed geometries (Molnar et al., 2015). Furthermore, classical mechanistic models incorporate a number of explicit and implicit simplifications: for example, that there are "clean bed" conditions (i.e. that the media grains are "clean" - there are no particles attached to the surface of the media grain), that previously attached particles do not impact the removal of subsequent particles, and that all media grains are the same size. In more heterogeneous, real systems, many of these simplifications are not valid. For example, in filters used for drinking water treatment, particles attach to filter media as they are removed from the water. The well-known phenomenon of filter ripening indicates that these attached particles impact the removal of subsequent particles. It also has been proposed and shown that previously removed particles can build-up on the surface of filter media and can affect the removal of subsequent particles (e.g., Darby & Lawler,

1990; Payatakes et al., 1981; Tien et al., 1977). Therefore, in drinking water filters, the assumption of "clean-bed" conditions and the assumption that previously attached particles do not impact the removal of subsequent particles are not valid. Media grain sizes also are not constant in filters used for drinking water treatment: there is a distribution of grain sizes. Furthermore, classical mechanistic models do not incorporate the impact of biofilm growth or development within the models. In drinking water biofilters, microorganisms grow on the surface of the filtration media, and it has been shown that both biofilm growth on surfaces and biofilm properties can affect the removal of particles (e.g. Shen et al., 2015; Janjaroen et al. 2013; Liu et al., 2007). Therefore, while mechanistic models are useful in describing idealized systems and generally improve the understanding of particle removal during filtration, they cannot be used to quantitatively predict particle removal in full-scale biofilters used for drinking water treatment.

2.2.2 Impact of Filter Media Roughness on Removal of Particles

The impact of surface roughness and filtration media roughness on the particle deposition[1] has been widely evaluated. Some studies have shown that increased surface roughness can improve the attachment of particles (e.g. Darbha et al., 2012; Chen et al., 2010; Darbha et al., 2010; Zan et al., 2008; Yoon et al., 2006; Vanhaecke et al., 1990), whereas others have shown the opposite effect (e.g. Chen et al., 2010[2]; Mitik-Dineva et al., 2009)[3]. Recent investigations have confirmed that the roughness of filtration media can affect particle removal and have proposed modifications to colloid filtration models to incorporate this effect (Jin et al., 2015a; 2015b). Jin et al. (2015b) showed that there is a non-linear, non-monotonic, relationship between particle size, the media roughness, the size of the media grains, and particle deposition (i.e. the removal of particles). They found that a critical level of media roughness could be identified that resulted in minimum particle removal: if the roughness of the media surface was smoother or rougher than this critical level of roughness, a greater amount of particle removal would be observed. Jin et al. (2015a) also observed the same trend in experiments using parallel plates and attributed the differences in particle deposition to changes in hydrodynamics caused by the surface roughness. This non-monotonic trend may help to explain why some studies have shown improved deposition with increased roughness, while others have seen the opposite effect.

[1] Both inert particles (e.g. microspheres) and biocolloids (i.e. bacteria) have been studied.
[2] Chen et al, 2010 conducted experiments studying particle deposition on metal and zeolite-coated surfaces with varying degrees of roughness. They observed that, in general, particle deposition increased with an increase in surface roughness. However, they observed two cases where an increase in roughness did not result in an increase in particle deposition.
[3] The interested reader is directed to Jin (2014) for a more detailed review of some of these studies and a more detailed discussion of the impact of roughness on particle removal.

Despite the recent advances in the understanding of the impact of media roughness on particle deposition, piloting is still required to determine whether media roughness would appreciably impact particle removal in drinking water biofilters at larger scales. The recent investigations by Jin et al. (2015a; 2015b), like many colloid filtration studies and studies of the impact of surface roughness on particle deposition, were conducted in a manner that represents "clean bed" conditions. As previously discussed in section 2.2.1, "clean bed conditions" are not representative of the conditions in drinking water biofilters. Furthermore, attached particles may form chains (as proposed by Tien et al., 1977) or deposits (as seen in photographs in Payatakes et al., 1981) that could change the effective surface roughness of a particle. Attached particles could also conceivably fill up "valleys" on the surface of media grains, resulting in smoother grains. Jin et al. (2015b), similar to other investigations, studied the removal of only select particle sizes, used only select media grain sizes, and used very controlled size distributions for the media. The media grain sizes used, the grain size distributions used, and particle sizes removed in drinking water filters vary to a wider degree than those studied in Jin et al. (2015a; 2015b). The roughness present on media surfaces can also vary to a wider degree than those studied in Jin et al. (2015a; 2015b), depending on the media type[4]. In biological filtration, the presence of microorganisms and biofilm on the surface of filter media may also affect the attachment of particles to media grains (e.g. Liu et al., 2007) and may change the overall roughness of the filter media (see, for example, SEMs presented in Lauderdale et al. (2012) that show a media grain with bacteria on a "crust" that was presumably formed by the bacteria and that show a media grain covered with a large variety of microorganisms. See also images in Shen et al. (2015) and Janjaroen et al. (2013) showing that biofilm can add roughness to surfaces[5]). Thus, the impact of using rough media during biofiltration cannot be predicted from current theoretical knowledge or from previous lab-scale experiments: piloting is required.

A pilot-scale investigation of the impact of filter media roughness on the removal of particles by conventional filtration was performed by Scott (2008). Rough engineered ceramic media were found to attenuate spike loadings of particles and provide higher average particle and turbidity removal than non-rough media (anthracite and sand). This improved removal was attributed to the roughness of the media. The filters used in Scott (2008) were likely not biologically active because of low-level pre-chlorination and intermittent filter operation (D. Scott, personal communication, March 4, 2016); therefore, the findings from Scott (2008) are not necessarily relevant to BAF. Furthermore, particle and turbidity

[4] For illustration of this point, compare the SEMs presented in this thesis to those presented in Jin et al. (2015a).
[5] Both of these studies show that biofilm roughness can impact the attachment of biocolloids (i.e. *E.coli* and *L. pneumophila*) and provide images of a rough biofilm that was grown on top of smooth PVC coupons.

removal provided by the rough engineered ceramic media used by Scott (2008) has not been assessed in comparison to removal provided by GAC, a filtration medium commonly used with BAF.

2.2.3 Removal of Particles by Biologically Active Filters

Goldgrabe et al. (1993) investigated particle removal by BAF. Biologically active filters provided over 2 log removal of particles, even though they provided 0.4-0.5 log lower removal of particles than non-biologically active filters. Biologically active filters with chlorinated backwash were found to require an acclimation period before providing particle removal equivalent to biologically active filters with non-chlorinated backwash.

While Goldgrabe et al. (1993) found that there was a difference in particle removal between biologically and non-biologically active filters, they did not find major differences in the turbidity removal. Good removal of turbidity by biologically active filters was observed (normally < 0.15NTU). LeChevallier et al. (1992) and Emelko et al. (2006) also found that biologically active filters were able to provide good turbidity removal[6].

2.3 Factors Affecting the Removal of Organic Matter

Several factors have been discussed in the literature that may impact the removal of organic matter by BAF. These factors include: the nature of the influent water, temperature, empty bed contact time [EBCT], presence of oxidants in the backwash, backwash protocol, surface area, and filtration media type.

2.3.1 Nature of Influent Water

The biodegradability of organic matter, the presence of oxidants, the presence or absence of particles in the influent water, and the ratio of nutrients have been suggested to impact the removal of organic matter by BAF.

2.3.1.1 Biodegradability of organic matter

If influent water contains a substantial fraction of easily biodegradable organic matter, it is possible for BAF to remove a substantial fraction of influent organic matter through biodegradation. The

[6] LeChevallier et al. (1992) found that biofilters were able to remove turbidity to <0.5 NTU, the regulatory limit for turbidity at that time. Emelko et al. (2006) found that individual biologically active filters maintained average filter effluent turbidities below 0.1 NTU, despite "brief turbidity peaks up to ≤ 0.2 NTU" (Emelko et al., 2006, p 70), and that combined effluent turbidity from four filters was always below 0.1 NTU. For reference, a turbidity of <0.3 NTU is required in 95% of turbidity measurements taken each month in order to get credit for *Cryptosporidium* removal (MOE, 2010).

biodegradability of organic matter in influent water depends on the composition of organic matter in that water and, thus, is site-specific. The fraction of organic matter that is biodegradable can be increased through ozonation of the influent water, with the fraction of organic matter generally increasing as the ozone dose increases (Rittmann & Huck, 1989; Price et al., 1993; Weinberg et al., 1993; LeChevallier et al., 1992, Carlson & Amy, 1997); however, past an optimal ozone dose, the fraction of biodegradable organic matter can plateau and increases in ozone dose will result in little to no increase in the fraction of biodegradable organic matter (e.g. Carlson & Amy, 1997).

2.3.1.2 Presence of Oxidants

The presence of oxidants, particularly chlorine, in the influent water may affect biofiltration by impairing microbial growth in the biofilters and thus impairing the removal of organic matter (Weinberg et al., 1993). However, this effect can be influenced by the type of media used in the biofilters. Weinberg et al. (1993), in a survey of the removal of aldehydes by several water treatment plants, saw that there was little to no removal of aldehydes in plants using prechlorinated anthracite-sand filters. LeChevallier et al. (1992), however, saw that biologically active GAC-sand filters could provide removal of AOC when the filter influent was either chlorinated or chloraminated, and they indicated that "free chlorine residuals were rapidly neutralized within the GAC filters and biological processes proceeded unimpaired" (p 142). Suidan et al. (1977) also indicated that GAC can dechlorinate water and present mathematical models to represent dechlorination by GAC. Therefore, it is possible to still have bacterial activity when chlorine is present in GAC biofilters.

Interestingly, hydrogen peroxide concentrations in the range of 0.1 to 1 mg/L have been shown to have little to no deleterious effect on the removal of organic matter. Hydrogen peroxide has recently been investigated as an amendment to biofilter influent water to help control headloss by minimizing EPS levels (Lauderdale et al., 2015; Azzeh et al., 2015). Lauderdale (2012) found that the addition of 1 mg/L of hydrogen peroxide to a biofilter influent for 10 days did not negatively affect DOC or MIB removal. Urfer and Huck (1997) found that the addition of hydrogen peroxide at 1 mg/L into a lab-scale anthracite biofilter influent did not inhibit the removal of acetate. They also found that the addition of hydrogen peroxide at 1 mg/L inhibited the removal of formate by the same biofilter during the first 2-3 months of operation but after this initial period formate removal was not inhibited. Azzeh et al. (2015) found that addition of 0.1 and 0.5 mg/L hydrogen peroxide did not affect the removal of DBP precursors; however, at a concentration of 1 mg/L, the addition of peroxide did reduce biopolymer, trihalomethane precursor, haloacetic acid precursor, and absorbable organic halogen precursor removals by between 2-12%. The addition of hydrogen peroxide at low levels may allow headloss in biofilters to be controlled without

impairing the removal of organic matter (e.g. Lauderdale et al., 2012). Given that there was minimal impact on organic matter removal with the addition of 1 mg/L hydrogen peroxide observed by Lauderdale et al. (2012) and Urfer and Huck (1997) but that some impairment of organic matter removal was observed by Azzeh et al. (2015), the maximum level of hydrogen peroxide that can be added to a biofilter without impacting the removal of organic matter is likely site specific and should be determined by piloting prior to implementation at full scale.

2.3.1.3 Particles and Coagulant

The impact of the presence or absence of particles and coagulant in the influent water on the removal of organic matter by biofiltration has been investigated and may impact the removal of select organic compounds. Liu et al. (2001) reported that the presence or absence of coagulant and particles in the influent water was not a significant factor affecting the pseudo-steady state removal of several compounds by biofiltration, except for glyoxal. Liu et al. (2001) propose that, while the effects of particles and coagulants did not significantly affect the removal of most compounds in their study, the effect of particles and coagulants "might become important if particle or coagulant concentrations were measurably higher" (Liu et al., 2001, p. 98).

2.3.1.4 Nutrients and Nutrient Ratios

Nitrogen and phosphorous are required for microbial growth. The concentration of nutrients present in the influent water, therefore, can affect microbial growth and, thereby impact the biological removal of organic matter during biofiltration.

Phosphorous limitation of microbial growth has been observed in waters present in drinking water plants. Nishijima et al. (1997) showed that coagulation and sedimentation of raw water removed phosphorous; this removal resulted in low phosphorous concentrations and limited both biological growth and DOC removal in bench-scale reactor experiments. Lehtola et al (2001) found that heterotrophic growth in water from several treatment plants, pre- and post-ozonation, was limited by the phosphorous concentration. Others have also found that the growth of microorganisms in raw, processed, and finished waters was limited by the concentration of phosphorus (e.g., Polanska et al, 2005; Lehtola et al., 2002; Miettinen et al., 1997; Yu et al., 2003; Sathasivan et al., 1997).

The ratio of C:N:P may also impact biofilter performance. It has been implied that molar C:N:P ratios equal to or greater than 100:10:1 may be required for optimal microbial growth and biofilter performance (e.g. LeChevallier et al., 1991, Lauderdale et al., 2012).This ratio of 100:10:1 has been cited often in recent discussions and literature; however, other ratios have been developed, the basis for this specific

ratio is unclear, and data suggest that this ratio may not be universally "optimal for biological filtration performance enhancement" (Wong, 2015, p 99)[7]. For example, Pharand et al. (2015) saw no correlation between C:P ratios on AOC or DOC removal in a full scale biofilter, even when the C:P ratios were <100:1, and Azzeh et al. (2015) observed a 25% decrease in biopolymer removal when a C:N:P ratio of 100:40:2 was used.

Improved biofilter performance has been observed with the addition of nutrients, especially phosphorous, to biofilter influent water. Improvements in organic matter removal (Lauderdale et al., 2012; Sang et al., 2003; Granger et al., 2014; Yu et al., 2003), headloss (Lauderdale et al., 2012; Wong, 2015), filter run time (Wong, 2015), biological growth (Lauderdale et al., 2015), and manganese removal (Lauderdale et al., 2012; Granger et al., 2014) have been observed. However, increases in organic matter removal have not been seen in all cases: slight improvements that diminish over time (Rahman et al., 2016), no improvement in DOC removal (Azzeh et al., 2015; Vahala et al., 1998; Wong, 2015), and a decrease in in biopolymer removal have also been observed. Furthermore, with the exception of Lauderdale et al. (2012), improvements in headloss, filter run time, biological growth, and/or manganese removal were only observed for select filter configurations or operating conditions[8]. Overall, the benefits of adding nutrients into biofilter influents and exact nutrient the C:N:P ratio required for optimum DOC removal are likely site specific. Further research is needed to fully understand the impact of C:N:P ratios and nutrient addition on the removal of organic matter by biofiltration.

2.3.2 Temperature

Temperature can affect the pseudo-steady state removal of organic matter by BAF (e.g. Servais et al., 1992; Moll et al., 1999; Liu et al., 2001; Emelko et al., 2006; Pharand et al., 2015; Hallé et al., 2015). The removal of biodegradable organic matter generally increases as temperature increases from cold water conditions (e.g. 1-8ºC) to warmer water conditions (e.g. 20-35ºC); particularly clear examples of this are presented by Moll et al. (1999), who showed greater removal of NOM in bench-scale biofilters operated at 20 and 35 ºC than in a biofilter operated at 5ºC, and Pharand et al. (2015), who showed a positive

[7] Interested readers are directed to Wong (2015, pp. 20-26) for a critical review of nutrient ratios. Wong (2015, pp. 95-101) also presents an analysis of consumed C:N:P ratios calculated from his own data and from the data presented in Lauderdale et al. (2012); the analysis showed that the ratio of C:N:P that was consumed in biofilters differed from 100:10:1.

[8] Granger et al. (2014) saw an improvement in manganese removal with nutrient enhancement at an influent water pH of 6 but not at a pH of 9-11. Wong (2015) saw an improvement in run time for GAC filters capped with an expanded clay [EC] media that had an influent C:N:P ratio of 100:10:1 and 100:10:2 at water temperatures ≥15°C; however, no improvement was observed for filters containing only GAC nor for other water temperatures. Wong (2015) also saw an improvement in the rate of headloss development in the EC capped filters when the influent C:N:P ratios were 100:10:2 and water temperatures were ≥15°C; however, again, no improvement was observed for filters containing GAC, for other water temperatures, nor for a C:N:P ratio of 100:10:1.

correlation between temperature and the removal of DOC, biopolymers, low-molecular-weight-humics/ low-molecular-weight-acids, and AOC in full scale biofilters. However, other factors may also impact the effect of temperature on organic matter removal. For example, Liu et al. (2001) observed that biodegradable organic matter removal was higher at higher temperatures in most cases, but the effect of temperature on biodegradable organic matter removal was also affected by media type and the presence of chlorine in the backwash water; the biodegradable organic matter removal was impaired the most in anthracite filters operated at cold water temperatures, with chlorine in the backwash water. They also noted that "The temperature effect was not as significant as might have been expected for easily biodegradable compounds because measurable BOM [biodegradable organic matter] removal occurred throughout the entire filter at lower temperatures, whereas it occurred only in the top layers of the filter at higher temperatures" (Liu et al., 2001, p. 97). Emelko et al. (2006), in a study of the removal of carboxylic acids and TOC in full scale biofilters, saw that the removal of oxalate by full scale anthracite and GAC biofilters was lower during cold water conditions than during warm water conditions; however, they also noted that the TOC removal was not statistically different during cold and warm water conditions. Pharand et al. (2015), though showing a correlation between temperature and the removal of certain types of organic matter, did not observe a statistically significant difference in the removal of other types of organic matter between temperatures >10°C and temperatures ≤10°C[9]. Therefore, the effect of temperature on organic matter removal can depend on several factors, including the media type used in the biofilter, the presence of chlorine in the backwash water, the depth of the bed utilized for BOM removal, and the organic compound(s) being removed.

2.3.3 Empty Bed Contact Time

Empty bed contact time [EBCT] is the amount of time it would take water to flow through an empty filter of the same depth as the filter bed and is calculated as the ratio of the media depth in a filter to the hydraulic loading rate. EBCT can affect the removal of organic matter by biofiltration (e.g., Servais et al., 1992; Merlet et al., 1992; LeChevallier et al., 1992; Krasner et al., 1993; Wang & Summers, 1996; Hallé et al., 2015). The length of time it takes for a biologically active filter to initially acclimate (i.e. provide relatively stable organic matter removal) can also be affected by EBCT, with shorter acclimation times observed for a given level of organic matter removal at higher EBCTs (e.g., Krasner et al., 1993). The magnitude of organic matter removal at a given EBCT and the sensitivity of removal to EBCT depend on the specific type of organic matter being removed; for example, Wang and Summers (1996) found that

[9] Specifically, there was no statistically significant difference (at a significance level of 0.05) between the removal of humics, "building blocks", and low-molecular-weight-neutral compounds at temperatures >10°C and temperatures ≤10°C.

the concentration of glyoxylic acid decreased by greater than 90% within an EBCT of 3 minutes but that the concentration of DOC only decreased by 16% within the same EBCT. In general, the removal of biodegradable organic matter increases as the EBCT increases (e.g. Servais et al., 1992; Merlet et al., 1992; LeChevallier et al., 1992; Krasner et al., 1993; Wang & Summers, 1996; Carlson & Amy, 1998; Seredyńska-Sobecka et al., 2006; Hallé et al, 2015); however, as the EBCT increases, the rate of increase in the removal of organic matter decreases (Merlet et al., 1992; Wang & Summers, 1996; Carlson & Amy, 1998). This indicates that there are diminishing benefits to increasing EBCT when increasing EBCT past a certain point and "EBCTs above a certain value may not be economically justifiable" (Urfer et al., 1997, p. 93).

2.3.4 Backwash

Backwashing is a procedure where water flow through a filter is reversed in order to clean the filter and wash out excess particles from the filter. Backwash protocols consist of a variety of factors, including the use and type of oxidants in the backwash water, presence of air scour, use of collapse pulsing, and use of extended terminal subfluidization wash (Amirtharajah, 1978; Amirtharajah, 1993; Amburgy & Amirtharajah, 2005; Snider, 2011)

2.3.4.1 Presence of Chlorine:

The presence of chlorine in the backwash water can have detrimental effects on the removal of organic matter (e.g., Miltner et al., 1995; Liu et al., 2001; Snider, 2011). The effect of the presence of chlorine in backwash water on the removal of organic matter, however, and the magnitude of this effect may be dependent on the duration of the backwash, concentration of the chlorine, water temperature, media type, and other backwash factors (Urfer et al., 1997; Liu et al., 2001; Snider. 2011).

Liu et al. (2001) found that chlorine in the backwash water affected the pseudo-steady-state removal of biodegradable organic matter by an anthracite filter at cold water temperatures but did not affect the pseudo-steady-state removal of biodegradable organic matter by a GAC filter at the same temperatures. Liu et al. (2001) also found that the removal of biodegradable organic matter by either filter was not affected by chlorine in the backwash water at warm water conditions.

Snider (2011) conducted three sets of factorial experiments examining the impact of media characteristics and backwash protocol on biofilter performance under winter (cold water) conditions. Backwash factors studied included the presence of chlorine, use of collapse pulsing in the backwash, the use of extended terminal subfluidization [ETSW] backwash, and length of time since the filter was backwashed. Each of the three sets of experiments examined the impact of one of three media characteristics (media type,

effective size, or uniformity coefficient), the impact of all of the backwash factors, and all possible interactions on the removal of DOC and BDOC. The presence of chorine was found to be a significant main factor that affected the removal of DOC in two of the three sets of experiments (effect of media type and effect of uniformity coefficient). Depending on the media characteristic under examination, statistically significant interactions were found between the presence of chlorine and other backwash-related factors. The statistically significant interactions with chlorine, the response variables that were affected by these interactions, and the number of experiments (out of three) for which the interactions were found to be significant are summarized in Appendix B.

Snider (2011) concluded that the presence of chlorine in backwash water negatively impacts the removal of both DOC and BDOC. Snider also concluded that the combination of chlorine in the backwash water and collapse pulsing backwash are particularly detrimental to the removal of organic matter.

2.3.4.2 Air Scour and Collapse Pulsing

The presence of air scour may affect the removal of organic matter by BAF under very select operating conditions. For example, Emelko et al. (2006) found that the presence of air scour resulted in higher levels of oxalate removal by biologically active filters containing GAC during cold water conditions (1-3°C); however, they also found that the presence of air scour did not affect the removal of TOC by biologically active filters containing GAC or anthracite as the filtration media. Liu et al. (2001) found that found that air scour impacted the removal of acetate and formaldehyde by biologically active filters containing anthracite when operated at 5ºC and the filters were backwashed with chloramine; however, air scour did not impact acetate and formaldehyde removal when chlorine was present in the backwash nor when higher operating temperatures were used. The impact of air scour on organic matter removal, therefore, may depend on the filtration media type, temperature, and the compound being removed.

The impact of using a collapse pulsing backwash on organic matter removal is also varied and may depend on other factors. Emelko et al. (2006) found that collapse pulsing had no effect on the removal of carboxylic acids or TOC by BAF, and Ahmad et al. (1998) found that differences in effluent nonpurgable organic carbon (NPOC) and AOC concentrations were not statistically different when collapse pulsing was used. Snider (2011), in contrast, found that a collapse pulse backwash decreased DOC and BDOC removal, particularly in anthracite filters, and that the use of collapse pulsing interacted with other backwash factors (see Appendix B for a list of all significant factors). Two particularly important interactions with collapse pulsing backwash were the interaction between the presence of chlorine and collapse pulsing backwash and the interaction between ETSW and collapse pulsing backwash. The presence of chorine in the backwash water during a collapse pulsing backwash was detrimental to organic

matter removal, whereas the use of ETSW mitigated some of the negative impacts caused by using a collapse pulsing backwash (Snider, 2011). Therefore, based on these results, if a collapse pulsing backwash is used with BAF, chlorine in the backwash water should be avoided and the use of ETSW should be considered to ensure that the removal of organic matter is not impaired by the backwash protocol. Further research into the impacts of collapse pulsing on organic matter removal and the mechanisms responsible for these impacts would be helpful for developing clearer guidance on the use of collapse pulsing with biologically active filters.

2.3.4.3 Extended Terminal Subfluidization Wash

The effect of extended terminal subfluidization wash (ETSW) on the removal of DOC and BDOC by biofiltration was investigated by Snider (2011). ETSW was found to be a significant main factor that affected the removal of DOC in one experiment and the use of ETSW was also found to interact with other backwash factors to affect the removal of DOC and BDOC (See Appendix B for a list of interactions). Snider (2011) concluded that the use of ETSW improved the removal of organic matter by biofiltration and may be able to mitigate the decreased removal caused by use of a collapsed pulse backwash. The reason why ETSW improved the removal of organic matter is unknown, but has been hypothesized to potentially "distribute detached bacteria throughout the filter bed, and improve their re-attachment efficiency through extended contact time with the media" (Snider, 2011, p 106).

2.3.5 Filtration Media Type

The impact of media type on the removal of organic matter by BAF has been extensively investigated (e.g. LeChevallier et al., 1992; Krasner et al., 1993; Wang et al., 1995; Huck et al., 2000; Melin & Ødegaard, 2000; Liu et al., 2001; Chaiket et al., 2002; Najm et al., 2005; Emelko et al., 2006; Persson et al., 2007; Wang et al., 2007; Chien et al., 2008; Snider, 2011; Azzeh et al., 2015). Table 2-1 summarizes findings and information that can be drawn from several of these studies.

It can be seen that GAC can sometimes provide better removal of organic matter than anthracite, particularly under conditions that are not ideal for biological removal of organic matter: low temperatures, chlorine present in backwash water, collapse pulsing backwash, and removal of compounds that are not easily biodegraded (e.g., Chien et al., 2008; Emelko et al., 2006; Liu et al., 2001; Wang et al., 1995; Snider, 2011). BAF by GAC is generally understood to provide equivalent or better removal of organic matter than anthracite; however improved removal of organics seems to depend on a variety of factors (i.e. temperature, presence of chlorine in the backwash, and type of organic matter being removed).

Table 2-1: Investigations of the Effect of Filtration Media Type on the Removal of Organic Matter by Biologically Active Filtration

Reference	Media Being Compared	Notes
Chaiket et al. (2002)	anthracite and GAC[2]	The removal of TOC, BDOC, and disinfection by-product formation potential (THMFP & haloacetic acid formation potential) was not affected by media type; data were not presented to illustrate this.
Chien et al. (2008)	anthracite and GAC	GAC provided better removal of AOC than anthracite. The configuration of the anthracite and GAC filters were different. The effective sizes of the two media types were different.
Emelko et al. (2006)	anthracite and GAC[2]	There was no difference in the removal of oxalate or TOC between GAC and anthracite at warm water conditions (21-25°C), but "GAC provided substantially better removal of oxalate and TOC than anthracite" at cold water conditions (1-3°C).
Liu et al. (2001)	anthracite and GAC[2]	Removal of organic matter was impaired in anthracite filters when the filters were operated with both low temperatures (5°C) and with chlorine in the backwash water. The same operating conditions "had only a minor effect on GAC filters." GAC filters provided greater removal of glyoxal (a "less readily biodegradable" compound) than anthracite filters.
Wang et al. (1995)	sand, anthracite, bituminous coal-based GAC[1], lignite coal-based GAC[1], and wood-based GAC[1]	Sand provided better removal of TOC than anthracite. Bituminous and lignite coal-based GAC provided better removal of TOC, THMFP, and total halide formation potential [TOXFP] than anthracite and sand. Wood-based GAC did not provide statistically different removal of TOC, THMFP, or TOXFP when compared to anthracite. Wood-based GAC did not provide statistically different removal of TOC than the sand filter.
Snider (2011)	GAC[2] and anthracite	GAC provided better removal of BDOC and DOC than anthracite, at pilot scale. The improved removal of organic matter by GAC at pilot scale was particularly evident when the filters were backwashed using collapsed pulsing and/or chlorine was present in the backwash. GAC removed more BDOC than anthracite at full scale; however, no differences were seen in the removal of THMFP and chlorine demand (Note: THMFP and chlorine demand were not measured for pilot scale; DOC results not reported for full scale)
Wang et al. (2007)	GAC and sand	GAC initially provided better removal of microcystin-LR and microcystin-LA than sand; however, after 211 days of operation, both the sand and GAC provided complete removal of both types of microcystin

1. GAC had been in use for at least 5 months before first organic matter measurements were taken.
2. GAC had been in use for at least 1.5 years before first organic matter measurements were taken.

Detailed and conclusive explanations of why GAC provides greater long-term removal of organic matter than anthracite under some conditions and not in others have not been presented. Determining why or when GAC may provide better removal of organic matter than anthracite is particularly difficult because of the lack of understanding of why differences in removal are seen. The contradictory results seen between studies (e.g. Chaiket et al., 2002 vs. Wang et al., 1995) and the potential dependence on operating conditions makes answering the question "when should a utility go to the expense of installing GAC instead of anthracite for BAF" challenging.

While there are several factors that may affect the results of a given study, one major limitation that confounds most comparisons of filter media type that have been conducted is that the media grain sizes

were not the same. Table 2-2 presents the effective sizes used in the studies summarized in Table 2-1 to illustrate this point.

Table 2-2: Effective Sizes of Filtration Media used in Select Studies that Compare Different Types of Filtration Media

Reference	Media Being Compared	Effective Size of Media (mm)
Chaiket et al. (2002)	Anthracite	1.1
	Exhausted GAC	1.1
Chien et al. (2008)	Anthracite	0.5-0.6
	GAC	1-1.2
Emelko et al. (2006)	Anthracite	Not Reported
	GAC	Not Reported
Liu et al. (2001)	Anthracite	1.1
	GAC	0.9
Wang et al. (1995)	Sand	0.44
	Anthracite	1.02
	Bituminous coal-based GAC	0.64
	Lignite coal-based GAC	0.68
	Wood-based GAC	1.52
Snider (2011)	GAC	1.46 (pilot scale); 1.45[2] (full scale)
	Anthracite	1.3 (pilot and full scale)
Wang et al. (2007)	GAC	1.0-1.4[1]
	Sand	1.0-1.4[1]

1. Both media types were sieved through a sieve with 1.0 mm openings and retained on a sieve with 1.4 mm openings.
2. The effective size was noted as being 1.3 in the original work; however, the actual effective size was 1.45. (Personal Communication, R. Snider, March 16, 2016).

Differences in media size may result in different amounts of surface area available for biological growth; thus, it cannot be concluded whether observed differences in organic matter removal were due to differences in the media type or due to differences in media size. Furthermore, an effective size is not an absolute measure of the size of all of the particles contained in the filtration medium: the effective size is a value taken from a measured distribution of particle sizes called a grain size distribution. Even in cases where the effective size is the same, there can be differences in the surface area present in the filter if the grain size distributions are different. Chaiket et al. (2002), for example, report that anthracite and GAC used both had effective sizes of 1.1 mm; however, no other information on the grain size distribution was presented[10], and it is unknown whether the grain size distribution or surface-area-present-in-the-filter was the same for both media types[11]. Conclusions in the current literature drawn from comparisons of the

[10] Neither grain size distribution data nor uniformity coefficients were reported.
[11] It is unlikely that the grain size distributions and/or uniformity coefficients of the different media types would be the same unless material with the same grain size distributions had been produced or purchased specifically for this study; had this been the case, it would have been expected that this would have been reported.

removal of organic matter by GAC and anthracite, or from comparisons of GAC created from different materials, therefore, may have been affected by the difference in media size or grain size distribution.

Of the studies reported in Table 2-2, the only study where media size and distribution may have been the same was Wang et al. (2007); however, the comparative response of the GAC and sand biofilters (specifically for the removal of microcystin-LR and microcystin-LA) is likely not representative of what would be seen in full scale biofilters that are operated for an extended of time. Furthermore, even though both media types were passed through and retained on the same sieves, the effective sizes may not have been precisely matched.

In Wang et al. (2007), one small GAC biofilter, one small sand biofilter, and one sterile[12] GAC column were fed water containing DOC, microcystin-LR, and microcystin-LA[13]. The two biofilters and the adsorber column all had the same configuration (15 cm of media in a glass column with a 2.5 cm inner diameter). The removal of microcystin through the biofilters and adsorber column was monitored for approximately 225 days. Initially, the GAC biofilter provided better removal of microcystin than the sand biofilter: the GAC biofilter provided complete removal of microcystin whereas the sand biofilter only removed between 0-40% of microcystin-LR and 0-20% of microcystin-LA. However, in the last few days of the study period, the sand biofilter began to provide complete removal of the microcystin: i.e. provided the same performance as the GAC biofilter. The change in microcystin removal indicates that the biomass in the sand biofilters may not have been fully established during the majority of the study period. The sterile GAC filter was also still removing microcystin (approximately 60-90% of microcystin-LR and 30-65% of microcystin-LA), indicating that the adsorptive capacity of the GAC for microcystin was not close to exhaustion[14]. Full scale biofilters can be operated for years; in a full scale biofilter that has been operating for a substantial period of time, the biomass would be well established and the GAC would likely be close to exhaustion[15]. A comparison of the organic matter removal between sand and GAC from Wang et al. (2007) is likely not representative of the long-term removal of organic matter provided by full-scale biofilters given (1) the somewhat short duration of this study compared to the life of a full scale biofilter, (2) that the biomass may not have been fully established, and (3) that there was still adsorption capacity for the main compounds being studied.

[12] Sterility of the GAC column contained autoclaved GAC. Sterility was maintained throughout the 225 days of experiments by autoclaving the "GAC, associated experimental apparatus and influent water" weekly (Wang et al., 2007, p 4263). Sterility was monitored using heterotrophic plate counts on R2A agar of the effluent from the sterile column. The heterotrophic plate counts showed no biological growth (Wang et al., 2007).
[13] All three compounds were fed to all three columns.
[14] The adsorptive capacity for DOC had been exhausted by the end of the study period.
[15] Barring the action of mechanisms such as bioregeneration (see the section on bioregeneration).

The degree to which media sizes can be matched is limited by the equipment available for sieving and characterizing media sizes. Media size and distribution are normally characterized by sieving media though a series of sieves. ASTM Standard E11 is a standard commonly applied to sieves and sieve cloths that are used for sieving and characterizing media. Inspection of ASTM Standard E11-04 (2004)[16] for sieve cloth indicates that there is a standard sieve with an opening between 1.0 and 1.4 mm: a sieve cloth with a 1.18 mm opening. Had the authors verified that both media types had a similar mass of media in the 1.4-1.18 mm and 1.18 mm-1.0 mm size ranges, it could be concluded that the effective size of the media and grain size distribution of the media were the same (at least as closely as possible with current sieves and standard sieving practices); however, since they used 1.0 and 1.4 mm sieves, it is unknown how closely the media sizes match between these two sieve sizes.

Therefore, despite the findings reported in Wang et al. (2007), there still does not seem to have been a comparison of different media types conducted where the media grain size distributions were precisely matched and where the results would be representative of the long-term operation of a drinking water biofilter. It is unknown whether the sometimes-observed differences in performance between filters containing different media types have been due to the difference in media type or the difference in media size/distribution.

2.4 Organic Matter Removal Mechanisms Associated with Filter Media Type

GAC can adsorb many types of organic matter, including that which is present in natural waters used as a source for drinking water. When fresh GAC is first installed into a biofilter, adsorption of organic matter occurs. During this initial period, the removal of organic matter by a biofilter containing GAC will be greater than that provided by a biofilter containing a nonadsorptive media (i.e. anthracite) because of the additional removal of organic matter due to adsorption. Over time, however, the adsorptive capacity of the GAC will be slowly exhausted. In the absence of mechanisms which maintain the adsorptive capacity of the GAC, the adsorptive capacity of the GAC will eventually be exhausted and the GAC will no longer adsorb organic matter. Once exhausted, and in the absence of other mechanisms that improve the biological removal of organic matter, biofilters containing GAC would be expected to provide the same removal of organic matter as biofilters containing nonadsorptive media (i.e. anthracite).

There are several mechanisms that may account for the difference in organic matter removal observed during biofiltration using GAC and nonadsorptive media (i.e. anthracite), over the long-term. These

[16] This is the version of ASTM E-11 that would have been current when Wang et al. (2007) conducted their research. At the time of writing this thesis, ASTM E11-15 (2015) is the current version of this standard.

mechanisms include bioregeneration of the adsorptive capacity of GAC by microorganisms (AWWA, 1981); mechanisms related to the surface roughness of media (Dussert & Tramposch, 1997; Emelko et al., 2006); enhanced microbial attachment due to GAC surface chemistry (Dussert & Tramposch, 1997); and "chemical reduction of oxidants/disinfectants" by GAC (Dussert & Tramposch, 1997). An additional mechanism which may result in removal of organic matter by GAC biofilters, that is not extensively discussed in the biofiltration literature, is the adsorption of organic matter due to changes in the concentration and composition of organic matter present in the biofilter influent. Adsorption of inhibitory substances by GAC resulting in improved biological removal (e.g. Choi et al., 2008), extension of the degradation time for slowly biodegradable substance through adsorption onto GAC (Çeçen & Aktaş, 2011), and concentration of substrates on the surface of GAC (Çeçen & Aktaş, 2011) may also result in biofilters containing GAC providing better removal of organics. All of these mechanisms are related to the properties of the filtration medium. Bioregeneration, adsorption of organic matter due to changes in the concentration and composition of organic matter, adsorption of inhibitory substances, extension of the degradation time of slowly biodegradable substances through adsorption onto the GAC, and concentration of substrates on the surface are associated with the adsorptive property of GAC. Mechanisms related to the surface roughness of the media are associated with the overall media roughness: for example, the number and size of asperities on the media surface and/or the size and distribution of crevices and pores in the media grain. Bioregeneration, mechanisms related to the surface roughness of the media, and the adsorption of organic matter due to changes in the concentration and composition of organic matter are discussed in further detail in the following sections. A brief discussion of the removal of organic matter by biofilms is also presented, in order to facilitate the discussion of the hypothesized mechanisms.

2.4.1 Removal of Organic Matter by Biofilms

The long-term removal of organic matter by biofiltration is due to the biological removal of organic matter. The removal of organic matter is effected by heterotrophic bacteria, which typically oxidize organic matter under aerobic conditions (Rittmann & Huck, 1989). These bacteria are attached to the filter media, forming a biofilm (Rittmann & Huck, 1989).

Conceptual and mathematical models of biofilm kinetics can be found in Rittmann and McCarty (2001), and similar conceptual models have been used as the basis for other mathematical models (e.g. Speitel et al., 1987; Chang & Rittmann, 1987a; Zhang & Huck, 1996). Figure 2-3 shows a schematic, based on these models, of the substrate concentration profile through a deep and a shallow biofilm on a particle that has an adsorptive capacity (e.g. a GAC particle).

The degradation of substrate[17] by organisms in the biofilm creates a concentration gradient that causes organic matter in the bulk fluid to diffuse to the surface of the biofilm and then into the biofilm itself. As organic matter diffuses through the biofilm, it is transported to the microorganisms in the biofilm, which utilize the organic matter as an electron donor and a carbon source. The microorganisms in the biofilm use the energy for cell maintenance and growth. The growth of biofilm is offset by endogenous decay and loss of biomass through shearing or sloughing. When the growth of a biofilm is equal to the decay, the biofilm is considered to be at steady state.

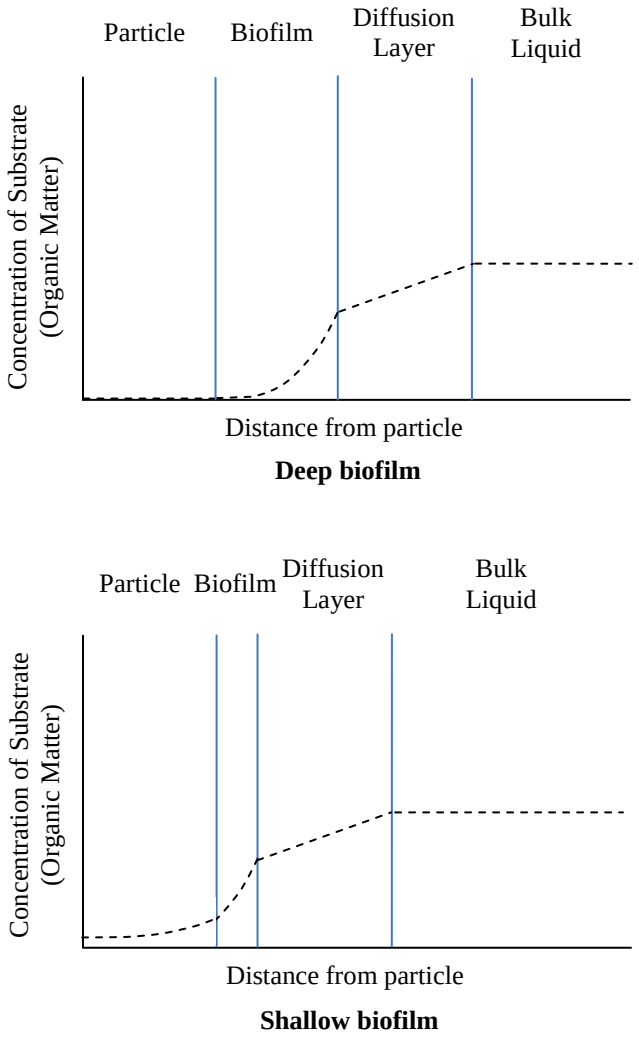


Figure 2-3: Conceptual schematic of the substrate concentration profile through a deep and a shallow biofilm for a particle with an adsorptive capacity

[17] for the drinking water biofilters discussed in this thesis, the substrate is organic carbon

Due to biodegradation and mass transfer resistance, the concentration of organic matter in the biofilm can either approach zero before the biofilm-particle interface or can be greater than zero at the biofilm-particle interface. When the organic matter "concentration and the concentration gradient approaches zero" (Rittmann & McCarty, 1978, p 891), the biofilm is referred to as a "deep biofilm" (Rittmann & McCarty, 1978). When the organic matter concentration is greater than zero, the biofilm is referred to as a "shallow biofilm" (Rittmann & McCarty, 1978). Whether or not a biofilm is deep or shallow depends on the density of the active biomass, the depth of the biofilm, the mass transfer resistance in the biofilm, and the rate of substrate utilization (Rittmann & McCarty, 2001). The depth and structure of the biofilm may affect whether and to what extent a mechanism causes improved removal of organic matter. Mechanisms which may cause improved removal of organic matter by GAC and the relationship between these mechanisms and the biofilm (or microorganisms that create and sustain the biofilm) are discussed in the following sections.

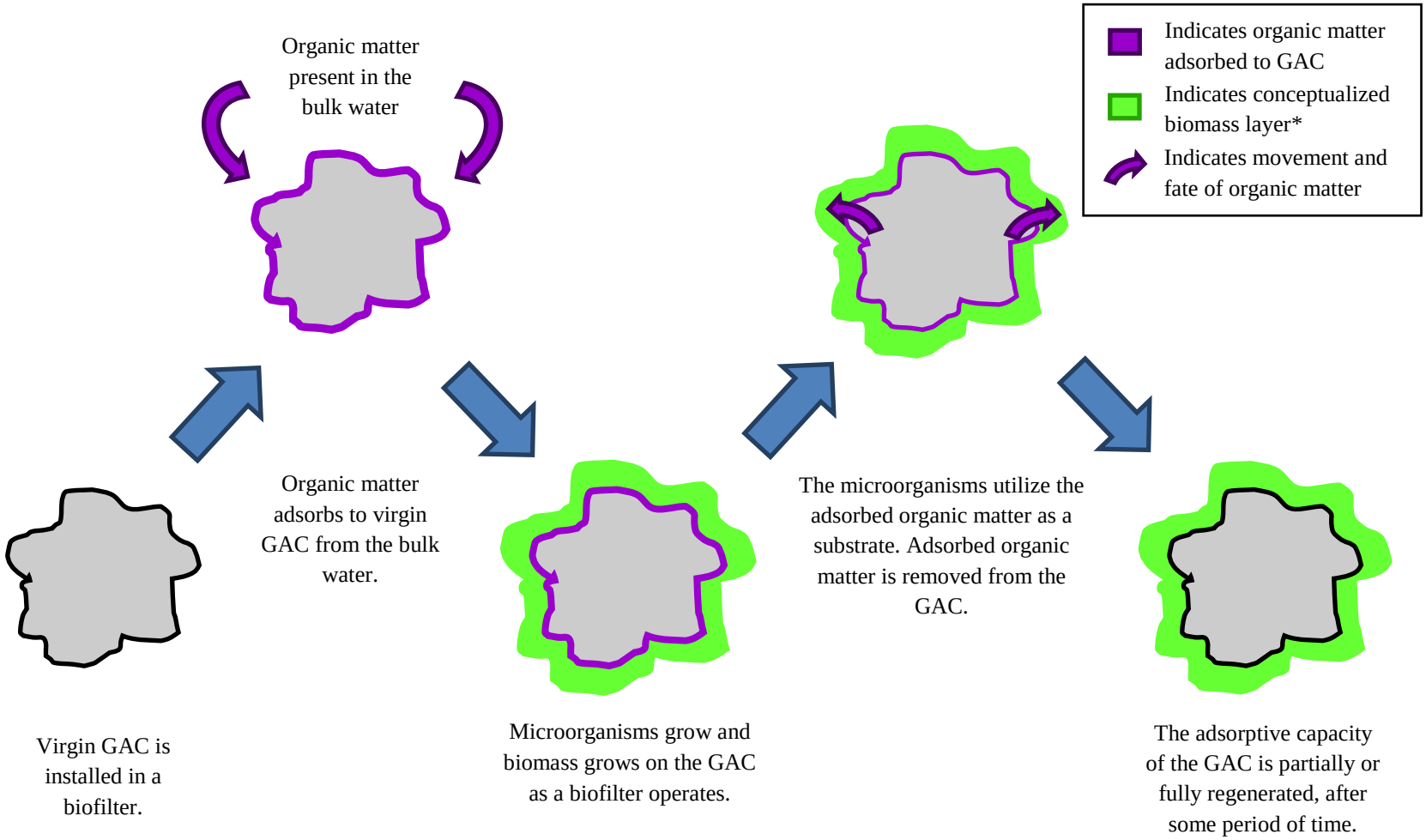
2.4.2 Bioregeneration of GAC

Regeneration of GAC is where compounds adsorbed to GAC are removed and a portion of the previously exhausted adsorptive capacity of the GAC is, again, made available for the adsorption of compounds. Bioregeneration is where regeneration is effected by the action of microorganisms that are attached to GAC particles (Aktaş & Çeçen, 2007). The process of bioregeneration is conceptually illustrated in Figure 2-4 (next page).

Bioregeneration can occur either in systems specifically designed to regenerate the carbon ex-situ (e.g. Klimenko et al., 2004; Silva et al., 2004) or can occur in-situ, in columns containing GAC (e.g. Lin & Leu, 2008; Putz et al., 2005; Speitel et al., 1989b; Speitel et al.,1989a; Speitel & DiGiano, 1987; Chudyk & Snoeyink, 1984). Studies have looked at in-situ bioregeneration where the system receives influent water and bioregeneration occurs simultaneously with biodegradation of compounds in the influent water (e.g. Putz et al., 2005; Speitel et al., 1989b; Speitel et al., 1989a; Speitel & DiGiano, 1987; Chudyk & Snoeyink, 1984); these systems are the most analogous to biofilters used for drinking water treatment.

Bioregeneration has been well studied[18] and bioregeneration of the adsorptive capacity of various types of GAC for different model compounds has been demonstrated (e.g. Speitel & DiGiano, 1987; Chang & Rittmann, 1987b; Aktaş & Çeçen, 2007; Lin & Leu, 2008). Aktaş and Çeçen (2007) present a review, in which the types of GAC that have been used, model compounds, and the extent of bioregeneration observed by several studies conducted from 1984 to 2006 are presented. Types of GAC that have been

[18] Readers who are interested in more information on bioregeneration are referred to the excellent book *Activated Carbon for Water and Wastewater Treatment* by Çeçen and Aktaş (2011).



*This is a general conceptualization. It is recognized that biomass can be patchy in drinking water biofilters.

Figure 2-4: Conceptual representation of bioregeneration

studied include bituminous coal based GAC, lignite coal-based GAC, and, in a more recent study, cornstalk lignin based GAC (Sun et al., 2010). Model compounds that have been used include phenol, *p*-nitrophenol, 2, 4-dichlorophenol, tetrachloroethylene, toulene, benzene, carbotetrachloride, trichloroethylene, sulfanol, surfactants, polyoxyethylene (Aktaş & Çeçen, 2007), as well as molinate (Silva et al., 2004), and azo-dye (Lin & Leu; 2008). Review of the extent of bioregeneration reported seems to indicate that the extent of bioregeneration is affected by both the type of GAC and model compound that is used.

Bioregeneration of GAC has been hypothesized as a possible mechanism accounting for the sometimes-observed improved removal of organic matter by biofilters using GAC (AWWA, 1981). If bioregeneration occurs in drinking water biofilters, it would maintain the adsorptive capacity of GAC. However, while bioregeneration has been shown to occur for several types of GAC and compounds, the manner in which bioregeneration would affect the long term removal of organic matter by drinking water biofilters is not clear for at least four reasons:

The first reason that the manner in which bioregeneration would affect the removal of organic matter by biofilters is not clear is that, as was previously mentioned, the extent of bioregeneration depends on the model compounds that are used; model compounds which have been used in the literature to demonstrate bioregeneration and the extent of bioregeneration, with the exception of studies by Goncharuk et al. (2007) and Klimenko et al. (2009), may not necessarily be representative of organic compounds (e.g.. carboxylic acids from ozonation) or measures of organic matter (e.g. DOC, BDOC, or AOC) of importance in drinking water treatment. Goncharuk et al. (2007) and Klimenko et al. (2009) assessed bioregeneration in GAC filters that had been treating tap water that contained TOC; these studies differed from the rest of the literature in that specific model compounds were not used and bioregeneration was assessed using measures of the effective specific surface area rather than direct measures of the adsorption of TOC. N-chloroaniline was used to determine the effective specific surface area. While these studies concluded that bioregeneration occurred, this conclusion relied on three implicit assumptions: (1) the effective specific surface area taken up by n-chloroaniline on the GAC was the same as that taken up by TOC[19], (2) n-chloroaniline did not adsorb competitively with TOC (i.e. did not displace TOC that was previously adsorbed to the GAC), and (3) that the GAC became loaded with TOC when the filters were originally placed in service. The third assumption is reasonable given results presented in Chang and Rittmann (1987b) and Lin and Leu (2008); however, to conclusively demonstrate bioregeneration, data

[19] i.e. that, upon adsorption to the GAC, n-chloroaniline would adsorb to the same target sites and, thus, occupy the same amount of GAC surface area as TOC

showing the extent of TOC loading prior to bioregeneration should have been presented. Furthermore, data were not presented to validate the first and second assumptions. Therefore, the studies of Goncharuk et al. (2007) and Klimenko et al. (2009), while presenting data that implies that bioregeneration might be occurring, do not conclusively prove that bioregeneration occurs in drinking water biofilters.

The second reason that the manner in which bioregeneration may affect the long term removal of organic matter is not clear is that, while it has been shown that bioregeneration exists, whether or how compounds re-adsorb to the GAC in biofilters used for drinking water treatment when a biofilm is present, once the adsorptive capacity is bioregenerated, has not been elucidated. How such re-adsorption, if it occurs, results in long-term improved removal of organic matter by GAC biofilters used for drinking water treatment also has not been fully elucidated. Depending on the thickness, activity, and/or extent of coverage of biofilm on the GAC particle, compounds may not reach the surface of the GAC (and, thus, may not re-adsorb) because of microbial degradation and/or mass transfer resistance in the biofilm; this would particularly be the case if the compound being adsorbed was the primary substrate for a deep biofilm. Even assuming that the biofilm in a drinking water biofilter is shallow (as seen in a bioregeneration model of experimental data; Speitel et al., 1987), equilibrium could eventually be reached between the concentration of the compound at the biofilm-GAC interface and the concentration of the compound adsorbed on the GAC surface (as mentioned in Speitel et al., 1987); in this case, the adsorptive capacity of the GAC would, again, be effectively exhausted. Therefore, for bioregeneration of the adsorptive capacity of GAC to affect the long-term removal of organic matter in a drinking water biofilter, (1) the biofilm must have characteristics such that the organic matter can reach the surface of the GAC particle and (2) some dynamic process that persists over the long term must occur that allows the adsorptive capacity of the GAC to be bioregenerated, utilized, and then bioregenerated again.

Herzberg et al. (2005) modeled a dynamic process for the removal of atrazine in fluidized bed reactors wherein atrazine adsorbs to GAC in areas where biofilm coverage is minimal and then diffuses through GAC pores to the biofilm-GAC interface. In the model, the degradation of organic matter at the biofilm-GAC interface provides a driving force for the continual diffusion of organic matter from the GAC surface, where the organic matter adsorbs to the GAC, to the biofilm. In this manner, the biofilm at the biofilm-GAC interface is able to actively contribute to the biodegradation of organic matter, and in theory could contribute to biodegradation even in cases where there is a deep biofilm. This process also allows the biofilm to effectively continuously bioregenerate the adsorptive capacity of the GAC: as the soon as organic matter adsorbs to the surface of the GAC, it starts diffusing to the biofilm, where it will be biodegraded, and thus the surface of the GAC is bioregenerated. Herzberg et al. (2005) also modelled the

removal of atrazine by a nonadsorptive media in a fluidized bed reactor: the same general model was used but the mechanism of atrazine diffusion through pores to the biofilm-particle interface was not included. Effluent values for fluidized bed reactors predicted by the model were close to observed effluent data for experimental fluidized reactors containing both GAC and a nonadsorptive media (Herzberg et al., 2005), thus adding credibility to the model. The modelled and observed effluent atrazine concentration for the reactor containing GAC was lower than the modelled and observed effluent concentration for a nonadsorptive media. The process modelled by Herzberg et al. (2005), theoretically, could allow a drinking water biofilter containing GAC to provide better removal of organic matter than a biofilter containing a nonadsorptive media type because more of the biofilm would be able to actively contribute to the removal of organic matter; however, it has not been shown whether or not this process is valid for the removal of natural organic matter by GAC biofilters used for drinking water treatment.

Chudyk and Snoeyink (1984) showed that GAC that had been pre-equilibrated with phenol, placed in a small column, and fed phenol and nutrients, could be bioregenerated by phenol-degrading microorganisms. They also showed that the GAC could attenuate influent phenol spikes to a greater degree after bioregeneration than prior to bioregeneration. These results indicate that it is possible for bioregeneration to free-up adsorption sites on the GAC and for influent organic matter spikes to subsequently adsorb to these freed-up sites; however, these results may not be representative of what would be seen in operating drinking water biofilters. Prior to the spike experiments, the GAC was pre-equilibrated with 0.8 mg/L of phenol. During the spike experiments a baseline influent concentration of 0.8 mg/L of phenol was fed up through the columns and spikes of phenol resulting in peak influent concentrations ranging from 126 to 164 mg/L were added to the influent. The peak spike concentrations were approximately 158 to 205 times that of the baseline phenol concentration. These peak spike concentrations were much higher than anything that would be expected to be seen in a drinking water biofilter. It is not surprising that the phenol spikes were able to re-adsorb to the GAC given the large magnitude of the spike concentrations. It is unknown whether influent spikes of smaller magnitudes, similar to what might be seen in a drinking water biofilter, would still re-adsorb after bioregeneration. The results from Chudyk and Snoeyink (1984) also did not indicate whether or not the phenol that adsorbed during the spikes was subsequently bioregenerated. It is reasonable to assume that the phenol that adsorbed to the GAC during the spike could be bioregenerated because the phenol that was originally adsorbed to the GAC prior to the spike experiments (i.e. the phenol that had been used to pre-equilibrate the GAC) was bioregenerated; however, it has been shown in other studies that bioregeneration of only a fraction of the adsorptive capacity of GAC occurs (e.g. Speitel et al., 1987; Klimenko et al., 2004; Silva et al., 2004). It is unknown whether the fraction of the adsorptive capacity that can be bioregenerated will

remain constant through cycles of adsorption-bioregeneration or whether this fraction will decrease, and potentially be eliminated, over time. Therefore, while it may be initially possible for spikes of organic matter to adsorb to GAC after it has been bioregenerated, it is unknown whether this is possible over the long term.

Overall, dynamic bioregeneration-adsorption mechanisms, as mentioned above, and the impact of biofilm thickness on bioregeneration have not been fully described or demonstrated for the removal of organic matter in drinking water biofilters.

The third reason that the manner in which bioregeneration may affect the long term removal of organic matter is not clear is that, even if bioregeneration occurs, the bioregenerated adsorption sites may eventually be taken up by nonbiodegradable substances. Natural organic matter contains a mixture of biodegradable and nonbiodegradable substances (see Nishijima et al., 1998; Kim et al., 1997a; Kim et al., 1997b). Results from Putz et al. (2005) and Speitel et al. (1989b) suggest that bioregeneration of GAC can free-up the adsorptive capacity of the GAC by oxidizing adsorbed biodegradable compounds to CO_2. Once the adsorptive capacity is freed-up, nonbiodegradable substances can then adsorb to the GAC (Spietel et al., 1989). In the short-term, this would extend the adsorptive life of the GAC in a biofilter and would cause a GAC biofilter to provide better removal of organic matter than a biofilter containing nonadsorptive media; however, nonbiodegradable substances cannot be bioregenerated. Over time, the adsorptive sites on the GAC may become filled with nonbiodegradable substances; if this occurs, bioregeneration of the GAC would no longer be possible. If bioregeneration stops occurring, it will not impact the removal of organic matter by a biofilter.

The fourth reason that the manner in which bioregeneration may affect the long term removal of organic matter is not clear is that many of the studies exhibiting bioregeneration have been performed on systems that were configured and operated in a different manner than those used for drinking water biofiltration. Drinking water biofilters tend to be packed columns that are operated in a downflow mode and are operated for many years. Water passes through a given drinking water biofilter once and the effluent is not recirculated back to the influent. The filters are backwashed periodically to remove accumulated particles and biomass. Downflow packed bed reactor configurations have not been used in most of the studies which show in-situ bioregeneration[20]; instead, upflow columns (e.g. Putz et al., 2005; Speitel et al., 1989b; Speitel et al., 1989a; Speitel & DiGiano, 1987; Chudyk & Snoeyink, 1983), batch reactors

[20] In-situ bioregeneration is where bioregeneration occurs in the same system where adsorption originally occurred. Klimenko et al (2004) did use experiments columns in a downflow configuration to assess bioregeneration of "biologically resistant surface-active substances (SAS)" (p. 141); however the GAC was equilibrated with the SAS in one column then removed and bioregenerated in a separate downflow system.

(e.g. Ha & Vinitnantharat, 2000), and columns with recirculation (e.g. Lin & Leu, 2008; Chang & Rittmann, 1987b; Kim et al., 1986) have been used. Many of the studies in the literature have been of a short duration compared to the operating life of a biofilter. With the exception of Goncharuk et al. (2007) and Klimenko et al. (2009), evidence of bioregeneration does not appear to have been shown for systems operated similarly to drinking water biofilters. The limitations of Goncharuk et al. (2007) and Klimenko et al. (2009) have already been discussed. One way of avoiding the limitations of Goncharuk et al., (2007) and Klimenko et al. (2009), when investigating bioregeneration in drinking water biofilters, would be to look for evidence of bioregeneration by tracking the fate of organic carbon in bifoilters (e.g. Kim et al., 1986). If it can be shown that organic matter which was adsorbed to the GAC was converted to CO_2, then this would provide direct evidence of bioregeneration; however, such a method does not appear to have been used to investigate bioregeneration by GAC in drinking water biofilters.

Ultimately it can be concluded that, while bioregeneration has been shown to occur in many systems, (1) it has not been conclusively demonstrated that this mechanism occurs in drinking water biofilters and (2) it has not been shown how this mechanism results in improved removal of organic matter in GAC biofilters over the long-term.

2.4.3 Mechanisms Related to the Surface Roughness of Filtration Media

The effect of the surface roughness of filtration media on the removal of organic matter has been studied to a lesser extent than bioregeneration.

SEM images have shown that GAC particles are rough and contain a large number of pores and crevices (e.g. Pirbazari et al., 1990). Images of anthracite particles, in comparison, show that particles are fairly smooth (Scott, 2008). Microorganisms have been shown to preferentially colonize the pores and crevices of filtration media (Pirbazari et al., 1990). These environments may protect microorganisms in biofilms from shear forces (Characklis, 1981), particularly during backwash, thus allowing for a greater mass of biofilm to be retained on the particle than if the particle was smooth. Furthermore, a media particle that is rough has a larger surface area than an equivalently sized smooth particle; portions of this larger surface area would be available for biofilm growth and may affect the removal of organic matter.

Mechanisms related to surface roughness would affect the removal of organic matter by affecting the biofilm present in the biofilter. Any design or operational factors which may affect the biofilm (e.g. backwashing) may also affect the dominance of these mechanisms. Furthermore, these mechanisms may not be limited to GAC but may occur in conjunction with any filtration medium that is rough; therefore, if these mechanisms are dominant mechanisms causing the sometimes-observed improved removals of

organic matter by GAC, any type of rough media (e.g.. pumice or rough engineered ceramic filtration media) may be able to provide improved removal of organic matter.

2.4.4 Adsorption due to changes in influent water concentration and composition

The concentration and the composition of a natural water source can change over time (e.g. see data in Hallé et al., 2015; Scharf et al., 2010; Babi et al., 2007; Nishijima et al., 1998; Kim et al., 1997a; Kim et al., 1997b; Zhang et al., 2010). These changes in concentration and composition may result in additional adsorption of organic matter by GAC, even after the adsorptive capacity of the GAC has been effectively exhausted. While not discussed extensively in the drinking water biofiltration literature, this mechanism can be deduced from knowledge of adsorption and information in the literature. Additional adsorption of organic matter in response to changes in the influent water may contribute to the sometimes-observed improved removal of organic matter provided by GAC.

2.4.4.1 Adsorption due to changes in influent water concentration

When the adsorptive capacity of GAC is exhausted, there is an equilibrium between the concentration of organic matter present in the water and the mass of organic matter adsorbed on the GAC (Summers et al., 2011) .The ultimate amount of organic matter that adsorbs to GAC (and thus the amount of organic matter that is removed from the water) is a function of the concentration of organic matter present in the filter influent. If the overall concentration of organic matter in the influent water increases, e.g. due to a spike of organic matter in the influent, further adsorption onto the GAC can theoretically occur. This additional adsorption could result in lower effluent concentrations of organic matter from a GAC biofilter, when compared to a biofilter containing a non-adsorptive media type (e.g. anthracite). This mechanism is conceptually illustrated in Figure 2-5 (next page).

Figure 2-5 shows conceptualizations of influent and effluent organic concentrations for GAC and anthracite biofilters. Initially, there is a steady-state period where the influent and effluent concentrations are constant. Organic matter is biologically removed by the GAC biofilter during this period but does not adsorb to the GAC, assuming that the adsorptive capacity of the GAC has been exhausted[21]. Organic matter also is biologically removed by the anthracite biofilter, assuming that active biomass is present in the biofilter. During this initial period, both biofilters will provide similar effluent organic matter concentrations if it is assumed that both filters have similar microbial communities, biomass concentrations, and microbial activities. A pulse of organic carbon is then introduced into the filters.

[21] Exhaustion, in this case, is presumed to indicate that equilibrium has been reached between the concentration of organic carbon present in the influent water and the mass of organic carbon adsorbed to the GAC.

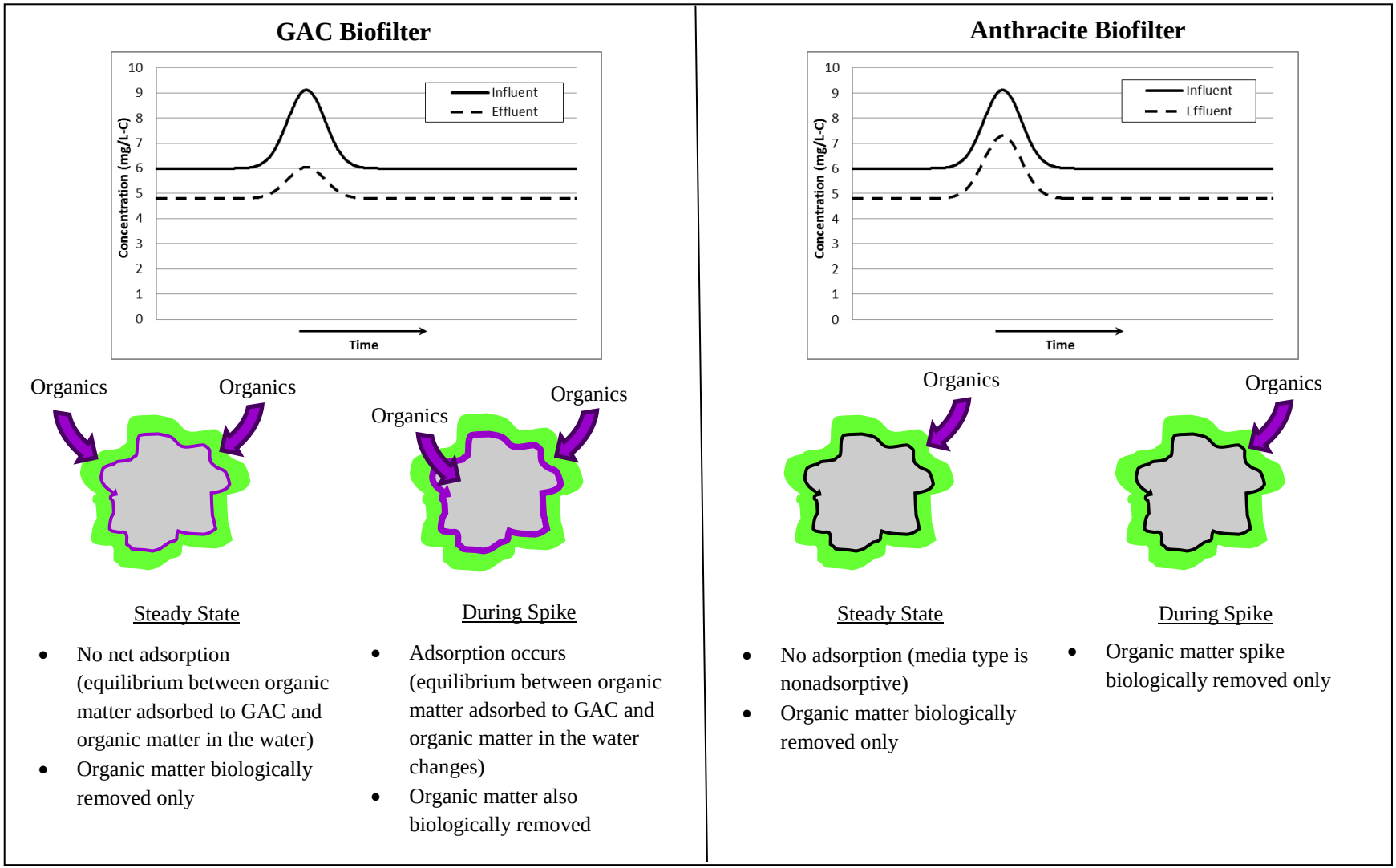


Figure 2-5: Conceptual comparison of GAC and anthracite biofilter response to increases in influent concentration (note: the data presented in all charts are conceptual)

After the pulse, organic matter is still biologically removed by both biofilters. However, in the GAC biofilter, organic carbon also adsorbs to the GAC. Adsorption occurs because the increase in the influent organic carbon concentration affects the equilibrium between the mass of organic carbon adsorbed to the GAC and the concentration of organic carbon present in the water. The adsorption of organic matter onto the GAC would result in the GAC biofilter achieving lower effluent concentrations than an anthracite biofilter.

The concentration of organic matter present in a biofilter influents is not constant and changes with respect to time (e.g. Scharf et al., 2010; Babi et al., 2007; Kim, et al. 1997a; Zhang et al. 2010) . Therefore, additional adsorption onto GAC due to increases in influent organic matter concentration could occur in practice and could partially account for the improved removal of organic matter provided by GAC biofilters.

2.4.4.2 Adsorption due to changes in influent water composition

The organic matter present in natural waters, and thus in drinking water filter influent, is a mixture of many different organic compounds with different properties. The relative concentrations of different compounds and different fractions of organic matter in the influent water can change over time (e.g. Kim et al., 1997a; Kim et al., 1997b; Nishijima et al., 1998). The change in the relative concentrations of these compounds, even if the total amount of organic matter stays constant, may result in further adsorption of organic matter onto GAC (even if the GAC was previously exhausted).

It was previously mentioned that additional adsorption of organic matter on GAC could occur due to changes in organic matter concentration in the influent water, even if the GAC had been previously exhausted. If the concentration of one compound in a mixture of compounds increases, that compound could adsorb further to the GAC. The additional adsorption of that compound would result in a lower effluent concentration for that specific compound than would be seen in a biofilter containing nonadsorptive media and, depending on the nature of the compound and the composition of the overall mixture, could also result in a lower overall organic matter concentration (i.e. a lower DOC concentration) than would be seen from a biofilter containing nonadsorptive media. In this manner, a change in the influent concentration of one or several compounds in a mixture could result in further adsorption onto GAC. This further adsorption would result in lower effluent organic matter concentrations and, thus, improved removal of organic matter in a GAC biofilter when compared to a biofilter containing nonadsorptive media.

It has also been shown that a more strongly adsorbing compound can displace (i.e. "kick-off") another previously adsorbed compound. In this case, the strongly adsorbing compound adsorbs on the GAC and is removed from the water, whereas the previously adsorbed compound is displaced into the bulk solution and ends up in the filter effluent (Thacker et al., 1983). Therefore, it can be surmised that, if the concentration of a strongly adsorbing compound increases in a mixture of compounds, the strongly adsorbing compound may adsorb to GAC by displacing other adsorbed compounds; in this manner a change in influent composition (specifically the increase of a strongly adsorbing compound) could result in further adsorption of a given compound, even when the GAC was previously exhausted. This further adsorption would result in a lower effluent concentration of the strongly adsorbing compound in a GAC biofilter and, thus, a biofilter containing GAC would provide better removal of that specific compound than a biofilter containing anthracite.

A scenario conceptually illustrating the impact of adsorption due to changes in influent composition is shown in Figure 2-6.

Two compounds are present in the influent of a GAC and an anthracite biofilter in the scenario illustrated in Figure 2-6. Compound A and B are both adsorbable and biodegradable. Initially, the adsorptive capacity of the GAC is exhausted for both compounds. Compounds A and B are biologically removed by both filters. The influent concentration of compound A increases, thus affecting the composition of the influent water, whereas the influent concentration of compound B remains the same. In both filters, compound A is still biodegraded and some of the spike is removed by biodegradation. However, compound A adsorbs to the GAC in the GAC biofilter, resulting in a lower effluent concentration for that specific compound. Compound A may adsorb due to two possible mechanisms. First, the increase of compound A in the influent may affect the equilibrium between the concentration of compound A present in the water and the mass of compound A adsorbed to the GAC; this change of equilibrium could result in further adsorption of compound A (similar to when the concentration of all organic matter in the influent increases – see Figure 2-5). Second, compound A may displace some of the compound B that was adsorbed to the GAC (e.g.Thacker, 1983). The displaced compound B ends up in the effluent of the GAC filter. Therefore, there is a trade-off between the removal of compounds A and B if adsorption by displacement occurs: the GAC biofilter will provide better removal of compound A than an anthracite biofilter but may provide worse removal of compound B.

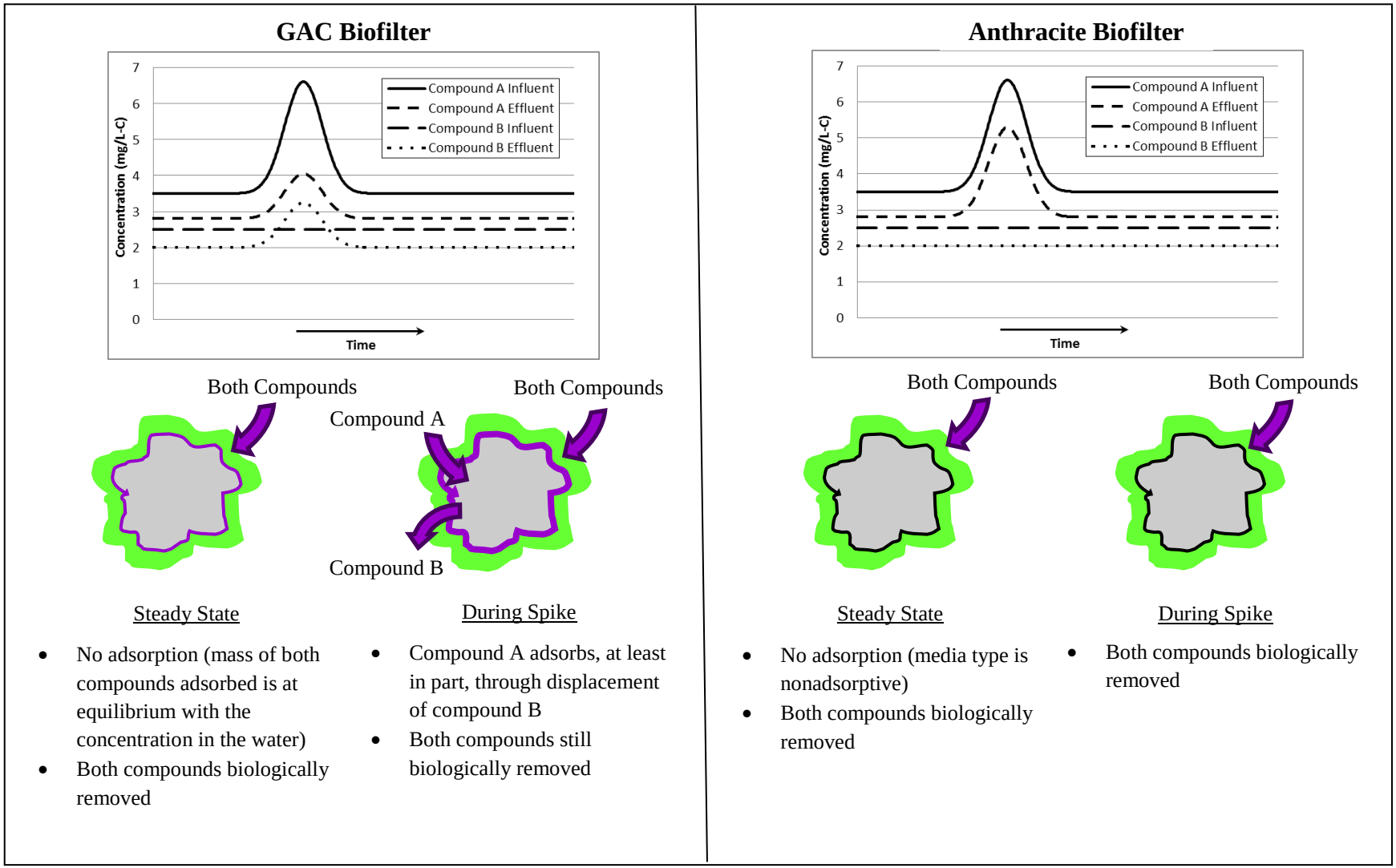


Figure 2-6: Conceptual comparison of GAC and anthracite biofilter response to changes in influent composition (note: the data presented in all charts are conceptual)

2.4.4.3 Evidence from the literature

The discussion to this point may seem theoretical and speculative; however, data presented in Kim et al. (1997a) provides some evidence that adsorption due to changes in influent water concentration or composition can improve the removal of organic matter by biofilters containing GAC.

Kim et al. (1997a) operated a set of three upflow pilot-scale drinking water biofilters. Two of the biofilters contained GAC and one of the biofilters contained anthracite. The removal of different fractions of DOC was monitored, and it was found that one of the two GAC filters no longer adsorbed the nonbiodegradable-adsorbable fraction of DOC; therefore, the GAC filter was considered to be effectively exhausted. Separate spikes of phenol (an adsorbable-biodegradable compound) and bromophenol (an adsorbable-nonbiodegradable compound) were introduced into the biofilter influents after several months of operation. The filters containing GAC provided greater removal of both phenol and bromophenol compounds than the filter containing anthracite.

The additional removal of bromophenol by the GAC biofilters indicates that bromophenol adsorbed to the GAC because the bromophenol was nonbiodegradable. The adsorption of bromophenol indicates that a change in influent concentration or composition (i.e. the addition of a spike of bromophenol to the influent) can result in adsorption of organic matter onto the GAC present in biofilters[22], including onto GAC whose adsorptive capacity for NOM is essentially exhausted. The results also imply that this adsorption caused the GAC biofilters to provide better organic matter removal than the biofilter containing nonadsorptive media because the GAC biofilters provided better bromophenol removal than the anthracite biofilter.

While it can be surmised that a change in influent concentration or composition resulted in adsorption of bromophenol and improved bromophenol removal by GAC, the mechanisms causing the bromophenol to adsorb to the GAC cannot be determined from the data presented in Kim et al. (1997a). The bromophenol could have been adsorbed as a result of a change in equilibrium due to the increase in influent concentration, the displacement of another adsorbed compound, or because it utilizes different adsorption sites on the GAC than the compounds present in the natural waters. The results, therefore, do not indicate exactly how (i.e. through what adsorption mechanism) the GAC biofilters provided better removal of bromophenol than the biofilter containing anthracite.

[22] At least under the conditions studied by Kim et al. (1997a).

2.4.4.4 Limitations and questions related to adsorption due to changes in influent water concentration and composition.

While the mechanisms described above may partially account for the improved removal of organic matter sometimes provided by GAC biofilters, there are several issues with attributing the improved removal solely to these mechanisms. These issues are as follows:

(1) Maximum adsorptive capacity:
As mentioned previously, there is an equilibrium between the mass of organic matter adsorbed and the mass of organic matter present in the influent water. However, there is a maximum concentration, past which an increase in the concentration of organic matter in the water will not result in increased adsorption. If the influent organic matter concentration in a biofilter is already at this maximum concentration, an increase in the influent organic matter concentration will not result in additional adsorption.

(2) Desorption of organic matter due to a decrease in influent concentration:
The equilibrium between the mass of organic matter adsorbed and the concentration of organic matter present in the influent water does not change only if the influent organic matter concentration increases: if the influent organic matter concentration decreases, some of the adsorbed organic matter can desorb. Desorption after a decrease in the influent organic matter concentration has been observed in several studies (e.g. Thacker et al., 1983; Babi et al., 2007; Corwin & Summers, 2011). If desorption occurs, a GAC biofilter could exhibit worse removal of organic matter than a biofilter containing anthracite, at least for a short period of time. It has also been shown that, for certain substances, a fraction of the total mass adsorbed to GAC can be irreversibly adsorbed and will not desorb (e.g. De Jonge et al., 1996; Thanthapanichakoon et al., 2005; Yonge et al., 1985). Therefore, the amount of desorption that may occur depends on the substance that adsorbs to the GAC and the degree of irreversible adsorption.

(3) Displacement of adsorbed organic matter due to changes in influent composition:
The displacement of adsorbed compounds by newly introduced compounds can result in the displaced compounds ending up in the filter effluent (e.g. Thacker et al., 1983). Depending on the exact compounds of interest during a given study, the displacement of certain compounds could result in a GAC biofilter having higher effluent concentrations for a given compound than an anthracite biofilter.

(4) Regeneration/freeing-up of used adsorption sites:
When additional organic matter is adsorbed onto GAC due to a change in influent concentration or composition, the organic matter takes up adsorption sites within the GAC. It is unknown how and under what circumstances those adsorption sites are freed-up. If the adsorption sites used to adsorb organic

matter after a change in influent concentration/composition are not freed-up, these adsorption sites will not be available to adsorb organic matter when another change in influent concentration/composition occurs. If adsorption sites are not freed-up, the capacity of the GAC to adsorb organic matter will become permanently exhausted over time and a GAC biofilter will eventually perform similarly to a biofilter containing a nonadsorptive media type. It may be possible that organic matter adsorbed during an increase in influent concentration desorbs after the influent concentration returns to normal; however, the extent of desorption will depend on whether or not irreversible adsorption occurs. Bioregeneration may also allow used adsorption sites to be freed-up after a spike of organic matter has passed through a system but such a mechanism has not been shown for drinking water biofilters.

(5) Limited evidence:
There seems to be limited experimental evidence demonstrating whether or not changes in influent water concentration/composition, resulting in improved adsorption of organic matter by GAC, causes improved removal of organic matter provided by GAC biofilters[23]. Furthermore, studies are needed that elucidate exactly how changes in influent water concentration/composition may impact the comparative performance of biofilters containing different types of media, especially over the long-term operation of a drinking water biofilter.

(5) Magnitude of improvements in DOC removal unknown:
The adsorption of spikes of bromophenol observed by Kim et al. (1997a) would have resulted in approximately a 0.07 mg/L[24] improvement in effluent DOC concentration in the GAC biofilters when compared to the biofilter with nonadsorptive media. While the additional removal of bromophenol may have been practically significant, the additional removal of DOC was small. It is unknown whether any significant improvements in DOC or TOC removal during biofiltration can be attributed to adsorption of organic matter onto used GAC, after a change in influent organic matter concentration/composition. Experiments need to be conducted that demonstrate whether or not significant improvements in DOC or TOC removal can be achieved.

Ultimately, the degree to which adsorption-of-organic-matter-due-to-changes-in-influent-water-concentration-and-composition contributes to the improved removal of organic matter provided by GAC biofilters is unknown. The degree to which these mechanisms actually matter is likely situation specific.

[23] Especially GAC biofilters containing media that have been used for an extended period of time.
[24] In the study by Kim et al. (1997a), approximately 160 μg/L of bromophenol was added to the biofilter influents; this corresponds to approximately 0.07 mg/L of organic carbon. The bromophenol was completely removed by the GAC biofilters. Minimal bromophenol removal was provided by the anthracite biofilters. Therefore, the additional DOC removal caused by adsorption of bromophenol to the GAC was approximately 0.07 mg/L.

Further research is needed to confirm whether these mechanisms significantly contribute to the improved removal of organic matter provided by GAC during biofiltration for drinking water treatment and if/how these mechanisms relate to other mechanisms that impact the removal of organic matter (e.g. bioregeneration).

2.4.5 Other Mechanisms

The final mechanisms mentioned in section 2.4 that may account for the improved removal of organic matter seen in GAC filters are enhanced microbial attachment due to GAC surface chemistry, "chemical reduction of oxidants/disinfectants" by GAC, adsorption of inhibitory substances by GAC, extension of the degradation time for slowly biodegradable substances through adsorption onto GAC, and concentration of substrates on the surface of GAC (Çeçen & Aktaş, 2011). Enhanced microbial attachment due to GAC surface chemistry has been mentioned by Weber et al. (1978), who indicated that enhanced attachment could be attributed to the variety of functional groups on the GAC surface. Enhanced microbial attachment may allow greater amounts of biomass to develop and/or be maintained on biofilters; however, it is questionable whether this will directly translate into better removal of organic matter over the long-term. The chemical reduction of oxidants/disinfectants by GAC has been shown by Suidan et al. (1977); however, these mechanisms may not affect the removal of organic matter in all cases. Chemical reduction of oxidants/disinfectants does not explain the improved removals seen when oxidants were not used in biofilers (e.g. Liu et al., 2001). Choi et al. (2008) showed that the adsorption of dissolved oxygen onto GAC preserved the ability of an anaerobic bioreactor to provide removal of perchlorate when oxygen concentrations in the reactor influent increased, whereas perchlorate removal in a bioreactor containing glass beads (a nonadsorptive media) was impaired when oxygen concentrations were increased. The adsorption of an inhibitory compound (in this case, oxygen) allowed a reactor with GAC to provide better removal of a compound than a reactor with a nonadsorptive media. Similarly, in a drinking water biofilter, the adsorption of inhibitory compounds may allow GAC biofilters to provide better removal of organic matter than biofilters containing a nonadsorptive media; however, it is questionable whether inhibitory substances (with the exception of chemical oxidants/disinfectants, which were discussed previously) are present in concentrations high enough to impact the removal of organic matter during the normal operation of a GAC biofilter used for drinking water treatment. The presence and concentration of such inhibitory substance would likely be very site specific. Çeçen and Aktaş (2011) proposed that adsorption of slowly biodegradable substances provide microorganisms with a longer period of time to degrade slowly biodegradable substances than if the substances merely remained in the bulk water. They also proposed that concentration of substrate onto the surface of GAC may allow

substrates that are present in low concentrations to be more readily available for microbial degradation. Further research is needed to determine whether or not adsorption of slowly biodegradable substances and/or concentration of substances onto the surface of GAC are primary mechanisms that result in GAC providing better long-term organics removal than anthracite during biofiltration for drinking water treatment.

2.4.6 Relationship between Mechanisms

A final comment that can be made with respect to the mechanisms discussed in the preceding sections is that the relative effect of these mechanisms on the removal of organic matter by BAF is unknown. It may be that only one mechanism, for example bioregeneration, causes the sometimes-observed improved removal of organic matter by GAC. Alternatively, the improved removal of organic matter may be due to some form of synergistic effect between multiple mechanisms. For example, organic matter may adsorb to GAC due to an increase in influent organic matter concentration and then the adsorbed organic matter may be bioregenerated, thus freeing-up the adsorptive capacity of the GAC for the next increase in influent concentration Furthermore, synergistic effects or the dominance of one mechanism versus another may change depending on the manner in which a biofilter is designed and operated. The relationship between mechanisms and the impact of different design and operational factors on the removal of organic matter through these mechanisms requires further investigation.

2.5 Impact of Media Type on Headloss and Filter Run Time

Only a few peer-reviewed studies of biofilter performance seem to have looked at headloss or filter run time during comparisons of media types (LeChevallier et al., 1992; Najm et al., 2005). In these studies, as with comparisons of DOC removal, the grain sizes and grain size distributions of media types being compared were not matched. Media size is known to impact headloss. Headloss, in turn, can affect filter run time: i.e., filters with higher headloss can have shorter run times. Therefore, it is not known whether differences in headloss or run time observed in these previous studies were due to the differences in media size or the differences in media type. Further research is needed to determine whether media type, itself, impacts headloss or filter run time in biologically active filters.

Chapter 3 Phase I Experiments

3.1 Introduction

Previous studies comparing the performance of biofilters containing different media types cannot definitively indicate which media type provides optimal performance because the grain size distributions of the media used in those investigations have not been matched. Thus, it is possible that observed performance differences (or lack thereof) may have been attributable to differences in media size distribution, rather than media type. This limitation makes it difficult to provide conclusive, *a priori* design guidance regarding the type of filtration medium that is optimal for use in BAF. It also prevents conclusive evaluation of the mechanisms that contribute to biofilter performance.

In experimental Phase I, a method of matching grain size distributions was developed and the performance of biofilters containing coal-based GAC, anthracite, rough engineered ceramic media [REC], and wood-based GAC with matched grain size distributions was compared. The filters were operated in a constant-head-constant-rate mode (i.e., constant water pressure was applied to the filter[25] and the flow rate through the filter was kept constant over time by automatically adjusting effluent valves as the filter was operated). These experiments were designed to address research Objectives 1, 2, 3, and 5.

An additional biofilter containing coal based GAC was operated in declining-rate mode (i.e., constant water pressure was applied to the filter and the flow rate through the filter decreased over time as the filter was operated), and was used as a pseudo-replicate of the biofilter containing coal-based GAC. The decrease in flow rate was due to clogging of the pores spaces between the media with particles that were removed from the water. Additional ancillary comparisons were conducted using data from this biofilter to determine whether additional organic matter removal could be achieved by operating a filter in declining-rate mode. It was also determined whether operating a biofilter in declining-rate mode could compensate for differences in organic matter removal provided by different media types.

[25] A constant water pressure was applied maintaining a constant depth of water in the filter. The constant depth of water was maintained by directing excess influent water to the filter and allowing the excess water to exit the filter through an overflow port that was set at a defined height.

3.2 Materials and Methods

3.2.1 General Experimental Approach

Five pilot scale drinking water filters were set-up at the Mannheim Water Treatment plant in Kitchener, Ontario. They were operated in a constant head, constant rate mode and fed water from the full scale plant after it had been flocculated, settled, and ozonated. The filters were dual media filters designed to be representative of full scale filters, consisting of a biological support medium (coal-based GAC, anthracite, REC, or wood-based GAC) over sand. The grain size distributions of the different media types were matched to ensure that any observed differences in filter performance could be attributed to differences in media type. The roughness and adsorptive properties of the filter media were also confirmed. An additional filter (Filter 5) containing coal-based GAC and was operated in declining-rate mode. The filters were operated continuously, except for brief periods for maintenance and repair, for 660 days (August 24, 2011 to June 14, 2013).

The performance of the filters was compared by evaluation of both traditional measures (i.e., headloss, turbidity removal, and filter run times) and organic matter removal. Media properties that impacted the removal of organic matter and turbidity were identified and provided mechanistic insight into how aerobic, biologically active filters remove organic matter. Seasonality and the impact of water temperature were evaluated whenever possible; thus, filter performance was compared separately for both warm (≥10°C) and cold (<10°C) water conditions.

Details regarding the measurements, analytical, and statistical techniques used for each of the performance assessments are presented in the following subsections.

3.2.2 Pilot Plant Specification and Operations

Details of the filter configurations are presented in Table 3-1 . The details of the backwash procedures are summarized in Table 3-2.

Table 3-1 Filter configurations

		Filter 1	Filter 2	Filter 3	Filter 4	Filter 5
Filter	Column Diameter (m)	0.203	0.203	0.203	0.203	0.203
	Column Height (m)	4.2	4.2	4.2	4.2	4.2
Filtration/ Biological Support Media	Media Type	Coal-based granular activated carbon[1,5]	Anthracite[2]	Rough engineered ceramic media[3]	Wood-based granular activated carbon[4]	Coal-based granular activated carbon[1,5]
	Effective size[6,8] (mm)	0.86	0.86	0.81	0.87	0.86
	Uniformity coefficient[7,8]	1.33	1.34	1.38	1.32	1.33
	Depth (m)	1	1	1	1	1
	EBCT (min)[9]	10.7	10.7	10.7	10.7	10.7
Sand Layer	Effective size[6] (mm)	0.49	0.49	0.49	0.49	0.49
	Uniformity coefficient[7]	1.31	1.31	1.31	1.31	1.31
	Depth (m)	0.3	0.3	0.3	0.3	0.3
	EBCT (min)[9]	3.2	3.2	3.2	3.2	3.2
Hydraulic Loading Rate	(m/h)	5.6	5.6	5.6	5.6	5.6
Flow Rate	(L/min)	3.0	3.0	3.0	3.0	3.0
Operational Mode[10]	-	Constant-rate	Constant-rate	Constant-rate	Constant-rate	Declining-rate

1. Norit® 830; Norit Americas Inc., Atlanta, Georgia
2. Anthrafilter, Brantford, Ontario
3. Macrolite®; Fairmount Water Solutions, Chardon, Ohio
4. Nuchar WV-B 30®; MeadWestvaco, Covington, Virginia
5. Coal-based GAC was taken from full scale filters. Coal-based GAC had been in use for seven years prior to collection.
6. The effective size of the media types is defined as the d_{10}. The d_{10} is the size of an opening that 10% of the media grains, by mass, will pass through. The effective size was determined from the average distribution of five grain size analyses on each media type except sand. Four grain size analyses were performed on the sand.
7. The uniformity coefficient is the d_{60}/d_{10}. The d_{60} is the size of an opening that 60% of the media grains, by mass, will pass through.
8. All media types were sieved and matched to the grain size distribution of the coal-based GAC. Effective sizes and uniformity coefficients are not necessarily the same as would be supplied by the manufacturer.
9. Empty bed contact time.
10. All filters operated with a constant head, regardless of the operational mode used

Table 3-2: Backwash procedures

Backwash Step	Details	Filter 1 (Coal-based Granular Activated Carbon)	Filter 2 (Anthracite)	Filter 3 (Rough Engineered Ceramic Media)	Filter 4 (Wood-based Granular Activated Carbon)	Filter 5 (Coal-based Granular Activated Carbon)
Collapse Pulsing Backwash (cold water)[1,2]	Air loading rate ($m^3/h/m^2$)	52	52	52	52	52
	Hydraulic loading rate (m/h)	9.3	10.4	14.2	7.4	9.3
	Duration (min)[3,4]	7-8	7-8	7-8	7-8	7-8
Collapse Pulsing Backwash (warm water)[1,2]	Air loading rate ($m^3/h/m^2$)	52	52	52	52	52
	Hydraulic loading rate (m/h)	12.0	12.6	15.2	8.3	12.0
	Duration (min)[3,4]	7-8	7-8	7-8	7-8	7-8
Settling	Duration (min)	2-3	2-3	2-3	5	2-3
High rate wash[1]	Expansion (%)	30	30	30	30	30
	Duration (min)[3,5]	7-10	7-10	7-10	7-10	7-10

1. Each filter was backwashed with its own filtrate. The backwash water was not chlorinated.
2. Collapse pulsing backwash consisted of a simultaneous air scour and subfluidization water wash
3. The same duration was used for all filters during a given filter cycle.
4. A collapse pulsing duration of 7 minutes was in almost all filter cycles. Different durations were used during the following periods: the period from the start of operations until November 5, 2011 and the period from November 13-23, 2011. During these periods the collapse pulse duration was varied to help determine an optimal backwash protocol.
5. A high rate wash duration of 10 minutes was used for all filter cycles except from the start of operations until November 13, 2011 and except during a few filter cycles where the air compressor was out of service for maintenance. When the air compressor was out of service for maintenance, a longer high rate wash was used and no collapse pulsing backwash was performed

The general filter configuration, with 1 m of biological support media over 0.3 m of sand, was similar to the configuration of full scale filters at the Mannheim Water Treatment Plant. All pilot filters were fed water from a common header and each filter was backwashed with its own unchlorinated filtrate. Filter 1 and Filter 5 both contained the same filter media and, therefore, the filtrate from these two filters was combined for backwashing. The filters were normally backwashed using a collapse-pulsing backwash, followed by high rate water wash, on a 40 to 48 hour schedule.

Collapse pulsing conditions were maintained during warm and cold water periods by adjusting wash water and air flow rates (Table 3-2). Collapse pulsing was visually confirmed during each backwash and the procedure was switched from warm and cold water procedures when collapse pulsing became less vigorous and inadequate. All filters were backwashed with either the cold water protocol or the warm water protocol and at no point were some filters backwashed with one protocol and others with a different one. Periodically, the filters were also taken out of service for maintenance, repair, and/or because of other operational issues.

3.2.3 Grain Size Distribution Matching Procedure

3.2.3.1 Choice, Preparation, and Characterization of Coal-Based GAC

Coal-based GAC[26] was collected from the top of full-scale GAC filters from the Mannheim Water Treatment Plant. The grain size distributions of the other media types were matched to this media type. This coal-based GAC was chosen for several reasons:

1. The GAC had been in continuous active use in full-scale filters for seven years; therefore, its adsorptive capacity was expected to have been exhausted (unless bioregeneration was occurring).
2. The grain size distribution of the GAC, and thus the distribution of the other media types matched to the GAC, would be representative of media which had been used in a full scale treatment plant.

Over 100 kg of coal based GAC was collected from the full-scale filters and air dried in a large frame (Figure 3-1).

[26] Norit® 830; Norit Americas Inc., Atlanta, Georgia

Figure 3-1: Drying frame used for drying GAC

The GAC was gently mixed by hand to counteract any settling of small grains that may have occurred during transport and to ensure that the media grains were homogeneously distributed within throughout the frame.

Once the GAC was dry, five samples were taken from different locations in the drying frame. The grain size distribution of each of the five samples was characterized by sieving the GAC through a series of 8" sieves per AWWA standard B604-05 (AWWA, 2006), with the following modifications: media samples of up to 300 g were analyzed and samples were weighed to the nearest 0.01g instead to the nearest 0.1g.

In brief, the sieving procedure was as follows:

1. A sample of GAC was weighed and was placed in the top of a stack of sieves.
2. The sieves were arranged such that the sieve with the largest mesh opening was at the top of the stack and the sieve with the smallest mesh opening was at the bottom. A pan was placed after the last sieve to catch fines. The sieve set that was used is listed in Table 3-3. W.S.Tyler[27] and Endecotts[28] sieves that met ASTM Standard E-11-04 (2004) were used.

[27] W.S. Tyler, St. Catharines, Ontario

[28] Endecotts, London, England

Table 3-3: Sieve set used for sieving media

US Sieve #	Mesh Size (Opening size, mm)
8	2.38
10	2.00
12	1.68
14	1.41
16	1.19
18	1.00
20	0.84
25	0.71
30	0.60
pan	0.00

3. The sieves, containing the media, were placed on an Oscillatap[29] sieve shaker and were sieved for 3 minutes.
4. The mass of media retained on each sieve was weighed after sieving. The percent of the total mass that passed through each sieve [cumulative percent passing] was calculated to give the grain size distribution.
5. The grain size distribution of each subsample was plotted with the mesh size on the x-axis and the cumulative percent of passing on the y-axis.

The average cumulative percent passing for each mesh size from the five subsamples was calculated and the average grain size distribution of the coal-based GAC was plotted. The effective size of the coal-based GAC and the uniformity coefficient were linearly interpolated from the calculated average grain size distribution values. The effective size was taken as being the d_{10} (i.e. the mesh size through which 10% of the cumulative mass passes). The uniformity coefficient was calculated as the ratio of the d_{60} to d_{10}.

3.2.3.2 Preparation of Media with Matched Grain Size Distributions

Bulk anthracite[30], REC[31], and wood-based GAC[32] were procured in a variety of size ranges and distributions, none of which matched that of the coal-based GAC. Therefore, a method was developed to match the grain size distributions of these media to the coal-based GAC.

[29] Testing Systems Inc, Millgrove, Ontario

[30] Anthrafilter, Brantford, Ontario

[31] Macrolite®, Fairmount Water Solutions, Chardon, Ohio

3.2.3.2.1 Grain Size Analyses

Preliminary tests were performed to determine the optimal initial mass of media to be used for grain size analysis and to determine the optimal sieving time for both the anthracite and the rough engineered ceramic media (data not shown). Grain size analyses for the anthracite, REC, and wood-based GAC were performed following the same procedure as the coal-based GAC, but with the following modifications:

1. Anthracite and REC were sieved for 10 minutes instead of 3 minutes. This was possible because these media were less friable than GAC.
2. An initial mass of less than 170 g of media was used during media characterization to prevent sieve overloading. The actual initial mass used depended on the sample size, and ranged from 50 to170 g. The initial mass used when characterizing the final grain size distributions of the mixed media was controlled to a greater degree than for the preliminarily sieved media; the initial masses ranged from 92 to120 g during characterization.
3. The mass of media retained on any given sieve was checked versus the sieve overloading limits listed in Table 3 of ASTM Standard D6913-04(2009) to help ensure that the sieves were not overloaded.

3.2.3.2.2 Preparation of Rough Engineered Ceramic Media

In dual media biological filters, the biological support media must have a density lower than that of sand to ensure that it settles above the sand layer, resulting in a stratified dual media configuration. The rough engineered ceramic media used in these experiments was a novel media type. Previous experience with the media (D. Scott, personal communication, 2008) and advice from the media manufacturer indicated that some media fractions, or grains in certain size ranges, might have had low densities, while other grains might have had densities similar to that of sand. Previous experience with the REC also indicated that there would be a small fraction of "floaters" (i.e., media grains with a density less than that of water, which would cause them to float out of the filters). If the media density was similar to that of sand, a large amount of media would mix with the sand layer, resulting in a filter that would not stratify properly. If media of certain size ranges floated out of the filters, it could compromise the matched grain size distributions. Furthermore, there was the potential that media from different batches might have had different densities. This could lead to stratification within that media layer after backwash, resulting in a tri-media configuration rather than a dual-media filter.

[32] Nuchar WV-B 30®; MeadWestvaco, Covington, Virginia

A quality control test was performed to ensure that the media from two batches had adequately similar densities so that they would mix during backwash and not stratify. Media grains from one batch were coloured red using tempera powder paint[33]. The colouring method consisted of the following steps: a volumetric paint to media ratio of approximately 4:1 was mixed with enough water to create a slurry and coat the media, the media were dried overnight in an oven at approximately 105°C, and the media were rinsed with water to remove excess paint. Both media batches were placed in a 2" column with the coloured media on the bottom and the non-coloured media on top, similar to what is shown in Figure 3-2.

Figure 3-2: Picture of media from two different REC batches installed in a backwashing column. (Media from one batch are grey and media from the other batch are dyed red)

A gravel layer, while not visible in Figure 3-2, was included in the bottom of the column to help evenly distribute water across the column during backwashing. The media in the column were backwashed and mixing was visually confirmed.

A separate set of quality control tests was conducted to identify whether floaters were present in the REC batches and whether or not the media density was similar to sand. Rough engineered ceramic media from each major batch of bulk media were tested. A gravel layer with a depth of approximately 5 cm was placed in the bottom of a 50 cm diameter glass column. Sand and REC media were placed on top of the gravel layer, with the REC media placed on top of the sand. The depths of the sand and REC media layers were each approximately 3 cm. The column was filled with tap water and the media were fluidized to ~30-40% bed expansion. The presence or absence of floaters was noted and, after reaching the specified bed expansion, the backwash flow rate was slowly decreased to attempt to stratify the rough engineered

[33] Rich Art Dust Free Powder Paint, Tempera; Rich Art Color Co.; Northvale, NJ, USA/

ceramic media on top of the sand. Pictures were taken of the media and the amount of media mixed with the sand was assessed. Finally, the media were backwashed using a backwash rate that caused a bed expansion greater than 30-40% to simulate an extremely high-rate backwash; the media were restratified after the second, higher backwash, and any differences in the amount of media mixed with the sand layer were noted. If significant mixing of media with the sand layer was observed after the first or second backwash, then at least some of the media in the batch and size range were considered to have a density similar enough to sand.

A "density separation" was performed on the bulk rough engineered ceramic media, prior to using it to create matched media, to ensure that floaters were not present in the matched media, and to minimize the number of high density media grains that would mix with the sand layer. The density separation apparatus is shown in Figure 3-3 and consisted of a 12 inch diameter acrylic column, filled with 18 cm of sand (E.S.= 0.50mm, U.C.=1.35) on top of 29 cm of small gravel (1/4"-1/8" diameter), and 32 cm of large gravel (1/2"-1/4" diameter).

Figure 3-3: Density separation apparatus

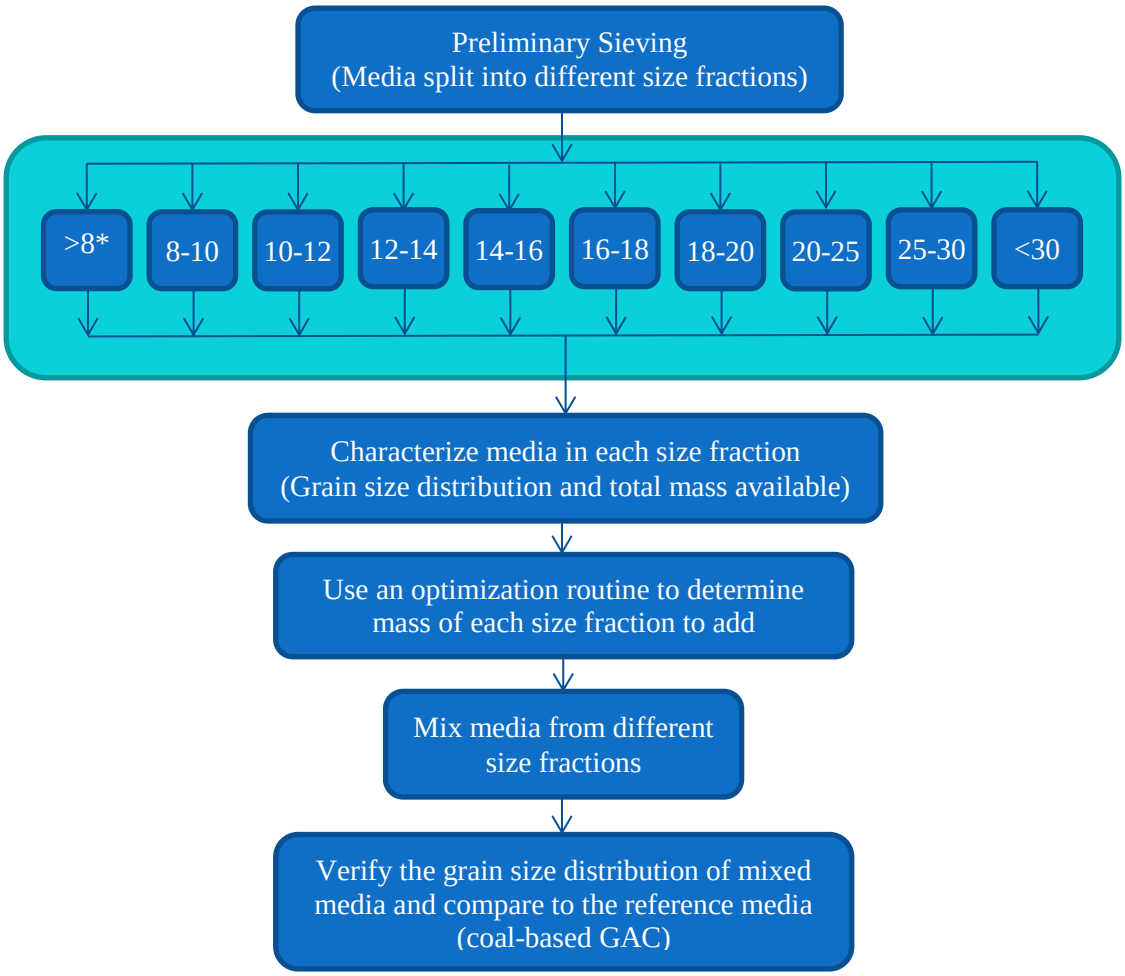
Each batch of rough engineered ceramic media was placed in the density separation column on top of the sand and was backwashed at a water rate that would result in at least a 20% expansion of the sand bed and a 50-70% expansion of the total bed. The media were backwashed for 15 minutes; during this time, floaters were washed out of the filter and discharged via the overflow-box on top of the filter. Afterward,

the water flow rate was decreased and the media were allowed to stratify. Any remaining floaters were skimmed from water at the top of the column and the filter was drained to the sand layer. Media that stratified on top of the sand was collected, dried, and used to create a matched grain size distribution. Media that mixed with the sand layer were discarded.

3.2.3.2.3 Protocol for Matching Grain Size Distributions

The grain size distributions of the other media types were matched to that of the coal-based GAC using the protocol summarized in Figure 3-4.

Preliminary sieving was conducted at the University of Waterloo and by an external contractor. During preliminary sieving, media were sieved through a set of 8" diameter sieves, matching those listed in Table 3-3, to approximately separate the media into different size ranges. Media in each preliminary-sieved size range was collected and the mass of media available in each size range was determined.



*Note: numbers represent US sieve sizes

Figure 3-4: Protocol for matching grain size distributions

It should be noted that the preliminary sieved media did not fully separate into the appropriate size range (i.e. not all media grains that were sieved through a #8 sieve and retained on a #10 sieve were actually within that size range—some media smaller than a # 10 sieve opening was still retained on the sieve). Grain size analysis was conducted on the media in each preliminary-sieved size range to characterize the grain size distribution of media in each given range. Microsoft Excel Solver™ was used to determine the mass of media required from each preliminary-sieved size-range to create a final grain size distribution that would match that of the coal-based GAC.

After the amount of media from each preliminary-sieved size range that was needed to create the final mixed media was determined, the media from each size fraction were weighed out and mixed by hand in

a large Rubbermaid® container. The media were then passed through a chute riffler, recombined, passed through the chute riffler for a second time, and re-mixed by hand to ensure that the different size fractions were well mixed. Five samples were collected from different locations in the Rubbermaid container and the grain size distribution of each of the samples was determined. The average grain size distribution for each mixed media type (anthracite, REC, and wood-based GAC) was calculated and compared to that of the coal-based GAC to verify that the grain size distribution of the mixed media closely matched that of the coal-based GAC.

3.2.4 Confirmation of Media Properties

Two media properties were important for interpretation of the results from this investigation: roughness of a media type and the ability of a media type to adsorb organic matter. Anthracite media grains were expected to be smooth in comparison to the REC, coal-based GAC, and wood-based GAC media grains. The GACs were expected to be adsorptive media types with respect to organic matter whereas the REC and anthracite were expected to be non-adsorptive. The relative roughness and ability to adsorb organic matter were confirmed for all media types.

3.2.4.1 Confirmation of Roughness

Scanning Electron Micrographs [SEMs] for each media type were obtained at magnifications of 22x to 2000x to confirm the roughness of the GACs and REC[34].

3.2.4.2 Confirmation of Adsorptive Media Surfaces

An adsorption test was conducted to confirm that the GACs could adsorb organic matter and to confirm that the anthracite and REC had non-adsorptive surfaces.

The media were crushed to minimize the duration of adsorption experiments[35,36]. Samples of each media type were manually ground to a powder using a mortar and pestle. The powder was placed in metal tins and dried at 105°C for approximately 72 hours. After drying, the powder was allowed to cool in a

[34] Media samples were taken from the mixed media batches with matched grain size distributions.

[35] Crushing the GAC reduces the amount of time required to reach equilibrium (Randtke & Snoeyink, 1983)

[36] Crushing the coal-based GAC, that had been used for several years prior to these experiments, exposed fresh GAC surfaces that could have adsorbed organic matter. The experimental design could be criticized by arguing that the exposure of these surfaces would result in an overestimation of the remaining adsorptive capacity on the used GAC; however, the purpose of these adsorption tests was to simply confirm that the media type, itself, was capable of adsorbing organic matter. The purpose was not to try and determine if the media grains were fully exhausted or to quantify the remaining adsorptive capacity on the used GAC. Given the purpose of these tests, crushing the coal-based GAC was acceptable, even though fresh GAC surfaces would be exposed.

desiccator until it reached room temperature. Between 0.9990 g and 1.0010 g of powder were placed into four clean glass jars. A separate set of four jars was used for each media type.

One jar in each set was filled with 200 mL of ultrapure Milli-Q water to check for carbon contamination of the media. The remaining three jars in each set were filled with 200 mL of pilot plant influent water (that contained natural organic matter, had been filtered through a 0.45 micron filter[37], and stored in a refrigerator at 4°C for <5 days until use). Nine aliquots of pilot plant influent water and three aliquots of ultrapure water were poured into TOC vials immediately after filling the jars. The aliquots were stored at 4°C until baseline DOC concentrations were measured. The jars were placed on an end-over-end shaker[38] and mixed at approximately 30 rpm.

After 4 hours of mixing, the water in the jars was filtered through 0.45 micron filters[39] to remove the powdered media. Filtered water from each jar was divided into three aliquots and DOC concentrations were analyzed using a Sievers M9 TOC analyzer. Seven measurements were collected per aliquot and the first three measurements were rejected[40]. The baseline DOC concentrations (of the water prior to mixing with the media) were also measured at this time.

The DOC concentration in the filtered water from the jars containing ultrapure water and media was compared to the baseline DOC concentration in the ultrapure water to determine whether any organic matter was released from the media. This assessment was made by comparing boxplots of all non-rejected DOC measurements and comparing the average DOC concentrations.

To confirm whether or not a media type was adsorptive, the DOC concentration of sample water that had been in contact with each media type was compared to the initial DOC concentration in the pilot plant influent water. As with the ultrapure water comparisons, boxplots of all non-rejected DOC measurements as well as the average DOC concentrations were compared. The average DOC concentration of the filtered water from each jar was calculated from all non-rejected DOC measurements associated with that jar. Because water from three jars was analyzed per media type, an overall average and standard deviation for the DOC concentration associated with a given media type was calculated from the jar averages.

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[37] ZapCap 0.45 µm bottle top filters (ZapCap-CR BT NYL 0.45; Maine Manufacturing, Maine, USA).

[38] The shaker was built for this research and was similar to the one shown in Figure 1 of ASTM Standard D3987-12 (2012).

[39] ZapCap 0.45 µm bottle top filters (ZapCap-CR BT NYL 0.45; Maine Manufacturing, Maine, USA).

[40] The first three measurements were rejected because previous testing showed that the TOC readings were not stable for the first three measurements.

Due to unexpected results implying some adsorption of organic matter on the crushed anthracite (see section 3.3.2.2), an additional adsorption test was conducted on the anthracite media to confirm that adsorption of DOC onto crushed anthracite occurred and to determine if either undried crushed anthracite or granular (i.e. uncrushed) anthracite would also adsorb organic matter. For this test, a portion of the crushed dried anthracite that was prepared previously, as described above, was used. The same granular anthracite that was used to prepare the crushed dried anthracite was also used for the granular anthracite in this test and was used to prepare crushed undried anthracite[41]. A portion of anthracite was left in granular form (i.e. uncrushed) and a second portion was crushed using a mortar and pestle, but not dried. Between 0.9980 and 1.0001 g of each form of anthracite was placed in 200 mL glass jars, with a separate glass jar used for each form of anthracite. 200 mL of pilot plant influent water (the same water used in the previous adsorption experiments, which had stored been in a refrigerator at 4°C for approximately 2 days after the previous adsorption experiments had been completed) was placed in each jar. Three aliquots of pilot influent water were poured into TOC vials to allow the initial DOC concentration to be determined. All jars were placed on an end-over-end shaker and mixed at approximately 30 rpm. After 4 hours, the water in the jars was processed in the same fashion as for the other adsorption experiments (i.e. filtered through 0.45 micron filters and analyzed for DOC). The three aliquots of influent water in the TOC vials were also analyzed at the same time to determine the initial DOC concentration. To determine whether or not adsorption had occurred, the DOC concentration of sample water that had been in contact with each anthracite preparation (crushed and dried, crushed and undried, and granular) was compared to the initial DOC concentration in the pilot plant influent water.

3.2.5 Organic Matter Removal

Three different metrics were chosen to assess the removal of organic matter through the filters: dissolved organic carbon [DOC], assimilable organic carbon [AOC], and trihalomethane formation potential [THMFP]. DOC was chosen because it is an aggregate measurement of the total amount of dissolved organic carbon present in the water and dissolved organic carbon would be primarily removed through

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[41] i.e. the same source of granular anthracite was used for the granular anthracite, crushed dried anthracite, and crushed undried anthracite in this experiment.

The crushed dried anthracite had been prepared from a sample of granular anthracite that was taken from a bulk container containing the anthracite that was used in the pilot experiments. Crushed dried anthracite was prepared from a portion of this sample. The remaining sample was used as the source for the granular anthracite used in this adsorption experiment and was also used to prepare the crushed undried anthracite.

It should be noted that the anthracite used for adsorption experiments had not been used in the pilot plant and had a grain size distribution that was matched to the other media types.

microbial utilization or adsorption[42]. AOC was chosen because it can decrease the biostability of treated water (e.g. LeChevalier et al., 1991). THMFP was chosen because it is representative of the presence of DBP precursors.

3.2.5.1 Dissolved Organic Carbon

3.2.5.1.1 DOC Sampling and Lab Analysis

Samples for DOC analysis were collected from the pilot plant influent and from each filter effluent several times over a period of approximately 1.5 years. Table 3-4 (p 63) summarizes the sampling events, the date of sample analysis, the water temperature, the temperature classification (warm or cold water conditions), the number of samples collected from each sampling location, the number of aliquots analyzed from each sample, and a data set number assigned to each sampling event.

All glassware used for sampling and DOC analysis was washed in a dishwasher, soaked in a 10% HCl solution overnight, and rinsed with ultrapure water[43] to remove any potential DOC contamination prior to use.

Samples were collected from sampling ports on the pilot plant influent and filter effluents, approximately 24 hours after the filters had been backwashed. The ports were opened and water was allowed to flow through sampling lines for at least 15 minutes to ensure that fresh sample water was collected during each sampling event. Samples were collected in clean acid-washed 1 L glass bottles. The 1-L bottles were rinsed three times with sample water prior to sample collection.

As can be seen in Table 3-4, whenever possible, multiple bottles of sample water were collected as a quality control measure and to allow a larger number of DOC measurements to be made. Initially, two pilot influent samples and one filter effluent sample were collected. In later sampling events, the number of filter effluent samples was increased. In these cases, all samples were filled within a few minutes of each other to minimize the impact of any temporal differences in DOC concentration.

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[42] Total organic carbon [TOC] measurements were not used because TOC is the sum of the particulate and dissolved fractions of organic carbon present in the water. The particulate fraction of organic carbon (PartOC) can be removed through physicochemical mechanisms that would be present in both nonbiological and biological filters. If TOC measurements were used, it would not be known whether differences in organic matter removal between different media types were due to biological activity, adsorption, or removal of particulate matter. By using DOC, differences in organic matter removal can be attributed to differences in biological activity and/or adsorption. Furthermore, DOC measurements represent the majority of the TOC at this study location because approximately 90% of TOC present in flocculated ozonated water has historically been in the form of DOC (Camper et al., 2000, see pp. 129-132).

[43] Produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada)

All samples were transported back to labs at the University of Waterloo [UW] on ice. All samples, except for those associated with data sets 5, 27, and 28, were stored unpreserved at 4 °C and were analyzed within 1 week of collection. Samples from data set 5 were preserved by decreasing the pH to <2.0 using acid. Samples from data sets 27 and 28 were stored at 4 °C and analyzed approximately one month after collection because of analytical issues with the TOC analyzer.

Each sample was filtered into a second glass bottle using a 0.45 μm pore size filter[44]. Between 2 and 3 aliquots[45] of filtered sample (from each bottle) were placed in acid-washed 40 mL glass TOC vials for DOC analysis. They were analyzed using a NPOC protocol on a Shimadzu TOC-VCPH TOC[46] analyzer with a high sensitivity catalyst. The aliquots were acidified by the analyzer to a pH < 2 with HCl and sparged for 12 minutes with ultrapure oxygen to drive off inorganic carbon. The sparged samples were injected onto the catalyst and the organic carbon concentration was measured. Between three and five measurements of DOC concentration were obtained from each vial. The "best" three of up to five measurements[47] were averaged to give the DOC concentration of each aliquot of sample.

[44]Initially 47 mm diameter Nylaflo filters were used with a glass filtration apparatus (NYLAFLO 0.45 μm filters; VWR, Canada). In later sampling events, ZapCap 0.45 μm bottle top filters were used to improve efficiency (ZapCap-CR BT NYL 0.45; Maine Manufacturing, Maine, USA).

[45] The number of aliquots of sample analyzed was also increased in later sampling events as a result of improvements in lab efficiency.

[46] Mandel Scientific, Guelph, Ontario

[47]The best three of up to five measurements was chosen based on the recommendations of the TOC analyzer supplier. In this mode of operation, the analyzer takes three measurements and the analyzer's software will compare the standard deviation of the measurements to a specified set-point. If the standard deviation is smaller than the set-point, the results are accepted. If the standard deviation of the measurements is greater than the set-point, an additional measurement is taken and the measurement which contributes the greatest variability to the average measurement (i.e. the measurement which deviates the most from the other measurements) is excluded. The standard deviation of the remaining three measurements is calculated and compared to the set-point. If the standard deviation is still larger than the set-point, a fifth measurement is taken and the two measurements which deviate the most from the other measurements are excluded. The results are then accepted and the average and standard deviation of the "best three of five" measurements is calculated. The benefit of this mode of operation is that outliers due to analyzer operation or unforeseen events (such as vibration near the analyzer) are automatically excluded. Considerable care was taken to ensure that the analyzer was in good working order and that the analyzer gave stable and reproducible results; as a result, only three measurements were needed for many of the analyses conducted. The set-point used was a standard deviation less than or equal to 2% of the average measurement.

Table 3-4: DOC sampling dates and details

Data Set	Collection Date (mm/dd/yyyy)	Analysis Date (mm/dd/yyyy)	Water Temperature (°C)	Temperature classification*	Sampling Locations	Number of bottles of sample water collected per location	Number of aliquots analyzed per bottle
1	12/07/2011	12/09/2011	6.25	Cold	Influent	2	3
					F1-F5 Effluents	1	3
2	01/17/2012	01/19/2012	2.00	Cold	Influent	2	2
					F1-F5 Effluents	1	2
3	01/26/2012	02/02/2012	2.00	Cold	Influent	2	3
					F1-F5 Effluents	1	2
4	01/30/2012	02/02/2012	2.00	Cold	Influent	2	3
					F1-F5 Effluents	1	2
5	03/01/2012	03/19/2012	3.30	Cold	Influent	2	2
					F1-F5 Effluents	2	2
6	03/05/2012	03/05/2012	2.80	Cold	Influent	2	2
					F1-F5 Effluents	2	2
7	03/15/2012	03/17/2012	4.35	Cold	Influent	2	3
					F1-F5 Effluents	2	3
8	03/21/2012	03/21/2012	9.50	Warm	Influent	2	2
					F1-F5 Effluents	2	2
9	04/02/2012	04/04/2012	9.25	Warm	Influent	2	3
					F1-F5 Effluents	2	3
10	04/12/2012	04/13/2012	9.80	Warm	Influent	2	3
					F1-F5 Effluents	2	3
11	04/24/2012	04/26/2012	12.95	Warm	Influent	2	3
					F1-F5 Effluents	2	3
12	06/07/2012	06/08/2012	17.90	Warm	Influent	2	3
					F1-F5 Effluents	2	3
13	06/09/2012	06/12/2012	21.10	Warm	Influent	2	2
					F1-F5 Effluents	2	2
14	06/19/2012	06/20/2012	24.60	Warm	Influent	2	3
					F1-F5 Effluents	2	3
15	06/21/2012	06/27/2012	27.40	Warm	Influent	2	3
					F1-F5 Effluents	2	3
16	06/27/2012	06/28/2012	24.30	Warm	Influent	2	3
					F1-F5 Effluents	2	3
17	07/17/2012	07/23/2012	27.70	Warm	Influent	2	3
					F1-F5 Effluents	1	3
18	07/29/2012	07/30/2012	-[1]	Warm	Influent	2	3
					F1-F5 Effluents	2	3
19	07/31/2012	07/31/2012	26.95	Warm	Influent	2	3
					F1-F5 Effluents	2	3
20	08/14/2012	08/15/2012	24.50	Warm	Influent	2	3
					F1-F5 Effluents	1	3
21	08/16/2012	08/17/2012	24.65	Warm	Influent	2	3
					F1-F5 Effluents	2	3
22	08/20/2012	08/21/2012	24.05	Warm	Influent	2	3
					F1-F5 Effluents	2	3
23	09/25/2012	09/27/2012	16.90	Warm	Influent	2	3
					F1-F5 Effluents	2	3
24	10/09/2012	10/10/2012	15.20	Warm	Influent	2	3
					F1-F5 Effluents	2	3
25	10/11/2012	10/12/2012	12.90	Warm	Influent	2	3
					F1-F5 Effluents	2	3
26	10/13/2012	10/13/2012	11.60	Warm	Influent	2	3
					F1-F5 Effluents	2	3
27	06/10/2013	07/11/2013	-[1]	Warm	Influent	3	3
					F1-F5 Effluents	3	3
28	06/14/2013	07/12/2013	18.60	Warm	Influent	3	3
					F1-F5 Effluents	3	3

1. Temperature not measured
2. A temperature classification of "Cold" indicates cold water conditions, wherein the influent water temperature was less than 10°C. A temperature classification of "Warm" indicates warm water conditions, wherein the influent water temperature was greater than or equal to 10°C.

3.2.5.1.2 DOC Data Analysis

DOC data from each sampling event were summarized, plotted, and reviewed to identify any potential outliers or erroneous results. Results from multiple bottles and aliquots from each sampling location were compared to check for laboratory errors or potential contamination. When it was suspected that the readings from a given bottle or aliquot were erroneous, results from that bottle or aliquot were excluded from further analysis. When potential contamination or analytical errors were identified and it was unclear which results from the sampling location (if any) were correct, all samples from that sampling location were excluded from further analysis.

A single factor analysis of variance [ANOVA] was conducted for each sampling event to: (a) evaluate DOC removal by the filters, (b) compare DOC removal between the media types, and (c) compare DOC removal by declining-rate and constant-rate modes of operation. Thus, in the ANOVAs, six treatments were used: influent water (Inf; no treatment), Filter 1 (F1; coal-based GAC), Filter 2 (F2; anthracite), Filter 3 (F3; REC), Filter 4 (F4; wood-based GAC), and Filter 5 (F5; coal-based GAC, declining rate mode). DOC concentration was the response variable and aliquots were considered to be replicates. The residuals from the ANOVA were reviewed for normality, homoscedasticity, and trends to determine whether the ANOVA was valid. Normal probability plots were used to assess normality. The modified Levene's test and residual plots were used to check for homoscedasticity. Residual plots were used to check for trends in the residuals. Where appropriate, additional outliers were identified and removed from the data. It should be noted that every attempt was made to use an entire data set and additional outliers were removed only in 4 cases (these additional data points were not removed solely because they were identified as outliers using statistical techniques; there are detailed reasons why these additional data points were removed and why the removal was considered acceptable. See Appendix B, data sets 4, 20, 27, and 28 for further explanation). P-values for all possible comparisons were calculated using either Tukey's test or Dunnett's T3 (Dunnett, 1980) test to determine if differences in DOC concentration were statistically significant[48]. Comparisons of influent DOC concentrations to effluent DOC concentrations indicated whether or not DOC was removed by the filters. Comparisons of effluent DOC concentrations among the filters containing different media types indicated whether a given media type provided better

[48] Dunnett's T3 test can be used if the data are heteroscedastic (i.e. the quantities being compared do not have the same standard deviation) whereas Tukey's test assumes a homogeneous variance (i.e. the quantities being compared have the same standard deviation). Dunnett's T3 test was used if the null hypothesis of Levene's test was rejected at a significance level of 0.1 or if heteroscedasticity was suspected based on a visual inspection of the residuals, otherwise Tukey's test was used. Readers who are unfamiliar with the Dunnett's T3 test are referred to Hochberg & Tamhane (1987, pp 188-192) for a brief discussion and a worked example illustrating the procedure.

DOC removal than the other media types[49]. Comparisons of effluent DOC concentrations between the declining-rate filter (Filter 5) and the constant-rate filters indicated whether operating a filter in declining rate could increase DOC removal. All statistical calculations for the individual ANOVAs and associated multiple comparisons were conducted using SPSS Statistics 21and 22[50].

The results from comparisons of filter effluents among filters containing different media types and among the filters operated in different modes were summarized by tabulating the number of times each filter performed statistically better than, statistically worse than, or not statistically different than another filter[51]. A p-value of 0.05 was used as the significance level for what was considered statistically different. A sign test was conducted on the tabulated results to determine whether one media type or mode of operation provided better overall DOC removal than another. In the sign tests, a "success" for a given comparisons was defined as when the ANOVA indicated that one filter had a statically lower DOC concentration than another and a "failure" was defined as when the opposite filter had a lower DOC concentration. Instances where DOC removal was considered the same (i.e. the effluent DOC concentrations were not statistically different) were ignored (as required for the sign test: see Conover, 1980). P-values were calculated for each sign test and were multiplied by the total number of comparisons conducted to control for experiment-wise error (i.e., a Bonferroni correction was used). One media type or mode of filter operation was considered to have provided better overall performance than another if the p-value from the sign test was small[52]. Sign test calculations were conducted in SPSS.

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[49] It should be noted that a direct comparison of the filter effluent DOC concentrations between two filters indicates which filter provides better DOC removal because (a) all filters were fed the same influent water and (b) each set of effluent water samples were collected from all filters at the same time.

[50] IBM

[51] See Table 3-18 in the results section.

[52] The p-value from a sign test indicates the probability of getting the observed number of "successes" (i.e. a given number of observed results) assuming that there is truly a 50% probability of observing a successes. If the p-value is low, it indicates that there is a low probability of getting the observed results, assuming that there is truly a 50% probability of observing a success; therefore, it can be concluded that there is not truly a 50% probability of observing a success. Practically, if there was no overall difference in DOC removal provided by two filters and if the observed differences in DOC removal were just due to random chance, one filter would be expected to provide better DOC removal than the other approximately 50% of the time and the opposite would be expected to be seen the other 50% of the time. If (a) multiple comparisons of the DOC removal were conducted, (b) a sign test was conducted on the results from the multiple comparisons, and (c) the p-value of the sign test was low, it would indicate that the probability that the difference in DOC removal was simply due to random chance was very low. Therefore, it could be concluded that one media type was providing better removal of DOC more than 50% of the time and, thus, that media type could be considered to provide better overall DOC removal than the other media type.

3.2.5.2 AOC Removal

3.2.5.2.1 General Methodology

AOC was evaluated in the common filter influent and from each filter effluent on March 21, 2012, April 12, 2012, June 27, 2012, August 8, 2012, and August 14, 2012. The samples were collected in glass bottles that had been acid washed and were transported to the UW lab on ice for immediate analysis. Samples were processed as per Standard Method 9217 B (Eaton et al., 2005), with the following modifications:

- The stock *Pseudomonas fluorescens* strain P-17 (hereafter referred to as P-17) and *Spirillum* strain NOX inocula were grown in an autoclaved solution containing sodium acetate and mineral salts instead of in autoclaved sample water. This was done to standardize the solution used to grow the inocula. The composition of the solution was slightly modified after the second sampling event. The compositions and volumes of the solution used are provided below.
- For the first two sampling events, the inocula were grown in 50 mL of the following solution: 11.4 mg/L sodium acetate trihydrate (2.01 mg-C/L), 7.0 mg/L K_2HPO_4, 3.0 mg/L KH_2PO_4, 0.1 mg/L $MgSO_4 \cdot 7\ H_2O$, 1.0 mg/L NH_4SO_4, 0.1 mg/L NaCl, and 1.0 µg/L $FeSO_4$. This composition was based off of a solution used in LeChevallier et al. (1993) and differs from LeChevallier (1993) only in that 11.40 mg/L of sodium acetate trihydrate was used instead of 11.34 mg/L.
- For the remaining three sampling events, the inocula were grown in 30 mL of the following solution: 5.667 mg/L sodium acetate trihydrate (1.000 mg-C/L), 7.0 mg/L K_2HPO_4, 3.0 mg/L KH_2PO_4, 0.1 mg/L $MgSO_4 \cdot 7\ H_2O$, 1.0 mg/L NH_4SO_4, 0.1 mg/L NaCl, and 1.8 µg/L $FeSO_4 \cdot 7\ H_2O$. The composition of this solution differs from that used in LeChevallier et al. (1993) only in the amount of sodium acetate and iron sulfate used. The modified composition and volume were provided by Dr. Michele Van Dyke (personal communication) and was adopted as part of attempts to improve the efficiency and reliability of AOC lab procedures.
- The procedures for cleaning glassware, Teflon-lined septa, and caps were modified. Glassware was soaked overnight in 1.2 N HCl, after being washed, instead of being rinsed with 0.1 N HCl. Teflon-lined septa and caps were soaked overnight in 1.2 N HCl instead of being soaked in a 10% sodium persulfate solution at 60 degrees C for 1 hour.
- Samples were collected in 1-L glass bottles that had been washed with detergent, rinsed with hot water, soaked in a 1.2 N HCl acid bath overnight, rinsed 3x with ultrapure water, and rinsed three times with sample water at the time of collection. The bottles were not heated in to 550 degrees C for 6 hours, as is specified in Standard Method 9217 B for glassware cleaning, because the glass bottles would break during heating.
- Sample water was poured from the 1-L glass bottles into the vials used for AOC testing.
- Inoculated samples were incubated at 21°C.
- An additional six vials of sample water were inoculated and processed for several samples to provide redundancy in case the P-17 and NOX had not reached stationary phase by the ninth day of incubation. This also provided additional data. This was done for samples from the effluent of

Filters 1 and 2 on the March 21 sampling event and was done for all samples on the June 27, August 8, and August 14 sampling events. Three of these additional vials were plated on the tenth day of incubation and the remaining three vials were plated on the eleventh day of incubation.

- Incubated samples were not plated in duplicate.

In brief, the samples were processed as follows. Sample water from each bottle was poured into 45 mL vials that had been cleaned and baked in a 550 degree oven for 6 hours. Each 45 mL vial was filled to the shoulder with sample water and capped with a Teflon-backed silicone septum. The filled vials were placed in a water bath and pasteurized at 70 °C for 30 minutes. The vials were allowed to cool to room temperature, were placed in a biosafety cabinet[53], and were inoculated with approximately 500 CFU/ mL of P-17 and NOX. The vials were inoculated on the same day that the samples were pasteurized except on the March 21, 2012 sampling event; on the March 21, 2012 sampling event, the samples were pasteurized on the same day that they were collected and were inoculated the next day. The inoculated samples were sealed and incubated at 21 °C. On days 7, 8, and 9, three vials were taken out of the incubator. Serial dilutions of the incubated samples were made using the mineral salt solution that was used to grow the inoculum for dilution water, without the sodium acetate added to the solution. When extra vials were prepared, an additional three vials were taken out of the incubator and diluted on days 10 and 11. The diluted samples were plated on R2A agar and incubated at 21 °C until countable colonies of P-17 and NOX had formed. The number of colonies on each plate was manually enumerated and the AOC concentrations associated with each sample were calculated from the plate counts. Plates with very high colony densities were deemed as too numerous to count (TNTC). In cases where confluent growth occurred or where the plate was severely contaminated by other colonies, the counts were excluded from analysis.

3.2.5.2.2 Quality Control

3.2.5.2.2.1 Quality Control Measures Recommended by Standard Methods

Growth control, yield control, and blank control samples were also prepared and analyzed, as per standard method 9217 B (Eaton et al., 2005), with the following modifications:

- Additional control sample vials were created and analyzed during each sampling event. This provided replication and redundancy for the control samples.

[53] Microzone BK-24; Microzone Corporation, Ottawa, On.

- During the first two sampling events, an alternative diluted mineral salt solution was used. The alternative dilute mineral salt solution was the mineral salts portion of the solution used to grow the inoculum (i.e. 7.0 mg/L K_2HPO_4, 3.0 mg/L KH_2PO_4, 0.1 mg/L $MgSO_4 \cdot 7\ H_2O$, 1.0 mg/L NH_4SO_4, 0.1 mg/L NaCl, and 1.0 μg/L $FeSO_4$). In the remaining three sampling events, the dilute mineral salt solution used was the one specified in standard methods[54].
- Sodium thiosulfate was not added to blank or yield controls because sodium thiosulfate was not used with the samples.
- On the March 21, 2013 sampling event, select control vials were re-plated on a second day.
- When undiluted, inoculated, incubated water from a control sample was plated, the sample was plated multiple times to create replicate plates.

Blank controls consisted of ultrapure Milli-Q water[55] spiked with mineral salts[56]. The purpose of blank controls was to check for background carbon contamination of glassware. Yield controls consisted of Milli-Q water spiked with mineral salts and with AOC in the form of sodium acetate. The purpose of yield controls was to confirm that the yield of microorganisms for a given amount of AOC was similar to the value used for used for calculating AOC values[57]. Growth controls consisted of sample water spiked with mineral salts and sodium acetate. The purpose of growth controls was to help confirm that the samples were carbon-limited and not inhibitory to the test microorganisms. It should be noted that according to Standard Method 9217B (Eaton et al., 2005), diluted mineral salt solution is to be used in the creation of growth controls. It is unclear, however, whether undiluted or diluted mineral salt solution should be used in the creation of the blank and yield controls; in this study, it was assumed that diluted mineral salt solution should be used to provide consistency with the growth control. All controls were processed in a similar manner to samples.

[54] In Standard Methods the diluted mineral salt solution is a 10:1 dilution of the stock mineral salts solution specified in the AOC method. See subsection 3 g) of method 9217B (Eaton et al., 2005) for the composition of the stock mineral salts solution and section 6 a) (Blank control) of the same method for the text mentioning diluting the stock mineral salts solution.

[55] Produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada)

[56] Mineral salts consisted of salts that would provide nutrients and micronutrients to the P-17 and NOX.

[57] It should be noted that the yield control only provides an approximate check on this value and is only meant, along with the other controls, as a "troubleshooting guide" (Eaton et al., 2005, p 9-46).

3.2.5.2.2.2 Additional Quality Control Measures

In addition to the quality control measures specified in Standard Methods (Eaton et al., 2005), replicate influent samples were collected and, in four of the sampling events, a process blank was created and analyzed. The replicate influent samples were collected to allow the reproducibility of the AOC method to be assessed. The process blank was collected to check for potential contamination during sampling and transport.

The replicate influent samples consisted of a second bottle of influent water that was collected within minutes of the first bottle being collected. The replicate influent samples were processed in the same manner as the other samples.

The process blank consisted of a 1-L glass sampling bottle. The sampling bottle was transported to the site with the other sampling bottles, was opened to the air for the length of time it took to collect one sample, and was transported back to UW. The process blank bottle was then filled with 1-L of a mineral salt solution with the same composition as the blank controls. The mineral salt solution used for the process blank introduced organic-carbon-free water and nutrients to the bottle. The water in the process blank bottle was then processed as a normal sample. Any AOC detected in the process blank would have been due to AOC contamination introduced during the AOC sampling and analysis procedure: either due to insufficient cleaning, contamination during sampling and transport, or contaminated reagents. Including the process blank helped ensure that the results were not biased by such contamination.

3.2.5.2.3 Calculation of AOC Concentrations from Plate Counts

To calculate the AOC concentration, the concentration of microorganisms in a sample was calculated from the plate count data. Plate counts between 30 and 300 were used to calculate the concentration of microorganisms, with the following exceptions: (a) for samples, a count slightly higher than 300 was used if count was less than 350 CFU and counts between 30 and 300 were not observed for any of the dilutions, (b) for process blanks, counts less than 30 were used during the March 21, 2013 and August 8, 2013 sampling events because the majority of the reliable counts were below 30, (c) for blank controls, all reliable counts for undiluted sample were used and averaged because the counts were low, (d) for blank controls, the count was considered to be zero if the counts at all dilution levels were zero and if the count for all plates plated with undiluted blank water was zero, (e) for yield controls, all reliable counts for undiluted samples were used when there were no counts between 30 and 300 at the higher dilutions, (f) for yield control vial 5 on the August 8, 2012 sampling event, a count of 423 was used due to the lack of other reliable counts at other dilution levels, and (g) for yield control vials on the August 14, 2012

sampling event, some counts associated with undiluted sample that were greater than 300 were used because these counts were considered more reliable than the very low counts at higher dilutions. When two plates both had counts between 30 and 300, Boxplots were created to determine if one of the two values could be considered an outlier. All Boxplots were created using SPSS 22. Outliers were defined as values that were beyond the 25^{th} or 75^{th} percentiles by a value greater than 1.5 times the interquartile range between the 25^{th} and 75^{th} percentiles[58]. If neither value was considered an outlier, the largest count was used. The concentration of microorganisms was calculated from the counts and dilution factors used.

The AOC concentration in each vial containing inoculated, incubated sample water was calculated for each vial where reliable P-17 and NOX count data were available. The AOC associated with P-17 and NOX were calculated separately, for each vial, using the following conversion factors: $4.1x10^6$ CFU-P-17/μg acetate-C and $2.9x10^6$ CFU-NOX/μg oxalate C (Eaton et al., 2005). The total AOC concentration for each vial was calculated by summing the AOC associated with P-17 and NOX, for that given vial[59]. The mean, median, and standard deviation of the total AOC concentrations from all vials associated with a given sample were calculated as summary statistics; however, only the mean and standard deviation will be presented in the results portion of this thesis[60] [61]. The same procedures were used to calculate the AOC concentrations for the process blanks and the control samples

3.2.5.2.4 Data Analysis Related to Samples

A Mann-Whitney test, a Kruskal-Wallis test, and a series of Mann-Whitney tests were performed on the AOC results from each sampling event to determine whether there was a statistically significant difference between the influent AOC concentrations measured from the replicate influent bottles, whether there was a statistically significant difference between the influent and each filter effluent (i.e., whether

[58] As described in Sheskin (2007, pp 40-44). See discussion on the calculation of the "inner fence" for identifying outliers.

[59] It should be noted that the total AOC concentration could only be calculated for a given vial if both P-17 and NOX AOC concentrations were available for that vial. If either P-17 or NOX AOC concentrations were unavailable due to contaminated plates or low counts, the total AOC could not be calculated.

[60] The median values are available in Appendix C, for the interested reader. It is noted that, for most cases, the mean and median values were close to each other and, therefore, reporting just one of these values acceptable.

[61] It should be noted that this procedure deviates from the one recommended in Standard Method 9217B (Eaton et al, 2005). Eaton et al (2005) recommend separately averaging the P-17 concentration and NOX concentrations from all vials associated with a given sample, applying the AOC conversion factors to the average values, and summing the P-17 and NOX AOC to get a total AOC value. The benefit of using the procedure outlined in this thesis is that a total AOC value is available for each vial and, thus, statistical analysis can be done using the total vial AOC concentrations. It should also be noted that the two procedures give the same total average AOC concentration when both P-17 AOC and NOX AOC values are available for all vials.

AOC was removed), and whether there were statistically significant differences between the filter effluent AOC concentrations (i.e. a difference in AOC removal provided by the different media types and the different modes of operation). The details of the tests are summarized in Table 3-5. It is highlighted that all of the tests listed in Table 3-5 were conducted for each sampling event.

The Mann-Whitney and Kruskal-Wallis tests are non-parametric analogues to t-tests and analysis of variance (ANOVA), respectively. Mann-Whitney tests and the Kruskal-Wallis test were used instead of t-tests and ANOVA because t-tests and ANOVA are both based on the assumption that the data are normally distributed, whereas the Mann-Whitney and Kruskal Wallis tests do not require this assumption. Microbial count data are not normally distributed and, therefore, AOC concentrations calculated from individual microbial counts (i.e. the AOC concentrations calculated for each vial) were also expected to non-normally distributed. Details on the Mann-Whitney test and Kruskal-Wallis test can be found in Conover (1980). Calculations were conducted using SPSS 22.

Table 3-5: Details of AOC data analysis

ID for (Set of) Test(s)	Test	Details	Data used from each sampling event	Null (Ho) and Alternative (H1) Hypothesis	Significance level[1] used and rationale
1	Mann-Whitney test on the influent concentrations	A Mann-Whitney test was performed to determine whether there was a statistically significant difference between the AOC concentrations measured for replicate influent samples. If there was no statistically significant difference in AOC concentration between the two replicates, data from the two influent samples were pooled prior to use in the subsequent tests.	Total AOC concentration calculated for each vial from: (a) Influent replicate 1 and (b) Influent replicate 2.	Ho: That the AOC concentrations came from distributions that were the same. H1: That the AOC concentrations came from distributions that were the same.	A significance level of 3.125×10^{-3} was used for this test to control the family-wise significance level at 0.05. Between test sets 1, 3, and 4, a total of 16 statistical comparisons were conducted on the data set from a given sampling event. To control the family-wise Type I error at 0.05, each test had to be performed at a significance level of $0.05/16 = 0.003125 = 3.125 \times 10^{-3}$.
2	Kruskal-Wallis test	A Kruskal-Wallis test was performed to determine whether there was a statistically significant difference between AOC concentrations measured at any of the following locations: the filter influent, Filter 1 effluent, Filter 2 effluent, Filter 3 effluent, Filter 4 effluent, Filter 5 effluent. "Influent/Filter" was used as the treatment. The influent and each of the filters were used as a treatment levels. If there was a statistically significant difference, this test was followed-up by test sets 3 and 4.	Total AOC concentration calculated for each vial from: (a) The pooled influent data, if there was no statistically significant difference between the influent replicates, or one of the influent replicates (randomly chosen) if there was a difference, (b) Filter 1 effluent, (c) Filter 2 effluent, (d) Filter 3 effluent, (e) Filter 4 effluent, and (f) Filter 5 effluent.	Ho: AOC concentrations from all treatment levels (i.e. Influent, Filter 1 effluent, Filter 2 effluent, etc.) come from the same distribution. H1: AOC concentrations from one (or more) of the sampling locations come from a distribution that provides higher or lower AOC concentrations than the other treatments.	This test was used as a screening test to determine if the remaining tests should be conducted; therefore, a significance level of 0.05 was considered appropriate.
3	Mann-Whitney tests on the influent AOC concentrations and the filter effluents	A series of Mann-Whitney tests were conducted. Each Mann-Whitney test compared the AOC concentration in the influent to the AOC concentration in a given filter effluent to determine if that filter provided removal of AOC. The influent AOC concentration was compared to the effluent AOC concentration for each filter, resulting in a total of 5 tests per sampling event.	Total AOC concentration calculated for each vial from: (a) The pooled influent data, if there was no statistically significant difference between the influent replicates, or one of the influent replicates (randomly chosen) if there was a difference, (b) Filter 1 effluent, (c) Filter 2 effluent, (d) Filter 3 effluent, (e) Filter 4 effluent, and (f) Filter 5 effluent.	Ho: AOC concentrations in the influent and the filter effluent came from distributions that were the same (i.e. there is no difference in AOC concentration). H1: AOC concentrations in the influent and the given filter effluent did not come distributions that were the same. H1': If the difference in the distributions is primarily due to a difference in distribution location (i.e. one distribution is shifted towards higher or lower values), then the mean influent and effluent concentrations are different.	Same as for Test set 1
4	Mann-Whitney Tests on the influent concentrations	A series of Mann-Whitney tests were conducted. Each Mann-Whitney test compared the effluent AOC concentration of one filter to the effluent AOC concentration of another filter to determine if one filter provided better AOC removal than the other. The effluent AOC concentration of each filter was compared to the effluent AOC concentration of all other filters, resulting in a total of 10 tests per sampling event.	Total AOC concentration calculated for each vial from: (a) The pooled influent data, if there was no statistically significant difference between the influent replicates, or one of the influent replicates (randomly chosen) if there was a difference, (b) Filter 1 effluent, (c) Filter 2 effluent, (d) Filter 3 effluent, (e) Filter 4 effluent, (f) Filter 5 effluent	Ho: AOC concentrations from two filter effluents came from distributions that were the same (i.e. there is no difference in AOC concentration). H1: AOC concentrations from two filter effluents did not come from distributions that were the same. H1': If the difference in the distributions is primarily due to a difference in distribution location then the mean influent and effluent concentrations are different.	Same as for Test set 1.

1. P-values were also calculated and inspected for each of the tests, even though a significance level was used for decision making.

3.2.5.2.5 Data Analysis Related to Quality Control Measures

The average and standard deviation of the total AOC concentrations for blank controls and process blanks were calculated. These values were reviewed to determine whether there was any contamination during the sampling and analysis. The results from Test set 1 were reviewed to determine whether the AOC tests provided reproducible results across different bottles. The average AOC concentration of the yield controls were also reviewed and compared to the blank control average AOC concentration to assess whether the AOC yield on the acetate was similar to the theoretical concentration of 100 μg/L. Finally, the results from the growth controls and samples were compared to the blank controls and yield controls, as recommended by Standard Method 9217B (Eaton et al., 2005), to determine whether the samples were carbon limited or not and whether the samples were inhibitory to the test organism.

3.2.5.3 Trihalomethane Formation Potential Reduction

3.2.5.3.1 Sampling and Analysis

Trihalomethane formation potential [THMFP] provides an indirect measure of the organic matter that contributes to the formation of trihalomethanes [THMs]. Sampling events were conducted on June 6, 2013 and June 10, 2013 to determine whether THMFP was reduced by the filters, to compare the reduction of THMFP between the filters containing different types of media, and to compare the reduction of THMFP between filters operated in declining rate and constant head modes. On each sampling event, several samples were collected from the common filter influent and each filter effluent. On the June 6, 2013 sampling event, three bottles were collected from each sampling location. On the June 10, 2013 sampling event six bottles were collected from each sampling location. Additional bottles were collected on the second sampling event to provide more data and to improve the chances of detecting differences in THMFP, in case no differences in THMFP were detected during the first sampling event. The samples were shipped in coolers to SGS Canada Inc[62] for THMFP analysis.

THMFP was analyzed as follows (C. Sullivan, personal communication, August 5, 2014). An aliquot of sample water was tested to allow the amount of chlorine required for the main test to be estimated. The remaining sample water was then spiked with an amount of chlorine that was projected to result in a final free chlorine concentration of 3-8 mg/L at the end of the test. The sample water and chlorine were allowed to react for seven days in the dark at room temperature. The concentrations of chloroform [CF], bromoform [BF], bromodichloromethane [BDCM], and dibromochloromethane [DBCM] were analyzed

[62] 185 Concession Street, P.O. Box 4300, Lakefield Ontario, Canada K0L 2H0

by GC-MS at the end of the test, after the samples had reacted for seven days. The samples had not been exposed to chlorine prior to the THMFP test; therefore, the formation potential for each of these compounds was taken to be the final concentration at the end of the reaction period. The total THMFP was calculated as the sum of the formation potential of all four component THMs. The total THMFP, CF formation potential, BF formation potential, BDCM formation potential, and DBCM formation potential were reported. The amount of chlorine added to the samples and the final free chlorine concentration were also reported.

3.2.5.3.2 Data Analysis

The data were initially plotted to allow visual inspection of the data and to identify any trends in the data. The mean and standard deviation of the formation potential concentrations was calculated for each trihalomethane and sampling event. Boxplots were also created, in select cases, to help identify outliers. A one-way ANOVA was conducted on the CF, BDCM, BDCM, and total THMFP data from each of the sampling events to determine whether the formation potentials differed across one or more sampling location (i.e. influent, Filter 1 effluent, Filter 2 effluent, Filter 3 effluent, Filter 4 effluent, and Filter 5 effluent). In each ANOVA, the sampling location was used as the treatment and the formation potential was used as the response variable. The ANOVA was conducted at a significance level of 0.05. Levene's test was conducted to check the homogeneity assumption for the ANOVA. Normal probability plots, plots of the residuals from the ANOVA versus the predicted values, and plots of the residuals from the ANOVA versus sampling location were also created and reviewed to determine whether any of the other ANOVA assumptions were violated.

When the ANOVA indicated that the formation potential was different in one or more locations, a series of multiple comparisons were conducted to determine (a) whether THMFP was reduced through the filters, (b) if the reduction in THMFP was greater for one media type than another, and (c) to determine whether the reduction in THMFP was greater for the filter operated in declining rate mode than the filters operated in constant head mode. If the results from Levene's test indicated that the ANOVA's homogeneity of variance assumption was not violated, then Tukey's test was used for the multiple comparisons. If Levene's test indicated that the ANOVA's homogeneity of variance assumption was violated, then Dunnett's T3 test was used for the multiple comparisons.

3.2.6 Headloss Performance

The headloss across the filters containing coal-based GAC, anthracite, REC, and wood-based GAC, all operated in constant-head-constant rate mode, was monitored using differential pressure transducers.

Readings were recorded every five minutes, continuously, throughout the experimental period. The headloss measurements were measured in units of inches of water and were converted to centimeters of water. The headloss values were analyzed to determine which media types provided the best performance with regards to headloss.

3.2.6.1 Defining the "Best" Headloss Performance

Defining the criteria that indicated the "best" headloss performance and determining a method for comparing the performance was somewhat challenging. Two different metrics were initially considered for comparing headloss performance: the headloss at the end of a filter cycle and the rate of headloss development (as indicated by the slope of a line on a plot of headloss versus time). The headloss at the end of a filter cycle could not be directly compared between the filters, in all cases, because the pressure transducers could only measure a maximum differential pressure (i.e. a maximum headloss) of 305 cm of water (120"). It was found that the terminal headloss (i.e. the headloss at which the flow through the filters could not be maintained at the target rate of 3.0 L/min) was greater than the maximum headloss which could be measured by the pressure transducers. In many cases, 305 cm of headloss was reached well before the end of the filter cycle, and therefore, the actual headloss at the end of the filter cycle could not be measured. The easiest way of comparing the rate of headloss development was plotting the headloss data with respect to time, estimating the slope of a line that represented the data, and comparing the slopes of the lines. Unfortunately, plots of the headloss data with respect to time were not always linear, making the use of a line to represent the data inappropriate in these cases. Furthermore, the headloss data were not normally distributed, were heteroscedastic, and were autocorrelated (analysis not shown); assumptions of normality, homoscedasticity, and/or independence (i.e. that the data are not autocorrelated) are built into many statistical procedures for estimating the slope of a line. Therefore, even in cases where the data were fairly linear, the slope of the line could not be properly estimated through standard procedures such as linear regression[63].

[63] A separate study was conducted on select headloss data to investigate the applicability of different types of statistical models for modelling headloss development and to attempt to identify a `model that could be used to quantify the rate of headloss development (Spanjers, 2013). In the study, simple linear models, autoregressive integrated moving average (ARIMA) models, transfer-function-noise (TFN) models, contemporaneous autoregressive moving average (CARMA) models, and linear models estimated using non-parametric linear regression were all assessed. It was found that most of the models were inappropriate for use in modelling and comparing the headloss data. Linear models using non-parametric linear regression (using the Theil-Sen method) were found to represent the headloss data well but the assumption of randomly distributed residuals (i.e. independence) was violated. Some areas for further investigation and research that were identified included: identification of estimators for TFN models that do not require data to be normally distributed or homoscedastic; investigation of the robustness of the Theil-Sen method to autocorrelation; investigation of methods of modifying

Ultimately, an ordered set of criteria was used to determine which media type provided better performance with respect to headloss when compared to another. These criteria were as follows:

1. First, it was determined whether the maximum measureable headloss was reached in a given filter cycle. If the maximum measureable headloss was reached, the time at which the maximum measureable headloss was reached was recorded. The maximum measurable headloss was considered to be reached only if ten or more measurements in a row were all at the maximum measurable headloss value of 305 cm.
2. Second, if maximum headloss was not reached, the headloss at the end of the filter cycle was recorded. The end of the filter cycle was defined as the time at which the filters were backwashed (generally, 40-48 hours after the filter cycle started).
3. Third, the headloss development between each set of filters was compared using the following logic:
    a. If both filters being compared reached the maximum measureable headloss, then the time at which the maximum measurable headloss was reached was compared. The filter which reached the maximum measurable headloss at the latest time had the slowest rate of headloss development and, therefore, was considered to have the best performance.
    b. If one filter reached the maximum measureable headloss and the other filter did not, the filter which did not reach the maximum measurable headloss was considered to have the slowest rate of headloss development and was considered to have the best performance.
    c. If both filters did not reach the maximum measureable headloss, the headloss measured from each of the filters at the end of the filter cycle was compared. The filter which had the lowest headloss was considered to have the lowest rate of headloss development and was considered to have the best performance.

The criteria outlined above allowed the filter which reached maximum headloss first or had the highest headloss at the end of the filter cycle to be identified: this provided a practical approach for comparing headloss, which overcame the limitations of the pressure transducers.

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the Theil-Sen method to account for autocorrelation; further testing the Theil-Sen method on other headloss data to assess practical applicability of this method; investigation of other robust, nonparametric methods of regression for simple linear models; and investigation of methods that test for parallelism of lines and that do not require a model to be fit to the data. The full report is available from the author, upon request.

3.2.6.2 Data Analysis

The headloss data from each filter cycle was plotted with respect to time and reviewed. The headloss at the end of the filter cycle or the time at which maximum measureable headloss was observed was determined for each filter cycle. The headloss performance was compared between all four filters, using the criteria outlined in the previous section.

The number of times each filter performed better than another was counted. Data collected from the following periods were excluded from these counts:

- data collected when maintenance was conducted on the filters or the pressure transducers
- data collected when there were unexplained flow perturbations or when flow data were uncertain (e.g. due to issues with the pilot plant SCADA or the actuators on the pilot plant),
- data collected when there were major water sampling events,
- and data collected when there were biomass sampling events.

It should be noted that, after these aforementioned data were excluded, there were still over 200 filter cycles with usable data.

The counts were tallied separately for each cold and warm water season to allow changes in performance with temperature and time to be identified. Cold water seasons were defined as periods of time where the water temperature was below 10° C. Warm water seasons were defined as periods of time where the water temperature was greater than or equal to 10° C. Table 3-6 lists the date range for each season.

Table 3-6: Date ranges for seasons used when analyzing headloss data

Season	Date Range
Warm Season 1	October 4, 2011-November 17, 2011
Cold Season 1	November 17, 2011-April 9, 2012
Warm Season 2	March 22, 2012-November 1, 2012
Cold Season 2	November 1, 2012-April 30, 2012
Warm Season 3	April 30, 2012-June 17, 2012

The end of Cold Season 1 and the beginning of Warm Season 2 overlap because there was a brief period where water temperatures changed back and forth between warm and cold water conditions; during this period, cycles with water temperatures less than 10° C were assigned to Cold Season 1 and cycles with water temperatures greater than or equal to 10°C were assigned to Warm Season 2.

Sign tests were used to determine whether a given media type, overall, provided better headloss than another during a given set of water conditions. A Bonferroni correction was applied to the p-values to control experiment-wise error because multiple comparisons were performed among the results from all media types (i.e. coal-based GAC vs anthracite, coal-based GAC vs REC, coal-based GAC vs wood-based GAC, anthracite vs REC, anthracite vs wood-based GAC, and REC vs wood-based GAC): the p-value from each comparison was multiplied by a factor of six.

3.2.7 Turbidity Removal

Effluent turbidity from the filters containing coal-based GAC, anthracite, wood-based GAC, and REC was monitored every two minutes, throughout the experimental period, using HACH 1720E low range turbidimeters[64]. Each filter had a dedicated effluent turbidimeter. Turbidity removal provided by the media types was compared using two metrics: lowest average effluent turbidity and attenuation of turbidity spikes (i.e. turbidity dampening).

3.2.7.1 Assessment of Turbidimeter Bias and Drift

The difference in turbidity readings (bias) between the four effluent turbidimeters was quantified by cross-referencing the turbidity readings from all four turbidimeters, to ensure that any observed difference was a "true" difference and not due to bias. To quantify the bias between the turbidimeters, low turbidity water (approximately 0.12 NTU) and "high" turbidity water (approximately 1.1 NTU) were each pumped through all four effluent turbidimeters for 20-25 minutes. The high turbidity water was created by adding formazin to a portion of the low-turbidity water. The low turbidity water was pumped through the turbidimeters first, followed by the high turbidity water. Both high and low turbidity waters were kept well mixed throughout the testing. Readings from the turbidimeters were collected at 0.5 minute intervals and stabilized approximately 10 minutes after the pump was turned on. For each type of water, the following quantities were calculated: the average turbidity readings after stabilization for each turbidimeter, the difference in average turbidity reading between each turbidimeter, a 99% confidence interval (CI) on the difference in turbidity between each analyzer, and a p-value indicating whether differences in turbidity were statistically significant. 99% confidence intervals and p-values were calculated using Dunnett's T3 procedure (Dunnett, 1980).

[64] HACH Canada; London, ON, Canada

Turbidimeter drift was assessed by comparing the average effluent turbidity readings from a short period just before and just after calibration. Had there been drift in the analyzer readings between calibrations, the average turbidity readings before and after calibration would have been different.

3.2.7.2 Comparison of Effluent Turbidity

All four filters received the same influent water; therefore, the removal of turbidity could be assessed by comparing the average, stable, effluent turbidities achieved by each filter. For each filter cycle, the effluent turbidities from all filters were plotted. The start and end of the ripening period and the start of turbidity breakthrough (if it occurred) were identified from the plots and the raw data. The ripening period was considered to begin at the beginning of the filter cycle and end when the effluent turbidity dropped below a specified turbidity cut-off value. If no ripening was observed, a default ripening period of 20 minutes was adopted . Breakthrough was considered to be reached when the turbidity increased above a specified cut-off value and was maintained above that value.

0.1 and 0.3 NTU values were used as cut-offs for both the end of ripening and for the start of turbidity breakthrough for all filter cycles. The 0.3 NTU cut-off was chosen because effluent turbidities below 0.3 NTU are regulatory targets in both the US and Canada (National Primary Drinking Water Regulations: Interim Surface Water Treatment Rule, 1998, National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule, 2002; MOE, 2006). A 0.1 NTU cut-off was chosen to represent an effluent turbidity goal that a utility might choose to adopt, particularly if trying to obtain additional *Cryptosporidum* removal credit required under the Long Term 2 Enhanced Surface Water Treatment Rule (National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule).

The arithmetic mean and a 99% confidence interval on the effluent turbidity[65], for each filter and for each filter cycle, were calculated for the relatively stable period between ripening and breakthrough. Data

[65] It was found that the turbidity effluent data were not normally distributed, as determined by inspection of normal probability plots, and were autocorrelated (analysis not shown). Parametric and nonparametric procedures for calculating a confidence interval assume either that the data are normally distributed, not autocorrelated, or both. In order to get some estimate of the uncertainty of the estimate on the mean, the confidence interval was calculated assuming a t-distribution. In order to account for the non-normality and autocorrelation, a more conservative 99% confidence interval was used instead of the 95% confidence interval that would have otherwise been used. It should be noted that the data set from each filter cycle was quite large: each data set for a single cycle consisted of 1500 to greater than 2000 data points. For a set of randomly-selected filter cycles, confidence intervals were also calculated using bootstrapping. Bootstrapping calculations were conducted using SPSS 22. It was found that the confidence intervals calculated using bootstrapping were essentially the same as those calculated using the t-distribution (analysis not shown); therefore, the confidence intervals calculated using the t-distribution were considered adequate and were used.

collected after the filter had reached terminal headloss (i.e. when the filters could no longer sustain the design flow of 3.0 L/min) were excluded from the calculation of the mean and confidence interval to ensure that the results were representative of actual practice: a full-scale filter would likely be taken out of service and backwashed once terminal headloss was reached. The arithmetic means of the effluent turbidities were adjusted to account for turbidimeter bias, using the reading from the turbidimeter on the coal-based GAC filter as a reference reading. The equations used for calculating the arithmetic mean of the effluent turbidity were as follows: -

$$\bar{x}_{adj} = \begin{cases} For\ coal\text{-}based\ GAC\ filter: \bar{x}_{F1} \\ For\ anthracite\ filter: \bar{x}_{F2} + \bar{x}_{T1-T2} \\ For\ REC\ filter: \bar{x}_{F3} + \bar{x}_{T1-T3} \\ For\ wood\text{-}based\ GAC\ filter: \bar{x}_{F4} + \bar{x}_{T1-T4} \end{cases} \quad \textbf{(Equation 3-1)}$$

Where:

- $\bar{x}_{adj}$ is the adjusted mean effluent turbidity for a given filter, for a given filter cycle
- $\bar{x}_{F1}$ is the calculated mean effluent turbidity for the filter containing coal-based GAC,
- $\bar{x}_{F2}$ is the calculated mean effluent turbidity for the filter containing anthracite,
- $\bar{x}_{F3}$ is the calculated mean effluent turbidity for the filter containing REC,
- $\bar{x}_{F4}$ is the calculated mean effluent turbidity for the filter containing wood-based GAC,
- $\bar{x}_{T1-T2}$ is the difference in turbidity reading between the effluent turbidimeter on the coal-based GAC filter and the effluent turbidimeter on the anthracite filter (i.e. the measured turbidimeter bias),
- $\bar{x}_{T1-T3}$ is the difference in turbidity reading between the effluent turbidimeter on the coal-based GAC filter and the effluent turbidimeter on the REC filter, and
- $\bar{x}_{T1-T4}$ is the difference in turbidity reading between the effluent turbidimeter on the coal-based GAC filter and the effluent turbidimeter on the wood-based GAC filter.

The biases calculated from the low turbidity water cross-referencing were used in these calculations because the effluent turbidities were closer in magnitude to the low-turbidity water than the high-turbidity water.

The uncertainty in the estimate of the adjusted mean was calculated using the general propagation of error formula for the uncertainty of the sum of two variables (Taylor, 1982)[66]:

$$\delta q \approx \delta x + \delta y \qquad \textbf{(Equation 3-2)}$$

Where:

- δx is the uncertainty associated with one variable (in this case the variable is the mean effluent turbidity)
- δy is the uncertainty associated with a second variable being added or subtracted to the first variable (in this case the variable is the turbidimeter bias)
- δq is the combined uncertainty in the sum or difference of the two variables, x and y (in this case the variable is the adjusted mean effluent turbidity).

The 99% confidence intervals, for the mean effluent turbidity and for the bias between turbidimeters, were taken as representing the uncertainty in the mean effluent turbidity and turbidimeter bias, respectively. The calculated uncertainties in the adjusted means were used to calculate uncertainty intervals for the adjusted means. The intervals for the adjusted mean effluent turbidities from filters containing different media types were compared to each other. It was determined whether one media type provided a lower effluent turbidity than another in a given filter cycle by comparing their uncertainty intervals. The media types were considered to have different effluent turbidities if the uncertainty intervals did not overlap. The media type which had the lowest interval (and, thus, lowest mean effluent turbidity) was considered to have the lowest effluent turbidity.

The number of times one media type provided lower mean effluent turbidity than another and the number of times there was no difference in the mean effluent turbidity were tabulated. The tabulations were done separately for data collected during cold and warm water conditions. There were not enough data to allow analysis to be conducted for each season (in the manner in which the headloss data were analyzed) because some of the turbidimeters had to periodically be taken out of service for maintenance. As with headloss data, cold water conditions were defined as periods where the water temperature was below

[66] This formula provides a conservative estimate of the combined uncertainty of two quantities being added or subtracted together. An alternative formula that is less conservative and, in the case of normally and independently distributed data, is more accurate is: $\delta q = \sqrt{\delta x^2 + \delta y^2}$. The effluent turbidity data were not normally distributed and were autocorrelated; therefore the more conservative formula was used.

10°C and warm water conditions were defined as periods where the water temperature was greater than or equal to 10°C. The date ranges for warm and cold water conditions are presented in Table 3-7.

Table 3-7: Date ranges for warm and cold water conditions

Water Conditions	Date Ranges
Warm	October 6, 2011-November 17, 2011
	March 22, 2012-April 1, 2012
	April 9, 2012-November 1, 2012
	April 30, 2013-June17, 2013[1]
Cold	November 17, 2011-March 22, 2012
	April 1, 2012-April 9, 2012
	November 1, 2012-April 30, 2013

1. End of experiments.

Sign tests were conducted and p-values were calculated to determine whether, overall, one media type provided better removal of turbidity during a given water condition.

3.2.7.3 Attenuation of Turbidity Spikes (Turbidity Dampening)

3.2.7.3.1 Attenuation of Turbidity Spikes and "Turbidity Dampening"

Assessment of turbidity spike attenuation provides an indication of filter resilience to events that may cause an increase in influent turbidity: for example, spring freshets, storm or run-off events, unoptimized coagulation, or coagulation system failure. Installing a media type that attenuates turbidity spikes to a greater extent than an existing media type improves filter resilience. Little to no information regarding turbidity spike attenuation by filters is available in the literature.

The term "turbidity dampening" will be used through the remainder of this thesis to describe the attenuation of an influent turbidity spike by a treatment process. The turbidity dampening provided by two filters treating the same influent water can be compared by comparing the difference between the baseline turbidity and the peak effluent turbidities observed for each filter. If two filters have similar baseline turbidities, the turbidity dampening can be compared by simply comparing the observed peak effluent turbidities. Figure 3-5 shows a conceptual example of turbidity dampening provided by two filters receiving the same influent water, where the two filters have similar baseline turbidities.

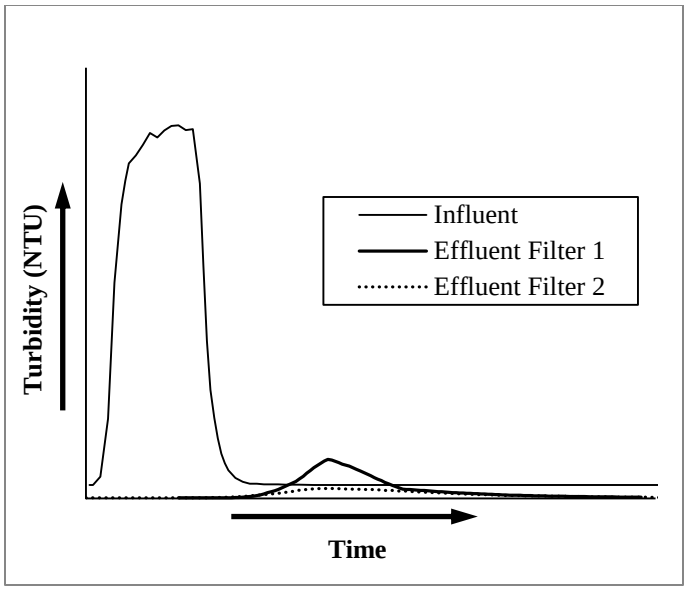


Figure 3-5: Illustration of turbidity dampening for two filters with similar baseline effluent turbidities

In Figure 3-5, it can be seen that both filters substantially reduce the peak of the influent turbidity spike, i.e. they provide turbidity dampening. Both filters have similar baseline turbidities and therefore, turbidity dampening provided can be evaluated by comparing the effluent peak turbidities. In this example, Filter 2 had the lowest peak effluent turbidity and, thus, provided the greatest turbidity dampening. A similar conceptual example is presented in Figure 3-6, but with two filters that have different baseline turbidities. The influent was not plotted so as to allow differences in effluent turbidity to be seen more clearly.

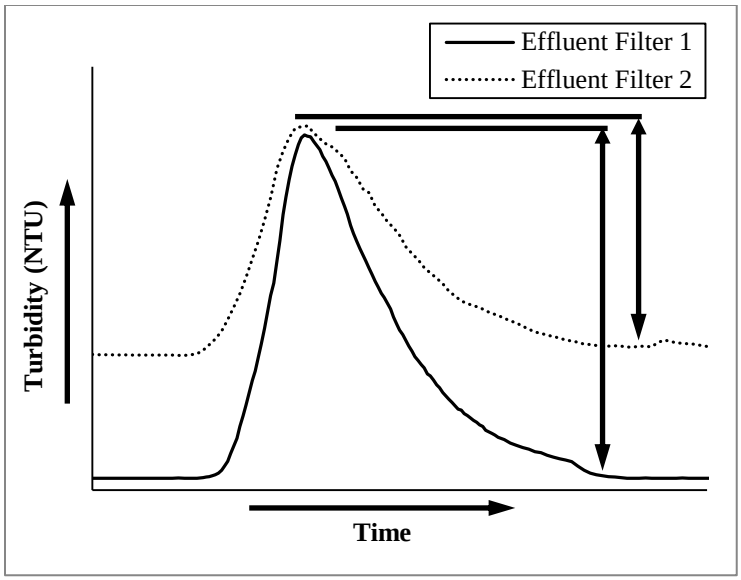


Figure 3-6: Illustration of effluent turbidity spikes from two filters after an influent turbidity spike. Filters have different baseline effluent turbidities.

It can be seen in this example that the baseline turbidity for Filter 2 is much higher than that for Filter 1. The peak effluent turbidity for Filter 2 is slightly higher than Filter 1because of the large difference in baseline turbidity. Notably, the influent turbidity spike had less impact on the effluent turbidity for Filter 2 than for Filter 1 when the difference between the peak effluent turbidity and the baseline turbidity was considered. Thus, Filter 2 provided greater turbidity dampening and was more resilient to changes in influent turbidity, even though its peak effluent turbidity was slightly higher.

3.2.7.3.2 Experimental Design

Five experiments were conducted to evaluate the turbidity dampening provide by different media types during biolfiltration. In each experiment, a 3000-4000 NTU kaolin clay suspension was pumped into the influent of the pilot plant for approximately 15-20 minutes to cause an influent turbidity spike. The preparation of the clay suspension and the method used to control the kaolin dosing to the filter are detailed in sections 3.2.7.3.3 and 3.2.7.3.4. The influent turbidity spike was always introduced after backwashing and after filter ripening had occurred. The influent and effluent turbidity was monitored. The degree of turbidity dampening provided was determined by calculating the difference between the baseline and peak turbidity.

The comparative ability of media types to provide turbidity dampening was assessed at different conditions by varying the season in which the turbidity spikes were conducted (and, thus, the water temperature), the magnitude of the influent spikes, and the filter run time at the time of the spike. Three

sets of experiments were conducted. The sets of experiments, the number of experiments in each set, and additional factors which were varied are summarized in Table 3-8.

Table 3-8: List and details of Experiment Sets used to investigate turbidity dampening

Experiment Set	Season	Number of Experiments	Additional Factor Varied		
			Turbidity Spike Magnitude	Filter Run Time	Water Temperature
1	Late winter/early spring 2012	2	X		X
2	Summer 2012	2		X	X
3	Fall 2012	1			X

During Experiment Set 1, a small turbidity spike was introduced to the pilot filters in the first experiment and a larger turbidity spike in the second experiment. The experiments were conducted during different filter cycles to ensure that kaolin removed during the first experiment did not affect the second experiment. The two experiments were performed within 12 days of each other. Both turbidity spikes were introduced near the beginning of the filter cycle, after backwashing and filter ripening, to minimize the impact of retained particles on the removal of the turbidity spike.

During Experiment Set 2, turbidity spikes of similar magnitude were introduced to the pilot filters at different times in the filter run. As with Phase 1, the turbidity spikes were introduced during different filter cycles to ensure that kaolin removed in the first experiment did not affect the turbidity dampening in the second experiment. The experiments were conducted within 5 days of each other to minimize the impact of changing water quality on the results.

During Experiment Set 3, a single experiment was conducted where a single turbidity spike was introduced to the pilot filters.

3.2.7.3.3 Preparation of the Kaolin Clay Suspension

A semi-stable kaolin suspension was prepared for the turbidity spike experiment by adding 40.0 g of kaolin clay powder[67] to 20 L of distilled water in a plastic carboy. The suspension was mixed by shaking

[67] J.T. Baker

the carboy. The carboy was subsequently allowed to stand for 1 hour to allow any easily-settleable kaolin particles to settle out. The top three-quarters of the suspension was siphoned off for use in the experiments and the remaining one-quarter was discarded. A fresh suspension was prepared before each experiment and was used within 48 hours. Kaolin from a single batch was used to prepare all suspensions in order to eliminate any variability that could have been introduced by using different batches of kaolin.

A semi-stable kaolin suspension, rather than a coagulated kaolin suspension or coagulated suspension of particles collected from a natural water source, was used to provide a greater level of experimental control. Using kaolin ensured that particles with consistent characteristics were used for the turbidity spikes in all experiments. It also helped ensure that particles did not settle out in the pilot header during the experiment and eliminated variability that could have been introduced had coagulated kaolin particles been used.

3.2.7.3.4 Kaolin Dosing and Control of Influent Turbidity Spike

The kaolin suspension was placed in a glass carboy and pumped into the pilot plant influent header, which fed all pilot filters. A peristaltic pump was used during Experiment Set 1 and 2; however, during two experiments the peristaltic pump tubing wore out and had to be replaced mid-experiment. In Experiment Set 3 a centrifugal pump, with a recycle line returning to kaolin the carboy, was used instead of the peristaltic pump; this was found to be a more reliable method for dosing the kaolin suspension. The turbidity of the influent kaolin suspension was checked before each experiment was started and the kaolin suspension was kept well mixed during each experiment. The magnitude of the influent turbidity spike was controlled by adjusting the flow rate of the suspension being pumped into the pilot plant influent.

3.2.7.3.5 Data Collection and Analysis

Filter influent turbidity was monitored until the turbidity spike had passed through the influent. The effluent turbidity from all four filters was monitored throughout the turbidity spike and until it dropped below 0.1 NTU. The turbidity readings were adjusted for turbidimeter bias, with the coal-based GAC turbidimeter used as the reference turbidimeter. When turbidity was below 0.4 NTU, the corrections for bias calculated from the low turbidity water cross-referencing were used. When turbidity was above 0.4 NTU, the corrections for bias calculated from the high turbidity water cross-referencing were used[68].

[68] A dividing point of 0.4 NTU was used to switch between low and high turbidity bias adjustments because it was found that this value allowed for a relatively smooth transition when turbidity values moved from low to high values. Significantly higher or lower dividing points would have introduced significant artificial inflection points

Baseline effluent turbidity values were estimated for each filter based on the data collected before and after the turbidity spike was observed in the effluent. The difference in turbidity between the baseline and peak effluent turbidity was estimated for each filter.

3.2.8 Filter Run Time

Filter run time was defined as the period of time from the start of a filter cycle until a backwash trigger was observed. Three triggers were used to signal the need for backwashing: terminal headloss, turbidity breakthrough, and time. These triggers are the same ones that might be used in a full scale plant. The criteria used to indicate terminal headloss, turbidity breakthrough, and a timed backwash during data analysis are presented in Table 3-9.

Table 3-9: Backwash triggers and criteria indicating backwashing is required

Backwash trigger	Criteria indicating backwashing is required
Terminal headloss	The flow through the filters could not be maintained at the design flow of 3.0 L/min
Turbidity breakthrough	Effluent turbidity rose above 0.1 NTU and was maintained at that level.
Time	Filters had operated continuously for approximately 40-48 hours.

It should be noted that the filters were always backwashed on the basis of time regardless of whether a backwash trigger was observed. This ensured that all filters were backwashed and started at the same time throughout the study.

The time at which each of the three backwash triggers occurred was identified during data analysis to determine what the filter run time would have been had the filters been backwashed immediately after any one of these triggers was observed. For each filter cycle, the primary backwash trigger[69] was identified and the filter run time was calculated. Filter run times were compared for the four different media types to determine which media types provided the longest run times. The number of times a given backwash trigger was identified as the primary trigger for a given media type were tallied to determine whether one primary backwash trigger occurred more frequently than another. The number of times each media type had a longer run time than another media type and the number of times there was no difference in run

into the turbidity data, as the turbidity values increased or decreased, when the bias adjustment was switched from the low turbidity bias adjustment to the high turbidity bias adjustment.

[69] The primary backwash trigger is the first backwash trigger that is observed during a filter cycle.

time between different media types were also tallied. Tallies were made separately for cold and warm water conditions in case water temperature affected the results. Finally, sign tests were conducted using the tallies to determine whether each given media type provided a greater number of filter cycles with longer filter run times than the other media types.

3.3 Results and Discussion

3.3.1 Grain Size Distribution Matching Procedure

3.3.1.1 Quality Control Tests on the Mixing of the Rough Engineered Ceramic Media

3.3.1.1.1 Mixing of Media Produced During Different Batches

A quality control test was performed to determine whether rough engineered ceramic media produced in different batches would mix together or stratify into separate layers after backwashing. One of the media batches was coloured red and the other was left its natural colour (grey). Figure 3-7 presents pictures of the two media batches before and after backwashing.

a)  b) 

Figure 3-7: Pictures of media from two batches in backwashing column: a) before backwashing and b) after backwashing. (Media from one batch is grey and media from the other batch has been dyed red)

Some minor stratification was observed, as can be seen by the small layer of red media at the top of the filter and the preponderance of red coloured media in the bottom of the filter; however, media from both batches mixed together and no major stratification was observed. It was concluded from this test that media produced during different batches would mix well enough to avoid any major stratification. Therefore, media from both years could be mixed together to create REC with a grain size distribution matching that of the coal-based GAC.

3.3.1.1.2 Presence of Floating Media and Mixing with Sand Media

Quality control tests were performed on every major batch of media to determine whether there were any media grains that would float out of the filter and to determine whether the media had a density that would mix with the sand media. Figure 3-8 shows representative pictures from two of these tests.

a)  b) 

Figure 3-8: Pictures from quality control tests on REC showing: a) low density media floating during backwashing and b) high density media mixed with the sand layer after backwashing

Floating media were identified in a number of the tests and mixing with the sand layer was also observed. The amount of floating media and sand mixing varied from batch to batch and seemed to be related, in part, to the media size. These tests highlighted the importance of performing density separations, described section 3.2.3.2.2, to ensure that media grains that would float out of a filter and media grains that would mix significantly with the sand layer were removed from the bulk media.

3.3.1.2 Grain Size Distributions of Coal-based GAC and Matched Media

The grain size distributions of five samples from the coal-based GAC were measured. The individual grain size distributions for each sample are shown in Figure 3-9 and the average grain size distribution for the coal-based GAC, with error bars representing one standard deviation, is shown in Figure 3-10.

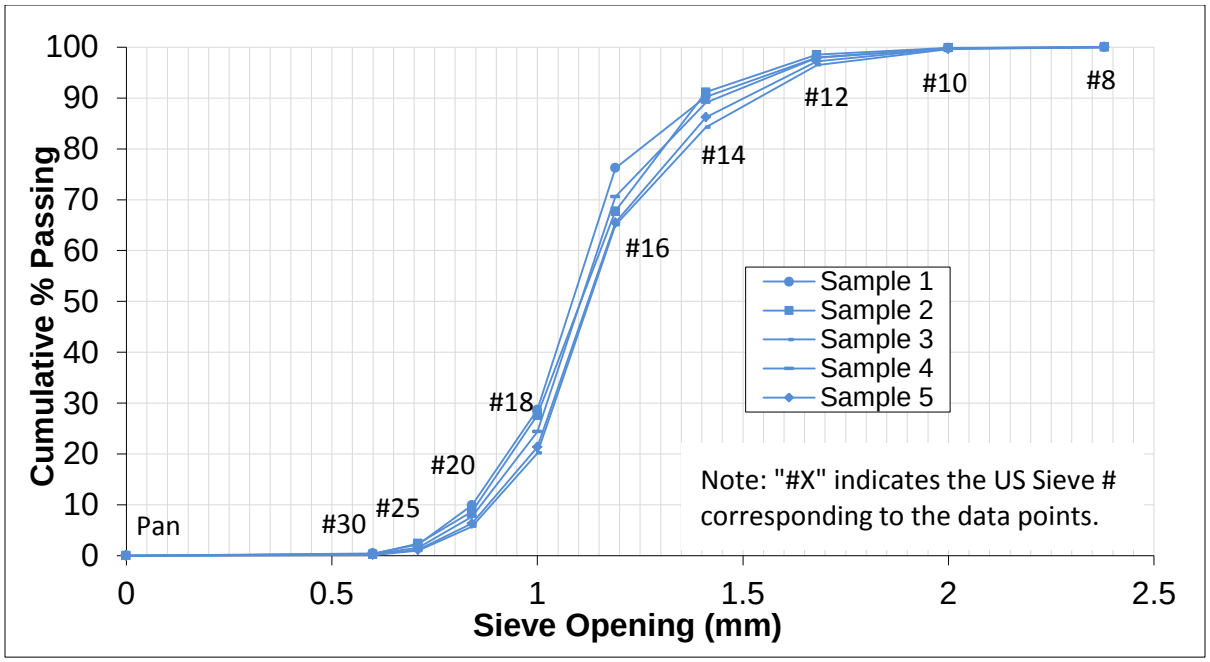


Figure 3-9: Grain size distributions for coal-based GAC collected from Mannheim WTP

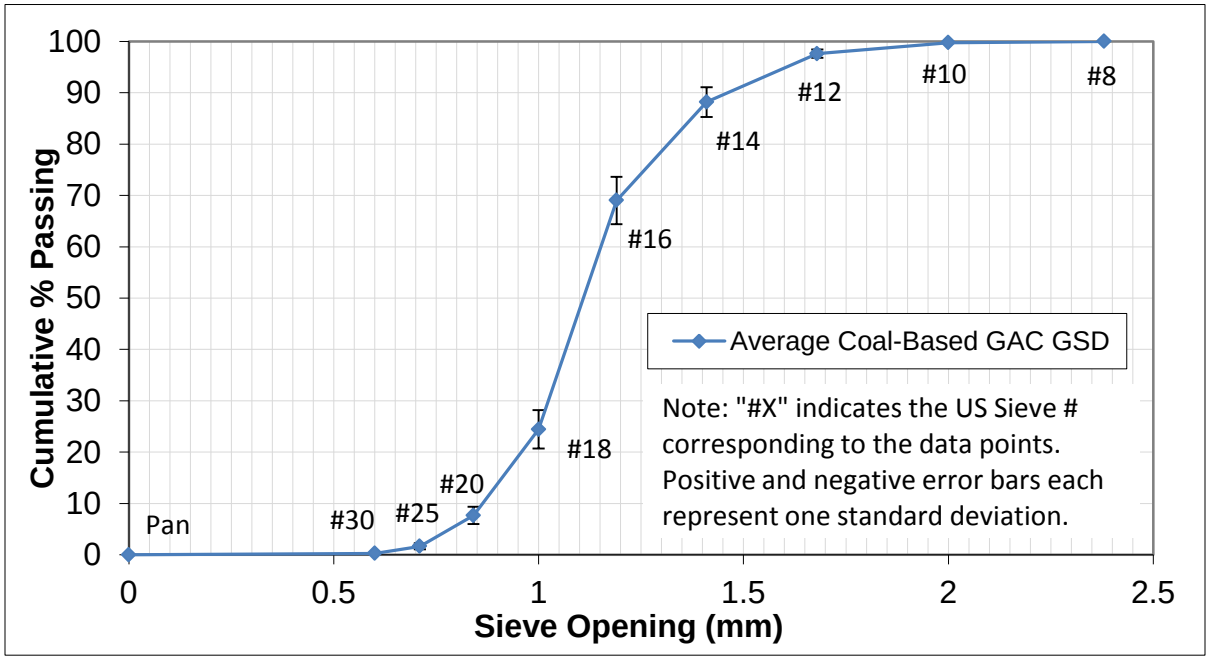


Figure 3-10: Average grain size distribution for coal-based GAC collected from the Mannheim WTP

It can be seen from Figure 3-9 and Figure 3-10 that there was little variation in the cumulative percent of the mass passing through each sieve opening; therefore, the results from the grain size analysis procedure

were reproducible and that the grain size distribution of the coal-based GAC, after hand mixing, was relatively homogenous.

The average grain size distributions of the three media types (anthracite, REC, and wood-based GAC), whose grain size distributions were matched to that of the coal-based GAC, and the average grain size distribution of the coal-based GAC are presented in Figure 3-11. For reference, the effective size and uniformity coefficient for each of the media types was calculated from d_{10} and d_{60} values interpolated from the appropriate average grain size distribution; the effective sizes (d_{10}), d_{60} values, and uniformity coefficients are summarized in Table 3-10.

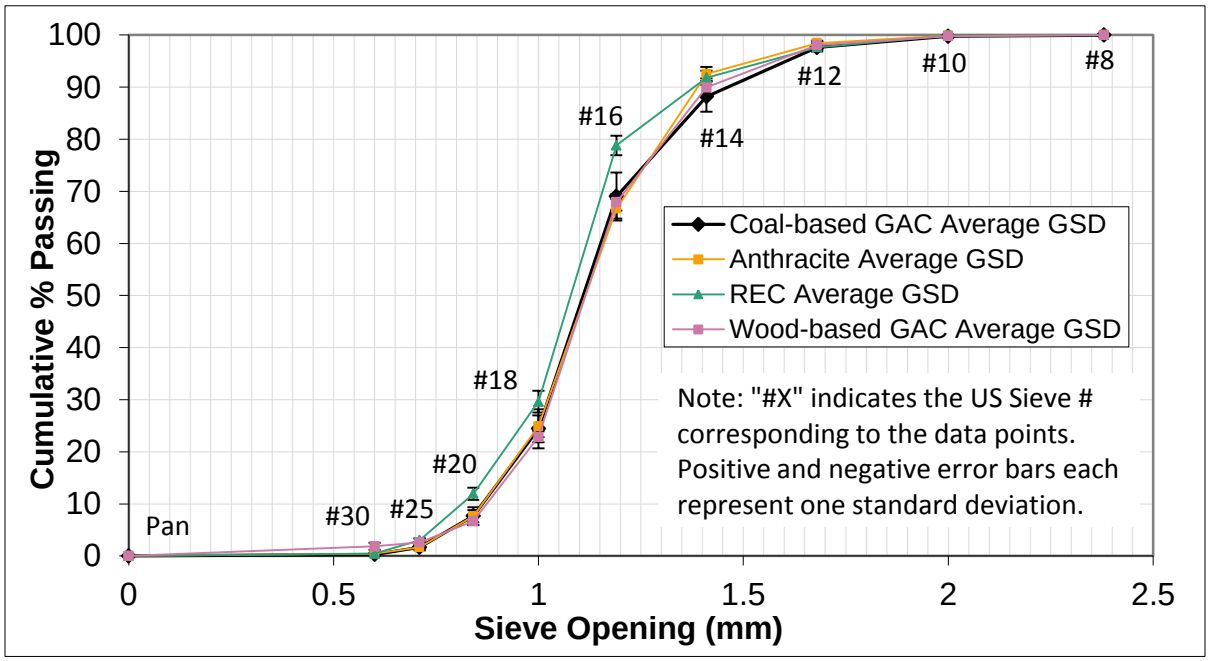


Figure 3-11: Average grain size distributions for matched media types

Table 3-10: Effective sizes, d_{60} values, and uniformity coefficients for matched media

Media Type	Effective Size (d_{10}) (mm)	d_{60} (mm)	Uniformity Coefficient
Coal-based GAC	0.86	1.15	1.33
Anthracite	0.86	1.16	1.34
REC	0.81	1.12	1.38
Wood-based GAC	0.87	1.16	1.32

The grain size distributions presented in Figure 3-11 and the data in Table 3-10 indicate that the average grain size distributions, effective sizes, and uniformity coefficients of all four media types were similar. The grain size distribution of the REC had slightly greater masses of media passing the #16, #18, and #20 sieves than the other media types; however, the difference in effective size between the REC and the coal-based GAC was very small: only 0.05 mm. The grain size distributions of all four media types, therefore, were thus considered matched.

The results indicate that it is possible to use the protocols described in section 3.2.3.2.3 to match grain size distributions of different media types. These protocols can be used in future studies that require media with matched grain size distributions. It should also be highlighted that on the basis of experience gained during this research, it is important to optimize sieving protocols when working with friable (e.g. GAC), spherical (e.g. REC), or new media types: media may be improperly sieved if sieving times, initial media masses, and/or overloading limits are not optimized. It is recommended that sieving protocols be confirmed to be appropriate for the media types being used (i.e. that the mass of media being sieved does not cause sieve blinding, that media grains do not do not break down into smaller sizes during sieving, that sieving times are long enough to ensure that media grains are properly divided into separate size fractions, etc.), prior to trying to match grain size distributions.

3.3.2 Confirmation of Media Properties

3.3.2.1 Confirmation of Roughness

SEMs of the filter media at 22x and 500x magnifications are presented in Figure 3-12 and Figure 3-13, respectively.

The SEM images highlight the many different morphological features a media type can have and illustrate that “rough” media types may have different types of roughness. The SEMs confirm that REC and the two types of GAC have rougher surfaces than anthracite. It can also be seen that the surface features of the REC and GACs differ: REC is spherical and covered with a variety of asperities that create micro-scale roughness whereas the two GACs are not spherical and have large valleys and troughs that create macro-scale roughness. The wood-based GAC also has a very porous surface in comparison to the other media types. It is interesting to note that the coal-based GAC had some surface asperities but also seemed to be coated by some sort of semi-rough “crust”. Figure 3-14 and Figure 3-15 show the “crust” on two of the coal-based GAC grains; sections of the media showing this “crust” are circled on the images. Figure 3-16 provides images of different locations on

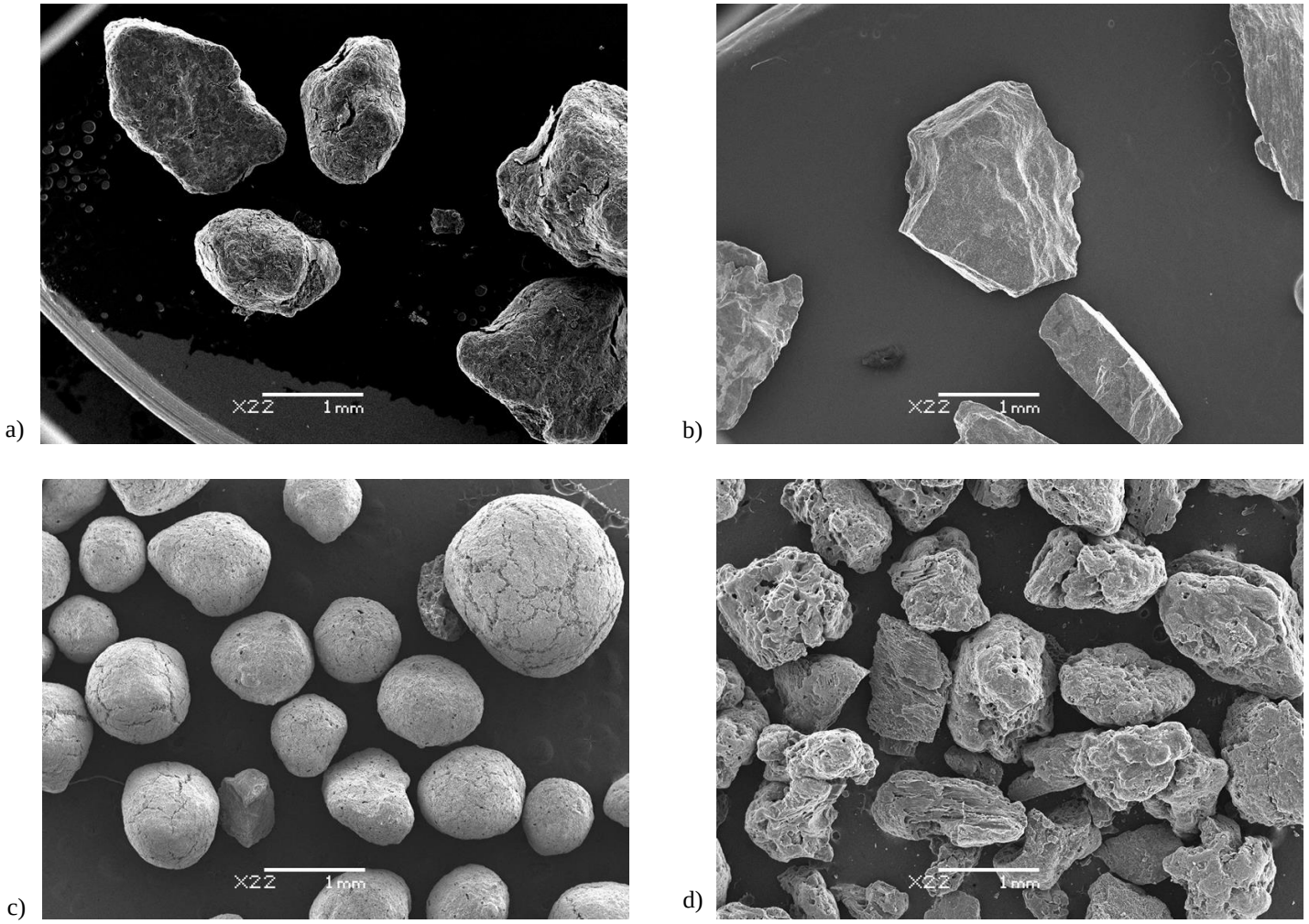


Figure 3-12: SEMs of filtration media at 22x magnification. a) coal-based GAC, b) anthracite, c) REC, and d) wood-based GAC.

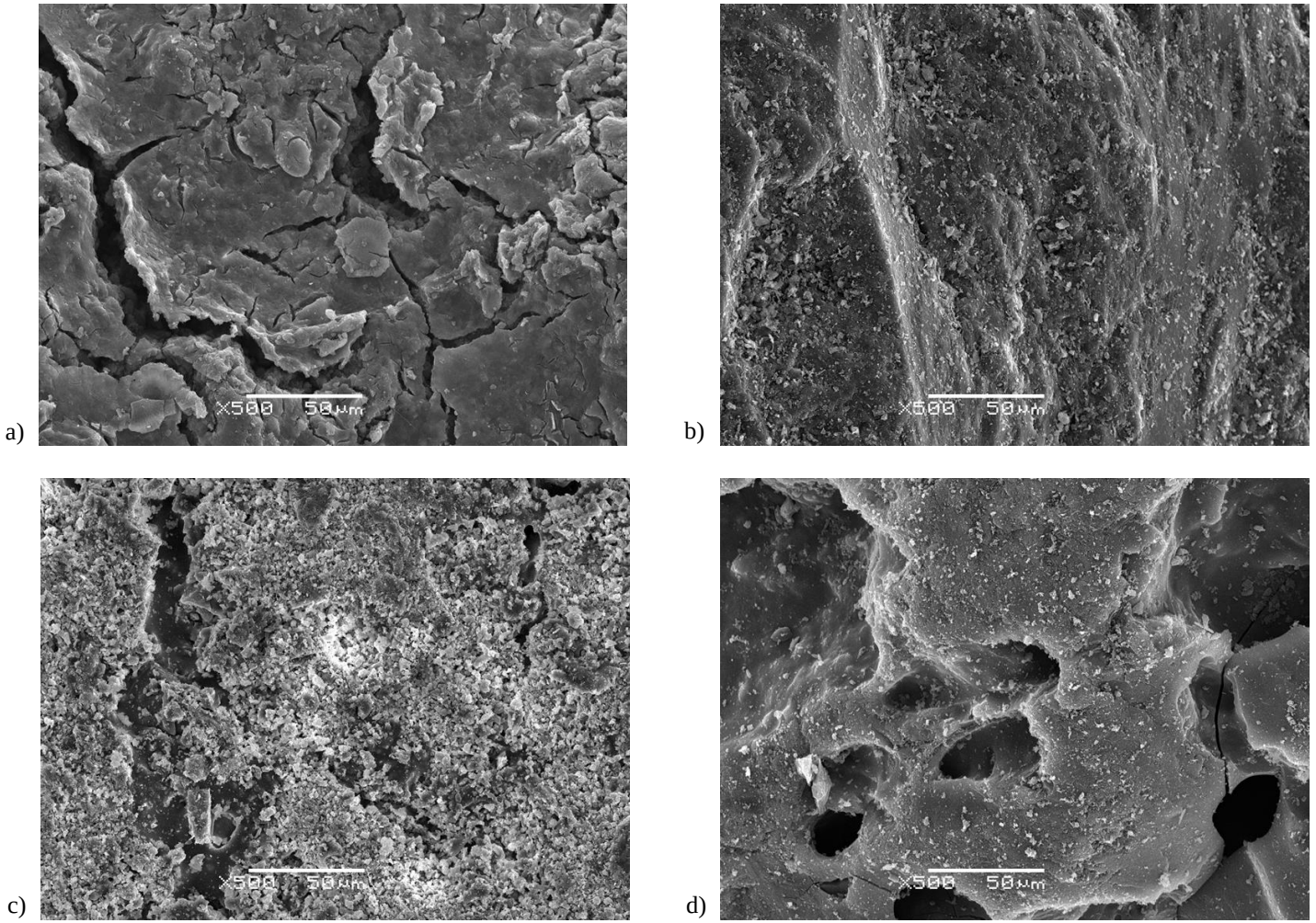


Figure 3-13: SEMs of filtration media at 500x magnification. a) coal-based GAC, b) anthracite, c) REC, and d) wood-based GAC. Note that the small white dots on the REC are surface asperities.

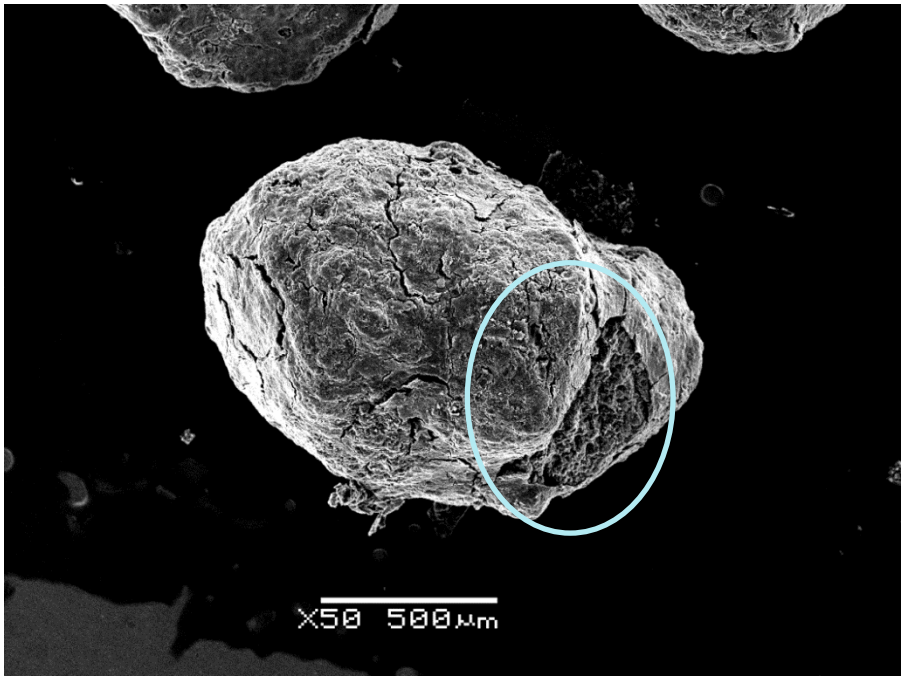


Figure 3-14: SEM at 50x magnification of a coal-based GAC grain showing a surface "crust"

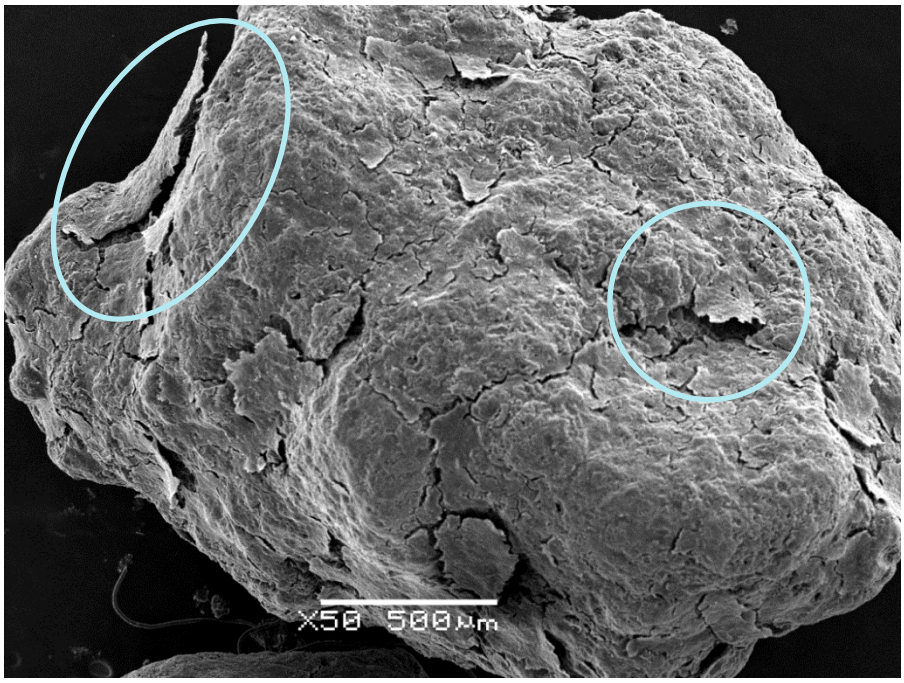
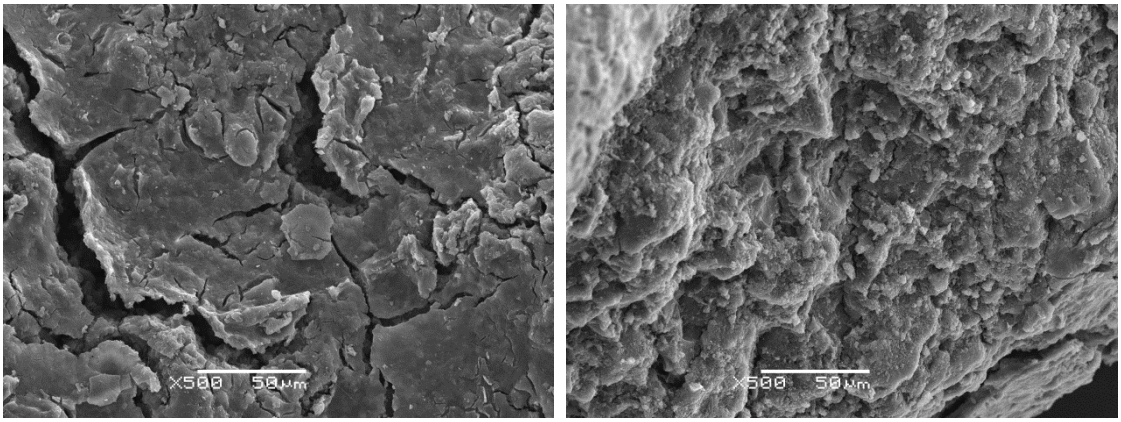


Figure 3-15: SEM at 50x magnification of a second coal-based GAC grain showing surface "crusts"



a) b)

Figure 3-16: SEMs at 500x magnification of different morphological areas on the coal-based GAC grain shown in Figure 3-14. a) a semi-rough surface on top of the "crust" and b) a rough exposed surface not covered by a "crust"

one of the coal-based GAC grains to highlight the different morphologies that were observed on a single media grain.

It can be seen that there are two different morphological areas on the coal-based GAC: a smoother semi-rough "crust" and, under the "crust", a rougher surface characterized by many asperities. The coal-based GAC had been in use for approximately seven years at a full scale plant prior to being used in this experiment. It is possible that the semi-rough "crust" of the coal-based GAC was biomass or other material that stuck to the surface of the coal-based GAC over its operational life[70]. It is noted that a similar "crust" was observed by Lauderdale et al. (2012) on media collected from a GAC biofilter; however, a "crust" was not observed on media from a biofilter that received additional phosphorous in the influent (Lauderdale et al., 2012). It is possible that influent water quality and operational conditions affect the formation of these "crusts".

[70] Visual inspection of the media when it was originally collected revealed a gummy, orange coloured material in the crevices of some of the filter media grains. It is suspected that this was some combination of biomass and floc which accumulated on the media grains over time.

3.3.2.2 Confirmation of Adsorptive Media Surfaces

3.3.2.2.1 Release of Carbon into Ultrapure Water

Crushed media[71] were added to ultrapure water to check for carbon contamination of the media and to aid interpretation of adsorption results. Figure 3-17 and Figure 3-18 show boxplots of all measurements that were made on the ultrapure water and on the water that was in contact with the media for four hours. The data presented in Figure 3-18 are the same as the data in Figure 3-17 except that the boxplot of the coal-based GAC data was excluded. Table 3-11 summarizes the mean and standard deviation of these DOC concentration data.

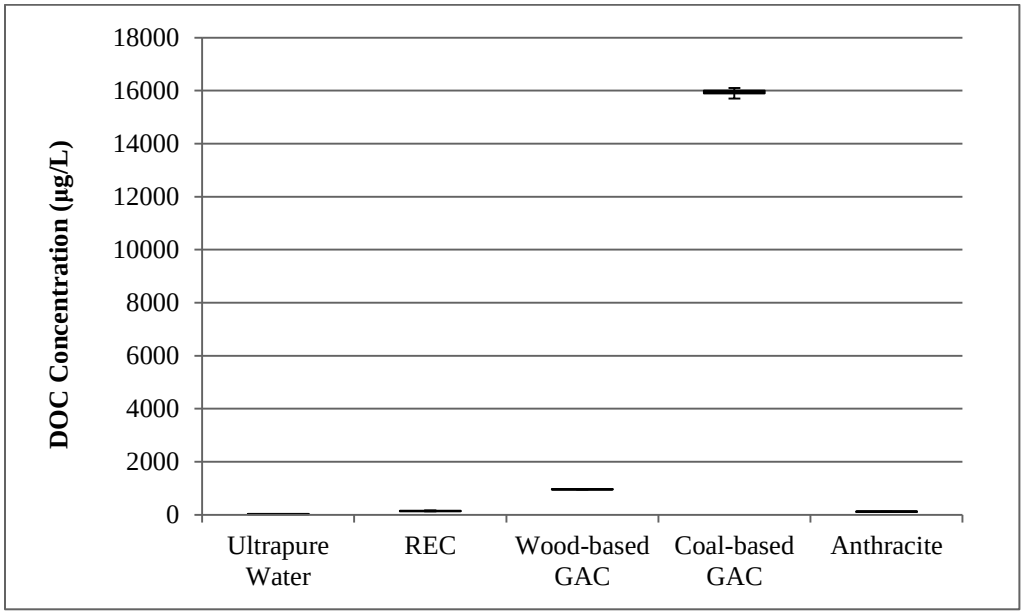


Figure 3-17: Boxplots of all measurements of the DOC concentration in ultrapure water and the DOC concentration after four hours contact with each type of media. (Bars indicate minimum and maximum values; bars are plotted for all boxplots but are not necessarily visible. n=12 for each boxplot)

[71] Granular media that had been crushed to a fine powder to reduce the time required to reach equilibrium (see Section 3.2.4.2 for a description of media preparation).

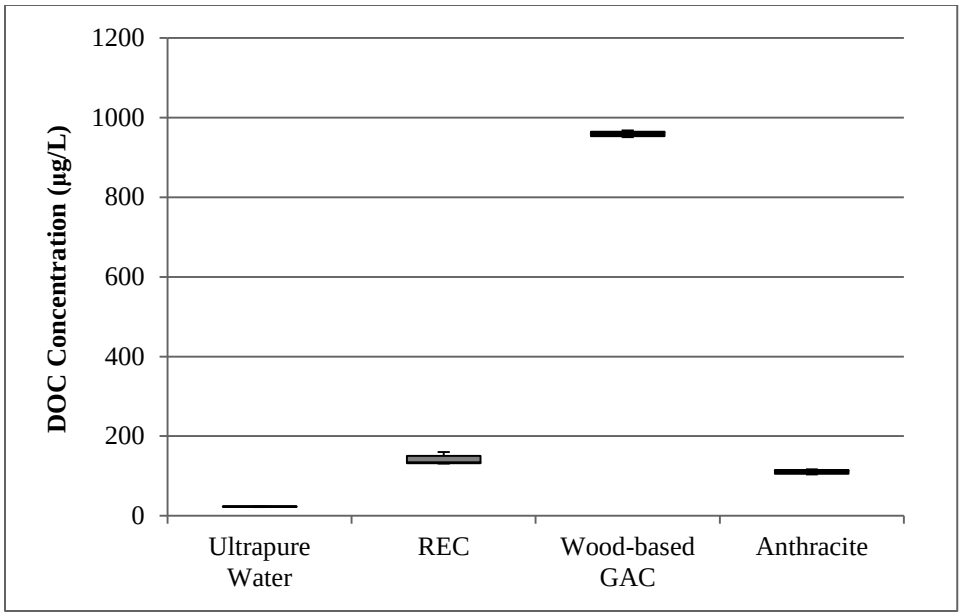


Figure 3-18: Boxplots of all measurements of the DOC concentration in ultrapure water and the DOC concentration after four hours contact with each type of media, excluding the boxplot associated with coal-based GAC. (Bars indicate minimum and maximum values; bars are plotted for all boxplots but are not necessarily visible. n=12 for each boxplot)

Table 3-11: Mean and standard deviation of the DOC concentration in ultrapure water and the DOC concentrations in ultrapure water after four hours contact with media

Statistic	Ultrapure water	REC	Wood-based GAC	Coal-based GAC	Anthracite
Mean DOC Concentration (µg/L)[1,2]	22.9	140	960	16000	111
Standard Deviation (µg/L)[1,2]	0.542	11.1	6.18	117	5.07

1. Values rounded to 3 significant figures
2. n=12

Anthracite and REC had very minimal organic carbon contamination (Figure 3-17, Figure 3-18, Table 3-11). The wood-based GAC released approximately 0.96 mg/L of organic carbon into the ultrapure water and the coal-based GAC released approximately 16 mg/L. Thus, the GAC media were contaminated with organic carbon, and the coal-based GAC was severely contaminated.

The source of the organic carbon contamination of the GACs is unknown; however, the GACs may have been contaminated by dust or other compounds during sieving or storage. The GACs may also have adsorbed organic matter from the air and some of this organic matter may have desorbed when the GAC was placed in contact with ultrapure water. The coal-based GAC was collected from an operating biofilter and had been in used for approximately seven years prior to collection. Visual inspection of the dried

media indicated that there was a brown powdery material in the media and a yellow-brown substance lodged in the crevices of the media. It is suspected that the powder and yellow-brown substance was dried biomass and other debris that had collected in the biofilter. It is also possible that organic carbon that had adsorbed onto the coal-based GAC during full-scale operation desorbed when the GAC was in contact with the ultrapure water. This contamination was not problematic for the pilot work because it was expected to wash out of the filters during the first backwash and first few days of operation. As well, the contamination of the coal-based GAC was taken into account when assessing whether or not the coal-based GAC could adsorb organic matter.

3.3.2.2.2 Confirmation of the Adsorptive Properties of the Media

Crushed media were placed in contact with 200 mL of pilot filter influent water for four hours to confirm which media types could adsorb organic matter. DOC concentrations in the pilot filter influent water before and after four hours contact with each type of media are summarized in Figure 3-19 and Table 3-12.

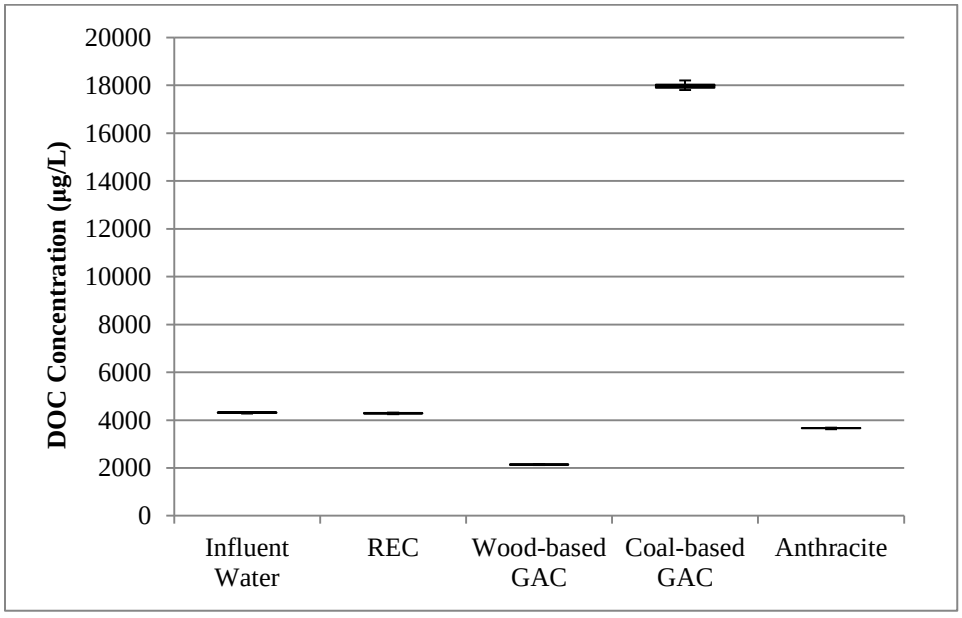


Figure 3-19: Boxplots of all measurements of the DOC concentration present in influent water and the DOC concentration present after four hours contact with each type of media. (Bars indicate minimum and maximum values; bars are plotted for all boxplots but are not necessarily visible. n=36 for each boxplot)

Table 3-12: Mean and standard deviation of the DOC concentration in influent water and the DOC concentration in influent water after four hours contact with media

Statistic	Influent Water	REC	Wood-based GAC	Coal-based GAC	Anthracite
Mean DOC Concentration (μg/L)[1,2]	4310	4290	2140	18000	3660
Standard Deviation (μg/L)[1,2]	16.3	4.91	5.29	106	6.82

1. Values rounded to 3 significant figures
2. n=36

The results confirmed that REC was a nonadsorptive media type and wood-based GAC was an adsorptive media type, as expected.

The final DOC concentration, after the water had been in contact with the coal-based GAC, was substantially higher than the initial DOC concentration. The increase in DOC concentration was likely due to the contamination of the coal-based GAC. To determine whether the coal-based GAC adsorbed organic matter, an adjusted initial concentration was estimated and was compared to the final concentration. The adjusted initial concentration of DOC was estimated by assuming that the amount of organic carbon added to the influent water from contamination would be the same as the amount of organic matter that was released from the GAC surface into ultrapure water (Table 3-11). The adjusted initial DOC concentration was then calculated by adding the amount of DOC contamination observed in the ultrapure water to the initial DOC concentration of the influent water; this resulted in an expected initial concentration of 20.3 mg/L. The final DOC concentration in the influent water, after being in contact with the coal-based GAC, was 2.3 mg/L lower than the adjusted initial concentration; therefore, it was concluded that the coal-based GAC adsorbed at least some organic matter. Thus, the coal-based GAC was considered to be an adsorptive media type.

The results from the anthracite were somewhat surprising: the aqueous DOC concentration decreased after being in contact with the media. Anthracite is generally understood to be a nonadsorptive media type; however, these results indicate that anthracite can adsorb some natural organic matter[72]. An additional adsorption experiment was conducted to confirm that crushed anthracite adsorbed organic

[72] It should be noted that the decrease in DOC was likely not due to biodegradation. The REC, anthracite, and wood-based GAC were virgin media that had all been stored in the same location. Biodegradation, therefore, would be expected to occur for *both the REC and anthracite* because the same influent water was used for all media types and both anthracite and REC were virgin media that were stored in the same environment. The DOC concentration in the jars containing REC was not lower than the initial DOC concentration; therefore biodegradation did not occur in the jars containing REC. Therefore, the decrease in DOC concentration associated with anthracite was likely due to adsorption and not due to biodegradation of the DOC.

matter, to determine whether undried crushed anthracite could also adsorb organic matter, and to determine anthracite is adsorptive in its granular form. The results from this experiment are presented in Figure 3-20 and Table 3-13.

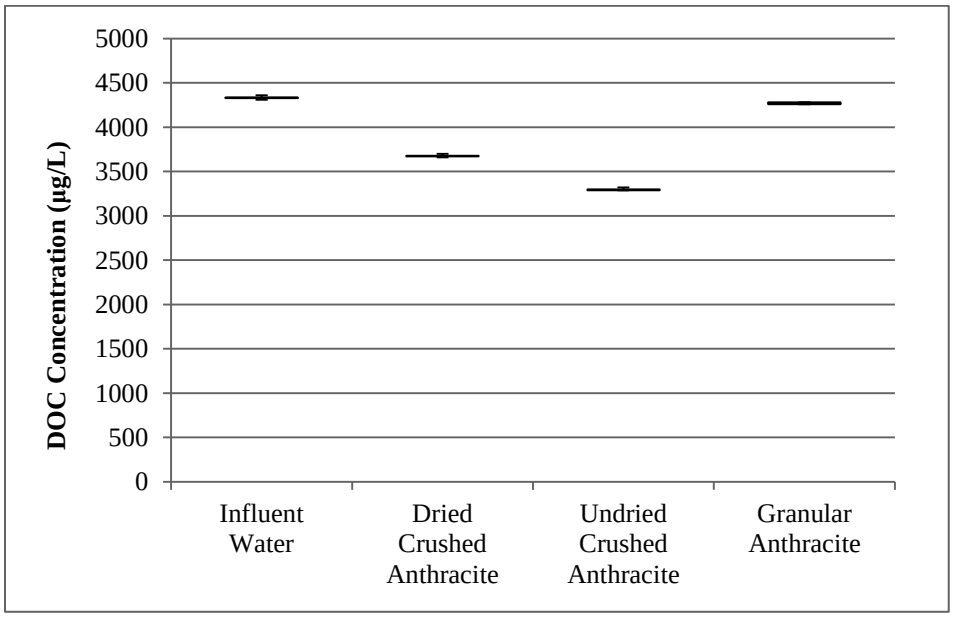


Figure 3-20: Boxplots of all measurements of the DOC concentration present in influent water and the DOC concentration present after four hours contact with anthracite that had been crushed, crushed and dried, and that was in granular form. (Bars indicate minimum and maximum values; bars are plotted for all boxplots but are not necessarily visible. n=12 for each boxplot)

Table 3-13: Mean and standard deviation of the DOC concentration in influent water and the DOC concentration in influent water after four hours contact with crushed, crushed and dried, and granular anthracite

Statistic	Influent Water	Dried Crushed Anthracite	Undried Crushed Anthracite	Granular Anthracite
Mean DOC Concentration (µg/L)[1,2]	4330	3680	3300	4270
Standard Deviation (µg/L)[1,2]	13.4	10.0	10.8	9.00

1. Values rounded to 3 significant figures
2. n=12

The crushed anthracite, in both dried and undried form, adsorbed organic matter; this confirmed the previous finding that anthracite can adsorb organic matter. The undried crushed anthracite adsorbed more organic matter than the dried anthracite. The exact reason for the difference in adsorbability between undried and dried crushed anthracite is ultimately unknown; however, it is possible that this was due to a small amount of volatile organic matter adsorbing onto the anthracite during the drying process, slight

reductions in the adsorptive capacity of the anthracite caused by the drying process, or variability in the anthracite adsorbability. Interestingly, despite differences in adsorption provided by undried and dried crushed anthracite, comparison of the results from the dried crushed anthracite from this confirmatory test to the initial adsorption tests (Table 3-12) indicates that amount of organic matter adsorbed on dried crushed anthracite was remarkably reproducible: the same amount of organic matter adsorbed both during the initial adsorption tests and in this confirmatory test – 0.65 mg/L (i.e. 650 μg/L).

The granular anthracite, in comparison to the crushed anthracite, adsorbed very little organic matter – a mere 0.06 mg/L. The exact reason the crushed anthracite adsorbed a substantially greater amount organic matter than granular organic matter is unknown, but it is possible that crushing the anthracite to a powder resulted in a significant enough increase in available surface area that more adsorption could occur or that crushing anthracite allowed equilibrium between the amount of organic matter adsorbed and the amount of organic matter in the water to be reached faster than with granular anthracite.

Overall, the amount of organic matter that was adsorbed by the dried crushed anthracite, which can be directly compared to the amount of organic matter adsorbed by the GACs since both media types were crushed and dried, was only 30 % of what was adsorbed by wood-based GAC and 20% of what was adsorbed by coal-based GAC. Therefore, the dried crushed anthracite had a much lower adsorptive capacity than GAC. Furthermore, granular anthracite, which is what was used in the pilot plant, adsorbed essentially no organic matter. Therefore, even though crushed anthracite can adsorb some organic matter, the anthracite used for Phase 1 experiments was, at most, a slightly adsorptive media type.

3.3.3 Organic Matter Removal

3.3.3.1 Dissolved Organic Carbon

3.3.3.1.1 Data Review and Importance of Quality Control Measures

DOC data from each sampling event were summarized, plotted, and reviewed to determine whether the data were reliable and could be used in further analysis; the raw data, plots of the data, lists of data that was excluded, and rationale for the exclusion of specific data points can be found in Appendix B. Overall, the majority of the data were found to be reliable: samples collected from the same source in multiple bottles, multiple aliquots from the same bottle, and multiple measurements from the same aliquot all had similar DOC values. However, in some cases average DOC concentrations of samples from two bottles collected at the same sampling location at the same time were clearly different from each other. In other cases, DOC measurements from multiple aliquots of the same sample deviated from each other. These

deviations may have been due to contaminated glassware, analytical errors, or temporal variability in the influent or effluent DOC concentrations. It is unlikely that differences in concentration were due to temporal variability in the influent or effluent DOC concentrations because (a) multiple bottles of sample water, collected from a given sampling location at a given time, were collected within a few minutes of each other and (b) the majority of bottles collected from a given sampling location, at a given time, had similar average DOC concentrations; therefore, the deviations were suspected to be due to contaminated glassware or analytical errors. Data exhibiting these deviations were considered suspect and were excluded from further analysis. Examples of an ideal data set and data sets where data were excluded are discussed in this section. Readers interested in reviewing exactly which data points were excluded for other data sets and the rationale for these exclusions are referred to Appendix B.

Table 3-14 and Figure 3-21 present data from data set 21, wherein all of the data were considered reliable. Table 3-14 shows the individual DOC measurements taken from each aliquot of water for all bottles collected and for all sampling locations. Table 3-14 also presents the average concentration for each aliquot of water and the average and standard deviation of the DOC concentration for each bottle collected.

Table 3-14: Data Set 21 DOC measurements

Bottle	Aliquot	Measurement	DOC Concentration at Location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.474	3.707	3.963	3.776	3.438	3.481
		2	4.519	3.782	3.902	3.840	3.483	3.547
		3	4.540	3.795	3.944	3.859	3.483	3.558
		Average	4.511	3.761	3.936	3.825	3.468	3.529
	2	1	4.403	3.791	3.823	3.769	3.449	3.453
		2	4.549	3.788	3.934	3.857	3.470	3.528
		3	4.557	3.814	3.964	3.874	3.509	3.577
		Average	4.503	3.798	3.907	3.833	3.476	3.519
	3	1	4.472	3.712	3.852	3.761	3.438	3.583
		2	4.551	3.729	3.912	3.846	3.502	3.586
		3	4.515	3.793	3.919	3.863	3.524	3.549
		Average	4.513	3.745	3.894	3.823	3.488	3.573
	Average		4.509	3.768	3.913	3.829	3.477	3.540
	Standard Deviation		0.0507	0.0403	0.0481	0.0453	0.0312	0.0461
2	1	1	4.463	3.554	4.042	3.852	3.447	3.568
		2	4.564	3.665	4.064	3.923	3.521	3.596
		3	4.568	3.677	4.092	3.946	3.504	3.654
		Average	4.532	3.632	4.066	3.907	3.491	3.606
	2	1	4.508	3.637	4.149	3.852	3.440	3.583
		2	4.534	3.703	4.085	3.910	3.506	3.598
		3	4.547	3.720	4.075	3.940	3.519	3.616
		Average	4.530	3.687	4.103	3.901	3.488	3.599
	3	1	4.467	3.618	3.953	3.868	3.451	3.581
		2	4.530	3.658	4.068	3.916	3.502	3.639
		3	4.564	3.726	4.053	3.919	3.553	3.628
		Average	4.520	3.667	4.025	3.901	3.502	3.616
	Average		4.527	3.662	4.065	3.904	3.494	3.607
	Standard Deviation		0.0402	0.0543	0.0519	0.0421	0.0389	0.0290

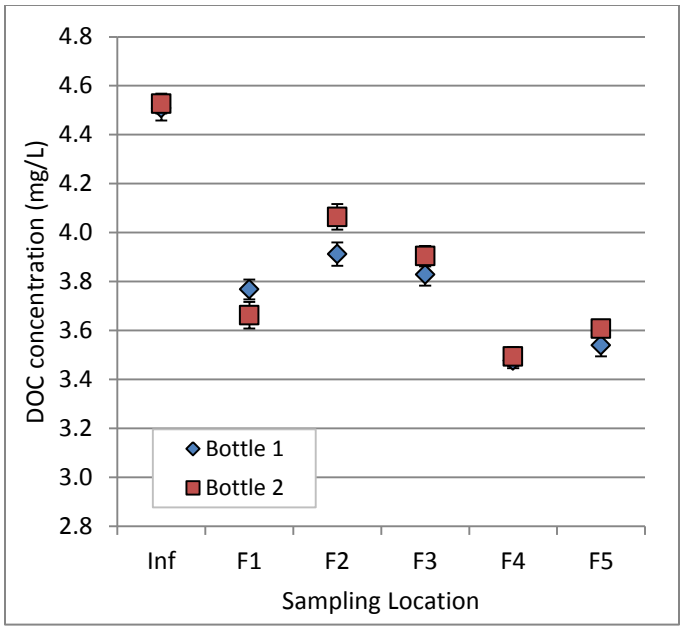


Figure 3-21: Plot of average DOC concentrations from Data Set 21 (positive and negative error bars represent one standard deviation; n=9. Sampling location "Inf" is the comment filter influent and locations F1-F5 are the effluent of filters 1 through 5)

It can be seen from Table 3-14 and Figure 3-21 that the average results from both bottles collected at each location were very similar. It can also be seen from Table 3-14 that, for each bottle collected, the average DOC concentrations for aliquots from the same bottle were similar. These results were, therefore, considered reliable and no data were excluded from further analysis.

Table 3-15 and Table 3-16 present data from data sets 1 and 5. In these tables, data which were considered suspect and excluded from further analysis are indicated by a superscript number 1 and are highlighted.

Table 3-15: Data Set 1 DOC measurements

Bottle	Aliquot	Measurement	DOC Concentration at Location (mg/L) Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	38.70[1]	3.891	3.906	3.852	3.554	3.972
		2	38.96[1]	3.906	3.92	3.852	3.56	3.861
		3	39.13[1]	3.922	3.97	3.889	3.543	3.836
		Average	38.93	3.906	3.932	3.864	3.552	3.890
	2	1	4.477	3.782	3.931	3.891	3.448	3.714
		2	4.395	3.83	3.994	3.975	3.47	3.773
		3	4.367	3.876	3.961	3.955	3.521	3.806
		Average	4.413	3.829	3.962	3.940	3.480	3.764
	3	1	4.167	3.814	3.942	3.884	3.501	3.744
		2	4.211	3.873	3.99	3.917	3.523	3.823
		3	4.261	3.913	3.957	3.948	3.573	3.865
		Average	4.213	3.867	3.963	3.916	3.532	3.811
	Average		4.313	3.867	3.952	3.907	3.521	3.822
	Standard Deviation		0.1191	0.0484	0.0302	0.0445	0.0420	0.0762
2	1	1	4.332	-	-	-	-	-
		2	4.363	-	-	-	-	-
		3	4.272	-	-	-	-	-
		Average	4.322					
	2	1	4.192	-	-	-	-	-
		2	4.229	-	-	-	-	-
		3	4.283	-	-	-	-	-
		Average	4.235					
	3	1	4.192	-	-	-	-	-
		2	4.242	-	-	-	-	-
		3	4.329	-	-	-	-	-
		Average	4.254					
	Average		4.270	-	-	-	-	-
	Standard Deviation		0.0620	-	-	-	-	-

1. Data excluded from further analysis

Table 3-16: Data Set 5 DOC measurements

Bottle	Aliquot	Measurement	DOC Concentration at Location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.019	3.267	3.965[1]	3.270	3.226	3.125[1]
		2	3.770	3.276	3.831[1]	3.483	3.353	3.280[1]
		3	4.006	3.261	3.824	3.290	3.230	3.171[1]
		Average	3.932	3.268	3.873	3.348	3.270	3.192
	2	1	3.879	3.406	3.826[1]	3.661	3.418	3.169[1]
		2	3.958	3.339	3.812[1]	3.699	3.288	3.171[1]
		3	3.950	3.357	3.937[1]	3.519	3.232	3.148[1]
		Average	3.929	3.367	3.858	3.626	3.313	3.163
	Average		3.930	3.318	3.866	3.487	3.291	3.177
	Standard Deviation		0.0928	0.0589	0.0669	0.1801	0.0793	0.0535
2	1	1	4.121	3.224	3.349[1]	3.313	3.127	4.371[1]
		2	4.019	3.295	3.360[1]	3.508	3.403	4.130[1]
		3	3.956	3.251	3.368[1]	3.320	3.058	4.092[1]
		Average	4.032	3.257	3.359	3.380	3.196	4.198
	2	1	3.789	3.491	3.546[1]	3.860	3.188	4.253[1]
		2	3.676	3.506	3.527[1]	3.730	3.052	4.174[1]
		3	3.784	3.533	3.604[1]	3.784	3.064	4.172[1]
		Average	3.750	3.510	3.559	3.791	3.101	4.200
	Average		3.891	3.383	3.459	3.586	3.149	4.199
	Standard Deviation		0.1683	0.1412	0.1126	0.2393	0.1352	0.1001

1. Data excluded from further analysis

The data from data set 1 provide an example of where data from a single aliquot was excluded: the data from influent water from bottle 1, aliquot 1 was excluded from further analysis. The measured DOC concentration of influent water from bottle 1, aliquot 1 was substantially higher than the measured DOC concentration of the other aliquots of influent water from bottle 1. In this particular case, the DOC concentration was higher because of a peculiarity in the firmware programming of the TOC analyzer, which prevented the aliquot from being properly sparged during analysis.

The data from data set 5 provide an example of where all data from a given location was excluded: DOC data related to the Filter 5 and Filter 2 effluents were excluded from further analysis. Inspection of the average DOC concentrations in the Filter 5 effluent in bottles 1 and 2 indicates that the concentration of

DOC in bottle 2 was approximately 1 mg/L higher than in bottle 1. These samples were collected within minutes of each other and therefore it would be expected that the DOC concentrations should be similar. The difference in concentration between bottles 1 and 2 for Filter 5 was likely due to contamination of the sample water in bottle 2 during sampling or analysis; however, because there was no way of verifying that the concentration in bottle 1 was correct, data from both bottles were excluded from further analysis. Similarly, inspection of the average DOC concentrations for sample water collected from the Filter 2 effluent in bottles 1 and 2 indicates that the concentration of DOC in bottle 1 was approximately 0.4 mg/L higher than the concentration in bottle 2. It was suspected that bottle 1 was contaminated during sampling or analysis and, as with Filter 5, data associated with Filter 2 on this occasion was excluded from further analysis.

These results presented in Table 3-15 and Table 3-16 highlight the importance of incorporating rigorous quality control measures when conducting DOC analysis of grab samples. Specifically, multiple aliquots of the same sample should be analyzed at the very least and, ideally, multiple samples from the same sampling location should be collected. Periodically analyzing a single grab sample from each of several sampling locations is not sufficient for analyzing DOC when conducting rigorous research as there is no way for the analyst to independently determine whether the results from that location are reliable and representative.

3.3.3.1.2 Results from Individual ANOVAs and Associated Multiple Comparisons

Individual ANOVAs and multiple comparisons were conducted on each of the data sets to compare DOC removal provided by the pilot filters. ANOVA tables, normal probability plots, plots of residuals versus predicted values, plots of residuals versus the different treatments, tables summarizing p-values, results from multiple comparisons, and brief point-form discussions of the results from each ANOVA can be found in Appendix B.

3.3.3.1.2.1 DOC Removal

DOC removal for each data set, for all filters, is shown in Figure 3-22. Summary statistics for the calculated DOC removals are shown in Table 3-17.

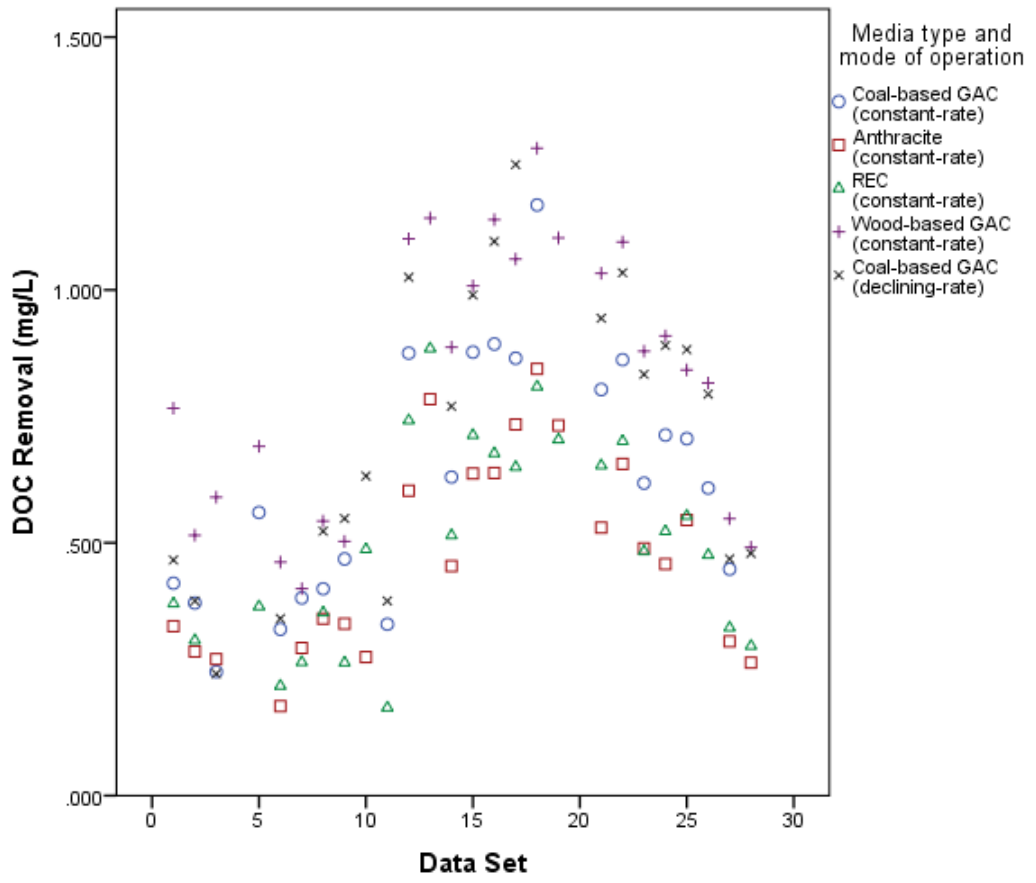


Figure 3-22: DOC removal across the entire experimental period differentiated by data set number (data set number increases incrementally with time)

Table 3-17: Summary statistics for DOC removal

Summary Statistic	DOC removal (mg/L)[1] Filter 1 Coal-based GAC	Filter 2 Anthracite	Filter 3 REC	Filter 4 Wood-based GAC	Filter 5 Coal-based GAC (declining-rate)
Mean	0.619	0.478	0.502	0.826	0.713
Standard Deviation	0.242	0.196	0.201	0.266	0.288
Max	1.168	0.844	0.884	1.280	1.248
Min	0.245	0.177	0.174	0.409	0.241
n	22	23	25	24	21

1. All filters operated in constant-rate mode unless otherwise noted

The filters removed between 0.174 and 1.280 mg/L of DOC. DOC removal by the filters was statistically significant (at a significance level of 0.05) in all except for two cases: Filter 1 (coal-based GAC) in Data Set 3 and for Filter 2 (anthracite) in Data Set 10. These DOC removals were, however, similar to those

observed during other sampling events[73]. In both of these cases, there were a limited amount of data available[74]. It is likely that these removals would have been found to be statistically significant if more data had been available.

It is interesting to note the somewhat cyclical trend in DOC removal with respect to data set number seen in Figure 3-22. The trend was suspected to be related to water temperature. A plot of DOC removal with respect to temperature was created to investigate this trend; this plot is shown in Figure 3-23.

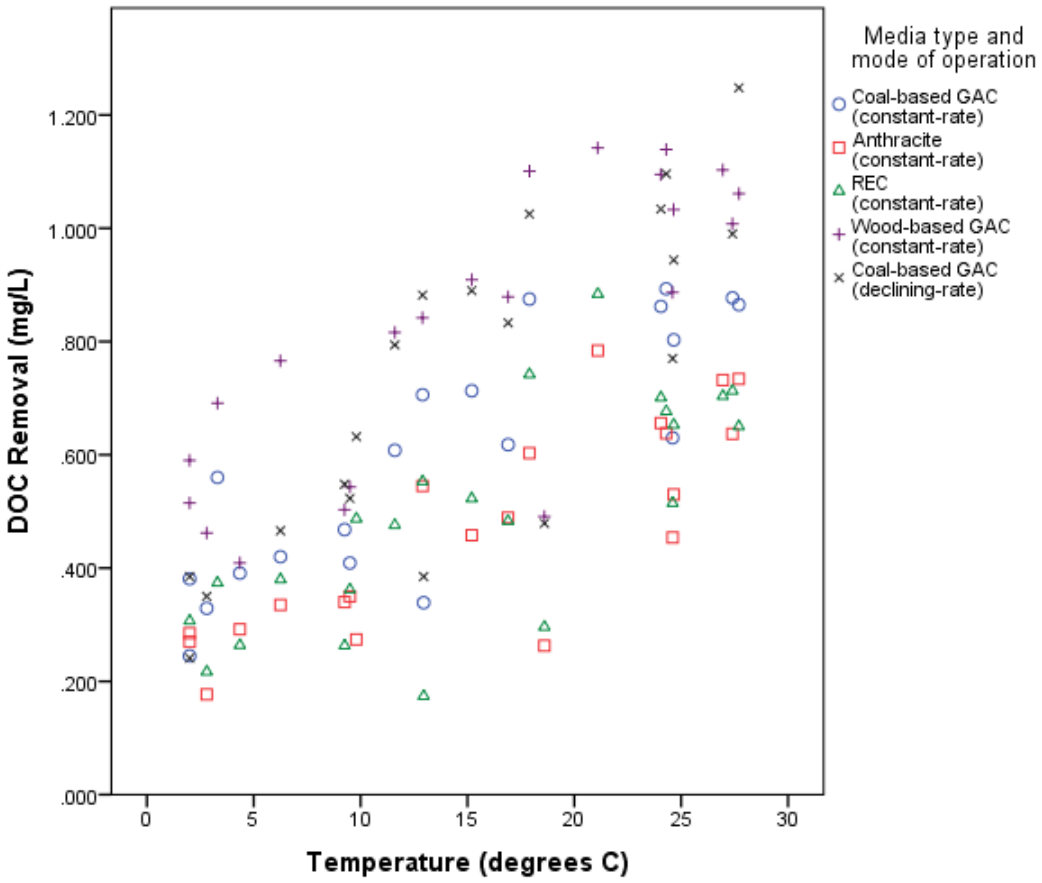


Figure 3-23: DOC removal with respect to temperature

It can be seen in Figure 3-23 that there was a clear correlation between water temperature and DOC removal for all media types. These results corroborate the correlation between organic matter removal and

[73] The DOC removal was 0.245 mg/L for Filter 1 in Data Set 3 and 0.274 mg/L for Filter 2 in Data Set 10.
[74] Only one bottle of sample water was collected during the sampling event for Data Set 3. There was a limited amount of sample water available for DOC analysis during the sampling event for Data Set 10 due to the use of sample water for AOC analysis.

temperature seen by others (e.g. Hallé et al., 2015; Pharand et al., 2015; Liu et al., 2001; Moll et al., 1999) and shows that this correlation exists for all media types.

3.3.3.1.2.2 Comparison of DOC Removal Provided by Various Media Types

Table 3-18 shows the number of sampling events where one media type provided a lower effluent DOC concentration (i.e. better DOC removal) than another at a significance level of 0.05, the number of sampling events where there was no statistically significant difference in effluent DOC concentration, and p-values from the sign tests. The filtration medium which, overall, had the lowest effluent DOC is presented in bold type and is underlined.

Interpretation of Table 3-18 can be illustrated by inspecting the row where coal-based GAC is filtration medium 1 and anthracite is filtration medium 2: the table indicates that coal-based GAC provided a lower effluent DOC concentration (i.e. better DOC removal) than anthracite at a significance level of 0.05 in 14 of the sampling events, that anthracite provided a lower effluent DOC concentration than coal-based GAC in none of the sampling events, and that there was no statistically significant difference in effluent concentration (i.e. no difference in DOC removal) in six sampling events. The p-value from the sign test was very small and, therefore, it can be concluded that the fact that the coal-based GAC provided better removal of DOC than anthracite in 14 of the filter cycles was not due to random chance. Therefore, it can be concluded that the coal-based GAC provided, overall, better removal of DOC than anthracite.

From the results presented in Table 3-18, it can be concluded that both coal-based GAC and wood-based GAC provided better removal of DOC than either anthracite or REC during the majority of the sampling events; that wood-based GAC provided better removal of DOC than coal-based GAC during the majority of the sampling events; and that, with the exception of one sampling event, REC did not provide better removal of DOC than anthracite in the majority of the sampling events. These findings indicate that, overall, GAC can provide better DOC removal than either anthracite or REC and that REC does not provide better DOC removal than anthracite even when the grain size distributions of all media types are closely matched.

Table 3-18: Summary of ANOVA and sign test results from comparisons of effluent DOC concentrations provided by different media types

Comparison[5]		Number of Sampling Events Where:			Adjusted P-value from Sign Test[3]
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 Provided Better DOC Removal (DOC 1<DOC 2)[1]**	**No Difference**	**Medium 2 Provided Better DOC Removal (DOC 1>DOC 2)[2]**	
Coal-based GAC	Anthracite	14	6	0	1.2×10^{-03}
Coal-based GAC	REC	15	7	0	6.1×10^{-04}
Coal-based GAC	**Wood-based GAC**	0	9	13	2.4×10^{-03}
Wood-based GAC	Anthracite	19	3	0	3.8×10^{-05}
Wood-based GAC	REC	22	2	0	4.8×10^{-06}
REC	Anthracite	1	21	0	-[4]

1. Effluent DOC concentration of the filter containing filtration medium 1 was lower than the effluent DOC concentration of the filter containing filtration medium 2.
2. Effluent DOC concentration of the filter containing filtration medium 2 was lower than the effluent DOC concentration of the filter containing filtration medium 3. P-values multiplied by 10 to provide a Bonferroni correction. A value of 10 used because a total of 10 comparisons were conducted (including comparisons of the declining rate mode filter to constant rate mode filters, not shown in this table).
4. Not calculated because there was only one event where REC provided better removal of DOC than anthracite
5. Note: all filters operated in constant-rate mode

Comparison of the GAC and anthracite results supports the general belief that can be drawn from the literature: GAC can provide equivalent or better organic matter removal than anthracite. The reason why no difference in DOC removal was observed during some studies and during some sampling events in this study remains unknown: it may be that there was a difference in DOC removal, but that the difference was too small compared to variability of DOC measurements or it may be that there was no difference due to some confounding factor.

3.3.3.1.2.3 Comparison of Declining-Rate Mode of Operation to Constant-Rate Mode of Operation

Table 3-19 summarizes the results from the comparisons of the declining-rate filter to the other filters and p-values from associated sign tests. The filter which, overall, had the lowest effluent DOC for a given comparison is presented in bold type and is underlined. Where no filter is presented in bold type, it indicates that neither filter was considered to have lower effluent DOC, overall.

The filter operated in declining-rate mode provided somewhat better overall DOC removal than the corresponding filter operated in constant rate mode. This was not surprising given (a) that the samples were collected 24 hours into the filter cycle, (b) that the flow through the declining-rate filter had decreased by this time, and (c) that the EBCT was greater in the declining-rate filter was greater than for the constant-rate filter at the time of sample collection. It is interesting to note that the declining-rate filter which contained coal-based GAC provided similar overall DOC removal to the filter which contained the wood-based GAC (see Table 3-17, Figure 3-22, and Figure 3-23), whereas the constant-rate coal-based GAC filter provided relatively less DOC removal than the wood-based GAC filter (see Table 3-18). Thus, operating filters in a declining-rate mode may (at least in some cases) compensate for differences in DOC removal provided by different media types, albeit at the cost of lower water production.

Table 3-19: Summary of ANOVA and sign test results from comparisons of effluent DOC concentrations provided by a filter operated in declining-rate mode to filters operated in constant-rate mode

Comparison[1]		Number of sampling events where:			
Filter 1	**Filter 2**	**Filter 1 Provided Better DOC Removal (DOC 1<DOC 2)[2]**	**No Difference**	**Filter 2 Better DOC Removal (DOC 1>DOC 2)[3]**	**Adjusted P-value from Sign Test[4,5]**
Coal-based GAC (declining rate)	Coal-based GAC (constant-rate)	8	12	0	7.8×10^{-02}
Coal-based GAC (declining rate)	Wood-based GAC (constant-rate)	1	13	6	$1.0 \times 10^{+00}$
Coal-based GAC (declining rate)	Anthracite (constant-rate)	15	4	0	6.1×10^{-04}
Coal-based GAC (declining rate)	REC (constant rate)	18	3	0	7.6×10^{-05}

1. For each filter, the media type and mode of operation are listed. The mode of operation is listed in brackets.
2. Effluent DOC concentration from filter 1 was lower than the effluent DOC concentration from filter 2.
3. Effluent DOC concentration from filter 2 was lower than the effluent DOC concentration from filter 1.
4. P-value multiplied by 10 to provide a Bonferroni correction. A value of 10 used because a total of 10 comparisons were conducted (including comparisons of different media types, not shown in this table).
5. The p-value for coal-based GAC (declining-rate) vs wood-based GAC (constant-rate) was recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. P-values greater than one are not possible. The unadjusted p-value was 1.25×10^{-01}.

3.3.3.1.3 Mechanistic Implications of DOC results

There are several mechanistic implications to the DOC results. The grain size distributions of all media types were closely matched; therefore, differences in DOC removal between filters were attributed to media type (i.e. the material that makes up the media grains and the properties associated with this material) and the associated media properties.

Media roughness is a key difference between REC and anthracite. Specifically, REC is rough whereas anthracite is relatively smooth (section 3.3.2.1). Given that there was no difference in DOC removal between the REC and anthracite in the majority of sampling events, media roughness is likely not a media property that significantly enhances DOC removal during biofiltration. These results further imply that mechanisms related to media roughness, such as biomass shielding, are not major mechanisms that impact DOC removal during biofiltration.

The primary difference between the two GACs and the other media types is that GAC is very adsorptive whereas the REC is nonadsorptive and the anthracite is only slightly adsorptive. The fact that the GACs provided better DOC removal than both the REC and the anthracite implies that the adsorptive property of the GAC somehow results in improved DOC removal during biofiltration[75]. It should be highlighted that use of the term "adsorptive property" does not imply that the GAC must be virgin GAC to provide improved removal DOC: in fact, the coal-based GAC had been in use for seven years prior to being used in this study and still provided improved DOC removal compared to REC and anthracite. Therefore, the improved DOC removal associated with the adsorptive property is not a short-term improvement associated with adsorption of organic matter onto virgin GAC, but rather the result of a mechanism that

[75] It is also known that GAC can reduce oxidants such as chlorine and ozone. Chlorine and ozone residuals can suppress biological growth; therefore, the reduction of chlorine or ozone residuals by GAC could result in GAC biofilters providing better biological removal of DOC than anthracite or REC. It could be argued that the difference in performance between the GACs and anthracite/REC could be attributed to the reduction of any residual ozone. However, the ozone residual in the pilot influent water was 0.0 mg/L for most of the time and was always below 0.2 mg/L during warm water conditions. Furthermore, reanalysis of the effluent DOC comparisons using only data from warm water conditions (analysis not shown) resulted in the same conclusions as using the whole data set. Therefore: (a) differences in performance between GACs and nonadsorptive media during warm water conditions were not due to the reduction of ozone because the ozone residual was low, (b) thus, differences in performance can still be attributed to the difference in the adsorptive properties of the media, and (c) attributing differences in DOC removal to the adsorptive properties of the media is still valid. During cold water conditions, the ozone residual ranged from 0.0 to 0.5 mg/L (average of 0.2 mg/L); therefore, during cold water conditions, reduction of ozone residual by GACs could have played a role in causing the difference in DOC removal during some sampling events. However, mechanisms related to the adsorptive property of the GAC which operated during warm water conditions also would have operated under cold water conditions.

provides improved DOC over the long term[76]. It could also be argued that, as well as being adsorptive, the GAC is rough and that this roughness could have impacted the DOC removal; however, as discussed previously, if the roughness of a filtration medium was the primary cause of improved DOC removal, the REC should have provided better DOC removal than anthracite (which it did not) and the REC and GACs should have had similar DOC removals (which they did not).

The results from this experimental phase indicate that the adsorptive property of GAC allows for long-term improved removal of DOC but the results do not indicate exactly how this property causes improved removal of DOC. Elucidating exactly how the adsorptive property causes improved removal of DOC in the long term is an area for further research. One mechanism suggested in the literature is GAC bioregeneration (e.g. AWWA, 1981). Another potential mechanism is the adsorption of spikes of organic matter followed by either desorption or bioregeneration of the adsorbed organic matter. Adsorption-related mechanisms were investigated in Phase II of this thesis. It is recommended that future studies investigate other mechanisms which may account for the difference in performance between filters containing GAC and filters containing anthracite.

A practical implication that can be derived from the above mechanistic implications is that GAC would be expected to provide long-term improved removal of DOC in cases where the fraction of adsorptive organic matter in the influent water is large but not necessarily in cases where the fraction of adsorptive organic matter is small. The fact that the GAC has an adsorptive property would not be expected to impact DOC removal if the organic matter in the influent is mainly nonadsorptive. Further research is needed to confirm this implication; however, if this implication is confirmed, engineers and utilities would be able to determine whether it is worth considering GAC for long-term use in biofiltration at a given location based on adsorbability of the organic matter present in the water to be treated.

3.3.3.2 Assimilable Organic Carbon

Raw AOC data, calculated AOC values, summary statistics of AOC results, and detailed statistical test results can be found in Appendix C. The results from the four sets of tests conducted on the AOC results and from the review of the quality control results are discussed in the following subsections.

[76] It is also noted, that although the wood-based GAC was virgin GAC at the start of this study, it was expected to be exhausted during the study due to: a) the influent DOC concentrations ranging from 3-4.8 mg/L and b) the almost two-year duration of the study.

3.3.3.2.1 Test Set 1: Comparison of Influent AOC Values from Replicate Bottles to Determine Whether Influent AOC Data Can Be Pooled.

Table 3-20 summarizes the mean and standard deviation of the influent AOC concentrations for the two replicate bottles and the p-value calculated from the Mann-Whitney test.

Table 3-20: Average influent AOC concentrations from replicate bottles and p-value from the Mann-Whitney tests comparing the AOC concentrations

Sampling Event	Influent Bottle 1			Influent Bottle 2			P-value[1,2]
	Average AOC[1] (µg/L)	Standard Deviation[1] (µg/L)	n	Average AOC[1] (µg/L)	Standard Deviation[1] (µg/L)	n	
21-Mar-12	840	110	8	810	180	8	0.88
12-Apr-12	510	89	9	480	89	8	0.96
27-Jun-12	630	120	11	590	140	12	0.45
8-Aug-12	500	100	10	470	150	10	0.35
14-Aug-12	530	120	10	480	70	12	0.28

1. All values rounded to two significant digits
2. P-values are exact 2-tailed p-values calculated using SPSS.

For all sampling events, the average AOC values for bottle 1 and bottle 2 were similar and that the p-values were quite high. In all cases the p-values were much greater than a significance level of 0.003125; therefore the null hypothesis that the AOC concentrations from both influent bottles came from distributions that were the same was accepted. All influent data from a given sampling event, therefore, were pooled for subsequent analyses.

3.3.3.2.2 Test Set 2: Determination of Whether There Was a Statistically significant difference in AOC Concentrations Between the AOC Concentrations Measured at the Different Sampling Locations (Influent and the Various Filter Effluents).

The average AOC concentrations from all sampling locations and each sampling event are presented in Figure 3-24 and Table 3-21.

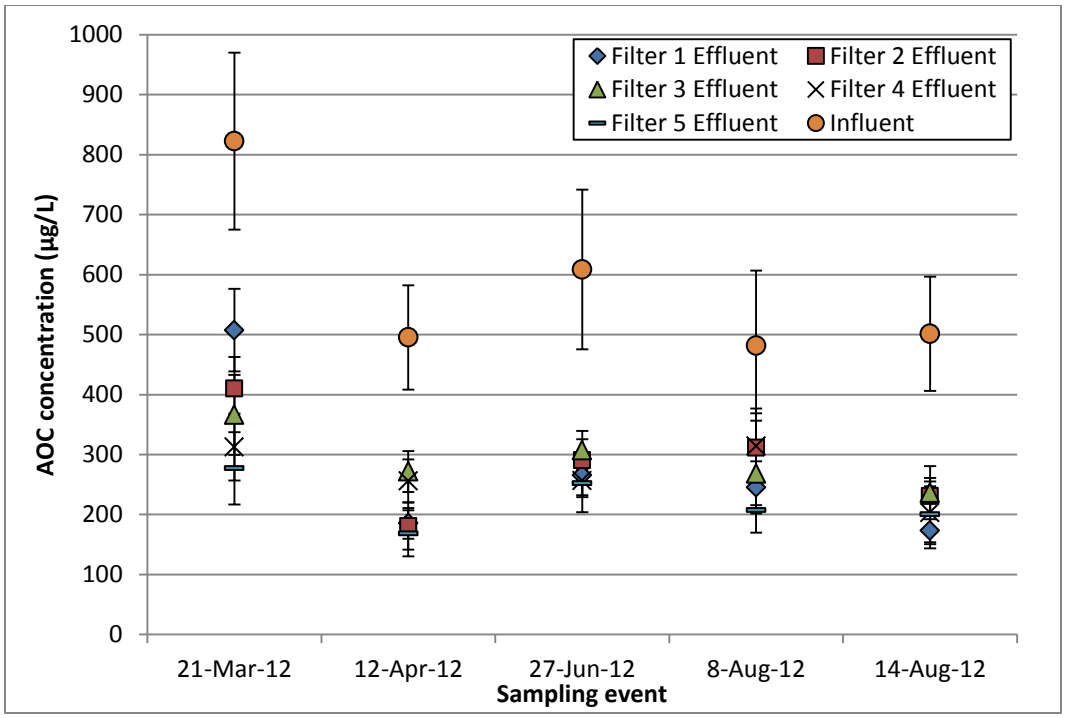


Figure 3-24: Plot of average AOC concentrations from all locations and sampling events. (Error bars represent one standard deviation; n=5)

Table 3-21: Average and standard deviations of AOC concentrations from all locations and all sampling events

Sample	Summary Statistic	Value from Sampling Event (µg/L AOC)[1]				
		21-Mar-12	12-Apr-12	27-Jun-12	8-Aug-12	14-Aug-12
Influent	Average	820	500	610	480	500
	Standard Deviation	150	87	130	130	95
	n	16	17	23	20	22
F1 Effluent	Average	510	190	270	250	170
	Standard Deviation	69	26	34	44	29
	n	15	8	11	10	14
F2 Effluent	Average	410	180	290	310	230
	Standard Deviation	53	39	35	65	30
	n	13	9	14	13	14
F3 Effluent	Average	370	270	310	270	240
	Standard Deviation	67	34	32	52	44
	n	8	9	12	13	15
F4 Effluent	Average	310	260	260	310	200
	Standard Deviation	56	36	28	55	52
	n	9	9	12	13	13
F5 Effluent	Average	280	170	250	210	200
	Standard Deviation	60	39	49	37	47
	n	7	8	9	13	10

1. All values rounded to two significant figures

It can be seen from inspection of Figure 3-24 and Table 3-21 that, for each sampling event, there was a difference in the AOC concentrations measured at the various locations. At the very least, there was a difference in AOC concentration between the filter influent and filter effluents. Table 3-22 summarizes the results from the Kruskal-Wallis Tests.

Table 3-22: Results from Kruskal-Wallis tests on AOC concentrations

Sampling Event	Test Statistic	Degrees of Freedom	P-value[1]
21-Mar-12	55.383	5	$1.1x10^{-10}$
12-Apr-12	47.616	5	$2.6x10^{-09}$
27-Jun-12	57.477	5	$4.0x10^{-11}$
8-Aug-12	54.173	5	$1.9x10^{-10}$
14-Aug-12	59.284	5	$1.7x10^{-11}$

1. Asymptotic significance level calculated by SPSS

The p-values from the Kruskal-Wallis tests were much smaller than a significance level of 0.05; therefore, in each sampling event, the AOC concentrations measured at one (or more) of the sampling locations were different than the AOC concentrations measured at the other sampling locations. Given this result, test sets 3 and 4 were conducted as follow-up tests to determine whether AOC was removed by the filters[77] and whether there was a difference in AOC removal provided by the different media types (i.e. whether there was a difference in AOC concentration between the filter effluents).

3.3.3.2.3 Test Set 3: Determination of Whether AOC Was Removed by the Filters

As would be expected, the AOC concentration in the filter influent was higher than the AOC concentration in all filter effluents and for all sampling events (Figure 3-24; Table 3-21). Mann-Whitney tests were conducted at a significance level of 0.003125. Table 3-23 summarizes calculated AOC removal values and the p-values from the comparisons. Summarized output from SPSS, including the calculated Mann-Whitney U values and results from alternative p-value calculations can be found in Appendix C.

[77] i.e. to determine whether there was a difference in AOC concentration between the filter influents and the filter effluent

Table 3-23: Calculated AOC removal and p-values from Mann-Whitney tests comparing influent AOC concentration and effluent AOC concentrations, for each sampling event

Comparison		P-values from the comparison done on data from the following sampling events				
		21-Mar-12	**12-Apr-12**	**27-Jun-12**	**8-Aug-12**	**14-Aug-12**
Influent AOC vs. Filter 1 Effluent AOC	AOC removal (μg/L)[1]	320	310	340	240	330
	P-value	$1.3x10^{-06}$	$1.8x10^{-06}$	$7.0x10^{-09}$	$4.7x10^{-07}$	$5.3x10^{-10}$
Influent AOC vs. Filter 2 Effluent AOC	AOC removal (μg/L)[1]	410	310	320	170	270
	P-value	$1.2x10^{-07}$	$6.4x10^{-07}$	$3.3x10^{-10}$	$2.4x10^{-05}$	$5.3x10^{-10}$
Influent AOC vs. Filter 3 Effluent AOC	AOC removal (μg/L)[1]	460	220	300	260	270
	P-value	$2.7x10^{-06}$	$4.5x10^{-06}$	$2.4x10^{-09}$	$3.4x10^{-07}$	$2.1x10^{-10}$
Influent AOC vs. Filter 4 Effluent AOC	AOC removal (μg/L)[1]	510	240	350	170	300
	P-value	$9.8x10^{-07}$	$1.2x10^{-03}$	$2.4x10^{-09}$	$1.5x10^{-05}$	$1.4x10^{-09}$
Influent AOC vs. Filter 5 Effluent AOC	AOC removal (μg/L)[1]	550	330	360	270	300
	P-value	$8.2x10^{-06}$	$1.8x10^{-06}$	$7.1x10^{-08}$	$3.5x10^{-09}$	$3.1x10^{-08}$

1. AOC removal calculations were conducted with 15 significant figures and rounded to two significant figures. If the AOC removal values are calculated from the rounded influent and effluent AOC concentrations in Table 3-21, the calculated AOC removal will differ by 10 μg/L from a few of the values reported in this table due to rounding error. Take the values in this table as correct. Refer to Appendix C for influent and effluent AOC concentrations, reported with a greater number of significant figures, which can be used to confirm calculations.

AOC removal through the filters ranged from 170 μg/L to 550 μg/L. In all cases, the p-values were lower than 0.003125; thus, the influent AOC concentrations came from a different distribution than the effluent AOC concentrations. Histograms were created to evaluate whether the difference in AOC concentration could be attributed to a difference in the distribution location (i.e. due to a difference in mean and/or median).

Figure 3-25 shows the histograms associated with March 21, 2012 sampling event, to provide an example of the histograms seen for the various sampling events.

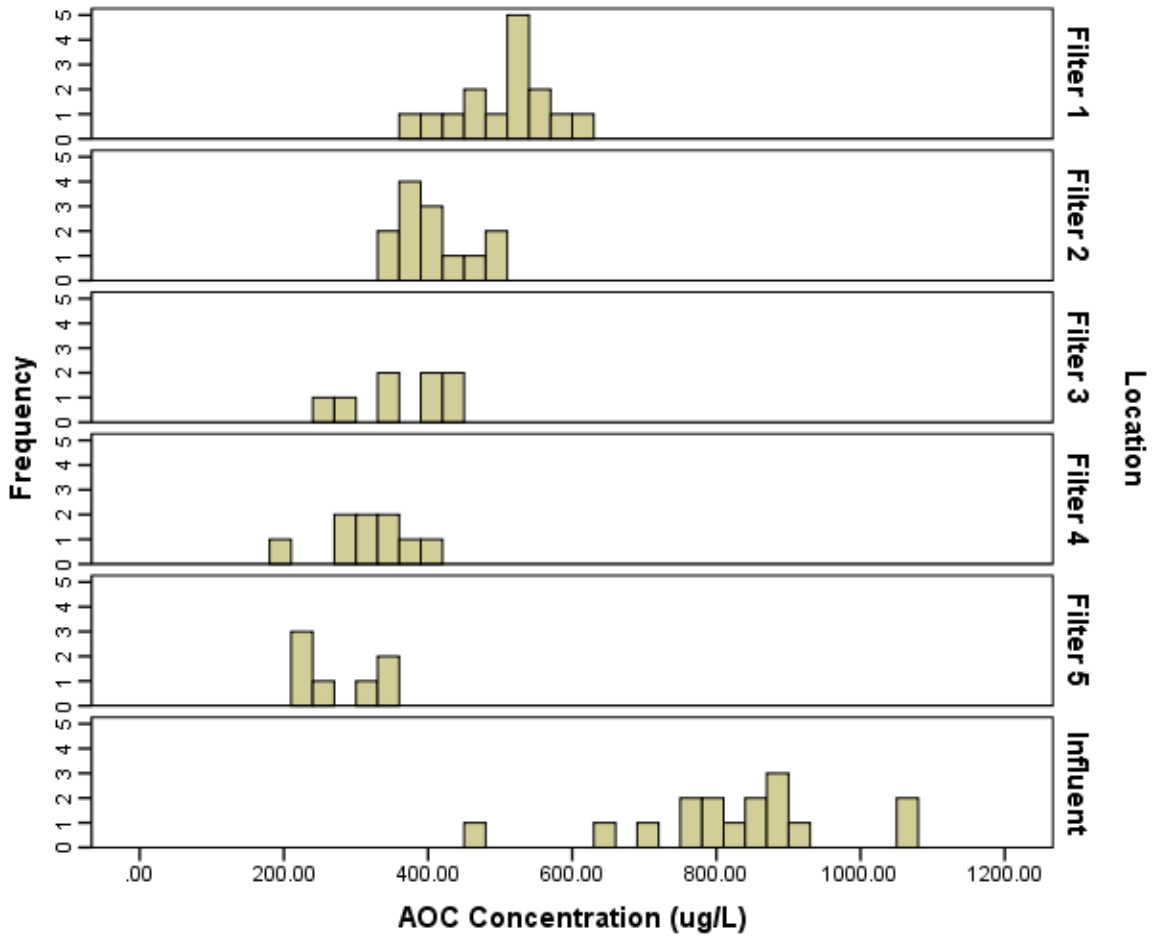


Figure 3-25: Histograms of total AOC concentrations from each sampling location for the March 21, 2012 sampling event

It can be seen in that there is a difference in the shape and spread of the histogram for the influent AOC concentrations when compared to the effluent histograms. However, the influent histogram is also shifted to the right—towards higher AOC values—when compared to the effluent histograms. Similar trends, with the influent histogram having a different shape and wider spread than the effluent histograms but with the location shifted to the right, were seen for the other sampling events (see Appendix C). This difference in location between the influent and effluent data can be considered the primary cause for the statistically significant differences in the Mann-Whitney tests. Therefore, it was concluded that there was a statistically significant difference in the mean AOC concentration between the influent and filter effluents in all sampling events. Thus, all of the filters removed AOC in all sampling events.

3.3.3.2.4 Test Set 4: Comparison of AOC Removal by Different Filtration Media

The difference in filter effluent AOC concentration between the pilot filters, and thus the difference in AOC removal provided by the media types, was smaller than the difference in AOC concentration between the filter influent and filter effluents (see Table 3-21). Mann-Whitney tests were conducted to determine whether the difference in effluent AOC concentrations between the filters was statistically significant. Table 3-24 summarizes the two-tailed p-values from the Mann-Whitney tests. Comparisons that were statistically significant at a significance level of 0.003125 are highlighted in grey. Mann-Whitney U values and other calculated p-values can be found in Appendix C.

Table 3-24: P:-values from Mann-Whitney tests comparing effluent AOC concentrations between different types of filter media and operating protocols

Comparison	Media Type 1[1, 3]	Media Type 2[2,3]	Sampling Event				
			21-Mar-12	12-Apr-12	27-Jun-12	8-Aug-12	14-Aug-12
			P-value	P-value	P-value	P-value	P-value
Filter 1 Effluent vs Filter 2 Effluent	Coal-based GAC	Anthracite	$5.6x10^{-04}$	$3.7x10^{-01}$	$9.5x10^{-02}$	$9.9x10^{-03}$	$1.3x10^{-04}$
Filter 1 Effluent vs Filter 3 Effluent	Coal-based GAC	REC	$3.9x10^{-04}$	$1.6x10^{-04}$	$4.5x10^{-03}$	$4.5x10^{-01}$	$4.0x10^{-04}$
Filter 1 Effluent vs Filter 4 Effluent	Coal-based GAC	Wood-based GAC	$3.1x10^{-06}$	$6.2x10^{-04}$	$3.2x10^{-01}$	$8.0x10^{-03}$	$3.9x10^{-02}$
Filter 1 Effluent vs Filter 5 Effluent	Coal-based GAC	Coal-based GAC (declining rate)	$1.2x10^{-05}$	$2.8x10^{-01}$	$5.0x10^{-01}$	$5.7x10^{-02}$	$8.4x10^{-02}$
Filter 2 Effluent vs Filter 3 Effluent	Anthracite	REC	$3.0x10^{-01}$	$4.9x10^{-04}$	$2.5x10^{-01}$	$5.0x10^{-02}$	$6.4x10^{-01}$
Filter 2 Effluent vs Filter 4 Effluent	Anthracite	Wood-based GAC	$2.7x10^{-04}$	$9.9x10^{-04}$	$1.3x10^{-02}$	$9.6x10^{-01}$	$2.0x10^{-01}$
Filter 2 Effluent vs Filter 5 Effluent	Anthracite	Coal-based GAC (declining rate)	$1.0x10^{-04}$	$4.8x10^{-01}$	$5.3x10^{-02}$	$9.7x10^{-05}$	$5.6x10^{-02}$
Filter 3 Effluent vs Filter 4 Effluent	REC	Wood-based GAC	$1.1x10^{-01}$	$3.2x10^{-01}$	$1.8x10^{-03}$	$4.4x10^{-02}$	$7.0x10^{-02}$
Filter 3 Effluent vs Filter 5 Effluent	REC	Coal-based GAC (declining rate)	$4.0x10^{-02}$	$1.6x10^{-04}$	$2.4x10^{-03}$	$2.9x10^{-03}$	$6.9x10_{-02}$
Filter 4 Effluent vs Filter 5 Effluent	Wood-based GAC	Coal-based GAC (declining rate)	$4.1x10^{-01}$	$1.1x10^{-03}$	$7.5x10^{-01}$	$3.8x10^{-07}$	$9.3x10^{-01}$

1. Media type present in the first filter listed in the comparison. For example, for the first row, coal-based GAC was present in Filter 1.
2. Media type present in the second filter listed in the comparison. For example, for the first row, anthracite was present in Filter 2.
3. All filters were operated at constant rate mode unless otherwise noted.

In some cases, the effluent AOC concentrations from one filter came from a different distribution than AOC concentrations from another filter (Table 3-24): these are the comparisons that are shaded in grey. As with the comparisons of influent to filter effluent, histograms of the AOC concentrations from the filter effluents were used to assess whether the statistically significant differences in AOC concentrations could be attributed to a difference in distribution location, and thus to a difference in mean effluent

concentration. Using the March 21 2012 sampling event and the histograms in Figure 3-25 as an example, it can be seen that most of the statistically significant differences can be attributed to differences in distribution location. The Filter 1 histogram is clearly centered to the right of the Filter 3, 4, and 5 histograms, indicating that there is a difference in distribution location and, thus, there is a difference in mean effluent AOC concentrations between Filter 1 and Filters 3, 4, and 5. The differences in location between Filter 3 and Filter 4 and between Filter 3 and Filter 5 are less pronounced, but still evident. Therefore, there was a difference in the mean effluent AOC concentrations (and thus a difference in AOC removal provided by the different media types) for all statistically significant comparisons for the March 21, 2012 sampling event, with the exception of the comparison between Filter 1 and Filter 2 .

The difference in location between Filter 1 and Filter 2 histograms was comparatively small. The statistically significant difference between Filter 1 and Filter 2 could be due to a difference in location (i.e. a difference in the mean and/or median of the distributions) but it could also be due to the difference in the distribution shape – the histogram for Filter 2 appears to be skewed to the left (favoring lower concentrations) whereas the Filter 1 histogram is more symmetrical. While it can be concluded that there was a difference in the distribution of the AOC concentration data from Filters1 and 2, during the March 21, 2012 sampling event, it could not be confidently concluded that this was primarily due to a difference in mean AOC concentration; therefore, Filter 1 and 2 were not considered to have provided different levels of AOC removal.

The same process of histogram inspection, as illustrated above, was conducted for the statistically significant differences from each sampling event. Histograms from all of the sampling events can be found in Appendix C. Based on the inspection of the histograms it was concluded that all statistically significant differences indicated a difference in mean effluent AOC concentration, with the following exceptions: the difference between Filter 1 and Filter 2 during the March 12, 2012 sampling event, the difference between Filter 3 and Filter 4 on the June 27, 2012 sampling event, and the difference between Filter 3 and Filter 5 on the June 27, 2012 sampling event.

The mean effluent AOC concentrations were compared to each other for each of the comparisons where there was a statistically significant difference to determine which media types provided better AOC removal. The number of times where one media type provided better removal than another and where there was no statistically significant difference in AOC removal between two media types was tallied and is summarized in Table 3-25 (Table 3-25 is analogous to Table 3-18 in the DOC section).

Table 3-25: Tallies of the number of comparisons where one filtration medium removed AOC better than another and where there was no difference in AOC removal between two filtration media

Comparison		Number of comparisons where		
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 Better (AOC 1<AOC 2)**	**No Difference**	**Medium 2 Better (AOC 1>AOC 2)***
Coal-based GAC	Anthracite	1	4	0
	REC	2	2	1
	Wood-based GAC	1	3	1
Wood-based GAC	Anthracite	1	3	1
	REC	0	5	0
REC	Anthracite	0	4	1
Coal-based GAC (declining rate)	Coal-based GAC	1	4	0
	Wood-based GAC	2	3	0
	Anthracite	2	3	0
	REC	2	3	0

No one media type consistently provided better AOC removal than any of the other media types (Table 3-25). Declining rate coal-based GAC had the most instances of better AOC removal relative to the other filters; however, there were not enough instances to conclude that operating the filter in a declining rate mode consistently resulted in better AOC removal. It was surprising and notable that there was no clear difference in AOC removal between the different media types, given that there were clear differences in DOC removal. Part of the reason why no difference was observed may have been due to the variability of the AOC data or the limited number of sampling events that were conducted during this study.

3.3.3.2.5 Quality Control Findings

Results from the quality control samples are presented and discussed in the following subsections. The first subsection presents the results from the blank controls and process blanks. The second subsection provides a brief discussion of the replicate influent sample results. The third subsection presents and discusses the results from the yield controls. Finally, the fourth subsection provides the results from the growth controls and an assessment of whether the results indicate carbon limitation of the samples and/or inhibition of the test organisms.

3.3.3.2.5.1 Blanks and Process Blanks

Table 3-26 presents the mean and standard deviation of the AOC concentrations from the blank control vials, from each sampling event. Table 3-27 presents the mean and standard deviation of the AOC concentrations from the process blanks.

Table 3-26: Mean and standard deviation of the AOC concentrations from the blank control vials

Sampling Event	Mean AOC Concentration (µg/L)	Standard Deviation (µg/L)	n
21-Mar-12	0.11	0.07	3
12-Apr-12	0.04	-	1
27-Jun-12	0.25	0.09	2
8-Aug-12	0.05	0.02	5
14-Aug-12	0.10	0.02	5

Table 3-27: Mean and standard deviation of vial AOC concentrations from process blanks

Sampling Event	Mean Vial AOC Concentration (µg/L)	Standard Deviation (µg/L)	n
21-Mar-12	0.47	0.24	3
12-Apr-12[1]	-	-	-
27-Jun-12	27	7.8	8
8-Aug-12	22	16	11
14-Aug-12	19	5	7

1. Process blank not processed on April 12, 2012 sampling event

The standard deviation for the AOC concentrations from the blank controls was not calculated for the April 12, 2012 sampling event because there was reliable AOC data from both P-17 and NOX plates for only one of five blank vials that were processed. In four of the five vials, the counts were too numerous to count: it is suspected that some of the blank control vials or blank control plates on the April 12, 2012 sampling event were contaminated. On the April 12, 2012 sampling event, a process blank was not processed. It can be seen, however, that the AOC concentrations in the blanks and in the process blanks were low compared to the AOC concentrations measured in the samples (cf. Table 3-21).Therefore, contamination of the samples was not a concern. The results from the April 12, 2012 sampling events were analyzed with some caution because of the high blank control AOC values; however, there were very few issues with any of the AOC concentrations related to the samples and, therefore, the sample data from the April 12, 2012 sampling event was considered reliable, accepted, and analyzed[78].

[78]The only issues identified with the sample data from April 12, 2012 were that: (a) there was one instance where there was a contaminated plate (this was only one plate associated with only one vial); and (b) there was one extremely high AOC concentration associated with one vial that was analyzed from Filter 4. Other than these two

3.3.3.2.5.2 Influent Replicates

Differences in the AOC concentrations measured in the influent replicate samples were not statistically significant (section 3.3.3.2.1). Therefore, AOC results from a given sample bottle were considered reproducible.

3.3.3.2.5.3 Yield Controls

AOC data for the yield controls and the difference between the yield control and blank control AOC values for each sampling event are presented in Table 3-28. The mean AOC concentration from the April 12, 2012 yield controls was not calculated because the data from that sampling event were not of a sufficient quality; specifically, the counts of P-17 and NOX were too low because of the dilutions that were plated. A wider range of dilutions were used in the subsequent sampling events to ensure that yield values could be calculated.

Table 3-28: Mean and standard deviation of the AOC concentrations from the yield controls and results from the calculation of the yield AOC minus the blank AOC value

Sampling Event	Mean AOC Concentration (µg/L)	Standard Deviation (µg/L)	n	Yield Minus Blank (µg/L)
21-Mar-12	120	76	3	120
12-Apr-12	-	-	-	-
27-Jun-12	37	-	1	37
8-Aug-12	9.6	7.1	2	9.6
14-Aug-12	50	96	4	49

The calculated value of the yield minus the blank should have equaled approximately 100 µg/L based on the amount of sodium acetate solution added to the yield controls and given the fact that the vials were filled to the vial shoulder (a volume of approximately 40 mL). The calculated yield minus blank AOC concentration for the first sampling event was around the expected value of 100 µg/L; however, the remainder of the yield control values did not provide concentrations near the expected value. The yield controls for the August 8, 2012 event, in particular, had a low mean AOC concentration. Moreover, the variability of the mean AOC concentrations calculated from the yield controls was very high relative to the mean concentration. While the reason for this variability is unknown, several factors may help to explain these results. First, a limited number of yield control samples were analyzed. If any errors in

issues, the rest of the data was acceptable and considered reliable. The raw data can be found and inspected in Appendix C.

processing were made (e.g. accidental plate contamination or an insufficient dilution range), they were excluded and even fewer data were available. Second, the inoculum was grown in a carbon-spiked mineral salt solution that contained a number of additional micronutrients. In the first two sampling events, the same mineral salt solution that was used for the inoculum was used to spike the yield controls. The yield control mean AOC value was acceptable in the first of these two sampling events (March 21, 2012). In the remaining three sampling events, where the mineral salt solution recommended in Standard Methods (Eaton et al., 2005) was used, the mean AOC concentration from the yield controls was low. It may be that a lack of micronutrients limited the growth of the test organisms, resulting in lower AOC concentrations. Third, the volume of water added to each yield control was approximate and therefore the true AOC concentration in each vial may have varied. Per Standard Methods (Eaton et al, 2005), the vials were filled to the shoulder, which should correspond to approximately 40 mL of sample. However, the volume of water in each vial was not exactly measured. Furthermore, some of the vials came from different manufacturers and the "to shoulder" volume of vials from different manufacturers may have been slightly different. Fourth, the incubation temperatures (21°C) for inoculated samples were higher than those originally used to determine the conversion factors and may have contributed to this outcome.

The fact that the yield minus the blank AOC concentrations did not give the expected result of 100 μg/L was not considered grounds for eliminating the sample AOC data from further consideration because several of the factors, discussed above, that may have impacted the yield controls would not have impacted the samples: several vials were processed for each sample and neither mineral salt solutions nor sodium acetate were added to the samples. Furthermore, growth of P-17 and NOX occurred in the samples, and inspection of the raw and reduced AOC data associated with the samples indicated that the AOC data were fairly reliable (i.e. there were enough data to allow calculation of means and standard deviations, the standard deviations were generally at a reasonable level compared to the mean AOC concentrations, and only a minimal number of plates or vials had to be excluded due to contamination). Finally, the primary purpose of the AOC analysis was to determine if there was a difference in AOC removal between filters containing different media types: even if the AOC concentrations were low (or high) because the actual P-17 and NOX yields per microgram of AOC were lower (or higher) than the values used to calculate AOC concentrations, the comparative performance of filters containing different media types could still be determined for each sampling event. Therefore, the sample AOC data were analyzed. It is recommended that the following be considered to improve future yield control results: (a) an exact amount of water be added to the yield control vials (e.g. with a pipette), (b) additional yield controls be analyzed, (c) additional micronutrients be added to the mineral salts solution, as necessary,

and (d) a different incubation temperature be used for incubating vials or a conversion factor for AOC at the specific incubation temperature be experimentally determined, as necessary.

3.3.3.2.5.4 Carbon Limitation and Sample Inhibition

Standard Method 9217B (Eaton et al., 2005) recommends subtracting the blank control AOC value from the yield control value (Y-B), subtracting the sample AOC value from the growth control value (G-S), and comparing these two values to determine whether the samples are: (a) carbon limited and not inhibitory, (b) not carbon limited, or (c) inhibitory to the test organisms. Further, the sample is considered "carbon limited and not inhibitory" if GC-S equals Y-B, inhibitory to the test organisms if GC-S is less than Y-B, and "not carbon-limited" (i.e. limited by some other nutrient) if GC-S is greater than Y-B (Standard Method 9217B; Eaton et al., 2005, p 9-46). Yield and blank control values were presented in the previous subsections. The AOC data associated with the growth controls and the calculated difference between the mean sample concentration and the growth control are presented in Table 3-29 to Table 3-33 (next pages). The sample concentrations and standard deviations are also re-presented, for ease of reference.

In most cases, the concentration of AOC in the growth controls was higher than the sample concentration, as would be expected given that AOC was spiked into the growth control vials. In several cases, however, the growth control AOC concentration was actually lower than the sample AOC (as indicated by the negative G-S values). The reason for the lower growth control AOC concentrations is unknown but it may be associated with natural variability in the AOC measurements.

Comparisons of the G-S to the Y-B values were not conducted given the variability in the growth control AOC concentrations, whose standard deviations are of a similar magnitude to the G-S values, and the aforementioned issues with the yield controls. Conclusions made from these comparisons would be questionable at best. As with yield controls, it is recommended that in future work, (a) additional growth controls be created and (b) that the volume of water added to the growth control vials be measured (e.g. with a pipette) rather than the vials being filled to the shoulder.

Table 3-29: Mean and standard deviation of the AOC concentrations from growth controls and samples from the March 21, 2012 AOC sampling event

Sample	Statistic	Growth Control(G)	Sample (S)	$G\text{-}S^2$
Influent 1	Mean AOC Concentration (µg/L)	810	840	-28
	Standard Deviation (µg/L)	76	110	-
	n	2	8	-
Influent 2	Mean AOC Concentration (µg/L)	750	810	-58
	Standard Deviation (µg/L)	-[1]	180	-
	n	1	8	-
Filter 1	Mean AOC Concentration (µg/L)	390	510	-110
	Standard Deviation (µg/L)	38	69	-
	n	2	15	-
Filter 2	Mean AOC Concentration (µg/L)	410	410	-3
	Standard Deviation (µg/L)	37	53	-
	n	2	13	-
Filter 3	Mean AOC Concentration (µg/L)	470	370	100
	Standard Deviation (µg/L)	41	67	-
	n	2	8	-
Filter 4	Mean AOC Concentration (µg/L)	530	310	210
	Standard Deviation (µg/L)	-[1]	56	-
	n	1	9	-
Filter 5	Mean AOC Concentration (µg/L)	360	280	84
	Standard Deviation (µg/L)	12	60	-
	n	2	7	-

1. Insufficient data to calculate a standard deviation
2. Mean AOC concentration for the growth control minus the mean sample AOC concentration

Table 3-30: Mean and standard deviation of the AOC concentrations from growth controls and samples from the April 12, 2012 AOC sampling event

Sample	Statistic	Growth Control (G)	Sample (S)	G-S[1]
Influent 1	Mean AOC Concentration (µg/L)	550	510	47
	Standard Deviation (µg/L)	92	89	-
	n	5	9	-
Influent 2	Mean AOC Concentration (µg/L)	590	480	30
	Standard Deviation (µg/L)	110	89	-
	n	5	8	-
Filter 1	Mean AOC Concentration (µg/L)	160	190	-30
	Standard Deviation (µg/L)	38	26	-
	n	3	8	-
Filter 2	Mean AOC Concentration (µg/L)	330	180	150
	Standard Deviation (µg/L)	110	39	-
	n	4	9	-
Filter 3	Mean AOC Concentration (µg/L)	200	270	-69
	Standard Deviation (µg/L)	30	34	-
	n	4	9	-
Filter 4	Mean AOC Concentration (µg/L)	350	260	92
	Standard Deviation (µg/L)	110	36	-
	n	4	9	-
Filter 5	Mean AOC Concentration (µg/L)	200	170	27
	Standard Deviation (µg/L)	65	39	-
	n	5	8	-

1. Mean AOC concentration for the growth control minus the mean sample AOC concentration

Table 3-31: Mean and standard deviation of the AOC concentrations from growth controls and samples from the June 27, 2012 AOC sampling event

Sample	Statistic	Growth Control (G)	Sample (S)	G-S[1]
Influent 1	Mean AOC Concentration (µg/L)	960	630	320
	Standard Deviation (µg/L)	63	120	-
	n	2	11	-
Influent 2	Mean AOC Concentration (µg/L)	540	590	-43
	Standard Deviation (µg/L)	34	140	-
	n	2	12	-
Filter 1	Mean AOC Concentration (µg/L)	410	270	140
	Standard Deviation (µg/L)	110	34	-
	n	3	11	-
Filter 2	Mean AOC Concentration (µg/L)	310	290	23
	Standard Deviation (µg/L)	16	35	-
	n	4	14	-
Filter 3	Mean AOC Concentration (µg/L)	390	310	86
	Standard Deviation (µg/L)	85	32	-
	n	2	12	-
Filter 4	Mean AOC Concentration (µg/L)	290	260	38
	Standard Deviation (µg/L)	49	28	-
	n	2	12	-
Filter 5	Mean AOC Concentration (µg/L)	230	250	-26
	Standard Deviation (µg/L)	15	49	-
	n	5	9	-

1. Mean AOC concentration for the growth control minus the mean sample AOC concentration

Table 3-32: Mean and standard deviation of the AOC concentrations from growth controls and samples from the August 8, 2012 AOC sampling event

Sample	Statistic	Growth Control (G)	Sample (S)	G-S[1]
Influent 1	Mean AOC Concentration (µg/L)	1700	500	1200
	Standard Deviation (µg/L)	280	100	-
	n	4	10	-
Influent 2	Mean AOC Concentration (µg/L)	1700	470	1200
	Standard Deviation (µg/L)	21	150	-
	n	3	10	-
Filter 1	Mean AOC Concentration (µg/L)	330	250	86
	Standard Deviation (µg/L)	49	44	-
	n	5	10	-
Filter 2	Mean AOC Concentration (µg/L)	430	310	120
	Standard Deviation (µg/L)	47	65	-
	n	5	13	-
Filter 3	Mean AOC Concentration (µg/L)	370	260	110
	Standard Deviation (µg/L)	76	67	-
	n	5	13	-
Filter 4	Mean AOC Concentration (µg/L)	650	310	330
	Standard Deviation (µg/L)	95	55	-
	n	5	13	-
Filter 5	Mean AOC Concentration (µg/L)	700	210	490
	Standard Deviation (µg/L)	100	37	-
	n	4	13	-

1. Mean AOC concentration for the growth control minus the mean sample AOC concentration

Table 3-33: Mean and standard deviation of the AOC concentrations from growth controls and samples from the August 14, 2012 AOC sampling event

Sample	Statistic	Growth Control (G)	Sample (S)	G-S[1]
Influent 1	Mean AOC Concentration (µg/L)	690	530	160
	Standard Deviation (µg/L)	91	120	-
	n	5	10	-
Influent 2	Mean AOC Concentration (µg/L)	590	480	110
	Standard Deviation (µg/L)	150	70	-
	n	5	12	-
Filter 1	Mean AOC Concentration (µg/L)	290	170	120
	Standard Deviation (µg/L)	86	29	-
	n	5	14	-
Filter 2	Mean AOC Concentration (µg/L)	280	230	49
	Standard Deviation (µg/L)	50	30	-
	n	4	14	-
Filter 3	Mean AOC Concentration (µg/L)	240	240	2
	Standard Deviation (µg/L)	120	44	-
	n	5	15	-
Filter 4	Mean AOC Concentration (µg/L)	280	200	81
	Standard Deviation (µg/L)	47	52	-
	n	3	13	-
Filter 5	Mean AOC Concentration (µg/L)	230	200	32
	Standard Deviation (µg/L)	47	47	-
	n	4	10	-

1. Mean AOC concentration for the growth control minus the mean sample AOC concentration

3.3.3.2.6 Summary of Conclusions and Recommendations Related to AOC

- All biofilters removed AOC, regardless of the media type,
- No media type consistently provided better removal of AOC than any of the other media types, and
- Additional yield controls and growth controls as well as precisely measured water volume addition for these controls are recommended for future studies.

3.3.3.3 Trihalomethane Formation Potential (THMFP)

The THMFP results are discussed in two subsections. The first subsection discusses the reduction of total THMFP (TTHMFP). The second subsection discusses the reduction of chloroform formation potential, bromoform formation potential, bromodichloromethane formation potential, and dibromochloromethane formation potential. Additional supplementary information, such as raw formation potential data, chlorine data, select boxplots of the data, detailed multiple comparison results (including calculated standard errors and confidence intervals), and results from ANOVA diagnostics can be found in Appendix D.

3.3.3.3.1 Total Trihalomethane Formation Potential (TTHMFP)

Figure 3-26 and Figure 3-27 are scatterplots of the total trihalomethane formation potentials measured at each sampling location, for the June 6, 2013 and June 10, 2013 sampling events, respectively.

When the spread of the data is taken into account, the total THMFP values were similar across the filter influent and effluents for the June 6, 2013 sampling event (Figure 3-26). The total THMFP values also were similar across the filter effluents for the June 10, 2013 sampling event and lower than in the influent, indicating reduction of total THMFP by biofiltration (Figure 3-27).

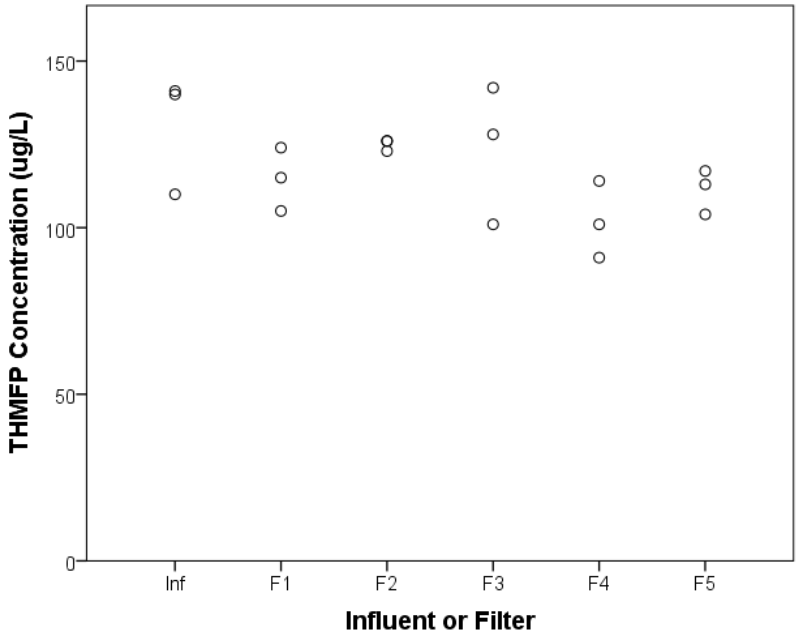


Figure 3-26: Total trihalomethane formation potentials measured from the June 6, 2013 sampling event. Each data point represents a trihalomethane formation potential measured from water collected in a separate sampling bottle.

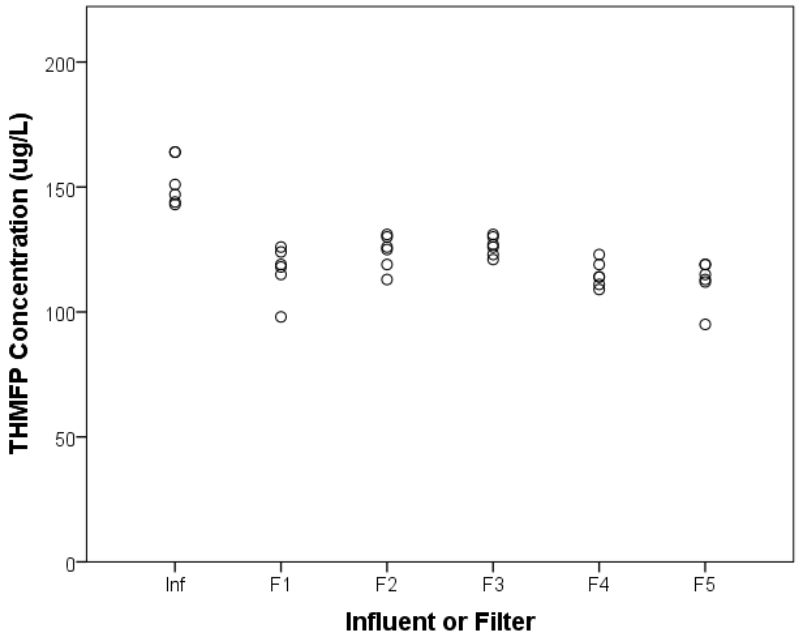


Figure 3-27: Total trihalomethane formation potentials measured from the June 10, 2013 sampling event. Each data point represents a trihalomethane formation potential measured from water collected in a separate sampling bottle.

Table 3-34 shows the mean and standard deviation of the total THMFP values and the number of samples.

Table 3-34: Mean and standard deviation of total THMFP at the sampling locations for the June 6, 2013 and June 10, 2013 sampling events.

Sampling Location (and Media Type)	Summary Statistic	Value (μg/L)[1]	
		June 6, 2013	June 10, 2013
Influent	Mean THMFP	130	152
	Standard Deviation	17.6	9.58
	Number of Samples	3	6
Filter 1 Effluent (Coal-based GAC)	Mean THMFP	115	117
	Standard Deviation	9.50	9.99
	Number of Samples	3	6
Filter 2 Effluent (Anthracite)	Mean THMFP	125	124
	Standard Deviation	1.73	6.87
	Number of Samples	3	6
Filter 3 Effluent (REC)	Mean THMFP	124	126
	Standard Deviation	20.8	3.88
	Number of Samples	3	6
Filter 4 Effluent (Wood-Based GAC)	Mean THMFP	102	115
	Standard Deviation	11.5	5.18
	Number of Samples	3	6
Filter 5 Effluent (Coal-based GAC-declining rate)	Mean THMFP	111	112
	Standard Deviation	6.66	8.91
	Number of Samples	3	6

1. Means and standard deviations rounded to three significant digits

Notably, the mean total THMFP values for the nonadsorptive (REC) and slightly adsorptive (anthracite) media were higher than the mean total THMFP values for the GAC, indicating that organic matter which contributed to THM formation was removed to a greater extent by filters containing GAC than by filters containing REC or anthracite. This is the same trend that was observed for DOC. Furthermore, the mean THMFP values from the two sampling events are very close to each other (i.e. are within 2 μg/L of each other), with the exception of influent and Filter 4. The consistency of THMFP across the two sampling events was unexpected and implies that the concentration of organic matter present in the filter effluents that contributed to THMFP was fairly stable over the four day period between sampling events. This raises the following questions: is the pool of organic matter that contributes to THMFP normally stable and is the pool of organic matter that contributes to THMFP more stable than the pool of organic matter

measured by DOC? Further work would be needed to investigate these points; however, that is beyond the scope of the present thesis.

An ANOVA was conducted on the total THMFPs for each sampling event to determine whether there was a difference in THMFP between the different sampling locations. Diagnostic plots on the residuals from the ANOVA and Levene's test for homoscedasticity were conducted. The diagnostic plots and results from Levene's test can be found in Appendix D. The residuals from the ANOVA were found to be normally distributed but, for the ANOVA on the June 6, 2013 sampling event, the data were slightly heteroscedastic (Levene's test, p-value=0.09). For the June 10, 2013 sampling event, two potential outliers were identified from the normal probability plot: THMFP measurements for the sixth bottle collected from Filter 1 effluent and the third bottle collected from Filter 5 effluent[79]. A smaller chlorine dose [80] was used when analyzing these particular samples, and likely caused the TTHMFP measurements for these samples to deviate from the other measurements (See Appendix D for chlorine data). ANOVA results and multiple comparisons both with and without the outliers are presented in this thesis. Table 3-35 shows the mean and standard deviation of the June 10, 2013 THMFP results with the outliers included and excluded for Filters 1 and 5.

Table 3-35: Mean and standard deviation total THMFP for June 10, 2013 with outliers included and excluded.

Sampling Location (and Media Type)	Summary Statistic	Value (µg/L)[1]	
		Outlier Included	Outlier Excluded[1]
Filter 1 Effluent (Coal-based GAC)	Mean THMFP	117	120
	Standard Deviation	9.99	4.51
	Number of Samples	6	5
Filter 5 Effluent (Coal-based GAC-declining rate)	Mean THMFP	112	116
	Standard Deviation	8.91	3.29
	Number of Samples	6	5

1. Means and standard deviations rounded to three significant digits

[79]Boxplots of the raw data from the June 10, 2013 data were also created (Appendix D). The boxplots also indicated that the same two data points could be considered outliers.

[80] 97.2 mg/L of chlorine was added to bottle 6 from Filter 1, whereas 243 mg/L was added to all other bottles from Filter 1. 117 mg/L of chlorine was added to bottle 3 from Filter 5, whereas between 194 and 243 mg/L of chlorine was added to all other bottles from Filter 5. These chlorine doses (92.7 mg/L and 117 mg/L) were the lowest chlorine doses used.

Removing the potential outliers increased the mean effluent total THMFP slightly and decreased the standard deviation of both the Filter 1 and Filter 5 effluent. Exclusion of the outliers was considered appropriate given that the outliers were likely caused by the lower initial chlorine dose used during the TTHMFP test, the increase in mean THMFP was small (only 3-4 μg/L), and that the standard deviations improved for both Filter 1 and Filter 5.

ANOVA tables from the June 6, 2013 sampling event, the June 10, 2013 sampling event with outliers included, and the June 10, 2013 sampling event with outliers excluded are presented in Table 3-36, Table 3-37, and Table 3-38, respectively.

Table 3-36: ANOVA table for ANOVA on total THMFP data from the June 6, 2013 sampling event

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter/Influent	1633.833	5	326.767	1.931	1.625E-001
Error	2030.667	12	169.222		
Total	3664.500	17			

Table 3-37: ANOVA table for ANOVA on total THMFP data from the June 10, 2013 sampling event with outliers included

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter/Influent	6436.222	5	1287.244	21.450	4.338E-009
Error	1800.333	30	60.011		
Total	8236.556	35			

Table 3-38: ANOVA table for ANOVA on total THMFP from the June 10, 2013 sampling event with outliers excluded

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter/Influent	5556.404	5	1111.281	30.252	1.820E-010
Error	1028.567	28	36.735		
Total	6584.971	33			

The p-value was 0.16 from the ANOVA on the June 6, 2013 sampling event data, indicating that differences in total THMFP between the different sampling locations on June 6, 2013 were not statistically significant. However, on the June 10, 2013 sampling event, total THMFP was different between the different sampling locations (p-value $<1x10^{-8}$). This result was due, at least in part, to the increased number of samples collected on that sampling date. If an increased number of samples had been

collected on June 6, 2013, even if the same mean values were observed, the difference in THMFP between the different locations may have been statistically significant. This highlights the importance of collecting a sufficient number of samples to detect differences in THMFP (i.e., three replicate samples may not be enough). Thus, a statistical power analysis should be considered prior to subsequent investigations to help ensure that a sufficient number of samples are collected.

Multiple comparisons were conducted on the THMFP data from June 10, 2013 to determine whether THMFP decreased through the filters and to determine whether there was a difference in effluent THMFP between the five filters. A difference in THMFP between two locations would indicate that there was a difference in the concentration of organic matter that contributes to THM formation. The comparisons were conducted with the outliers excluded. Diagnostic plots indicated that the residuals from this ANOVA were normally distributed; however, Levene's test indicated that the data were heteroscedastic (p-value =0.05)[81]. Dunnett's T3 test was used to conduct the multiple comparisons because the data were heteroscedastic. The results from the multiple comparisons are summarized in Table 3-39 and Table 3-40 (p 141). The full results from the multiple comparisons, including calculated standard error values and confidence intervals on the differences can be found in Appendix D.

THMFP significantly decreased after filtration, regardless of media type and operational mode (all p-values≤0.01; Table 3-39). Moreover, differences in THMFP between Filter 4 and Filter 3, and Filter 5 and Filter 3 were statistically significant (Table 3-40). In both of these cases the mean THMFP in the REC effluent was higher than the THMFP in the GAC effluent. Therefore, wood-based GAC and coal-based GAC operated in a declining rate mode removed organic matter that contributed to THM formation to a greater extent than REC. Differences in THMFP were not statistically significant for the other comparisons. It should be highlighted that while there was a difference in effluent THMFP between the REC and two other media types, this difference was small (11 μg/L); therefore, the additional THMFP reduction provided by the GACs is of questionable practical significance. It is recommended that additional confirmatory experiments be conducted at various locations, with additional sampling events and a larger number of replicates, to confirm whether or not wood- and coal-based GAC deliver lower THMFP than REC; the results from this experiment provide a starting point but the findings cannot be generalized given that differences in THMFP were observed only in one sampling event at one location.

[81] See Appendix D for the results from this analysis

Table 3-39: Results from comparisons of influent total THMFP to effluent total THMFP

Comparison	Media Type in Filter	Difference in Mean THMFP (i.e. decrease in THMFP through the filter, µg/L)	P-value
Influent vs Filter 1	Coal-based GAC	32	<0.01
Influent vs Filter 2	Anthracite	28	<0.01
Influent vs Filter 3	REC	26	0.01
Influent vs Filter 4	Wood-based GAC	37	<0.01
Influent vs Filter 5	Coal-based GAC (declining rate mode)	37	<0.01

Table 3-40: Results from comparisons of effluent total THMFP among the different filters

Comparison		Medium 1[1] (M1)	Medium 2[1] (M2)	Difference in Mean THMFP (µg/L) (M1-M2)	P-value
Filter 1 vs	Filter 2	Coal-based GAC	Anthracite	-3.6	0.98
	Filter 3	Coal-based GAC	REC	-5.9	0.39
	Filter 4	Coal-based GAC	Wood-based GAC	5.4	0.64
Filter 4 vs	Filter 2	Wood-based GAC	Anthracite	-9.0	0.28
	Filter 3	**Wood-based GAC**	REC	-11	0.02
Filter 3 vs	Filter 2	REC	Anthracite	2.3	1.00
Filter 5 vs	Filter 1	Coal-based GAC (declining rate)	Coal-based GAC	-4.8	0.60
	Filter 2	Coal-based GAC (declining rate)	Anthracite	-8.4	0.27
	Filter 3	**Coal-based GAC (declining rate)**	REC	-11	0.01
	Filter 4	Coal-based GAC (declining rate)	Wood-based GAC	0.6	1.00

1. The media type which provided a statistically significant lower effluent total THMFP, for a given comparison, is noted in bold type and underlined.

3.3.3.3.2 Chloroform, Bromoform, Bromodichloromethane, and Dibromochloromethane Formation Potentials.

3.3.3.3.2.1 Plots and Review of the Data

Total trihalomethane formation potential is the sum of the bromoform [BF], chloroform [CF], dibromochloromethane [DBCM], and bromodichloromethane [BDCM] formation potentials. The concentration of BF was less than the method detection limit (<0.34 µg/L) for all samples and, thus BF

data were not plotted or analyzed. Figure 3-28 through to Figure 3-33 are plots of the CF, DBCM, and BDCM formation potentials for the two sampling events.

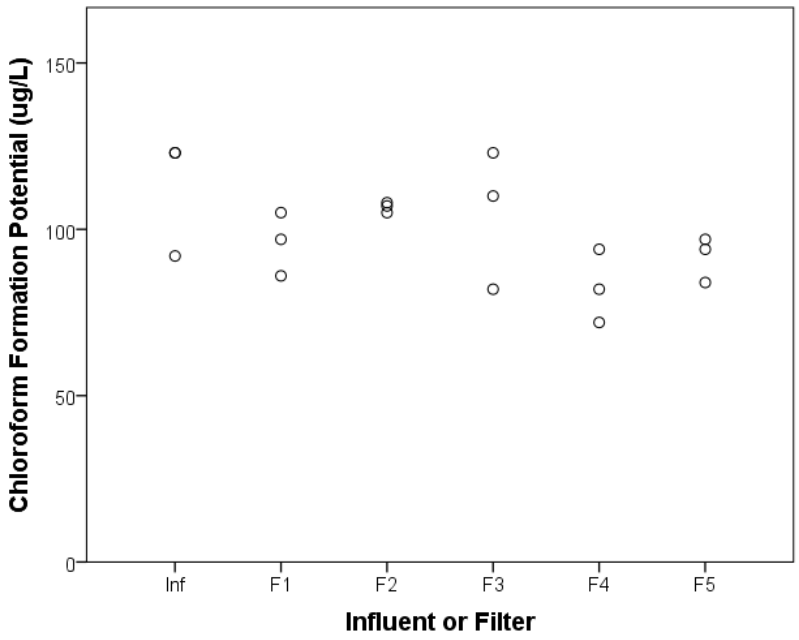


Figure 3-28: Chloroform formation potential from the June 6, 2013 sampling event

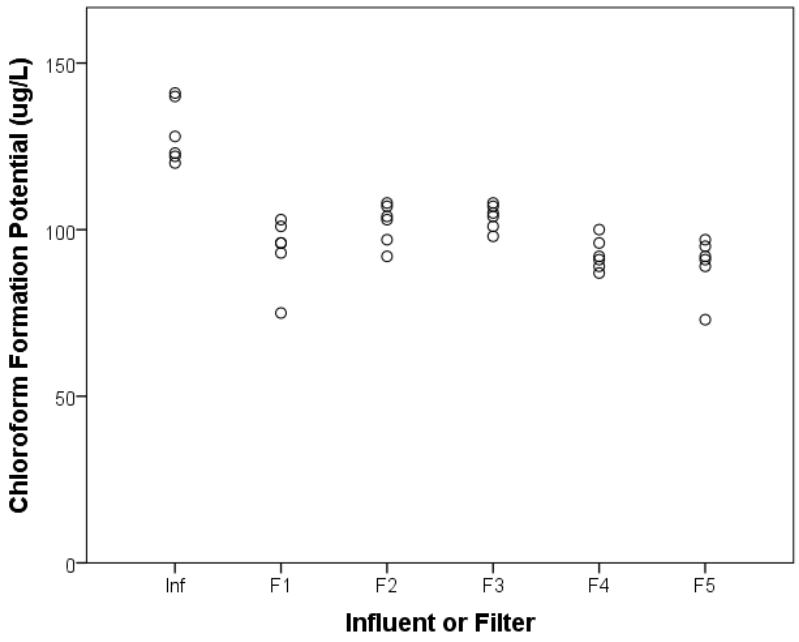


Figure 3-29: Chloroform formation potential from the June 10, 2013 sampling event

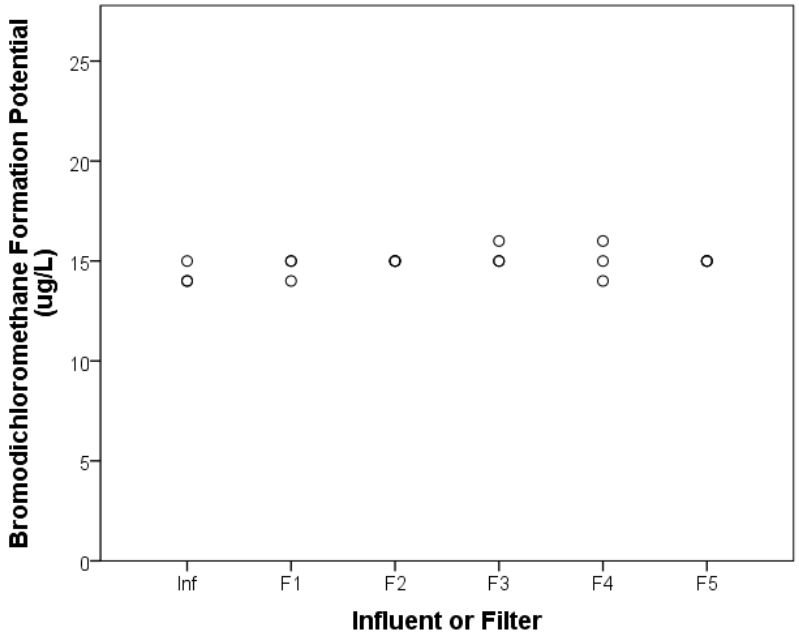


Figure 3-30: Bromodichloromethane formation potential from June 6, 2013 sampling event

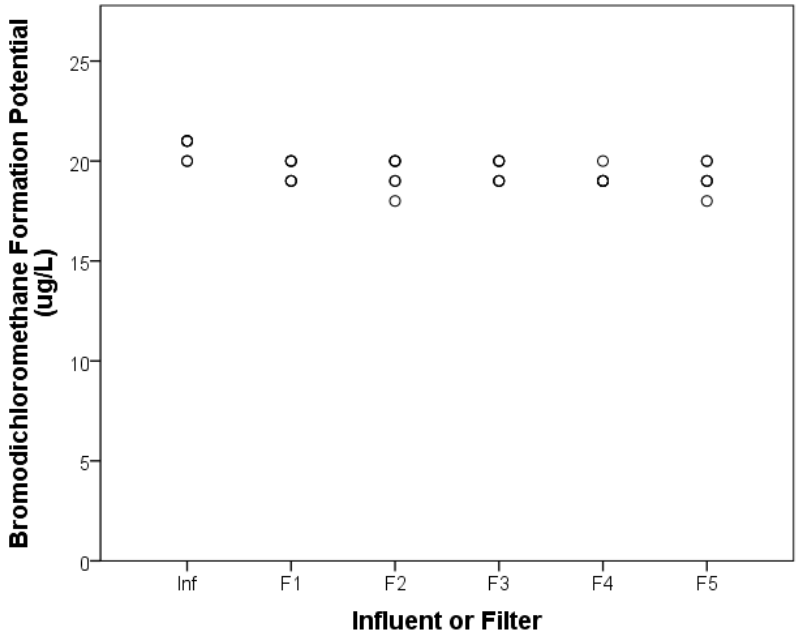


Figure 3-31: Bromodichloromethane formation potential from the June 10, 2013 sampling event

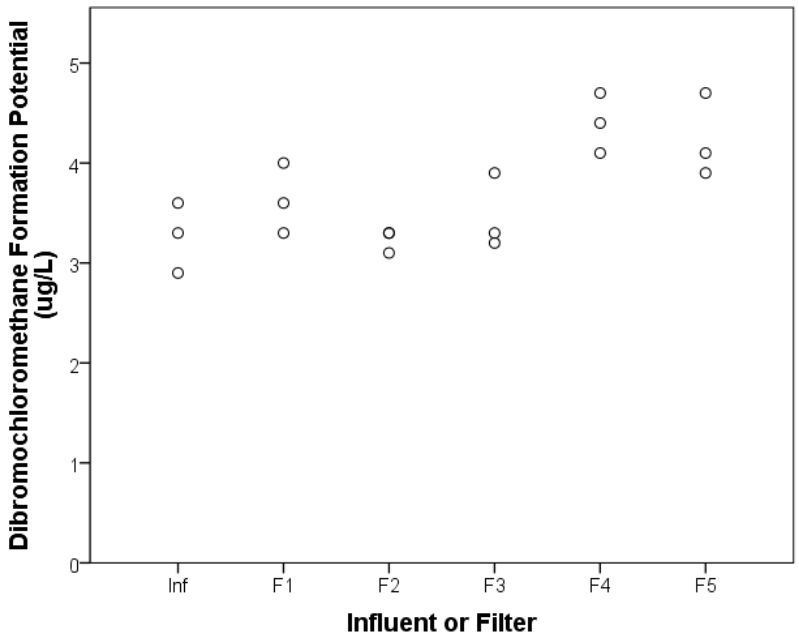


Figure 3-32: Dibromochloromethane formation potential from the June 6, 2013 sampling event

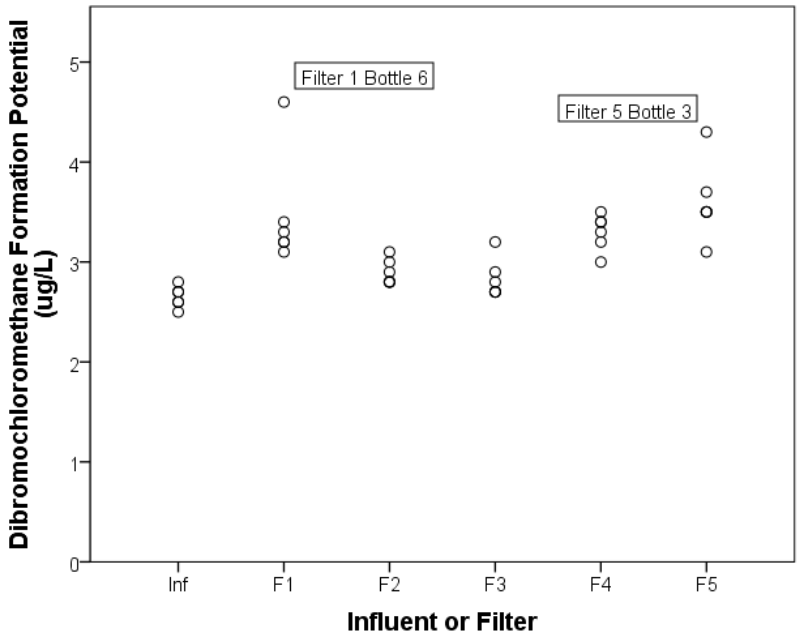


Figure 3-33: Dibromochloromethane formation potential from the June 10, 2013 sampling event

Chloroform contributed the most to the THMFP, followed by BDCM and DBCM (Figure 3-32and Figure 3-33). The trends in chloroform formation potential were similar to those for total THMFP. BDCM formation potential was essentially constant between the influent and all filter effluents for both sampling

events. DBCM formation potential had an interesting trend in both sampling events; notably, the DBCM formation potential was higher in several filter effluents than in the filter influent. Effluent from Filter 4 and Filter 5 also both had higher DBCM formation potentials than the other filter effluents. This trend in DBCM formation potential is discussed further in section 3.3.3.3.2.4.

Two potential outliers were identified in the raw data for DBCM formation potential from the June 10, 2013 sampling event: these values were from Filter 1 bottle 6 and Filter 5 bottle 3. These two bottles were the same two bottles whose data were identified as outliers in the analysis of total THMFP. These data points were excluded from analysis of the DBCM formation potential data because there was a large deviation of these values from the rest of the DBCM data, which may have been caused by a lower initial chlorine dose that was used during the analysis of these samples[82].

3.3.3.3.2.2 ANOVA and Multiple Comparisons on Chloroform Formation Potential

ANOVAs and multiple comparisons were conducted on the CF formation potential data. As with the total THMFP results, two potential outliers were identified in the normal probability plot of the residuals from the June 10, 2013 sampling event. Boxplots of the raw data (see Appendix D) indicated that these data points also were outliers. The outliers were associated with the same samples that were outliers for the total THMFP data – the third bottle collected from Filter 5 effluent and the sixth bottle collected from Filter 1 effluent. ANOVA calculations were done with and without these outliers. The ANOVA tables for the June 6, 2013 sampling event, the June 10, 2013 sampling event including the outliers, and the June 10, 2013 sampling event excluding the outliers are presented below.

Table 3-41: ANOVA table for ANOVA on chloroform formation potential data from the June 6, 2013 sampling event

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter/Influent	1833.111	5	366.622	2.156	1.279E-01
Error	2040.667	12	170.056		
Total	3873.778	17			

[82] 97.2 mg/L of chlorine was added to bottle 6 from Filter 1, whereas 243 mg/L was added to all other bottles from Filter 1. 117 mg/L of chlorine was added to bottle 3 from Filter 5, whereas between 194 and 243 mg/L of chlorine was added to all other bottles from Filter 5. These chlorine doses (92.7 mg/L and 117 mg/L) were the lowest chlorine doses used. See Appendix D for raw chlorine data.

Table 3-42: ANOVA table for ANOVA on chloroform formation potential data from the June 10, 2013 sampling event with outliers included

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter/Influent	6255.556	5	1251.111	22.412	2.621E-09
Error	1674.667	30	55.822		
Total	7930.222	35			

Table 3-43: ANOVA table for ANOVA on chloroform formation potential data from the June 10, 2013 sampling event with outliers excluded

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter/Influent	5379.469	5	1075.894	32.932	6.750E-11
Error	914.767	28	32.670		
Total	6294.235	33			

Diagnostic plots indicated that the residuals from the ANOVAs were normally distributed. Levene's test indicated that the data were homoscedastic for the June 10, 2013 sampling event when the outliers were included (p-value=0.44) but that they were heteroscedastic for the June 6, 2013 sampling event and the June 10, 2013 sampling event when outliers were excluded (p-values= 0.07 and 0.03, respectively). As with the total THMFP results, differences in CF formation potential between the various sampling locations were not statistically significant on June 6, 2013 (Table 3-41); however, they were statistically significant on June 10, 2013 (Table 3-42and Table 3-43).

Multiple comparisons were conducted using Dunnett's T3 test on the CF formation potential data from June 10, 2013. The outliers were excluded from this analysis. The results from the multiple comparisons are summarized in Table 3-44 and Table 3-45.

As with the total THMFP results, CF formation potential decreased through all the filters (Table 3-44). It also decreased more in filters containing wood-based GAC and coal-based GAC operated in declining rate mode, than in the filter containing REC.

Table 3-44: Results from comparisons of influent chloroform formation potential to effluent chloroform formation potential

Comparison	Media Type in Filter	Difference in Mean Chloroform Formation Potential (i.e. decrease in through the filter, µg/L)	P-value
Influent vs Filter 1	Coal-based GAC	31	<0.01
Influent vs Filter 2	Anthracite	27	<0.01
Influent vs Filter 3	REC	25	0.01
Influent vs Filter 4	Wood-based GAC	37	<0.01
Influent vs Filter 5	Coal-based GAC (declining rate mode)	36	<0.01

Table 3-45: Results from comparisons of effluent chloroform formation potential among the different filters

Comparison		Medium 1[1] (M1)	Medium 2[1] (M2)	Difference in Mean Chloroform Formation Potential (µg/L) (M1-M2)	P-value
Filter 1 vs	Filter 2	Coal-based GAC	Anthracite	-4.0	0.93
	Filter 3	Coal-based GAC	REC	-6.0	0.30
	Filter 4	Coal-based GAC	Wood-based GAC	5.3	0.56
Filter 4 vs	Filter 2	Wood-based GAC	Anthracite	-9.3	0.16
	Filter 3	**Wood-based GAC**	REC	-11	0.01
Filter 3 vs	Filter 2	REC	Anthracite	2.0	1.00
Filter 5 vs	Filter 1	Coal-based GAC (declining rate)	Coal-based GAC	-5.0	0.48
	Filter 2	Coal-based GAC (declining rate)	Anthracite	-9.0	0.14
	Filter 3	**Coal-based GAC (declining rate)**	REC	-11	0.01
	Filter 4	Coal-based GAC (declining rate)	Wood-based GAC	0.30	1.00

1. The media type which provided a statistically significant lower effluent CF formation potential, for a given comparison, is noted in bold type and underlined.

3.3.3.3.2.3 ANOVA and Multiple Comparisons on Bromodichloromethane Formation Potential.

The ANOVA results from the analysis of BDCM formation potential for the June 6, 2013 and June 10, 2013 sampling events are summarized in Table 3-46 and Table 3-47, respectively.

Table 3-46: ANOVA table for ANOVA on bromodichloromethane formation potential from the June 6, 2013 sampling event

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter	1.778	5	0.356	1.067	0.43
Error	4.000	12	0.333		
Total	5.778	17			

Table 3-47: ANOVA table for ANOVA on bromodichloromethane formation potential from the June 10, 2013 sampling event

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter	9.556	5	1.911	5.059	<0.01
Error	11.333	30	0.378		
Total	20.889	35			

Differences in BDCM formation potential between the different sampling locations were not statistically significant on June 6, 2013 (p=0.43;Table 3-46); however, they were statistically significant on June 10, 2013 (p<0.01; Table 3-47). Review of the diagnostic plots from the ANOVAs indicated that the residuals from the ANOVA were broadly normally distributed and that the data were homoscedastic for the June 10, 2013 sampling event; however, review of Levene's test for the June 6, 2013 sampling event indicated that the data were heteroscedastic (p-value=0.06). Given that the assumption of homoscedasticity was violated for the June 6, 2013 sampling event, Dunnett's T3 test was used when conducting multiple comparisons. Multiple comparisons were conducted on the data from the June 10, 2013 sampling event using Tukey's test because the data were homoscedastic. The results from the multiple comparisons are summarized in Table 3-48, Table 3-49, Table 3-50, and Table 3-51.

Table 3-48: Results from comparisons of influent bromodichloromethane formation potential to effluent bromodichloromethane formation potential for the June 6, 2013 sampling event

Comparison	Media Type in Filter	Difference in Mean Bromodichloromethane Formation Potential (i.e. decrease through the filters, µg/L)[1]	P-value
Influent vs Filter 1	Coal-based GAC	-0.33	1.00
Influent vs Filter 2	Anthracite	-0.67	0.63
Influent vs Filter 3	REC	-1.0	0.54
Influent vs Filter 4	Wood-based GAC	-0.67	0.97
Influent vs Filter 5	Coal-based GAC (declining rate mode)	-0.67	0.63

1. Note: a negative value indicates that the effluent formation potential was greater than the influent formation potential.

Table 3-49: Results from comparisons of influent bromodichloromethane formation potential to effluent bromodichloromethane formation potential for the June 10, 2013 sampling event

Comparison	Media Type in Filter	Difference in Mean Bromodichloromethane Formation Potential (i.e. decrease through the filters, µg/L)[1]	P-value
Influent vs Filter 1	Coal-based GAC	1.2	0.03
Influent vs Filter 2	Anthracite	1.3	0.01
Influent vs Filter 3	REC	1.2	0.03
Influent vs Filter 4	Wood-based GAC	1.5	<0.01
Influent vs Filter 5	Coal-based GAC (declining rate mode)	1.5	<0.01

1. Note: a negative value indicates that the effluent formation potential was greater than the influent formation potential.

Table 3-50: Results from comparisons of effluent bromodichloromethane formation potential among the different filters for the June 06, 2013 sampling event.

Comparison		Medium 1[1] (M1)	Medium 2[1] (M2)	Difference in Mean Bromodichloromethane Formation Potential (µg/L) (M1-M2)	P-value
Filter 1 vs	Filter 2	Coal-based GAC	Anthracite	-0.33	0.96
	Filter 3	Coal-based GAC	REC	-0.67	0.86
	Filter 4	Coal-based GAC	Wood-based GAC	-0.33	1.00
Filter 4 vs	Filter 2	Wood-based GAC	Anthracite	0.00	1.00
	Filter 3	Wood-based GAC	REC	-0.33	1.00
Filter 3 vs	Filter 2	REC	Anthracite	0.33	0.96
Filter 5 vs	Filter 1	Coal-based GAC (declining rate)	Coal-based GAC	0.33	0.96
	Filter 2	Coal-based GAC (declining rate)	Anthracite	0.00	-[2]
	Filter 3	Coal-based GAC (declining rate)	REC	-0.33	0.96
	Filter 4	Coal-based GAC (declining rate)	Wood-based GAC	0.00	1.00

1. The media type which provided a statistically significant lower effluent BDCM formation potential, for a given comparison, is noted in bold type and underlined.
2. All measured values for Filter 2 effluent and Filter 5 effluent were exactly the same, therefore statistical comparison was unnecessary.

Table 3-51: Results from comparisons of effluent bromodichloromethane formation potential among the different filters for the June 10, 2013 sampling event.

Comparison		Medium 1 (M1)	Medium 2 (M2)	Mean Difference in BDCM Formation Potential (µg/L) (M1-M2)	P-value
Filter 1 vs	Filter 2	Coal-based GAC	Anthracite	0.17	1.00
	Filter 3	Coal-based GAC	REC	0.00	1.00
	Filter 4	Coal-based GAC	Wood-based GAC	0.33	0.93
Filter 4 vs	Filter 2	Wood-based GAC	Anthracite	-0.17	1.00
	Filter 3	Wood-based GAC	REC	-0.33	0.93
Filter 3 vs	Filter 2	REC	Anthracite	0.17	1.00
Filter 5 vs	Filter 1	Coal-based GAC (declining rate)	Coal-based GAC	-0.33	0.93
	Filter 2	Coal-based GAC (declining rate)	Anthracite	-0.17	1.00
	Filter 3	Coal-based GAC (declining rate)	REC	-0.33	0.93
	Filter 4	Coal-based GAC (declining rate)	Wood-based GAC	0.00	1.00

1. The media type which provided a statistically significant lower effluent BDCM formation potential, for a given comparison, is noted in bold type and underlined.

None of the decreases in BDCM formation potential provided by the filters on the June 6, 2013 were statistically significant. Moreover, the differences in effluent BDCM formation potential between the various filters were not statistically significant on either the June 6, 2013 or June 10, 2013. Decreases in BDCM formation potential were statistically significant (p-values <0.05) on the June 10, 2013 sampling event; however, the reduction of BDCM formation potential through the filters on the June 10, 2013 sampling event was small in comparison to the reduction in chloroform formation potential and, therefore, the reduction in BDCM was only a small contributor to the total THMFP reduction.

3.3.3.3.2.4 ANOVA and Multiple Comparisons on Dibromochloromethane Formation Potential

In addition to data from Filter 1 bottle 6 and Filter 5 bottle 3, two additional potential outliers were identified on the June 10, 2013 sampling event from the normal probability plots and were confirmed to be outliers from boxplots of the data (see Appendix D for boxplots). These were data points associated with Filter 3 effluent bottle 4 and Filter 5 bottle 1. The ANOVA for the June 10, 2013 sampling event was calculated with the initial two outliers excluded and a second ANOVA was also calculated with the additional two outliers excluded. The ANOVA tables for DBCM formation potential from the June 6, 2013 and June 10, 2013 sampling events are presented in Table 3-52, Table 3-53, and Table 3-54.

Table 3-52: ANOVA table for ANOVA on dibromochloromethane formation potential data from the June 6, 2013 sampling event

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter	3.716	5	0.743	6.689	3.385E-03
Error	1.333	12	0.111		
Total	5.049	17			

Table 3-53: ANOVA table for ANOVA on dibromochloromethane formation potential data from the June 10, 2013 sampling event with data from Filter 1 bottle 6 and Filter 5 bottle 3 excluded

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value
Filter	2.772	5	0.554	21.200	9.787E-09
Error	.732	28	0.026		
Total	3.505	33			

Table 3-54: ANOVA table for ANOVA on dibromochloromethane data from the June 10, 2013 sampling event with data from Filter1 bottle 6, Filter 5 bottle 3, Filter 3 bottle 4, and Filter 5 bottle 1 excluded.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P-values
Filter	3.068	5	0.614	39.009	2.806E-11
Error	0.409	26	0.016		
Total	3.477	31			

Differences in DBCM formation potential between the different sampling locations were statistically significant during both sampling events. Notably, both ANOVAs for the June 10, 2013 sampling event indicated that there was a statistically significant difference in DBCM formation potential between the sampling locations, regardless of whether the additional outliers were included or excluded. Normal probability plots indicated that, for all ANOVAs, the residuals were broadly normally distributed. The results from Levene's tests indicated that the residuals were homoscedastic. Comparisons of the DBCM formation potential between the different sampling locations were conducted for the June 6 and June 10, 2013 sampling events. Comparisons for the June 10, 2013 sampling event were conducted excluding data from Filter 1 bottle 6, Filter 5 bottle 3, Filter 3 bottle 4, and Filter 5 bottle 1. Tukey's test was used to conduct the comparisons because the residuals were not heteroscedastic. Table 3-55 and Table 3-57 summarize the results from the comparisons for the June 6, 2013 sampling event. Table 3-56 and Table 3-58 summarize the results from the multiple comparisons for the June 10, 2013 sampling event.

Table 3-55: Results from comparisons of influent dibromochloromethane formation potential to effluent dibromochloromethane formation potential for the June 6, 2013 sampling event

Comparison	Media Type in Filter	Difference in Mean Dibromochloromethane Formation Potential (i.e. decrease through the filters, µg/L)[1]	P-value
Influent vs Filter 1	Coal-based GAC	-0.37	0.76
Influent vs Filter 2	Anthracite	0.03	1.00
Influent vs Filter 3	REC	-0.20	0.97
Influent vs Filter 4	Wood-based GAC	-1.13	0.01
Influent vs Filter 5	Coal-based GAC (declining rate mode)	-0.97	0.04

1. Note: a negative value indicates that the effluent formation potential was greater than the influent formation potential.

Table 3-56: Results from comparisons of influent dibromochloromethane formation potential to effluent dibromochloromethane formation potential for the June 10, 2013 sampling event

Comparison	Media Type in Filter	Difference in Mean Dibromochloromethane Formation Potential (i.e. decrease through the filters, µg/L)[1]	P-value
Influent vs Filter 1	Coal-based GAC	-0.59	<0.01
Influent vs Filter 2	Anthracite	-0.25	0.05
Influent vs Filter 3	REC	-0.11	0.63
Influent vs Filter 4	Wood-based GAC	-0.65	<0.01
Influent vs Filter 5	Coal-based GAC (declining rate mode)	-0.90	<0.01

1. Note: a negative value indicates that the effluent formation potential was greater than the influent formation potential.

Table 3-57: Results from comparisons of effluent dibromochloromethane formation potential among the different filters for the June 06, 2013 sampling event.

Comparison		Medium 1[1] (M1)	Medium 2[1] (M2)	Difference in Mean Dibromochloromethane Formation Potential (µg/L) (M1-M2)	P-value
Filter 1 vs	Filter 2	Coal-based GAC	Anthracite	0.40	0.69
	Filter 3	Coal-based GAC	REC	0.17	0.99
	Filter 4	Coal-based GAC	Wood-based GAC	-0.77	0.12
Filter 4 vs	Filter 2	Wood-based GAC	**Anthracite**	1.2	0.01
	Filter 3	Wood-based GAC	**REC**	0.93	0.04
Filter 3 vs	Filter 2	REC	Anthracite	0.23	0.95
Filter 5 vs	Filter 1	Coal-based GAC (declining rate)	Coal-based GAC	0.60	0.30
	Filter 2	Coal-based GAC (declining rate)	**Anthracite**	1.0	0.03
	Filter 3	Coal-based GAC (declining rate)	REC	0.77	0.12
	Filter 4	Coal-based GAC (declining rate)	Wood-based GAC	-0.17	0.99

1. The media type which provided a statistically significant lower effluent DBCM formation potential, for a given comparison, is noted in bold type and underlined.

Table 3-58: Results from comparisons of effluent dibromochloromethane formation potential among the different filters for the June 10, 2013 sampling event.

Comparison		Medium 1 (M1)	Medium 2 (M2)	Difference in Mean Dibromochloromethane Formation Potential (µg/L) (M1-M2)	P-value
Filter 1 vs	Filter 2	Coal-based GAC	**Anthracite**	0.34	<0.01
	Filter 3	Coal-based GAC	**REC**	0.48	<0.01
	Filter 4	Coal-based GAC	Wood-based GAC	-0.06	0.97
Filter 4 vs	Filter 2	Wood-based GAC	**Anthracite**	0.40	<0.01
	Filter 3	Wood-based GAC	**REC**	0.54	<0.01
Filter 3 vs	Filter 2	REC	Anthracite	-0.14	0.46
Filter 5 vs	Filter 1	Coal-based GAC (declining rate)	**Coal-based GAC**	0.31	0.01
	Filter 2	Coal-based GAC (declining rate)	**Anthracite**	0.65	<0.01
	Filter 3	Coal-based GAC (declining rate)	**REC**	0.79	<0.01
	Filter 4	Coal-based GAC (declining rate)	**Wood-based GAC**	0.25	0.05

1. The media type which provided a statistically significant lower effluent DBCM formation potential, for a given comparison, is noted in bold type and underlined.

There was a small, statistically significant (p-value ≤0.05) increase in dibromochloromethane formation potential through the filters containing wood-based GAC and coal-based GAC operated in declining rate mode, during both sampling events. On the June 10, 2013, DBCM formation potential increased through all filters except the REC filter. The increase in DBCM formation potential was greater through the wood based GAC filter than the filters containing anthracite and REC. It was also greater through the filter containing coal-based GAC operated in a declining rate mode than the anthracite filter. On the June 10, 2013 sampling event, when more samples were taken and analyzed, the increase in DBCM formation potential was greater in all the filters that contained very adsorptive media than in the filters containing nonadsorptive or slightly adsorptive media (p values ≤ 0.05).

The increase in DBCM formation potential through the filters and the greater increase in DBCM through the filters containing GAC were unexpected, particularly given that the opposite trends were observed for DOC, THMFP, and CF formation potential. The increase in DBCM through the filters suggests that the filters were either leaching organic carbon that contributes to DBCM formation or that the filters were converting carbon to a form that favours the formation of DBCM. It seems unlikely that all of the filters would be leaching the same form of organic carbon and, therefore, it is suspected that organic carbon was being biologically converted in the filters to a form that contributed to DBCM formation.

Biological conversion of organic matter to a form that favours the formation of DBCM is also congruent with the greater increase in DBCM formation potential across the GAC filters, and especially across the filters containing wood-based GAC and coal-based GAC in declining rate mode, given the observed removals of DOC and CF formation potential. The GAC filters provided greater removal of organic matter (DOC) than either the anthracite or REC filters. The filters containing wood-based GAC and coal-based GAC, in declining rate mode, provided greater removal of CF formation potential than REC. Increased conversion of organic matter to different forms, and possibly to forms which contribute to DBCM formation potential, would be expected if the increased DOC removal by the GAC filters and the increased CF formation potential removal was caused by increased biological activity.

An alternative hypothesis to explain why the DBCM formation potential was higher in the effluent of the GAC filters than the anthracite or REC filters is that the GAC filters were desorbing organic matter that contributes to DBCM formation potential. If, at some point in the past, a spike of organic matter that contributes to DBCM formation potential was introduced to the filters and if this spike was adsorbed onto the GAC filters, some desorption could occur once the concentration of organic matter decreased. This desorption of organic matter could account for the increased DBCM formation potential in the GAC

biofilters. It is unknown whether this series of events actually occurred in the filters under observation in this study. It also seems unlikely that this mechanism was the primary mechanism resulting in increased DBCM formation potential because the REC had higher DBCM formation potential in the filter effluents than in the influent and the REC is nonadsorptive.

It is questionable whether the increases DBCM formation potential would have any practical consequences. Certainly, at this location, for these sampling events, the increase in DBCM formation potential and the differences in the increases provided by the different media types was very small (<2 μg/L) and of little or no practical significance. However, these are academically tantalizing results that imply that biofilters can convert organic carbon from one form into another undesirable form. Further research is needed to determine whether the increases in DBCM formation potential occur in other biofilters, to confirm the cause for the increase in DBCM formation potential, and to determine whether the increase in DBCM can be large enough to be a concern.

3.3.3.3.3 Summary of Conclusions and Recommendations Related to THMFP

- Total THMFP and chloroform formation potential was removed to a statistically significant extent (p-value ≤0.01) on one of two sampling events. The filters removed between 25 and 37 μg/L of total THMFP and between 25 and 37 μg/L of chloroform formation potential on this sampling event. Removal of THMFP was primarily due to the removal of organic matter that contributes to chloroform formation.
- Filters containing coal-based GAC operated in a declining rate mode and wood-based GAC removed more organic matter that contributed to THM formation (both total THMs and chloroform) than REC in one of two sampling events. The difference in total THMFP between the GAC filters and the REC filter was 11 μg/L and the difference in chloroform formation potential was also 11 μg/L. The differences were statistically significant at significance levels less than 0.03 and 0.01, respectively. These results were from two detailed sampling events at one location. Further research is needed to confirm whether filters containing wood-based GAC and coal-based GAC generally provide better removal of organic matter that contributes to THM formation than REC.
- Dibromochloromethane formation potential increased through the filters containing coal-based GAC operated in a declining rate mode and through wood-based GAC during the first of two sampling events. Dibromochloromethane formation potential increased through all filters except the filter containing REC during the second sampling event. This was the opposite of what was

seen for DOC, total THMFP, and chloroform formation potential. The increases were small (<2 μg/L) but statistically significant (p-value <0.01). The results suggest that organic matter was biologically converted in the biofilters to a form which contributes to dibromochloromethane formation potential. Further research is needed to determine whether the increases in dibromochloromethane formation potential occur in other biofilters, to confirm the cause for the increase in dibromochloromethane formation potential, and to determine whether the increase in dibromochloromethane can be large enough to be a practical concern.

- The filter containing wood-based GAC had higher effluent dibromochloromethane formation potential than filters containing REC or anthracite in both sampling events. The filter containing coal-based GAC operated in declining rate mode had higher effluent dibromochloromethane formation potential than a filter containing anthracite in both sampling events. All filters containing GAC had higher effluent dibromochloromethane formation potential than filters containing nonadsorptive media (i.e. REC) or slightly adsorptive media (i.e. anthracite) in the second sampling event. These differences were statistically significant (p-values≤0.05). This was the opposite of what was seen for other measures of organic matter and further research is needed to elucidate the cause of these results.
- In conducting comparisons of the removal of organic matter that contributes to THM formation, through comparisons of effluent THMFP, it is critical that replicate samples be taken. It is recommended that a statistical power analysis be conducted prior to future comparisons to determine the number of replicate samples to be taken.

3.3.4 Headloss Performance

Extensive plots of temporal changes in headloss from all filter cycles are not included for space considerations; however, three representative plots are presented to show the type of data that were collected and to illustrate how headloss performance was compared between the different media types. Figure 3-34, Figure 3-35, and Figure 3-36 are representative plots of headloss accumulation from filter cycles 33, 111, and 203, respectively. Filter cycle 33 occurred during Cold Season 1, filter cycle 111 occurred during Warm Season 2, and filter cycle 203 occurred during Cold Season 2.

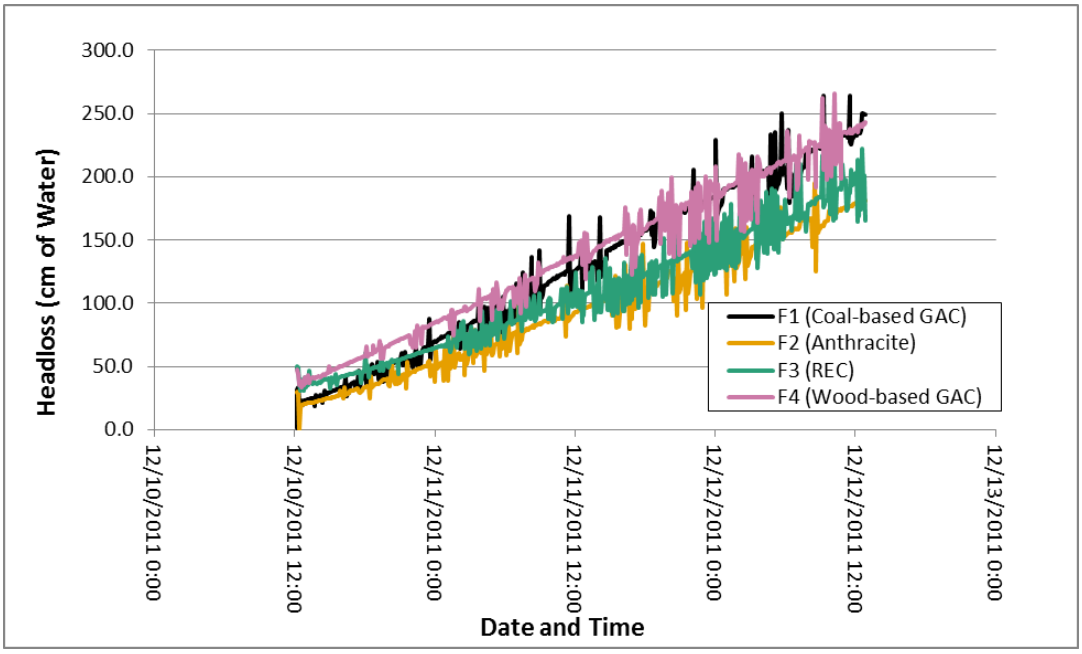


Figure 3-34: Plot of headloss versus time for filter cycle 33

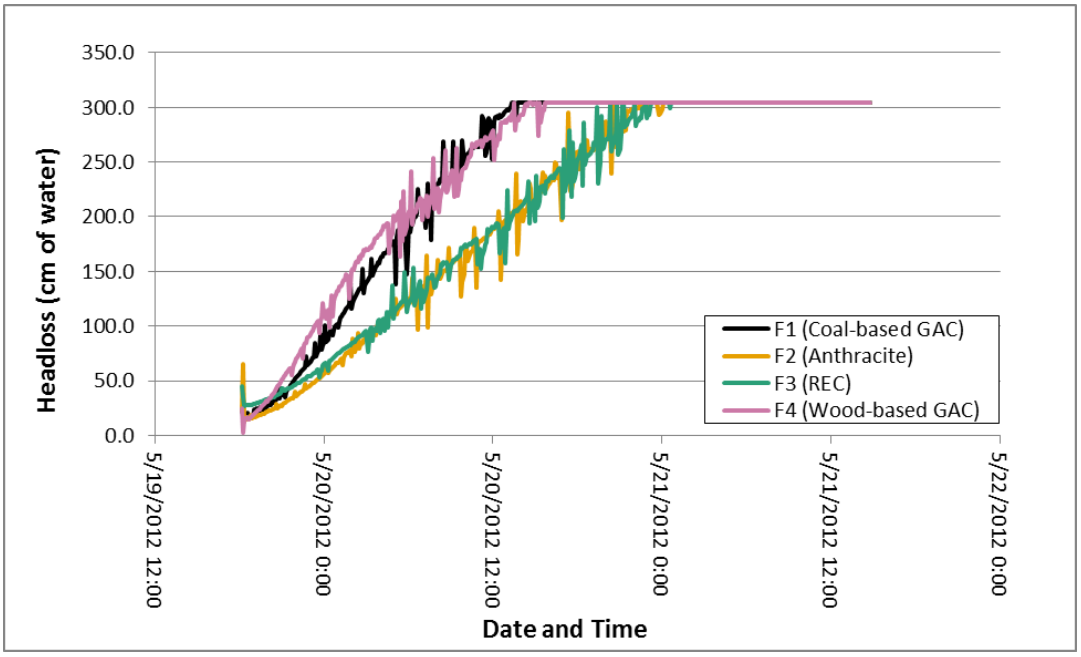


Figure 3-35: Plot of headloss versus time for filter cycle 111

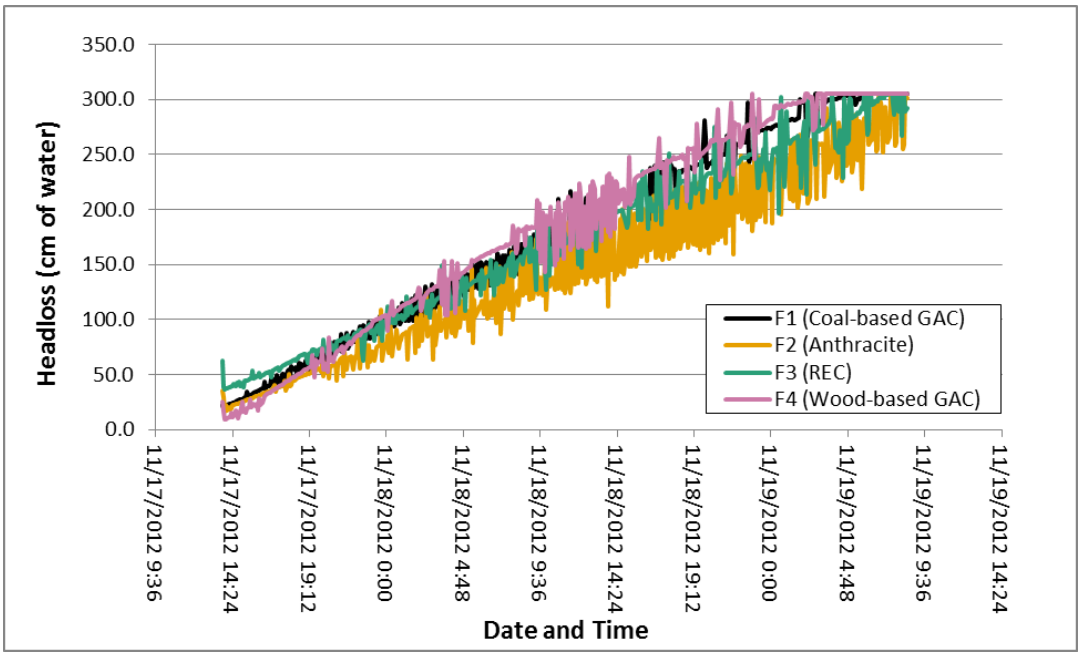


Figure 3-36: Plot of headloss versus time for filter cycle 203

Figure 3-34, provides an example of a filter cycle where all media types did not reach the maximum measurable headloss before the end of the filter cycle. Anthracite had the lowest headloss at the end of the filter cycle followed by REC, coal-based GAC, and wood-based GAC. Therefore, anthracite provided the best performance with respect to headloss, followed by REC, coal-based GAC, and wood-based GAC. This plot also provides an illustration of a filter cycle where the relationship between headloss and time was linear.

Figure 3-35 provides an example of a filter cycle where all media types reached the maximum measurable headloss. In filter cycles such as this, the time at which a filter containing a given media type reached and stayed at the maximum measurable headloss was compared to determine which media type provided the best performance. In this case, coal-based GAC reached maximum measurable headloss first, followed by wood-based GAC, anthracite, and then REC; therefore, REC provided the best performance with respect to headloss, followed by anthracite, wood-based GAC, and coal-based GAC. Some curvature in the headloss data with respect to time can also be seen in this figure. The curvature in the data illustrates the point that headloss data with respect to time cannot necessarily be represented by straight line; therefore, the rate of headloss development cannot necessarily be compared between different filters by comparing the slope of a line fitted to the data.

Finally, Figure 3-36 provides an example of a filter cycle where some of the media types reached maximum measurable headloss and some did not. In this cycle, the two GACs reached maximum measurable headloss, unlike the two less adsorptive media types. The wood-based GAC reached maximum measureable headloss first, followed by the coal-based GAC. Therefore, the wood-based GAC provided the worst headloss performance, followed by the coal-based GAC. The headloss at the end of the filter cycle was higher for the REC than for anthracite; therefore REC provided the next best headloss performance and anthracite provided the best headloss performance of all media types.

In all three figures, the "noisy" nature of the headloss data is evident. Some of the noise could be attributed to noise in the effluent flow due to automatic adjustment of the filter effluent valves by the SCADA system. Regardless, it is clear that anthracite and REC provided better performance with respect to headloss than both types of GAC (Figure 3-34,Figure 3-35, and Figure 3-36).

The number of times each media type performed better than another and p-values from sign tests associated with each comparison, for each season, are summarized in Table 3-59 through to Table 3-63. Media types that performed better than the other media type to a statistically significant degree are presented in bold type and underlined.

Table 3-59: Number of times a media type provided better headloss performance than another during Warm Season 1and p-values from associated sign tests

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Headloss Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Headloss Performance than Medium 1**	**Adjusted P-value[1]**
Coal-based GAC[3]	Anthracite	-	-	-	-
Coal-based GAC[3]	REC	-	-	-	-
Coal-based GAC[3]	Wood-based GAC	-	-	-	-
Wood-based GAC	**Anthracite**	0	0	14	$7.3x10^{-4}$
Wood-based GAC	**REC**	0	0	13	$1.5x10^{-3}$
Anthracite	**REC**	0	0	15	$3.7x10^{-4}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. Pressure transducer on the filter containing coal-based GAC out of service.

Table 3-60: Number of times a media type provided better headloss performance than another during Cold Season 1 and p-values from associated sign tests

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Headloss Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Headloss Performance than Medium 1**	**Adjusted P-value[1]**
Coal-based GAC	**Anthracite**	0	0	39	$2.2x10^{-11}$
Coal-based GAC	**REC**	5	0	34	$1.5x10^{-05}$
Coal-based GAC	Wood-based GAC	28	0	9	$1.5x10^{-02}$
Wood-based GAC	**Anthracite**	2	0	41	$1.3x10^{-09}$
Wood-based GAC	**REC**	4	0	39	$1.9x10^{-07}$
Anthracite	REC	35	2	9	$6.4x10^{-04}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.

Table 3-61: Number of times a media type provided better headloss performance during Warm Season 2 and p-values from associated sign tests

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Headloss Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Headloss Performance than Medium 1**	**Adjusted P-value[1]**
Coal-based GAC	**Anthracite**	1	0	69	$2.7x10^{-13}$
Coal-based GAC	**REC**	0	0	67	$8.1x10^{-20}$
Coal-based GAC	**Wood-based GAC**	16	0	48	$4.6x10^{-04}$
Wood-based GAC	**Anthracite**	11	1	57	$7.6x10^{-08}$
Wood-based GAC	**REC**	13	0	54	$2.7x10^{-06}$
Anthracite	**REC**	23	1	46	$4.6x10^{-02}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.

Table 3-62: Number of times a media type provided better headloss performance during Cold Season 2 and p-values from associated sign tests

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Headloss Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Headloss Performance than Medium 1**	**Adjusted P-value[1]**
Coal-based GAC	**Anthracite**	2	0	66	$9.3x10^{-17}$
Coal-based GAC	**REC**	9	0	58	$4.1x10^{-09}$
Coal-based GAC	Wood-based GAC	32	0	29	$4.8x10^{00}$
Wood-based GAC	**Anthracite**	6	1	53	$1.1x10^{-09}$
Wood-based GAC	**REC**	14	0	45	$3.9x10^{-04}$
Anthracite	REC	55	1	11	$2.2x10^{-07}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. The p-value for coal-based GAC vs wood-based GAC was recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. P-values greater than one are not possible. The unadjusted p-value was $8.0x10^{-01}$.

Table 3-63: Number of times a media type provided better headloss performance than another during Warm Season 3 and p-values from associated sign tests

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Headloss Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Headloss Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	Anthracite	6	0	11	$1.0x10^{00}$
Coal-based GAC	REC	10	0	7	$1.0x10^{00}$
Coal-based GAC	Wood-based GAC	4	0	13	$2.9x10^{-01}$
Wood-based GAC	Anthracite	10	0	7	$1.0x10^{00}$
Wood-based GAC	REC	14	0	3	$7.6x10^{-02}$
Anthracite	REC	14	0	3	$7.6x10^{-02}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-values for coal-based GAC vs anthracite, coal-based GAC vs REC, and wood-based GAC vs anthracite was recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. P-values greater than one are not possible. The unadjusted p-values were: $3.3x10^{-01}$, $6.3x10^{-01}$, $6.3x10^{-01}$, respectively.

The nonadsorptive media (REC) and slightly adsorptive media (anthracite) provided better headloss performance than the very adsorptive media (GAC) in most of the filter cycles, except for during Warm Season 3. Between the two relatively nonadsorptive media and between the two adsorptive media, the media type that provided the best headloss performance changed depending on water conditions. For example, during warm water conditions REC performed better than anthracite whereas the opposite was observed at cold water conditions. It should be noted that there was no clear indication as to why the coal-based GAC performed better than the wood-based GAC during Cold Season 1, but did not during Cold Season 2.

The reason why different trends in headloss performance were observed during Warm Season 3 relative to the other seasons is also unknown; however, this was a short operational period at the end of the experimental phase. Given more time, the trends may have stabilized to be similar to those of the other operational periods. The change in trends highlights the possibility that there may be other factors, including operational changes, which impact the comparative performance of different media types. Further research is needed to identify these factors and determine how they impact the choice of the optimal media type for a given set treatment plant.

Theoretically, differences in performance between biological filters containing different media could be caused by differences in grain size distribution, differences in the solids loading to each filter, and/or due to differences in biological growth/activity in the filters. The grain size distributions were essentially the same for the different media types used in this study and the solids loading to the filters was the same; therefore, it is likely that the differences in performance were attributable to differences in biological growth, with the filters containing GAC having more biological growth than the filters containing anthracite or REC.

The fact that the filters containing GAC removed more DOC than the filters containing REC or anthracite may also support the conclusion that differences in headloss were due to differences in biological growth. Figure 3-37 was created to help investigate this point further. Figure 3-37 shows the number of filter cycles where the GACs provided a different headloss performance than the REC or anthracite with respect to DOC removal.

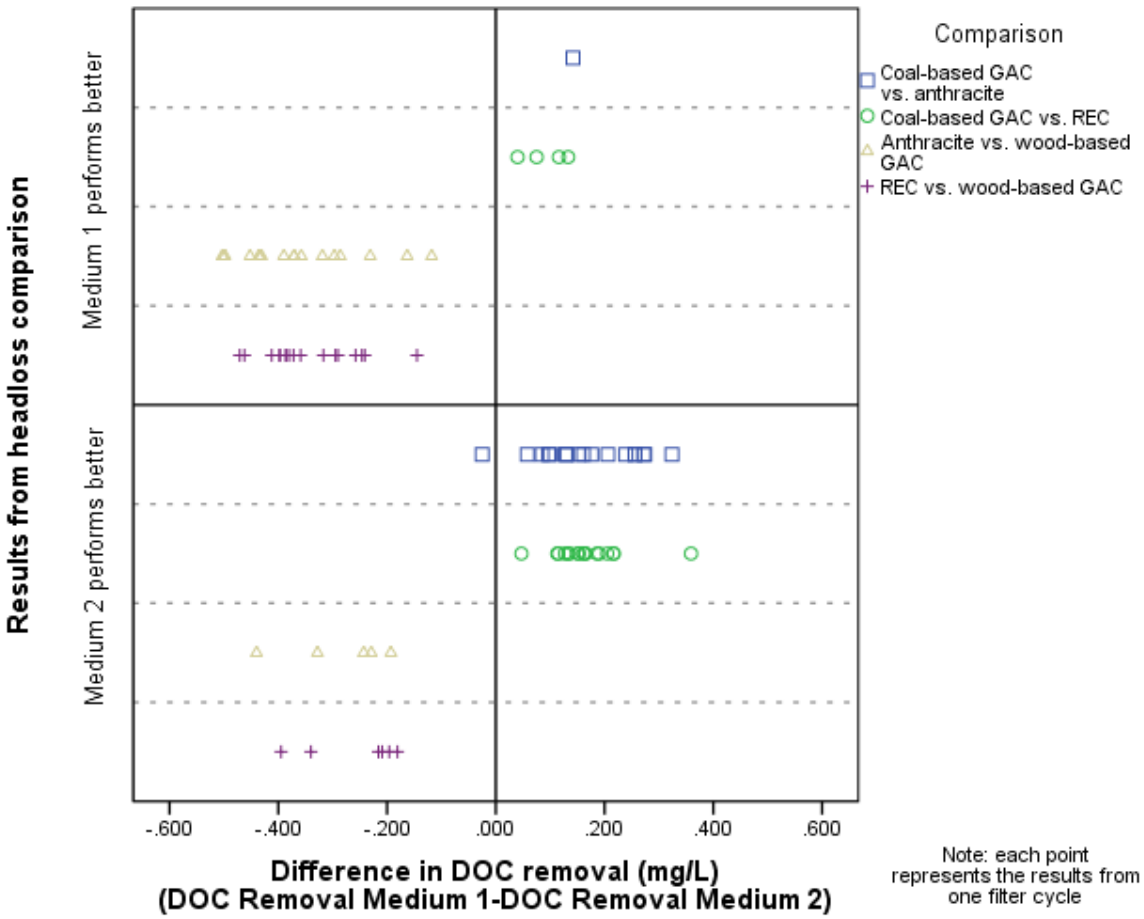


Figure 3-37: Plot of results from headloss comparisons versus the difference in DOC removal between filters containing different types of media

In Figure 3-37, the x-axis represents the difference in DOC removal between two filters, for a given filter cycle. The difference in DOC removal between the two filters was calculated as follows:

$$Difference = DOC\ Removal\ of\ Medium\ 1 - DOC\ removal\ of\ Medium\ 2 \quad \textbf{(Equation 3-3)}$$

where the DOC Removal of Medium 1 is the DOC removal provided by the first media type listed in the comparison and the DOC Removal of Medium 2 is the DOC removal provided by the second media type in the comparison. For example, in the comparison of coal-based GAC vs. anthracite, DOC Removal of Medium 1 is the DOC removal provided by coal-based GAC and DOC Removal of Medium 2 is the DOC removal provided by anthracite. Therefore, in Figure 3-37, a positive value on the x-axis indicates that the first media type listed in a given comparison provided a higher DOC removal and a negative value indicates that the second media type in the comparison provided a higher DOC removal. The y-axis is categorical in nature: the upper portion of the axis represents filter cycles where the first media type in a

given comparison provided better (i.e. lower) headloss than the second media type, the lower portion of the axis represents filter cycles where the second media type provided lower headloss than the first media type, and the line dividing the two halves represents filter cycles where the two filters being compared had the same headloss. Each point on the plot indicates the observed difference in DOC removal between two media types (read off the x-axis) for a given filter cycle and indicates the media type that provided the best headloss performance (read off the y-axis) in the same filter cycle. The shape of each point indicates which of the two media types were compared.

The majority of the data is grouped in the upper left and lower right quadrants of the plot for comparisons of GACs to REC or anthracite: this indicates that, in general, GAC filters tended to have worse headloss performance when they provided a greater amount of DOC removal. Differences in DOC removal between GACs and non-adsorptive media would have been caused either by adsorption of organic matter or differences in biological growth and microbial utilization[83]. Improved DOC removal caused abiotically through adsorption would not have impacted headloss performance; therefore the trend of worse headloss performance with higher DOC removals supports the hypothesis that differences in headloss performance between the different media types were due to differences in biological growth. These results also indicate that there may be a trade-off between optimizing DOC removal and optimizing headloss performance in biofilters.

Overall, the experimental data demonstrated that REC and anthracite generally can provide better headloss performance than GAC during biofiltration. The type of GAC that provides the best headloss performance (i.e. between coal-based GAC and wood-based GAC) and the type of less adsorptive filtration medium (i.e. between REC and anthracite) which provides the best headloss performance is dependent on the water conditions. Thus, during biofiltration there may be a trade-off between choosing a media type that provides the greatest DOC removal and one that provides the best headloss performance.

3.3.5 Turbidity Removal

3.3.5.1 Turbidimeter Bias and Drift

3.3.5.1.1 Note on Nomenclature

[83]Note that these results do not imply that adsorption played absolutely no role in causing the difference in DOC removal between the various media types; they merely support the conclusion that differences in biological growth are a likely cause of the difference in headloss development. Adsorption and the adsorptive properties of the media could still have played a role: either by allowing spikes of organic matter to be adsorbed (see Phase II) abiotically, by somehow impacting biological growth, or by allowing cycles of adsorption followed by bioregeneration to occur.

In the following subsection, the nomenclature denoted in Table 3-64 will be used to identify the turbidimeter associated with filter.

Table 3-64: Nomenclature for turbidimeters associated with each filter

Turbidimeter	Filter	Media Type Installed in Filter
T1	F1	Coal-based GAC
T2	F2	Anthracite
T3	F3	Rough engineered ceramic [REC]
T4	F4	Wood-based GAC

3.3.5.1.2 Low Turbidity Water (0.12 NTU)

Turbidimeter readings from low turbidity water that were used to assess turbidimeter bias are presented in Figure 3-38 (see section 3.2.7.1 for methodological details).

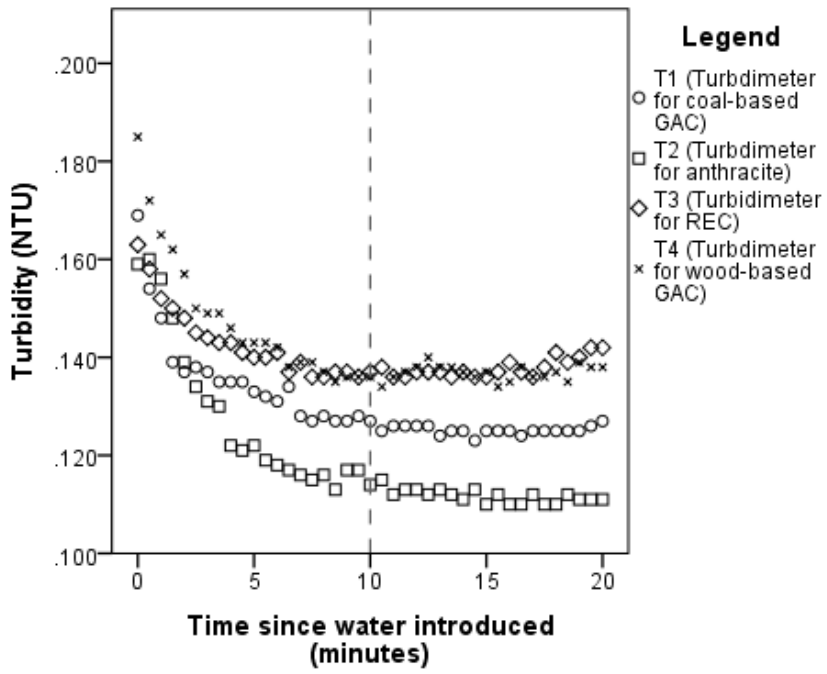


Figure 3-38: Effluent Turbidity during turbidimeter cross referencing with low turbidity water

Turbidimeter readings stabilized after low turbidity water was pumped through the turbidimeters for approximately 10 minutes. Analysis was performed only on data collected after the first 10 minutes. The difference in turbidity readings, 99% confidence intervals, and p-values for the differences are presented in Table 3-65.

Table 3-65: Results from analysis of turbidimeter cross-referencing with low turbidity water

Comparison	Difference between Mean Turbidity Readings (NTU)	99% Confidence Interval		P-values	Significant at a significance level of 0.05?[1]
		Lower Limit	Upper Limit		
T1-T2	0.014	0.012	0.015	$<1.0x10^{-15}$	Y
T1-T3	-0.013	-0.014	-0.011	$1.3x10^{-15}$	Y
T1-T4	-0.012	-0.013	-0.010	$2.7x10^{-15}$	Y
T2-T3	-0.026	-0.028	-0.024	$4.9x10^{-15}$	Y
T2-T4	-0.025	-0.027	-0.024	$<1.0x10^{-15}$	Y
T3-T4	-0.001	-0.001	0.003	$4.2x10^{-01}$	N

1. Indicates whether or not results are statistically significant at a two-tailed significance level of 0.05.

The published accuracy of the turbidimeters is +/-2% of the reading or +/- 0.015 NTU, whichever is greater, for water with turbidity in the range of 0-40 NTU (HACH, 2004); over half of the differences in mean turbidity were within this range. The difference in turbidity between each turbidimeter was statistically significant for all comparisons except between T3 and T4. It was concluded that T1 read high compared to T2 and read low compared to T3 and T4. It was also concluded that T2 read low compared to T3 and T4. Therefore, turbidimeter readings around 0.15 NTU were adjusted to account for turbidimeter bias when turbidity readings from different filters were compared.

3.3.5.1.3 High Turbidity Water (1.1 NTU)

Turbidimeter readings from the high turbidity water are presented in Figure 3-39.

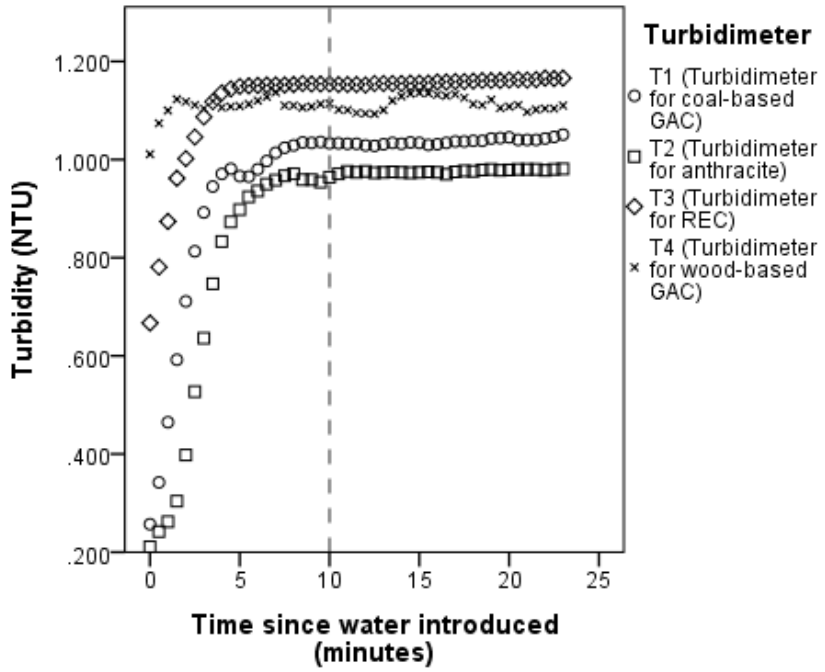


Figure 3-39: Effluent Turbidity during turbidimeter cross referencing with high turbidity water

As with the low turbidity water, the turbidimeter readings also stabilized after approximately 10 minutes. The readings from T4, however, did not stabilize as well as the other turbidimeters and a somewhat cyclical trend in the data can be seen. A normal probability plot of data from T4 (plot not shown), after the first 10 minutes, indicated that the data from T4 departed somewhat from normality. The departure from normality may have affected the 99% confidence intervals calculated using Dunnett's T3 procedure. The results from the high turbidity cross-referencing are presented in Table 3-66.

Table 3-66: Results from analysis of turbidimeter cross-referencing with high turbidity water

Comparison	Difference between Mean Turbidity Readings (NTU)	99% Confidence Interval		P-values	Significant at a Significance Level of 0.05?[1]
		Lower Limit	Upper Limit		
T1-T2	0.061	0.056	0.065	5.6E-16	Y
T1-T3	-0.122	-0.127	-0.117	<1.0E-16	Y
T1-T4	-0.077	-0.087	-0.066	<1.0E-16	Y
T2-T3	-0.182	-0.186	-0.179	<1.0E-16	Y
T2-T4	-0.137	-0.147	-0.127	3.3E-16	Y
T3-T4	0.045	0.035	0.055	1.2E-14	Y

1. Indicates whether or not results are statistically significant at a two-tailed significance level of 0.05.

The differences in turbidity among the four analyzers were higher than those from the low turbidity water cross-referencing, indicating that the turbidimeter bias was a function of the magnitude of the turbidity being measured. All differences in mean turbidity were statistically significant, indicating that the turbidimeters did provide different readings on the same water. The differences in mean turbidity for all comparisons were beyond the published accuracy range for the turbidimeters, indicating the importance of performing cross-referencing: the range of the bias between turbidimeters would have been greatly underestimated had the published accuracy been used to estimate the range of the bias. While the T4 data revealed a departure from normality, it was assumed that the departure from normality and calculation of the p-value did not affect the conclusion that there was a difference between the turbidimeter readings because the differences were statistically significant. Furthermore, while it is accepted that the calculated 99% confidence intervals may deviate slightly from the true 99% confidence interval, most differences in turbidity observed in this study were outside the calculated 99% confidence interval by a large margin and, therefore, slight inaccuracies in the 99% confidence intervals are not expected to have affected the final conclusions of this study.

3.3.5.1.4 Turbidimeter Drift

Table 3-67 summarizes the dates of turbidimeter calibrations, the mean effluent turbidity measured from the pilot plant before and after calibration, the standard deviation of the mean effluent turbidity, the number of samples used to calculate the mean effluent turbidity, and the difference in mean turbidity before and after calibration. It should be noted that not all turbidimeters were calibrated during all calibration dates.

Table 3-67: Turbidimeter readings before and after calibration

Calibration Date	Turbidimeter Calibrated	Before Calibration (BC)			After Calibration (AC)			Difference in Mean Effluent Turbidity (BC-AC)
		Mean Effluent Turbidity (NTU)	Standard Deviation (NTU)[2]	n[1]	mean Effluent Turbidity (NTU)	Standard Deviation (NTU)[2]	n[1]	
November 13, 2011	F3	0.049	0.00055	11	0.046	0.00074	35	0.003
January 2, 2012	F3	0.035	0.0039	63	0.035	0.000072	61	0.000
January 15, 2012	F1	0.040	0.0013	61	0.035	0.0012	40	0.004
	F2	0.036	0.00093	61	0.038	0.00089	33	-0.002
	F3	0.033	0.000076	61	0.035	0.00029	37	-0.002
	F4	0.037	0.00011	61	0.038	0.00028	48	0.000
February 23, 2012	F1	0.037	0.00098	61	0.036	0.00033	61	0.001
	F2	0.040	0.00091	60	0.041	0.00016	60	-0.001
	F3	0.029	0.00046	61	0.037	0.00018	60	-0.008
	F4	0.037	0.00017	61	0.038	0.00015	60	-0.001
October 10, 2012	F1	0.046	0.0017	30	0.047	0.0014	95	0.004
	F3	0.051	0.00061	40	0.049	0.00052	32	0.001
	F4	0.041	0.0045	26	0.042	0.0034	46	-0.001

1. Number of data points (measurements).
2. Values rounded to two significant digits.

If there had been drift in the turbidimeter readings over time, the effluent turbidity value measured before and after calibration would have changed significantly. It can be seen that the turbidity only changed slightly after calibration, even after several months had passed between calibrations; therefore drift in the turbidimeter readings was not a concern.

3.3.5.2 Comparison of Effluent Turbidity

Plots from three filter cycles will be presented and discussed to illustrate some of the features seen during review of the turbidity data and to illustrate the data analysis procedure. Plots from other filter cycles were created but are not presented for space considerations. Figure 3-40, Figure 3-41 and Figure 3-42 are three representative plots of the effluent turbidity from all four filters.

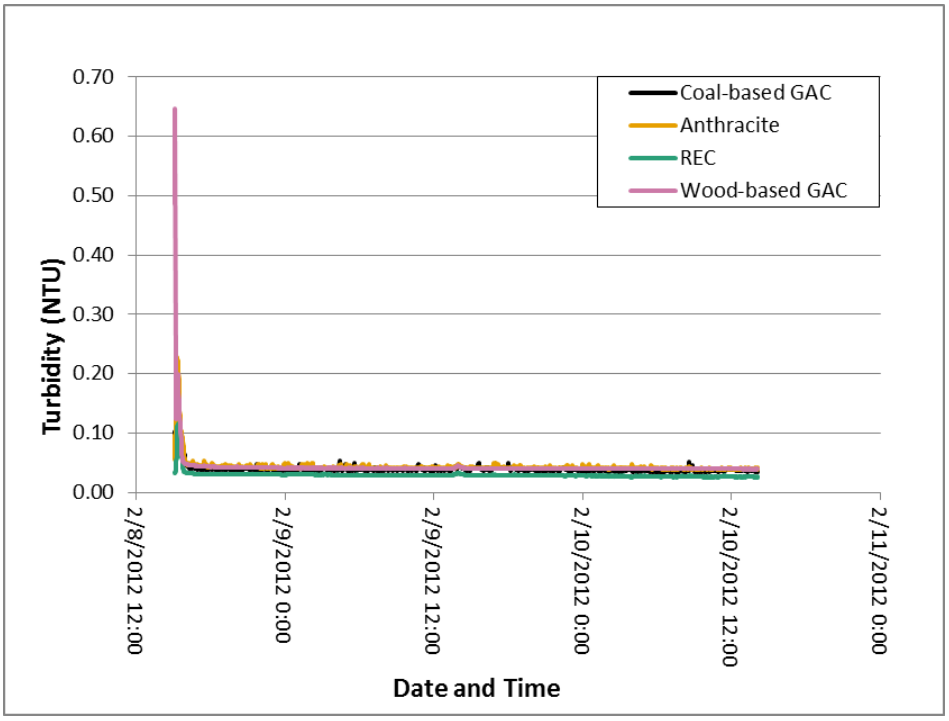


Figure 3-40: Effluent turbidity from filter cycle 60 (February 8, 2012 to Februrary10, 2012)

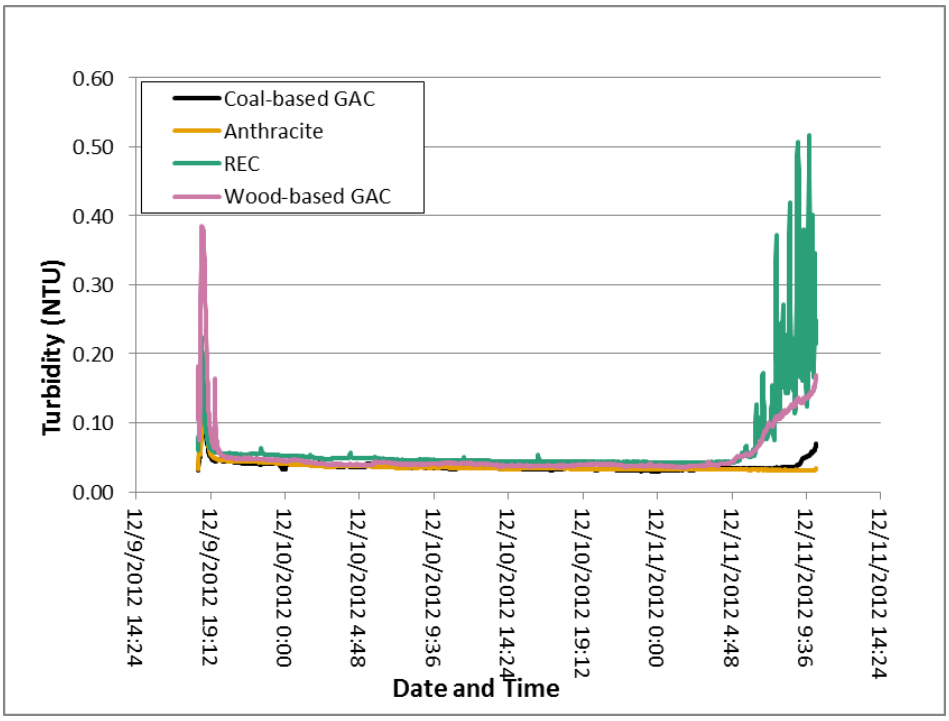


Figure 3-41: Effluent turbidity from filter cycle 212 (December 9, 2012 to December 11, 2012)

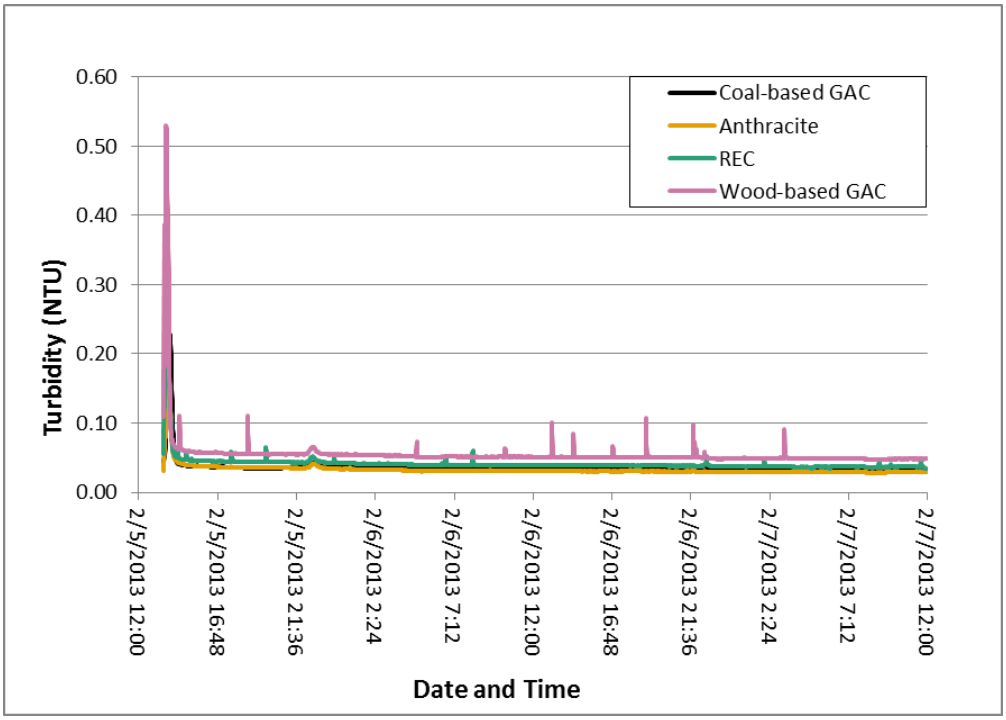


Figure 3-42: Effluent turbidity from filter cycle 239 (February 5, 2013 to February 7, 2013)

There was a clear ripening period for each filter cycle, breakthrough during filter cycle 212, and brief spikes in the wood-based GAC filter effluent during filter cycle 239. The effluent turbidities were generally stable between ripening and breakthrough; therefore representation of the turbidity by a mean value was acceptable for this stable period. Conclusions from the analysis were the same regardless of whether the 0.1 or 0.3 NTU cut-offs were used for ripening and breakthrough; therefore, only the results calculated using the 0.1 NTU cut-off will be discussed.

Ripening was observed in most filter cycles during the study and breakthrough was observed in less than 10% of the filter cycles. One or more brief effluent turbidity spikes of a magnitude around 0.1 NTU, similar to those seen in Figure 3-42, were seen in the effluent of at least one filter in approximately 20% of the filter cycles. The brief spikes generally lasted only 2-4 minutes and may have been caused by flow perturbations in the filters (due to actuators automatically adjusting the effluent flow), to sloughing of biomass, or bubbles passing through the turbidimeter. The brief turbidity spikes were taken to be true readings, given that there was no evidence to support their exclusion, and were included in the calculation of the average effluent turbidity. The brief spikes were not considered to represent breakthrough given the short duration of the spikes.

Table 3-68 shows the unadjusted mean effluent turbidity values for the period between ripening and breakthrough, the adjusted mean effluent turbidity values, and the interval for the adjusted mean effluent turbidity values for the three filter cycles presented in Figure 3-40, Figure 3-41, and Figure 3-42.

Table 3-68: Mean effluent turbidities from filter cycles 60, 212, and 239

Filter Cycle	Filter Containing:	Unadjusted Mean Effluent Turbidity[1]	Adjusted Mean Effluent Turbidity[2]	Interval for the Adjusted Mean Effluent Turbidity[3, 4]
60	Coal-based GAC	0.039	0.039	0.039-0.039
	Anthracite	0.041	0.055	0.055-0.055
	REC	0.029	0.016	0.016-0.016
	Wood-based GAC	0.041	0.029	0.029-0.029
212	Coal-based GAC	0.035	0.035	0.034-0.035
	Anthracite	0.035	0.048	0.048-0.049
	REC	0.046	0.033	0.033-0.033
	Wood-based GAC	0.039	0.027	0.027-0.027
239	Coal-based GAC	0.032	0.032	0.032-0.032
	Anthracite	0.030	0.043	0.043-0.043
	REC	0.038	0.026	0.026-0.026
	Wood-based GAC	0.050	0.039	0.038-0.039

1. Mean effluent turbidity during the relatively stable period after ripening and before breakthrough. An effluent turbidity of 0.1 NTU was used to define the end of ripening and start of breakthrough.
2. Mean effluent turbidity adjusted for bias in the readings between different turbidimeters. The effluent turbidimeter on the filter containing coal-based GAC was used as the reference turbidimeter: all effluent turbidity readings were adjusted to match the readings from this turbidimeter.
3. Interval calculated from the 99% confidence interval on the unadjusted average effluent turbidity and the 99% confidence interval on the magnitude of the bias between turbidimeters.
4. Intervals for the adjusted average turbidity were very small (variation was in the fourth decimal place); there appears to be no interval, in some cases, due to rounding.

The results in Table 3-68 highlight the importance of adjusting for turbidimeter bias. When the unadjusted mean effluent turbidity values are compared, anthracite seems to have provided the lowest effluent turbidities in filter cycles 212 and 239; however when the results are adjusted for turbidimeter bias, the exact opposite is concluded—anthracite provided the highest effluent turbidities. The reason the anthracite filter initially seemed to provide better removal of turbidity was because the turbidimeter for the anthracite filter was reading systematically low compared to the other turbidimeters (see Table 3-65). Thus, it is highly recommended that turbidimeter bias be tested and accounted for in general, whenever comparative analysis is conducted.

Comparison of the adjusted average effluent turbidity values in Table 3-68 indicates that the GACs and REC all provided better removal of turbidity than anthracite during the three filter cycles. REC also provided better turbidity removal than coal-based GAC and anthracite in all three filter cycles and better

removal of turbidity than wood-based GAC in two of the three filter cycles. Finally, wood-based GAC provided better removal of turbidity than coal-based GAC in two of the three filter cycles.

It should be noted that even though the differences in turbidity between the different media types were fairly small, they have both practical and mechanistic significance. Practically, the lower effluent turbidity is indicative of better particle removal through the filters. Furthermore, the difference in performance provided by the different media types used in this study would likely be larger in situations where higher influent turbidities occurred (a point which is amply illustrated in the turbidity dampening sections) and in situations where smaller filter media depths are used. Mechanistically, the grain size distributions of the different media types were the same and therefore the differences in performance can be attributed to the difference in media properties. By comparing the properties of the different media types, conclusions can be made as to which media properties contribute to improved turbidity removal.

Table 3-69 and Table 3-70 summarize the total number of filter cycles where one media type performed better than the other, the number of filter cycles where there was no difference in mean effluent turbidity between two media types, and the adjusted p-values from the sign tests. The results in Table 3-69 are from all filter cycles conducted during warm water conditions and the results in Table 3-70 are from all filter cycles conducted during cold water conditions.

Certain media types clearly provided better removal of turbidity than others. REC provided better removal of turbidity than either anthracite or coal-based GAC under all water conditions and provided better removal of turbidity than wood-based GAC under cold-water conditions. Wood based GAC provided better removal of turbidity than anthracite under all water conditions and better removal of turbidity than coal-based GAC under warm water conditions. Coal-based GAC provided better removal of turbidity than anthracite under cold water conditions. Anthracite provides the worst removal of turbidity of all the media types.

REC, wood-based GAC, and coal-based GAC are all rough media types compared to anthracite. Given that REC, wood-based GAC, and coal-based-GAC-under-cold-water-conditions provided better removal of turbidity than anthracite, media roughness was a property that generally improved the ability of filter media to remove turbidity during biofiltration. This conclusion agrees with the findings of Scott (2008), from comparing REC to anthracite in

Table 3-69: Comparison of the removal of turbidity during warm water conditions by different filter media

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Turbidity Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Turbidity Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	Anthracite	21	0	23	$1.0x10^{+00}$
Coal-based GAC	**REC**	1	1	73	$2.1x10^{-13}$
Coal-based GAC	**Wood-based GAC**	8	1	56	$3.3x10^{-09}$
Wood-based GAC	Anthracite	45	0	0	$3.4x10^{-13}$
Wood-based GAC	REC	48	1	26	$8.4x10^{-02}$
Anthracite	**REC**	0	0	61	$5.2x10^{-18}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-value for coal-based GAC vs anthracite recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. The unadjusted p-values was: $8.8x10^{-01}$

Table 3-70: Comparison of the removal of turbidity during cold water conditions by different filter media

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Turbidity Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Turbidity Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	Anthracite	71	0	0	$5.1x10^{-21}$
Coal-based GAC	**REC**	1	2	103	$4.5x10^{-13}$
Coal-based GAC	Wood-based GAC	38	3	44	$1.0x10^{+00}$
Wood-based GAC	Anthracite	62	0	2	$4.5x10^{-13}$
Wood-based GAC	**REC**	13	1	74	$9.5x10^{-11}$
Anthracite	**REC**	0	0	70	$1.0x10^{-20}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-value for coal-based GAC vs wood-based GAC recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. The unadjusted p-value was: $5.8x10^{-01}$

non-biological filtration, and with the more fundamental findings that media roughness can impact the collection efficiency of particles (Jin et al., 2015a). However, there is some factor (or factors), that was correlated with temperature, that impacted the comparative performance of one rough media type versus another. This factor also impacted the comparative performance of a rough media type to a smooth media type. It was observed that REC provided better turbidity removal than wood-based GAC under cold water conditions but under warm water conditions there was not a clear benefit to using REC over wood-based GAC. It was also observed that coal-based GAC provided better turbidity removal than anthracite under cold water conditions but under warm water conditions there was no consistent benefit to using coal-based GAC. The reason for the change in the comparative performance of coal-based GAC versus anthracite and of REC versus wood-based GAC with changes in water temperature is unknown. It is speculated that the change in comparative performance could be due, in part, to biomass growth impacting the properties of the media or to changes in the influent water quality. It should also be highlighted that the nature of the surface roughness was different across the different media types (see SEMs in section 3.3.2.1): the REC had a large variety of surface asperities, the surface of the wood-based GAC was very porous, and the coal-based GAC had some surface asperities but also seemed to be coated by some sort of semi-rough "crust". The semi-rough "crust" of the coal-based GAC may have been biomass or other material that stuck to the surface of the coal-based GAC over its operational life. The type of roughness may also impact the comparative performance of different media types in biofilters and may have interacted with other factors related to water temperature to result in the change in comparative performance. It has been shown, for example, that there is a non-linear, non-monotonic relationship between particle removal, media surface roughness, media grain size, and the size of a particle being removed from water (Jin et al., 2015a). Further research is needed to identify the factor or factors which impact the comparative performance of one rough media type versus another and of rough media versus smooth media.

3.3.5.3 Attenuation of Turbidity Spikes (Turbidity Dampening)

The impact of media type was studied in three sets of spike experiments, each conducted in a different season. The results from each experiment set are presented and discussed in the following subsections[84]. A final discussion on the impact of media type and other factors on turbidity dampening is also provided.

3.3.5.3.1 Experiment Set 1 Results and Discussion

[84] Methodological details of the spike experiments can be found in Section 3.2.7.3: Attenuation of Turbidity Spikes (Turbidity Dampening)

Experiment set 1 was conducted between March 14 and 30, 2012. Figure 3-43 and Figure 3-44 show the influent and effluent turbidity readings from the first and second experiments conducted during Experiment Set 1, respectively.

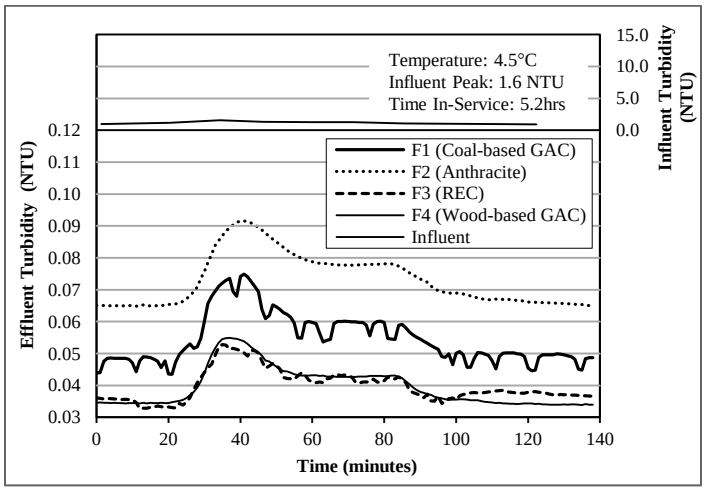


Figure 3-43: Impact of media type on turbidity dampening. Influent and effluent turbidities from Experiment Set 1, Experiment 1.

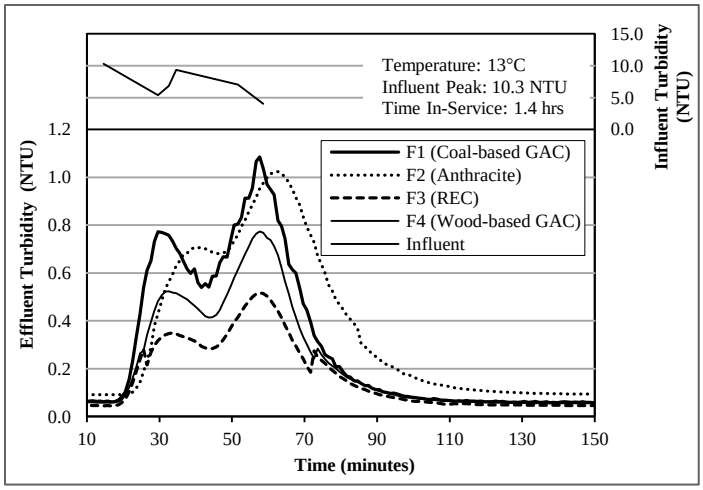


Figure 3-44: Impact of media type on turbidity dampening. Influent and effluent turbidities from Experiment Set 1, Experiment 2.

Table 3-71 summarizes the estimated baseline turbidity, the observed peak effluent turbidity, and the difference between the baseline and peak turbidity for all media types. The media type with the smallest difference between peak and baseline turbidity provided the best turbidity dampening. The media type which provided the best turbidity dampening is written in bold type and underlined.

Table 3-71: Baseline turbidity, peak effluent turbidity and difference between peak and baseline turbidities for turbidity dampening experiments conducted during Experiment Set 1.

Experiment	Media Type[1]	Baseline Turbidity (NTU)	Peak Effluent Turbidity (NTU)	Difference (Peak-Baseline) (NTU)
1	Coal-based GAC	0.048	0.075	0.027
	Anthracite	0.065	0.092	0.026
	REC	**0.036**	**0.053**	**0.017**
	Wood-based GAC	0.034	0.055	0.021
2	Coal-based GAC	0.064	1.086	1.022
	Anthracite	0.091	1.024	0.933
	REC	**0.046**	**0.517**	**0.471**
	Wood-based GAC	0.058	0.773	0.715

1. The media type written in bold and underlined provided the best turbidity dampening

In both experiments the REC provided the greatest turbidity dampening, followed by the wood-based GAC. The coal-based GAC and anthracite provided the worst turbidity dampening. It was also observed that in the second experiment, when a larger influent turbidity spike was used, peak effluent turbidities and the difference between peak effluent turbidities associated with the four media types were much larger. Therefore, it was concluded that the magnitude of the influent turbidity spike can affect both the magnitude of the effluent turbidity peaks and the difference between the effluent turbidity peaks.

3.3.5.3.2 Experiment Set 2 Results and Discussion

Experiment Set 2 was conducted between July 10, 2012 and July 16, 2012. Figure 3-45 and Figure 3-46 show the influent and effluent turbidity readings from the first and second experiments conducted during Experiment Set 2, respectively.

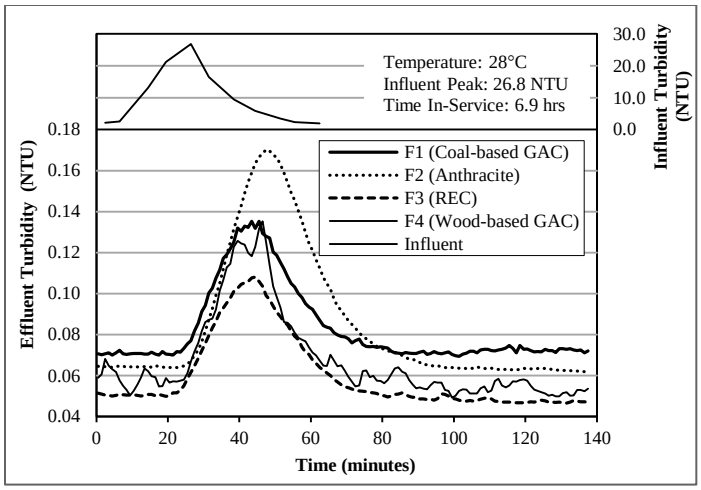


Figure 3-45: Impact of media type on turbidity dampening. Influent and effluent turbidities from Experiment Set 2, Experiment 1.

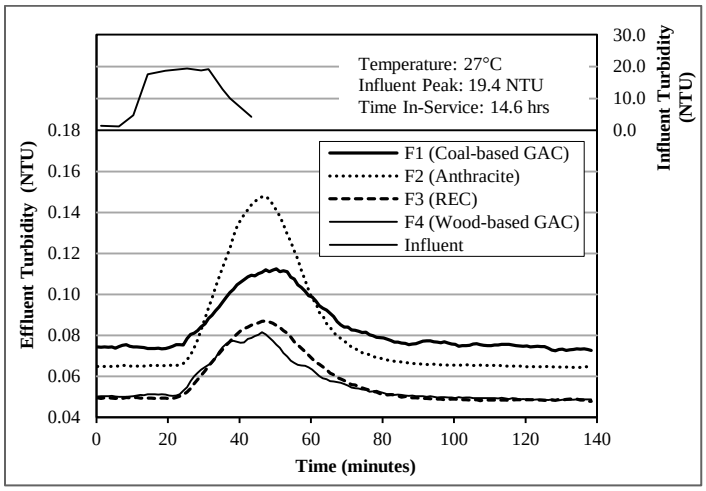


Figure 3-46: Impact of media type on turbidity dampening. Influent and effluent turbidities from Experiment Set 2, Experiment 2.

Table 3-72 summarizes the estimated baseline turbidity, the observed peak effluent turbidity, and the difference between the baseline and peak turbidity for all filters during Experiment Set 2. Again, the media type which provided the best turbidity dampening is written in bold type and is underlined.

Table 3-72: Baseline turbidity, peak effluent turbidity and difference between peak and baseline turbidities for turbidity dampening experiments conducted during Experiment Set 2.

Experiment	Media Type	Baseline Turbidity (NTU)	Peak Effluent Turbidity (NTU)	Difference (Peak-Baseline) (NTU)
1	Coal-based GAC	0.071	0.135	0.064
	Anthracite	0.064	0.170	0.107
	REC	**0.049**	**0.108**	**0.059**
	Wood-based GAC	0.056	0.135	0.080
2	Coal-based GAC	0.074	0.112	0.038
	Anthracite	0.065	0.148	0.083
	REC	0.049	0.087	0.038
	Wood-based GAC	**0.050**	**0.082**	**0.032**

The media type which provided the best turbidity dampening and the comparative turbidity dampening provided by the different media types varied between experiments during Experiment Set 2. In both experiments anthracite provided the worst turbidity dampening and REC provided either the best or second best turbidity dampening. In experiment 1 wood-based GAC provided better turbidity dampening than anthracite but worse turbidity dampening than either coal-based GAC or REC, whereas in experiment 2 wood-based GAC provided the best turbidity dampening. Coal-based GAC provided good turbidity dampening compared to anthracite during both experiments. The reason for the change in the comparative performance of wood-based GAC to the other media types is unknown. The comparative performance could have been impacted by the filter run time because the turbidity spike in experiment 2 was introduced later into the filter cycle than the turbidity spike in experiment 1; however, if this were the case, the wood-based GAC would have been expected to provide better turbidity dampening than coal-based GAC during experiment 1 given that (a) the turbidity spike was introduced early in the filter cycle during experiment 1, (b) that the wood-based GAC provided better turbidity dampening than coal-based GAC during both experiments in Experiment Set 1, and (c) that the turbidity spikes were introduced early in the filter cycle during both experiments in Experiment Set 1. Overall, the results from this experiment set indicate that REC provides excellent turbidity dampening, given that it provided either the best or second best turbidity dampening of all media types, and that all media types provide better turbidity dampening than anthracite.

It should also be highlighted that comparison of the results from this experiment set to those from experiment set 1 indicates that temperature or a factor related to temperature impacts the ability of biological filters to provide turbidity dampening. The influent turbidity spikes used in experiment set 2 were larger than those used in Experiment Set 1; despite this, the peak effluent turbidities were much

smaller during Experiment Set 2 than in Experiment Set 1. The exact factor or factors which resulted in additional turbidity dampening during the higher water temperatures is unknown but it could be due to the combined effect of changes in coagulant dosing and influent water quality or due to biomass growth on the media. The combined effect of changes in coagulant dose and water quality may have allowed the semi-stabile kaolin clay suspension to flocculate in the water column above the filtration media during warm water conditions. Biomass growth is affected by temperature and additional biomass growth during warm water conditions may have impacted the physico-chemical properties of the filtration media. Determining exactly what factors and mechanisms caused the temperature impact on turbidity dampening is an area for future research.

3.3.5.3.3 Experiment Set 3 Results and Discussion

Experiment Set 3 was conducted during October 15-16, 2012. Figure 3-47 shows the influent and effluent turbidity from Experiment Set 3

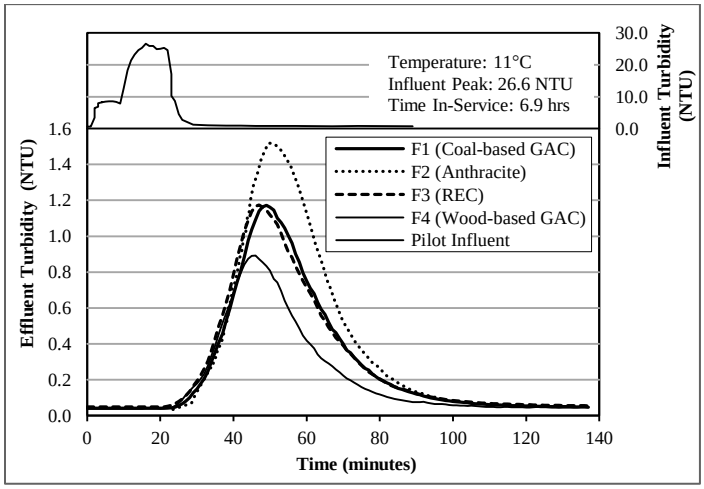


Figure 3-47: Impact of media type on turbidity dampening. Influent and effluent turbidities from Experiment Set 3.

Table 3-73 summarizes the estimated baseline turbidity, the observed peak effluent turbidity, and the difference between the baseline and peak turbidity for all filters during Experiment Set 3.

Table 3-73: Baseline turbidity, peak effluent turbidity and difference between peak and baseline turbidities for the turbidity dampening experiment conducted during Experiment Set 3

Experiment	Media Type	Baseline Turbidity (NTU)	Peak Effluent Turbidity (NTU)	Difference (Peak-Baseline) (NTU)
1	Coal-based GAC	0.046	1.172	1.126
	Anthracite	0.049	1.580	1.531
	REC	0.040	1.052	1.013
	Wood-based GAC	**0.030**	**0.816**	**0.785**

During Experiment Set 3, wood based GAC provided the best turbidity dampening followed by REC, coal-based GAC, and anthracite. Again, a factor related to temperature impacted the ability of all media types to provide turbidity dampening: The water temperature during this experiment *dropped* from the higher temperatures observed during Experiment Set 2 and the observed effluent turbidity peaks were much higher than those observed during Experiment Set 2. In fact, the turbidity peaks observed during this experiment set were closer to those observed during experiment 2 of Experiment Set 1, where water temperatures were similar.

3.3.5.3.4 Final Discussion Related to Turbidity Dampening

Overall, REC and wood-based GAC provided the greatest degree of turbidity dampening of all media types; REC provided better turbidity dampening than coal-based GAC in all experiments; anthracite provided the least amount of turbidity dampening (in all except one experiment, experiment 2 of Experiment Set 1); and both the REC and wood-based GAC always provided better turbidity dampening than anthracite. REC provided the greatest degree of turbidity dampening during all experiments in Experiment Set 1 and in experiment 1 of Experiment Set 2. Wood-based GAC provided the greatest degree of turbidity dampening during experiment 2 of Experiment Set 2 and during Experiment Set 3. REC and both GACs provided greater turbidity dampening than anthracite, with the exception of coal-based GAC during Experiment Set 1 experiment 2, thereby suggesting that the properties of these filter media are advantageous for providing turbidity dampening. Filter media roughness was a property that seemed to improve the ability of filter media to provide turbidity dampening during biofiltration given that the rough media (i.e. REC, wood-based GAC, and coal-based GAC) provided better turbidity dampening than the smooth media (i.e. anthracite). As with the comparisons of effluent turbidity, there may also be a factor which impacts the comparative performance of coal-based GAC versus anthracite and that caused the coal-based GAC to provide worse turbidity dampening that anthracite during experiment 2 of Experiment Set 1; identification of this factor is an area for further research.

Two other factors were also observed to impact the turbidity dampening provided by biofilters: (a) an unidentified factor related to water temperature and (b) the magnitude of the influent turbidity spike. Increased turbidity dampening occurred during higher water temperatures, though the mechanism by which this occurs is unknown. The difference in turbidity dampening provided by different media types and the peak effluent turbidities increased with larger influent turbidity spikes. Practically, these two factors should be taken into consideration when conducting pilot studies and comparing different media types for use in biofiltration. During pilot studies, the resilience of filters to turbidity spikes should be tested under both cold and warm conditions and should be tested with the maximum expected influent turbidity to ensure that the resilience of the filters is properly assessed and the best media type is chosen.

3.3.5.4 Final Discussion on the Removal of Turbidity by Different Media Types

Overall, REC and wood-based GAC consistently provided the best removal of turbidity: both these media types consistently provided lower mean effluent turbidities and better turbidity dampening than anthracite in essentially all situations. Anthracite consistently provided the highest mean effluent turbidity and the worst turbidity dampening. Coal-based GAC provided a lower mean effluent turbidity than anthracite under cold water conditions and better turbidity dampening than anthracite under most conditions, but this additional removal was dependent on other factors: improved effluent turbidity was not consistently seen under warm water temperatures and there was one experiment where coal-based GAC provided worse turbidity dampening than anthracite. It is noted that the coal-based GAC used in this study had been in use for approximately seven years prior to being used in this study. It is possible that the properties of the media, particularly its surface, could have changed over that seven year period. It is also possible that biomass growth obscured the roughness of the media, as was implied by “crusts” on the GAC that were seen in SEMS. Had virgin coal-based GAC been used, it would have performed similar to the wood based GAC; however, further research with virgin coal-based GAC would be needed to demonstrate this. Given the excellent turbidity removal provided by REC and GAC, it is recommended that these two media types be considered for use in biological filters, particularly if the removal of turbidity is challenging or influent turbidity is highly variable at a given location.

The differences in turbidity removal observed in this study were due to the fundamental differences in the media properties and not due to differences in the grain size distribution. Given that REC and the GACs are rough media compared to anthracite, it can be concluded that media roughness generally improved the ability of a filter media to provide turbidity removal and turbidity dampening. However, elucidating exactly how media roughness improves turbidity removal and identifying what other factors might impact the ability of rough media types to provide enhanced improved turbidity requires future research.

3.3.6 Filter Run Time

Table 3-74 and Table 3-75 summarize the number of times a given backwash trigger was observed for each media type during warm and cold water conditions, respectively. In Table 3-74 and Table 3-75, the percentage of the filter cycles where a given backwash trigger was observed, for a given media type, are also presented in brackets.

Table 3-74: Number of filter cycles and percentage of the filter cycles where a backwash trigger was observed during warm water conditions

Media Type	Number of Times (and percentage of filter cycles) the Backwash Trigger was Observed			Total Number of Filter Cycles
	Time	Terminal Headloss	Turbidity Breakthrough	
Coal-based GAC	3 (4%)	68 (93%)	2 (3%)	73
Anthracite	20 (32%)	42 (68%)	0 (0%)	62
REC	32 (32%)	64 (65%)	3 (3%)	99
Wood-based GAC	7 (9%)	66 (88%)	2 (3%)	75

Table 3-75: Number of filter cycles and percentage of the filter cycles where a backwash trigger was observed during cold water conditions

Media Type	Number of Times (and Percentage of Filter Cycles) the Backwash Trigger was Observed			Total Number of Filter Cycles
	Time	Terminal Headloss	Turbidity Breakthrough	
Coal-based GAC	67 (64%)	30 (29%)	7 (7%)	104
Anthracite	59 (83%)	8 (11%)	4 (6%)	71
REC	71 (65%)	31 (28%)	7 (6%)	109
Wood-based GAC	42 (48%)	36 (41%)	9 (10%)	87

During warm water conditions, terminal headloss was the most frequent backwash trigger observed, for all media types, and time was the second most frequent backwash trigger. During cold water conditions, however, terminal headloss occurred less frequently and time became the most frequently observed

backwash trigger. Turbidity breakthrough was the least frequently observed backwash trigger for all media types, for both cold and warm water conditions.

The increased occurrence of terminal headloss during warm water conditions when compared to cold water conditions could have been due to different influent water characteristics or to increased biological growth. Solids loading on the filters could have been higher during warm water conditions due to increased influent turbidity or different coagulant doses. Increased temperatures are also expected to be correlated to higher amounts of biological growth. The headloss and DOC data implied that there was a correlation between headloss and DOC removal due to biomass growth. DOC removal increased with temperature and, therefore, it would be expected that the number of filter cycles with headloss as a backwash trigger would also increase. Turbidity breakthrough did not seem to occur often with any of the media types. It was concluded that filter run time was primarily correlated to headloss and that turbidity was not a major backwash trigger.

Table 3-76 and Table 3-77 summarize the number of times one media type had a longer run time than the other, the number of times there was no difference in filter run time, and p-values from sign tests on filter run time comparisons. Table 3-78 and Table 3-79 provide summary statistics for the calculated run times, for reference.

Table 3-76: Comparison of the filter run times during warm water conditions by different filter media

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Run Time Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Run Time Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	**Anthracite**	1	22	38	$8.7x10^{-10}$
Coal-based GAC	**REC**	2	3	64	$3.5x10^{-13}$
Coal-based GAC	**Wood-based GAC**	11	2	49	$4.5x10^{-06}$
Wood-based GAC	Anthracite	20	1	22	$1.0x10^{+00}$
Wood-based GAC	**REC**	22	3	48	$1.5x10^{-02}$
Anthracite	REC	21	16	21	$1.0x10^{00}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-values for wood-based GAC vs anthracite and anthracite vs REC were recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. The unadjusted p-values were: $8.8x10^{-01}$ and $1.0x10^{00}$ for the comparisons of wood-based GAC vs anthracite and anthracite vs REC, respectively.

Table 3-77: Comparison of the filter run times during cold water conditions by different filter media

Comparison[2]		Number of filter cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had better Run Time performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Run Time Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	**Anthracite**	1	46	24	$9.3x10^{-06}$
Coal-based GAC	REC	28	55	20	$1.0x10^{+00}$
Coal-based GAC	Wood-based GAC	37	35	11	$1.3x10^{-03}$
Wood-based GAC	**Anthracite**	12	39	25	$6.5x10^{-03}$
Wood-based GAC	**REC**	2	29	33	$2.2x10^{-07}$
Anthracite	REC	30	40	0	$1.1x10^{-08}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-value for coal-based GAC vs REC recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. P-values greater than one are not possible. The unadjusted p-values was: $3.1x10^{00}$

Table 3-78: Summary statistics for filter run time during warm water conditions

Statistic	Filter Run Time (Hours)			
	Coal-based GAC	Anthracite	REC	Wood-based GAC
Average	28	37	36	33
Minimum	17	22	13	15
Maximum	44	50	50	44
Standard Deviation	7	7	7	7

Table 3-79: Summary statistics for filter run time during cold water conditions

Statistic	Filter Run Time (Hours)			
	Coal-based GAC	Anthracite	REC	Wood-based GAC
Average	43	45	43	41
Minimum	28	35	27	22
Maximum[1]	61	73	55	58
Standard Deviation	5	6	5	7

1. The filters were allowed to run for more than 48 hours for a few filter cycles. The filters were backwashed around 40-48 hours into the filter cycle for the majority of the filter cycles.

It should be noted that the average and standard deviations of filter run times are only provided for reference and should not be used for any sort of statistical comparison: the standard deviations are inflated due to temporal variation in filter run time, whereas the sign test method used is not impacted by temporal variation in filter run time[85]. It was found that anthracite and REC provided better overall run times than the coal-based GAC and wood-based GAC, except for the comparison of anthracite to wood-based GAC under warm water conditions and the comparison of coal-based GAC to REC during cold water conditions. Anthracite provided longer run times than REC during cold-water conditions. Finally, wood-based GAC provided longer run times than coal-based GAC during warm water conditions but the opposite was observed during warm water conditions. The large number of filter cycles where there was no difference between media types (especially during cold water conditions) were, in part, due to the fact that time was used backwash trigger; had the filters been allowed to run until either terminal headloss or

[85] "Temporal variation in filter run time" is meant to indicate the fact that the filter run time may change from filter-cycle to filter-cycle. Temporal variation in filter run time can be due to factors that have nothing to do with comparing different media types: for example, a brief period of high influent turbidity may cause all filters to have a shorter run time. In the sign test method, (a) the run time observed for each filter was compared to the run time for all other filters for each individual filter cycle, (b) the number of filter cycles where one media type performed better than the other are tallied, (c) and a statistical test (sign test) is conducted to determine whether the number of times one media type performed better than the other was statistically significant. The sign test method avoids the problem of temporal variability in filter run time by comparing the filter run times for each individual filter cycle instead of comparing the averages and standard deviations calculated for the entire experimental period.

turbidity breakthrough was observed, it is expected that more filter cycles would have shown a difference in run time between the media types.

Overall, it was concluded that anthracite provided longer run times than coal-based GAC and REC provided longer run times than wood-based GAC because, when there was a difference in filter run time, anthracite and REC provided longer run times than the respective GAC during all water conditions. For all other comparisons of different media types, the media type which provides the best run time seems to depend on the water conditions.

Comparison of the headloss results to the filter run time results indicated that the same trends seen for headloss were also seen for filter run time, with four exceptions: the comparison of wood-based GAC to anthracite under warm water conditions, the comparison of anthracite to REC under warm water conditions, comparison of coal-based GAC to REC under cold water conditions, and the comparison of coal-based GAC to wood based GAC during cold water conditions (when compared to the data from cold season 2). The correlation between headloss and filter run time, for most of the comparisons, was not surprising given that terminal headloss was observed as a major backwash trigger[86] in many of the filter cycles. The exceptions to the correlation between headloss and filter run time trends were likely due to the reduced data set that was used for calculation of filter run time. Filter run time was determined using both flow[87] and turbidity data; therefore, filter run time could only be determined for filter cycles where both flow and turbidity data were reliable. The turbidity data set was smaller than the flow data set because turbidity data that were collected when turbidimeters were in need of maintenance and during turbidimeter maintenance were excluded from analysis. Table 3-80 and Table 3-81 show the comparisons of filter run time re-calculated using flow data only.

[86] Note that backwash triggers were identified and used to determine the potential filter run time; however, filters were backwashed approximately every 40-48 hours regardless of whether the trigger was observed or not.

[87] Flow is correlated to headloss and was used to identify terminal headloss. See the Materials and Methods section related to filter run time.

Table 3-80: Comparison of the filter run times during warm water conditions by different filter media

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Run Time Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Run Time Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	**Anthracite**	7	4	91	$5.2x10^{-19}$
Coal-based GAC	**REC**	13	4	80	$3.7x10^{-12}$
Coal-based GAC	**Wood-based GAC**	19	3	71	$1.9x10^{-07}$
Wood-based GAC	**Anthracite**	29	5	68	$5.6x10^{-04}$
Wood-based GAC	**REC**	26	4	69	$7.1x10^{-05}$
Anthracite	REC	39	30	36	$1.0x10^{00}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-values for anthracite vs REC was recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. P-values greater than one are not possible. The unadjusted p-value was: $8.2x10^{-01}$ for the comparisons of anthracite vs REC.

Table 3-81: Comparison of the filter run times during cold water conditions by different filter media

Comparison[2]		Number of Filter Cycles Where:			
Filtration Medium 1	**Filtration Medium 2**	**Medium 1 had Better Run Time Performance than Medium 2**	**No Difference in Performance**	**Medium 2 had Better Run Time Performance than Medium 1**	**Adjusted P-value[1,3]**
Coal-based GAC	**Anthracite**	2	78	39	$4.7x10^{-09}$
Coal-based GAC	REC	26	68	26	$1.0x10^{+00}$
Coal-based GAC	**Wood-based GAC**	46	56	15	$5.3x10^{-04}$
Wood-based GAC	**Anthracite**	4	60	53	$3.6x10^{-11}$
Wood-based GAC	**REC**	14	59	45	$3.9x10^{-04}$
Anthracite	REC	37	81	2	$1.7x10^{-08}$

1. P-value multiplied by a factor of six to provide a Bonferroni correction.
2. Media types underlined and in bold provided the best overall headloss performance of the media types being compared. The difference in performance was statistically significant.
3. P-value for coal-based GAC vs REC recorded as being equal to 1.0. The adjusted p-value that was calculated was greater than 1 because of a large unadjusted p-value. P-values greater than one are not possible. The unadjusted p-value was: $1.0x10^{00}$

The number of filter cycles that could be analyzed were much larger when only the flow data were considered. Also, only two of the filter run time trends differed from the headloss trends: the comparison of anthracite to REC during warm water conditions and the comparison of coal-based GAC to REC during cold water conditions. The reason why these two trends differed from the headloss trends is unknown. It may be that, had the filters been allowed to run to terminal headloss, for all filter cycles, that the trends in filter run time would have matched the trends for headloss. Alternatively, had headloss data been able to be collected for the entire filter cycle (i.e. if the pressure transducers had a larger analytical range), headloss conclusions may have matched those for filter run times. Regardless of cause of the difference in trends between headloss and filter run time, it cannot be concluded that either anthracite or REC provided longer run times than the other media type during warm water conditions. It also cannot be concluded that either coal-based GAC or REC provided longer filter run times during cold-water conditions.

3.4 Detailed Summary of Findings

The various findings from Phase I are summarized as follows. While a detailed summary of the findings is provided here, overall conclusions can be found in Chapter 5.

3.4.1 Practical Findings

1. The grain-size-distribution-matching procedure developed in this work allowed the grain size distributions of different types of filtration media to be closely matched.
2. REC, coal-based GAC, and wood-based GAC are rough media types compared to anthracite.
3. The REC used herein was a nonadsorptive media type, whereas the GACs were adsorptive media types.
4. Unexpectedly, anthracite exhibited some adsorptive capacity for DOC when crushed to a powder.
5. Crushed anthracite did not adsorb as much organic matter as the GACs, and granular anthracite, which was used in the pilot plant, adsorbed essentially no organic matter. Therefore, the anthracite media used for Phase 1 experiments was, at most, a slightly adsorptive media type.
6. Comparison of biofilter performance with biofilters containing different media types indicated the following.

   Biofiltration with wood-based GAC provided:

   a. removal of DOC, THMFP, and AOC,

b. improved removal of DOC compared to coal-based GAC, anthracite, and REC,
c. improved removal of organic matter that contributed to total THM formation than REC in one of two sampling events,
d. more production of organic matter that contributed to the formation of dibromochloromethane than REC or anthracite (note: the difference was less than 1 μg/L but was statistically significant. Only two sampling events were conducted.),
e. worse headloss performance than anthracite or REC in all except one season,
f. lower effluent turbidities than coal-based GAC,
g. lower effluent turbidities than anthracite,
h. a greater degree of turbidity dampening than anthracite, and
i. longer filter run times than coal-based GAC under warm water conditions.

Biofiltration with anthracite provided:

a. removal of DOC, THMFP, and AOC,
b. less production of organic matter that contributed to the formation of dibromochloromethane formation than wood-based GAC,
c. improved headloss performance compared to both GACs during all except one season,
d. improved headloss performance compared to REC during cold water conditions,
e. the highest effluent turbidity in most filter cycles,
f. the least amount of turbidity dampening in all except one experiment, and
g. longer filter run times than coal-based GAC.

Biofiltration with REC provided:

a. removal of DOC, THMFP, and AOC,
b. less production of organic matter that contributed to the formation of dibromochloromethane formation than wood-based GAC,
c. less production of organic matter that contributed to the formation of dibromochloromethane formation than coal-based GAC in one of two sampling events.
d. improved headloss performance compared to both GAC during all except one season,
e. improved headloss performance compared to anthracite during warm water conditions,
f. lower effluent turbidities than coal-based GAC and anthracite under both warm and cold water conditions,
g. lower effluent turbidities than wood-based GAC under cold water conditions,

h. longer run times than wood-based GACs, and
i. a greater degree of turbidity dampening than anthracite and coal-based GAC.

Biofiltration with coal-based GAC provided:

a. removal of DOC, THMFP, and AOC,
b. improved DOC removal compared to anthracite and REC,
c. greater production of organic matter that contributed to the formation of dibromochloromethane than anthracite or REC in one of two sampling events,
d. worse headloss performance than anthracite or REC in all except one season,
e. lower mean effluent turbidities than anthracite during all filter cycles under cold water conditions,
f. a greater degree of turbidity dampening than anthracite in all except one experiment, and
g. longer filter run times than wood-based GAC under cold water conditions.

7. Comparison of the performance of a biofilter containing coal-based GAC and operated in declining-rate mode to filters operated in constant-rate mode indicated the following:

    a. Operating a filter in declining-rate mode improved DOC removal, albeit at the cost of lower water production.
    b. Operating a filter containing coal-based GAC in declining-rate mode provided greater removal of organic matter that contributes to total THM formation than REC. In contrast to this, the filter containing coal-based GAC and operated in constant-rate mode did not provide greater removal than REC.
    c. Operating a filter operated in declining-rate increased the production of organic matter that contributes to dibromochloromethane formation and can provide greater production of organic matter that contributed to the formation of dibromochloromethane than anthracite

8. The results from this study imply that GAC would be expected to provide long-term improved removal of DOC in cases where there is a large fraction of adsorptive organic matter in the influent water but not necessarily in cases where the fraction of adsorptive organic matter is small. Further research is needed to confirm this implication.

9. REC did not produce organic matter which contributed to the formation of dibromochloromethane during either of two sampling events where dibromochloromethane formation potential was measured.

10. In conducting comparisons of the removal of organic matter that contributes to THM formation through comparisons of effluent THMFP, it is critical that replicate samples be utilized. It is recommended that a statistical power analysis be conducted prior to future comparisons to determine the number of replicate samples to be utilized.
11. A trade-off likely exists between choosing a media type that provides the greatest DOC removal and a media type that provides the best headloss performance.
12. Adjusting for turbidimeter bias is critical to preventing erroneous conclusions when comparing turbidity removal between filters. It is highly recommended that turbidimeter bias be tested and accounted for in future studies comparing turbidity between different filters or media types to ensure that conclusions are valid.
13. Terminal headloss was a major backwash trigger, more so than turbidity breakthrough.

3.4.2 Mechanistic Implications

1. Media roughness is not a media property that significantly enhances DOC removal during biofiltration. Thus, mechanisms related to media roughness, such as biomass shielding, do not significantly contribute to increased DOC removal by GAC relative to other media during biofiltration at the conditions studied.
2. The adsorptive property of GAC is critical for enhancing DOC removal during biofiltration relative to other media. This applies to new and spent GAC (i.e. media that have been used for many years). It also implies that mechanisms related to a medium's adsorptive properties (e.g. bioregeneration, adsorption of organic matter spikes) are significant to DOC removal during biofiltration in the long-term.
3. Filter media roughness generally enhanced turbidity removal and turbidity dampening; however, elucidation of the exact mechanisms that enable this performance benefit in biofilters requires further research.

Chapter 4 Phase II Experiments

4.1 Introduction

In Phase I, biofilters containing GAC provided better removal of DOC than biofilters containing nonadsorptive or slightly adsorptive media (anthracite and REC). This improved removal of DOC by GAC was seen even for GAC that had been in use for approximately seven years prior to being used in Phase I experiments. The results from Phase I implied that the adsorptive properties of GAC are the cause of improved DOC removal over the long-term; however, the results did not indicate **how** those properties cause the improved removal of DOC. Two mechanisms which may account for the improved removal of DOC include (1) adsorption due to changes in influent organic matter concentration and/or composition and (2) bioregeneration (AWWA, 1981).

Theoretically, organic matter may adsorb onto GAC in response to changes in influent organic matter concentration and/or composition, even if the GAC has been used for extended periods of time and/or is exhausted. This effect may help explain why GAC biofilters can provide better removal of organic matter than biofilters containing nonadsorptive media, even over the long-term. However, only a very limited amount of data in the literature implies that this effect can occur during biofiltration. Much work still needs to be done to comprehensively elucidate how this effect works and quantify the magnitude of any benefits in organic matter removal. Furthermore, the practical implications of this effect, such as the improvement of DOC removal during biofiltration, have not been demonstrated.

Bioregeneration is where microorganisms use organic matter that is adsorbed to GAC as a substrate, thus regenerating the adsorptive capacity of the GAC. Bioregeneration has been shown in many experimental systems; however, direct evidence of bioregeneration in aerobic drinking water biofilters is still lacking. The manner in which bioregeneration would affect the long term removal of organic matter by biofilters is also unclear.

Bioregeneration of GAC, after spikes of organic matter have adsorbed to the GAC in a biofilter, may be one way in which bioregeneration contributes to the long-term removal of organic matter. When a spike of organic matter passes through a GAC biofilter, organic matter may adsorb to the GAC. This adsorption of organic matter would decrease the magnitude of the organic matter spikes to a greater degree than biodegradation alone); thus, if this adsorption occurs, a biofilter containing GAC would provide better removal of organic matter than a biofilter containing a nonadsorptive filtration medium. However, the adsorbed organic matter would occupy adsorption sites within the GAC. Eventually, all the adsorption

sites on the GAC would become occupied and the GAC would be exhausted unless these adsorption sites are freed-up. Bioregeneration is one mechanism that may free-up these adsorption sites and allow for further adsorption in the future. However, bioregeneration has not been demonstrated for biofilters used for drinking water treatment.

Tracking the fate of organic carbon through a biofilter can help demonstrate bioregeneration or other mechanisms which produce similar effects to bioregeneration. The fate of organic carbon in a biofilter can be determined through comparison of the amount of total organic carbon [TOC] removed and the amount of inorganic carbon produced. This is conceptually represented, for a single media grain, in **Error! Reference source not found.**.

In an aerobic biofilter, the oxidation of organic carbon to carbon dioxide by heterotrophic bacteria produces inorganic carbon. When IC production equals TOC removal, it indicates that all TOC removed by a biofilter is converted to inorganic carbon (i.e. CO_2); carbon is neither stored nor removed from storage in the biofilter. When TOC removal is greater than IC production, it indicates that only a portion of the TOC removed by a biofilter is converted to inorganic carbon (i.e. CO_2); thus, the portion of the TOC that is not converted to inorganic carbon is stored in the biofilter. The organic carbon that is stored in the biofilter can be stored through a number of mechanisms: for example, the carbon can adsorb to the GAC or be incorporated into biomass. The exact amount of carbon stored in the can be calculated by subtracting the amount if IC produced from the TOC removed. When IC production is greater than TOC removal, it indicates that organic carbon stored in the biofilter is being used for biological respiration and is oxidized to inorganic carbon (i.e. CO_2). Oxidation of the organic carbon that was adsorbed to GAC to CO_2 indicates bioregeneration.

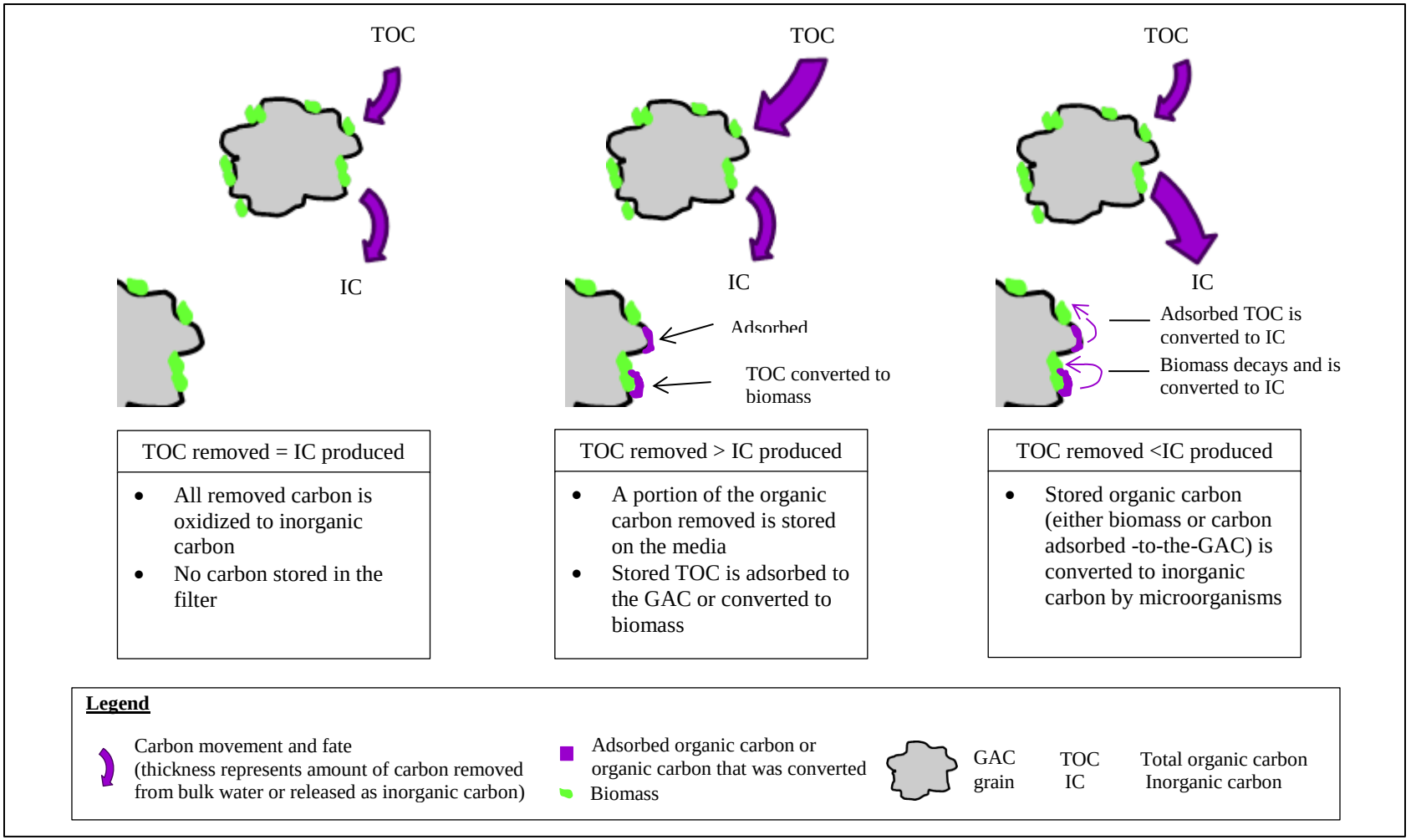


Figure 4-1: Conceptual representation of carbon fate in a biofilter

Oxidation of organic carbon that was incorporated into biomass to CO_2 indicates a net decay of biomass from the filter. Thus, if IC production is greater than TOC removal, bioregeneration or net decay of biomass is occurring. A mass balance illustrating these concepts can be found in Appendix H.

Comparison of TOC removal to IC production, unfortunately, does not allow bioregeneration to be differentiated from net decay of biomass. However, to the knowledge of the author, adsorption of organic matter spikes followed by net decay of biomass has not been demonstrated for drinking water biofilters. Demonstrating that bioregeneration and/or net decay of biomass occurs in drinking water biofilters, even if these mechanisms cannot be differentiated, would be a significant step forward in understanding the mechanisms impacting organic matter removal in biofiltration.

Thus, the main objectives Phase II were:

- to demonstrate that organic matter spikes can adsorb onto GAC that has been used for an extended period of time,
- to determine whether adsorption of organic matter spikes onto used GAC can substantially improve TOC removal during biofiltration, and
- to look for evidence of bioregeneration and/or net decay of biomass after spikes of organic matter are adsorbed onto the GAC present in biofilters configured similarly to those used for drinking water treatment.

4.2 Materials and Methods

4.2.1 General Experimental Approach:

Spikes of organic matter were introduced into pilot-scale biofilters at two locations: the University of Waterloo in Waterloo, Ontario [UW] and Toronto, Ontario [Toronto]. The biofilters at both locations contained GAC that had been in use for an extended period of time. The pilot plant at Toronto also had a biofilter containing anthracite; this allowed direct comparison of the performance of a biofilter containing anthracite to a biofilter containing GAC.

It was expected that the absorbable organic compound would be preferentially removed by the GAC if spikes of organic matter adsorb onto used GAC. The effluent TOC concentrations achieved by the biofilters during the spikes were compared to each other to determine whether organic matter adsorbed onto the GAC during the spikes and to determine whether this adsorption significantly improved the removal of TOC during biofiltration. The TOC removal and inorganic carbon [IC] production provided

by the biofilter at UW were monitored and compared to investigate whether bioregeneration of adsorbed organic matter occurred after the spikes. The effluent TOC concentrations provided by the GAC biofilter and the anthracite biofilter during the spikes at Toronto were also compared to confirm that adsorption of organic matter spikes onto GAC can significantly improve TOC removal during biofiltration and to demonstrate that the adsorption of organic carbon spikes onto GAC can help explain why GAC biofilters can provide better organic matter removal than anthracite biofilters. Additional insights into the removal of organic carbon during biofiltration were also noted, as appropriate.

4.2.2 Spike Compounds Used and Characterization of Spike Compounds

Acetate[88] was chosen as the nonadsorptive compound and maltose[89] was chosen as the adsorptive compound. Acetate was chosen because it is an ozonation disinfection byproduct that has been seen in pilot-scale drinking water treatment (e.g. Carlson & Amy, 1998), has been used in previous biofiltration and bioregeneration studies (e.g. Liu et al., 2001; Chang, 1985), and has been shown to be essentially nonadsorptive (Chang, 1985). Maltose was chosen because it was expected to be both biodegradable and adsorbable[90]. The biodegradability and adsorbability of the two compounds were experimentally confirmed.

4.2.2.1 Confirmation of Biodegradability

The biodegradability of acetate and maltose was assessed to confirm that both compounds were biodegradable and to compare the rate of biodegradation of the two compounds. The biodegradability of the compounds was assessed using a method modified from Servais (1987, 1989). In brief, the compound being tested (acetate or maltose) was added to a solution containing nitrogen, phosphorous and other nutrients. The composition of the solution that was used is outlined in Table 4-1.

[88] Anhydrous Sodium acetate (≥99.0%); Fisher Scientific, Ottawa, ON

[89] D-(+)- Maltose monohydrate (≥99%); Sigma Aldrich, Oakville, ON

[90] Phenol and benzaldehyde were also tested as potential adsorptive compounds. These chemicals could have been used; however, there were health and safety concerns with using both of these chemicals. Maltose was a relatively benign chemical; therefore, it was chosen.

Table 4-1: Biodegradation test solution

Compound	Concentration
Test Compound (sodium acetate or maltose)	3.00 mg/L-C
Sodium bicarbonate	1.54 mg/L-C
Potassium dihydrogen phosphate	12.22 mg/L
Sodium hydrogen phosphate	9.945 mg/L
Potassium nitrate	4.062 mg/L
Magnesium sulfate	13.90 mg/L
Calcium chloride dihydrate	46.04 mg/L

The test solution was then sterilized by filtration through a sterile 0.22 micron filter[91]. An inoculum was created by filtering water containing test microorganisms through a 2 micron filter[92] to remove large particles and protozoa, as recommended in Servais (1987). The test solution was inoculated with a volume of inoculum equal to 1% of the total solution volume prior to inoculation. The inoculated solution was then poured into sterile, carbon-free, glass TOC vials under aseptic conditions. The vials were sealed and the solution was allowed to biodegrade at room temperature.

Four vials were sacrificed for TOC analysis at the beginning of the test and every few days thereafter. The TOC concentration of the solutions prior to inoculation was also determined. TOC analysis was conducted using a Sievers M9 TOC analyzer[93].The average TOC concentration from each vial and 99% confidence intervals on the average TOC concentrations were evaluated versus time to assess whether a given compound degraded and to allow the rate of degradation to be compared between the two compounds.

The biodegradability of the compounds was assessed twice: once using an inoculum from the pilot plant at UW and once using an inoculum from Toronto. The inoculum from the pilot plant at UW was created by collecting GAC and biomass from the top of the UW biofilter, placing the GAC and influent water from the pilot plant into a sterile jar, and vigorously shaking the GAC to suspend biomass in the influent water. The influent water containing suspended biomass was then passed through the 2.0 micron filter. The inoculum from Toronto was created by collecting biofilter influent water from the Toronto pilot plant and passing this water through the 2.0 micron filter.

[91] Sterivex GV 0.22 μm filter unit; EMD Millipore, Etobicoke, ON

[92] Milliex-AP Syringe Filter Unit (Borosilicate glass fiber membrane,AP20, prefilter 50mm, non-sterile); EMD Millipore, Etobicoke, ON

[93] GE Analytical Instruments, Boulder, Colorado

Tests for both compounds (maltose and acetate), using a given inoculum, were started on the same day. Vials containing each type of compound were sacrificed on the same days to ensure that the results from tests on both compounds were directly comparable.

4.2.2.2 Confirmation of Adsorbability

Two adsorption experiments were conducted to confirm the adsorbability of each compound on different types of GAC. One experiment was conducted using virgin wood-based GAC[94] and one using coal-based GAC that was taken from the UW pilot plant[95]. The adsorption experiments were conducted as per ASTM D3860-98 (2008), with the following modifications:

1. 200 mL of test solution was used.
2. The GAC and test solution were placed into 250 mL glass jars rather than Erlenmeyer flasks.
3. Virgin wood-based GAC was ground using a jet mill and GAC from the pilot plant at UW was ground using a mortar and pestle.[96]
4. Tests confirming that 95% of the crushed GAC from the UW pilot plant could pass through a U.S. 325-mesh sieve were not conducted.
5. Tests were conducted at room temperature and no water bath was used.
6. Additional quality controls were added to each test.

In brief, GAC was crushed to a powder and dried in an oven at 105°C. Various masses of dried GAC were added to clean 250 mL glass jars. Test solutions of acetate and maltose were created in ultrapure water[97] and 200 mL of the solution containing the compound being tested was added to each jar. The test solutions had an initial concentration of approximately 10 mg/L-C for tests with the virgin wood-based GAC. The test solutions had an initial concentration of approximately 15 mg/L-C for the tests with coal-based GAC from the UW pilot column. The jars were placed on an end-over-end shaker and agitated to keep the crushed GAC suspended. After the test solution had been in contact with the crushed GAC for two hours, the solutions were filtered through 0.45 micron ZapCap filters to remove the crushed GAC[98].

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[94] Nuchar WV-B 30®; MeadWestvaco, Covington, Virginia

[95] Filtrasorb 816®; Calgon Carbon; Pittsburgh, PA, U.S.A.

[96] Hosokawa Alpine Jet Mill. Grinding done by MWV, Specialty Chemicals Division, SC.

[97] Produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada)

[98] ZapCap-CR BT NYL 0.45; Maine Manufacturing, Maine, USA

Filtered water from each jar was subdivided into several vials for TOC analysis. The TOC concentration in the filtered water was measured using a Sievers M9 TOC analyzer.

Several additional analyses were added to each test as quality controls. The reproducibility of equilibrium TOC concentrations was confirmed by processing replicate jars for select masses of GAC. The time to equilibrium was confirmed by allowing an additional replicate jar to agitate for a longer period of time (four hours instead of two hours). A jar containing ultrapure water was processed as a sample to check for contamination from laboratory apparatus or procedures. Contamination of the GAC was also checked by processing a jar containing ultrapure water and crushed GAC.

The average TOC concentration and a 99% confidence interval on the average TOC concentration were calculated for each jar that was tested. The adsorbability of acetate and maltose were confirmed by analyzing the final equilibrium TOC concentrations. The results from the quality controls were also reviewed to aid in the interpretation of the results.

4.2.3 UW Pilot Plant Experiments

4.2.3.1 Pilot plant

A laboratory-scale pilot plant was set-up at University of Waterloo. The pilot plant was designed to mimic the design and operations of a drinking water biofilter. The pilot plant consisted of a column containing coal-based GAC[99] over a gravel underdrain, which was fed synthetic influent water containing acetate and nutrients. Figure 4-2 provides a block diagram of the pilot plant and Table 4-2 provides the pilot plant specifications for the pilot plant.

[99] Filtrasorb 816®; Calgon Carbon; Pittsburgh, PA, U.S.A.

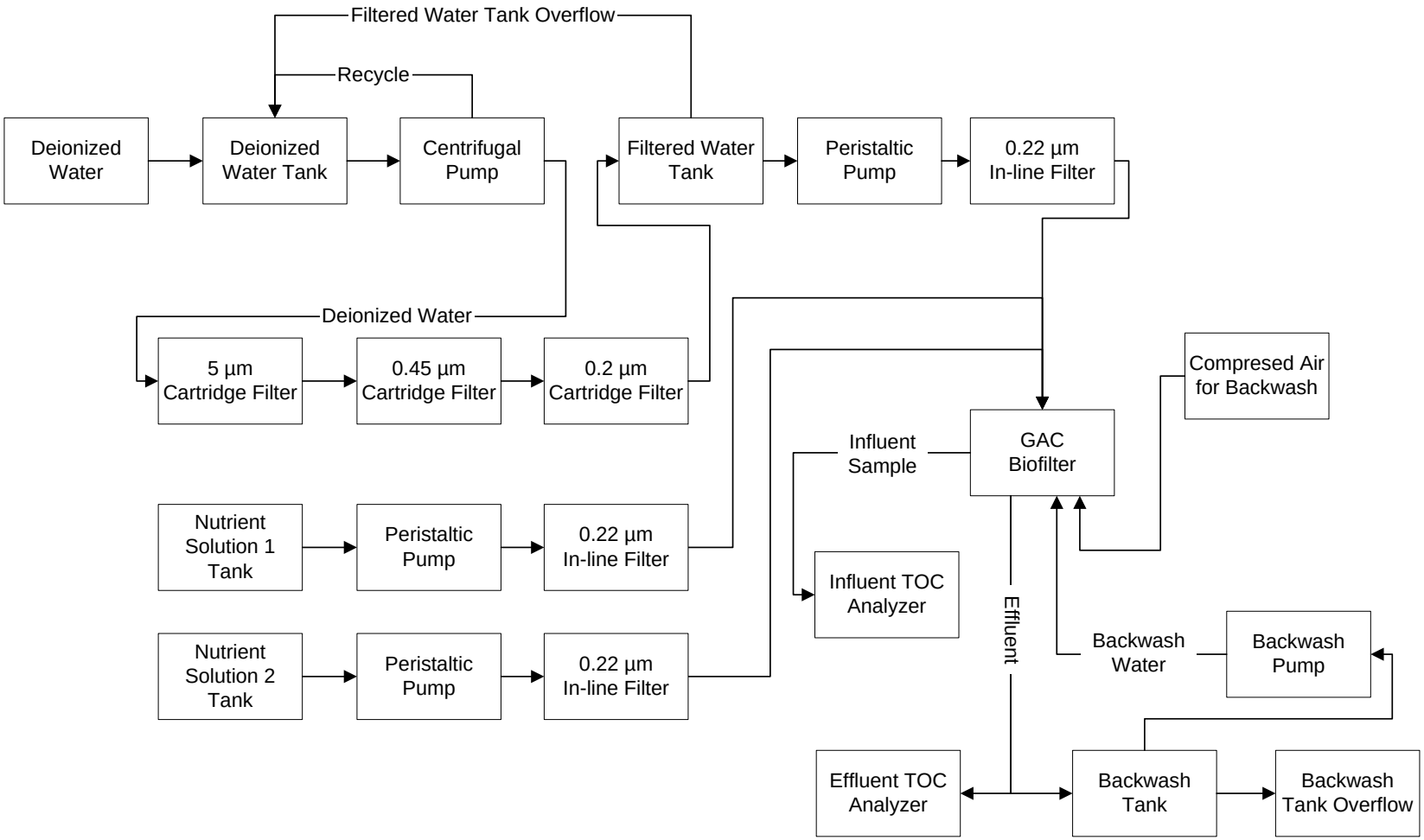

Figure 4-2: Block diagram of UW pilot plant

Table 4-2: UW pilot plant specifications

Filter Column	Material & Type	2" Schedule 40 Clear PVC Pipe
	Column Inner Diameter (m)	0.053
	Column Height (m)	1.90
Filtration Media	Media Type	Filtrasorb® 816 coal-based GAC[1]
	Depth (m)	0.5
	ES (mm)[2]	1.3-1.5
	UC (max.)[2]	1.4
Underdrain	Depth (m)	0.152
	Details	0.076 m of 1/4"-1/8" gravel over 0.076 m of 1/2"-1/4"gravel
Flow rates	Stock Solution 1 (mL/min)	6.52
	Stock Solution 2 (mL/min)	13.13
	Deionized Water (mL/min)	210
	TOC Analyzer Sample Flow Rate (mL/min)	50
	Net Flow Rate to Filter (mL/min)	180
Hydraulic Parameters	Hydraulic Loading Rate (m/hr)	4.99
	EBCT (min)	6

1. Calgon Carbon, Pittsburgh, PA, U.S.A.
2. Information taken from Manufacturer's specifications for Filtrasorb ® 816

The synthetic influent water was created by diluting two stock solutions with deionized water. The final composition of the influent water was broadly based off of the mineral medium noted in Chang (1985)[100]. Table 4-3 provides specifications of the stock solutions used to create the synthetic influent water and Table 4-4 provides the final concentration of the influent water after the stock solutions were diluted. Concentrations as mg/L–C, mg/L-N, and mg/L-P are provided in brackets in In Table 4-3 and Table 4-4 for compounds containing these nutrients.

[100] The mineral salts noted in Chang (1985) and the molar ratio of mineral salts to organic carbon were used as a starting point when developing the synthetic influent water composition. The final composition was designed to provide organic carbon, inorganic carbon, nitrogen, phosphorous, and other nutrients (Na, K, Mg, Ca, and S) so that biomass would grow in the filters.

Table 4-3: Stock solution composition

Stock Solution	Compound	Formula	Concentration (mg/L)
Stock Solution 1	Sodium acetate	CH_3COONa	427 (125 mg/L-C)
	Sodium bicarbonate	$NaHCO_3$	437 (62.5 mg/L-C)
	Potassium dihydrogen phosphate	KH_2PO_4	509.5 (146.4 mg/L-P)
	Sodium hydrogen phosphate	Na_2HPO_4	414.5 (114.2 mg/L-P)
Stock Solution 2	Potassium nitrate	KNO_3	87.43 (12.12 mg/L-N)
	Magnesium sulfate	$MgSO_4$	299.3
	Calcium chloride dihydrate	$CaCl_2*2H_2O$	990.9

Table 4-4: UW pilot plant influent composition

Compound	Formula	Concentration (mg/L)
Sodium acetate	CH_3COONa	12.1 (3.55 mg/L-C)
Sodium bicarbonate	$NaHCO_3$	12.4 (1.77 mg/L-C)
Potassium dihydrogen phosphate	KH_2PO_4	14.47 (4.156 mg/L-P)
Sodium hydrogen phosphate	Na_2HPO_4	11.77 (3.241 mg/L-P)
Potassium nitrate	KNO_3	4.999 (0.6927 mg/L-N)
Magnesium sulfate	$MgSO_4$	17.11
Calcium chloride dihydrate	$CaCl_2*2H_20$	56.65

GAC was collected from a full scale filter at the Mannheim Water Treatment Plant[101] and was installed in the pilot plant. The GAC had been in use for at least 25 months prior to being collected. It was expected that the GAC would be biologically active given that prechlorination was not used at this plant and given that filters at this location had previously been considered to be biologically active (Emelko et al.,

[101] Kitchener, Ontario.

2006)[102]. GAC from a full-scale plant was used to minimize the time required for initial growth and acclimation. Using GAC from a full scale plant also ensured that the microorganisms initially present in the pilot plant were the same as those present in a full scale plant.

Prior to installing the GAC, the interior of the pilot columns and all pilot plant lines were disinfected by filling them with a 3% hydrogen peroxide solution and retaining the solution in the plant for approximately three hours. The gravel in the underdrain was installed prior to disinfection and, thus, was also disinfected. After the three hours, the solution was drained out of the pilot plant and the filter column was backwashed with autoclaved water to rinse out the column. Bursts of pressurized air were used to help detach debris from the gravel underdrain. The pilot plant was then rinsed using deionized water to remove any residual peroxide or debris. 0.22 micron sterilizing filters[103], plumbed in-line (see Figure 4-2), were used to maintain relatively microbe-free conditions within the filter column when rinsing the pilot plant.

The deionized water used to create the pilot plant influent was filtered through a series of cartridge filters to remove any particles present in the influent water. 0.22 micron sterilizing filters[103] were used to minimize the introduction of other environmental microorganisms into the filter column from the deionized water lines and the stock solution lines. It should be noted that all headloss which developed in the pilot plant was solely due to biological growth given that particulate matter was removed from the waters used to create the influent water.

The amount of available head at the pilot lab was limited; therefore, the pilot plant was operated under pressure to provide sufficient head to maintain flow. The pilot filter was backwashed every two to seven days because of headloss build-up due to biomass growth[104]. The backwash protocol consisted of 3 minutes of air scour, followed by a 10 minute high-rate-water wash. During high-rate-water washes, the water flow rate was set to provide a bed expansion of approximately 30%. The filter was backwashed with its own filtrate.

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[102] It should be noted that the media present in the filters had been changed since the study conducted by Emelko et al. (2006). However, the full scale process was essentially the same and 25 months of continuous operation was expected to be long enough to re-establish biological activity in the filters.

[103] Opticap® XL 2 Capsule (Cat # KVGLA02NN3); EMD Millipore, Etobicoke, ON

[104] The required backwashing frequency increased over time.

The GAC was installed on May 12, 2015. The pilot plant was operated continuously, except for two periods where the pilot plant was shut for maintenance; these periods consisted of a 7 hour period on May 15, 2015 and a 22 hour period starting on May 19, 2015.

4.2.3.2 Spike Experiments

Two spike experiments were conducted: one on May 13, 2015 and one on May 28-29, 2015. In each experiment, one spike of sodium acetate and one spike of maltose were introduced into the filter influent. The spikes were introduced by pumping a stock solution containing a high concentration of sodium acetate or maltose into the pilot influent lines for a period of 2.6 to 2.9 hours. In the first experiment, the acetate spike was introduced first, followed by the maltose spike. In the second experiment, the maltose spike was introduced first, followed by the acetate spike. A 2.6 to 3 hour period was left between spikes to allow the remaining carbon from the previous spike to wash out of the system, to allow any response to the cessation of the spike to be observed, and to provide the microorganisms in the filter with a period of stable operations between spikes

The pilot influent and effluent TOC and IC concentrations were monitored using Sievers M9 TOC analyzers operated in online mode. The Sievers M9 analyzer measured both TOC and IC simultaneously. TOC and IC measurements were taken every two minutes. TOC sampling lines were disinfected with a 3% hydrogen peroxide solution prior to conducting each spike experiment to eliminate biomass in the sampling lines and prevent the biodegradation of the test solution between the filter column and the TOC analyzers[105].

Preliminary work with the online TOC analyzers (data not shown) indicated that the two analyzers did not give exactly the same TOC reading when the same standard solution was analyzed, even when both analyzers had been properly calibrated[106]. Furthermore, it was found that the difference in readings could change over time. To adjust for bias between the two readings, a set of synthetic samples containing sodium acetate and sodium bicarbonate were analyzed simultaneous on both analyzers after each spike experiment. The samples were created from sodium acetate and sodium bicarbonate added to ultrapure

[105] It was found that biomass would grow in the TOC sampling lines over a period of a few days. The biomass growth resulted in a decrease in the measured TOC concentration and an increase in the measured IC concentration (data not shown). Disinfecting the lines with 3% hydrogen peroxide was found to be a sufficient method for controlling the impact of biomass growth on TOC measurements for the duration of the spike experiments; however, future researchers are cautioned that a rigorous disinfection program and/or an alternative pilot design would be needed if long-term TOC and IC monitoring is desired.

[106] TOC analyzers were calibrated using the manufacturer's protocols and certified standards provided by the manufacturer.

water. The results from both analyzers were compared. The TOC results from one analyzer were corrected to match the readings of the other analyzer.

4.2.3.3 Analysis of TOC Results from Spike Experiments

The effluent TOC concentrations observed for the two compounds were compared to each other to determine whether the maltose (the adsorbable compound) adsorbed to the GAC. The influent TOC concentrations were also reviewed to confirm that the influent TOC spike magnitude did not confound the results (i.e. that the spike magnitudes were similar for both compounds).

4.2.3.4 Analysis of TOC Removal and IC Production

The fate of organic carbon in the biofilter and the occurrence of bioregeneration were investigated by comparing the TOC removal and the IC production through the biofilter.

TOC removal was calculated as being the TOC concentration in the influent minus the TOC in the effluent. IC production was calculated as being the IC concentration in the effluent minus the IC concentration in the influent. Influent concentrations were matched with the effluent concentrations that occurred ten minutes later to account for the travel time through the filter when calculating TOC removal and IC production. Example calculations for TOC removal and IC production can be found in Appendix G.

4.2.4 Toronto Pilot Plant Experiments

4.2.4.1 Pilot Plant

The Toronto pilot plant a large scale pilot plant that was configured for biofiltration experiments on Lake Ontario water. Figure 4-3 provides a schematic of the pertinent sections of the pilot plant and Table 4-5 and Table 4-6 provide the pilot plant specifications. Raw Lake Ontario water was fed to the pilot plant. Average raw water characteristics of the influent water are presented in Table 4-7 . The raw water was ozonated, coagulated, flocculated, and then passed through biofilters. Biofilters containing GAC and anthracite were available at the plant.

The biofilters had been operating for three years prior to conducting the experiments. The GAC in the filters was expected to be exhausted (Dave Scott, personal communication, February 9, 2016).

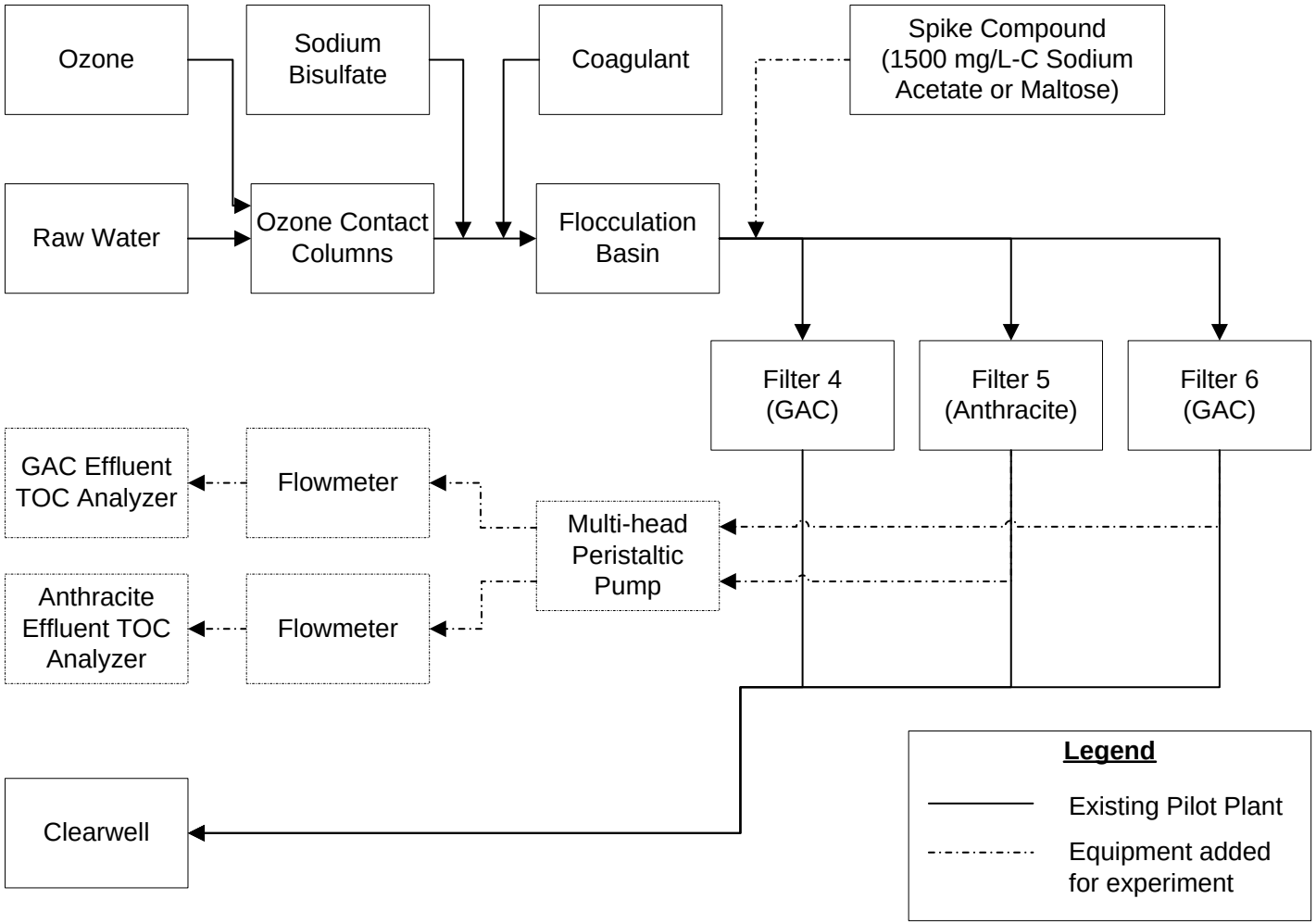

Figure 4-3: Toronto pilot plant schematic

Table 4-5: Treatment chemical concentrations in Toronto pilot plant during spike experiments

Chemical	Concentration
Ozone	Initial[1]: 1.021mg/L After quenching[2]: 0.008
Polyaluminum Chloride	0.750
Sodium bisulfate	1.5-3.5 mg/L

1. Average ozone residual after the diffuser.
2. Average ozone residual after full contact time and quenching with sodium bisulfate.
3. Average coagulant dose.
4. Minimum and maximum setpoints used for sodium bisulfate dosing.

Table 4-6: Toronto pilot filter specifications

		F4	F5	F6
Filter Column	Material	Glass	Glass	Glass
	Diameter (m)	6”	6”	6”
Filtration Media	Media Type	GAC	Anthracite	GAC
	Depth (m)	1.5	1.5	1.5
	ES (mm)	0.95	0.95	0.95
Sand Layer	Depth	0.25	0.25	0.25
	ES (mm)	0.48	0.48	0.48
Hydraulic Parameters	Flow rate (L/min)	1.2	1.2	1.2
	Hydraulic Loading Rate (m/hr)	3.9	3.9	3.9
	EBCT (min)	23	23	23

Table 4-7: Toronto pilot plant raw water characteristics during experiments

Range	Range of values
pH	7.73-7.92
Temperature	6.73-14.23 °C
TOC	2.2 mg/L
Free chlorine	0.06-0.18 mg/L
Turbidity	0.12-0.34 NTU

4.2.4.2 Spike Experiments

1500 mg/L-C stock solutions of acetate and maltose were created and brought to the Toronto pilot plant. Maltose and acetate spikes were introduced to the biofilters by pumping the appropriate stock solution into the flocculation basin effluent for a period of six hours. Two acetate spike experiments were conducted: one on August 25, 2015 and one on August 27, 2015. The maltose spike was conducted on August 26, 2015.

Effluent water from one of the anthracite filters (F5) and one of the GAC filters (F6) was pumped through a 60 micron inline filter to remove large particles. The filtered effluent water was analyzed using Sievers M9 TOC analyzers operated in online mode. As with the experiment at UW, a set of synthetic samples were analyzed simultaneous on both analyzers to allow corrections for the bias between the two analyzers to be calculated. A set of synthetic samples containing sodium acetate were analyzed before the first spike experiment. A single synthetic sample containing approximately 5 mg/L-C of sodium acetate was analyzed at the end of the experiment to check for drift in the comparative performance of the analyzers.

The effluent TOC concentrations from the anthracite and GAC filters were compared with each other. The effluent concentrations observed for each compound were also compared. It was determined whether the GAC biofilters adsorbed the maltose spike and, thus, improved the removal of TOC during biofiltration.

4.3 Results and Discussion

4.3.1 Characterization of Spike Compounds

Results from the assessment and comparison of biodegradability and the assessment and comparison of adsorbability are presented and discussed in the following sections. Additional data related to these assessments and additional plots of the data can be found in Appendices E to F.

4.3.1.1 Assessment and Comparison of Biodegradability

Figure 4-4 shows the biodegradation of acetate and maltose using the inoculum from UW.

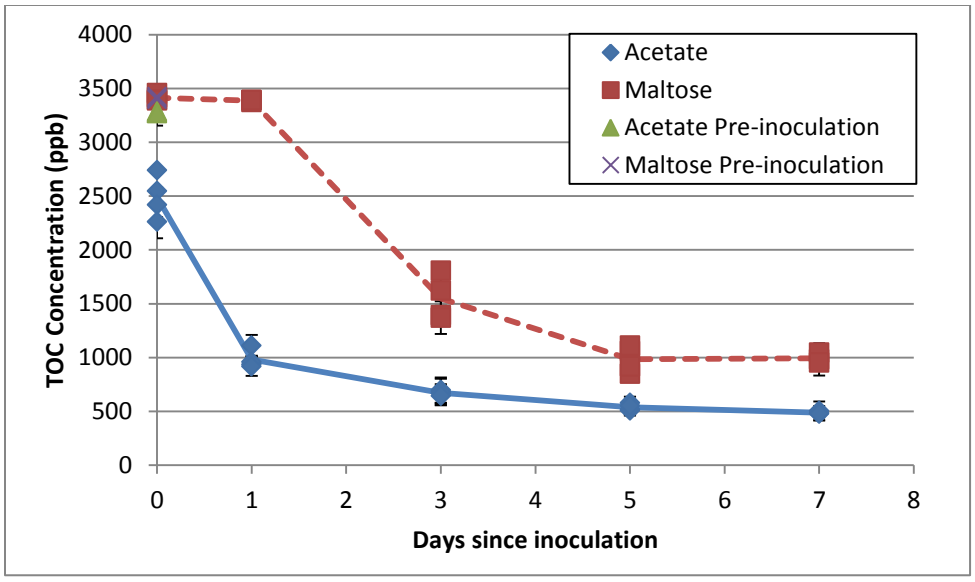

Figure 4-4: Average TOC concentration in vials containing acetate and maltose test solutions before and after inoculation with inoculum from the UW pilot plant. (Each data point represents the average TOC concentration in a given vial. Error bars represent 99% confidence intervals. n=3 for each data point.)

In Figure 4-4, each point represents the average TOC concentration from one vial, the error bars represent the 99% confidence interval on the average TOC concentrations, and the lines show the general trend in TOC concentration. It should be noted that four vials were analyzed and results from four vials are plotted for each compound on days 0, 1, 3, and 5: it appears that there is one point on some of these days only because the data points overlap. Three vials were analyzed on day 7.

Both compounds had similar initial concentrations prior to inoculation. After inoculation, acetate underwent a very rapid initial biodegradation – so rapid that the acetate concentration decreased by approximately 0.5 mg/L-C between inoculation and TOC analysis. The initial rapid biodegradation of acetate was not surprising given that, after bioactive GAC was installed in the pilot plant, the biomass in the pilot plant at UW had been fed sodium acetate as the only carbon source (see Table 4-4). The maltose, in contrast, had an initial lag in biodegradation, with very little biodegradation occurring in the first day. Both compounds then degraded over the seven day period of the test.

Overall, it can be seen that both compounds were biodegradable by the microorganisms present in the UW pilot plant and that acetate could be degraded at a faster rate than maltose.

Figure 4-5 shows the biodegradation of acetate and maltose using the inoculum from Toronto pilot plant.

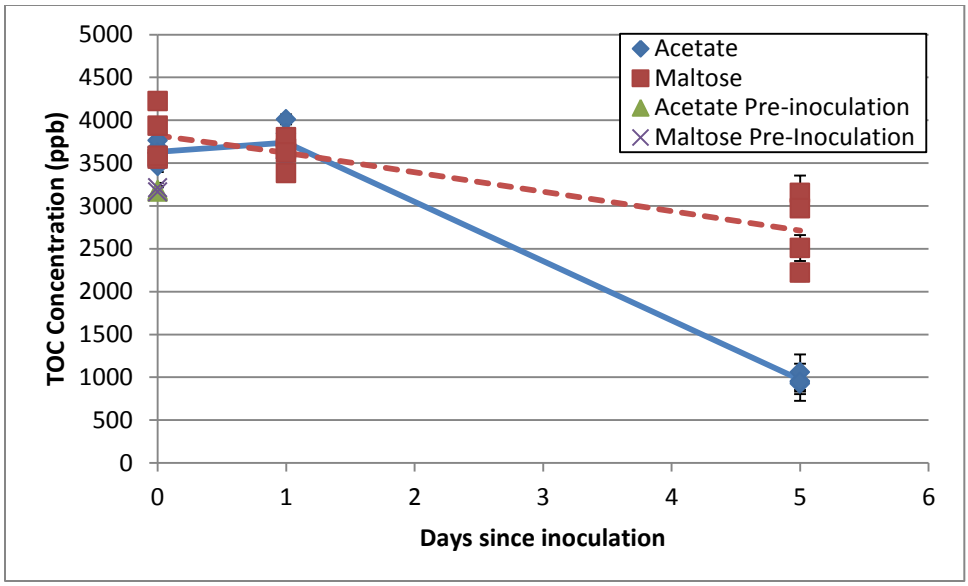

Figure 4-5: Average TOC concentration in vials containing acetate and maltose test solutions before and after inoculation with inoculum from the Toronto pilot plant. (Each data point represents the average TOC concentration in a given vial. Error bars represent 99% confidence intervals. n=3 for each data point.)

As with the assessment using inoculum from the UW pilot plant, both compounds had similar initial concentrations prior to inoculation. The TOC concentration increased slightly after inoculation, remained relatively constant over the first day, and then subsequently decreased. Unlike the experiment done with inoculum from UW, there was no rapid decrease in acetate concentration between inoculation and TOC analysis.

The initial increase in TOC concentration post inoculation (Figure 4-5) may have been due to contamination of the sample water between inoculation and filling of the vials. During this particular test, ethanol was used to disinfect the biosafety cabinet used to maintain sterile conditions during inoculation and vial-filling. A small amount of ethanol may have contaminated the materials used for inoculation or contaminated a few of the vials and resulted in the increase in TOC concentration.

There was not an initial rapid decrease in acetate concentration between inoculation and TOC sampling, unlike the experiment using an inoculum from the UW pilot plant. The lack of a rapid decrease in acetate concentration between inoculation and TOC analysis may have been due to a smaller number of microorganisms in the inoculum or may have been due to a difference in the microbial community present in the inoculum. The microorganisms in the inoculum from UW had been fed sodium acetate as the only carbon source and, thus, had likely developed the ability to provide rapid degradation of sodium acetate. The microorganisms present in the inoculum from Toronto were the microorganisms present in the

natural waters being treated by the pilot plant; it is likely that the microorganism were not as optimized for degradation of acetate given that natural waters contain a variety of different organic compounds,. Therefore, it was not surprising that the initial rapid decrease in acetate was not observed in the test using inoculum from Toronto. Despite the lack of a rapid initial decrease in acetate concentration, it can still be seen that overall rate of biodegradation for acetate was faster than that of maltose.

Based on the results from both tests, it was concluded that both acetate and maltose could be biodegraded by the microorganisms present at both pilot plant locations. The rate of biodegradation was concluded to be faster for acetate than for maltose.

4.3.1.2 Assessment and Comparison of Adsorbability

4.3.1.2.1 Quality Control Results

GAC was in contact with the test solution for two hours during the primary adsorption experiments. The time to equilibrium was confirmed by allowing an additional replicate jar to agitate for a longer period of time. Figure 4-6 and Figure 4-7 show, for each test solution, the average TOC concentration for test solution that was in contact with GAC for two hours and the average TOC concentration for test solution that was in contact with GAC for four hours.

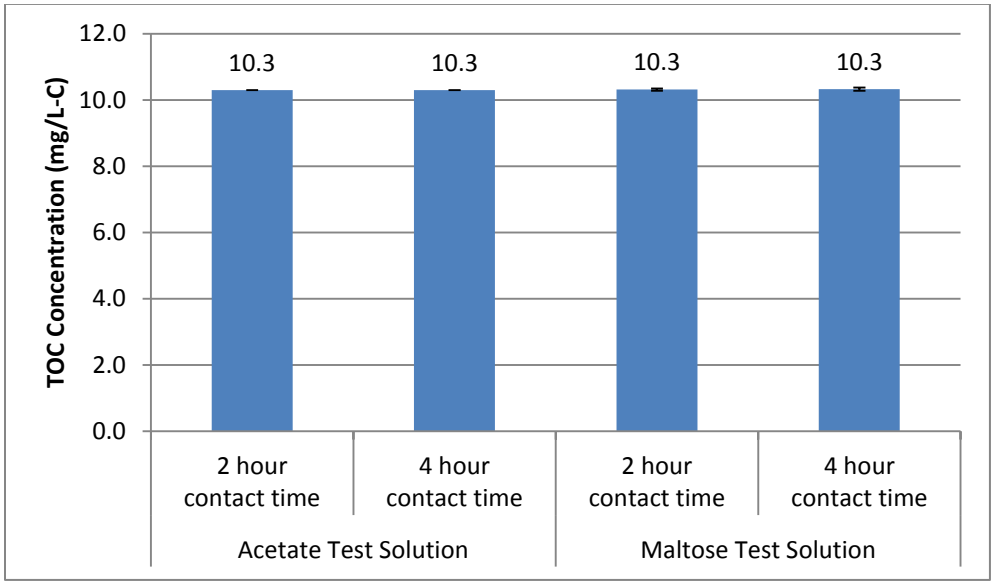

Figure 4-6: Average equilibrium TOC concentration of test solutions after two hours and four hours contact time with crushed virgin wood-based GAC. (Error bars represent 99% confidence intervals on the average TOC concentration. n=9 for all calculated values.)

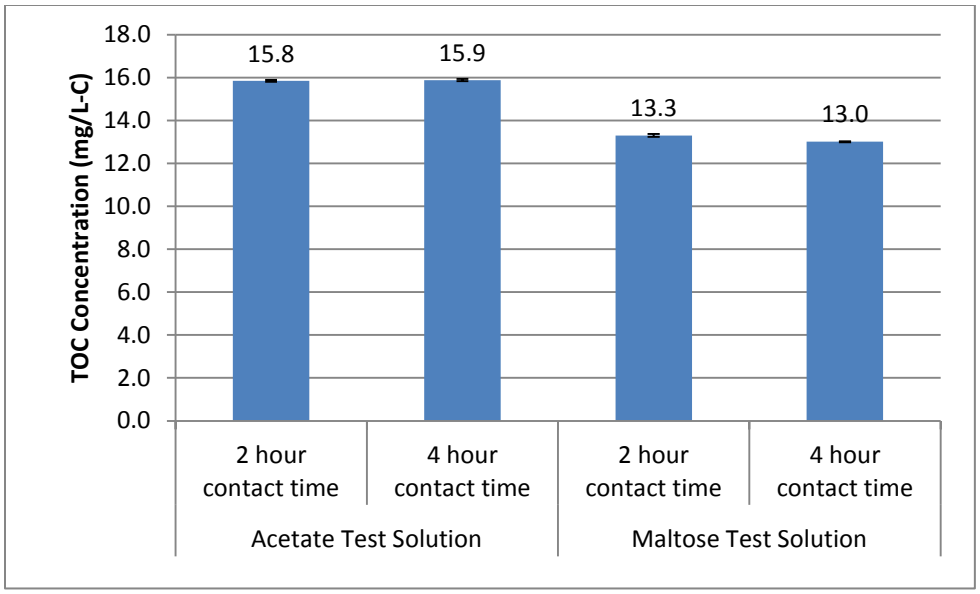

Figure 4-7: Average equilibrium TOC concentration of test solutions after two hours and four hours contact time with crushed coal-based GAC from the UW pilot plant. (Error bars represent 99% confidence intervals on the average TOC concentration. n=12 for all calculated values.)

It can be seen from Figure 4-6 and Figure 4-7 that the final TOC concentrations for the acetate test solutions were essentially the same, regardless of the contact time used. The equilibrium TOC concentration for the maltose test solution was slightly lower for the four hour contact time for the adsorption experiment with crushed coal-based GAC from the pilot plant at location 1; however, the difference in effluent TOC concentration was considered to be minimal when the total amount of TOC adsorbed and the reporting precision of the analyzer was considered[107]. Furthermore, it was ultimately found that maltose adsorbed whereas acetate did not (see section 4.3.1.2.2); the minimal additional adsorption or maltose provided by the four hour contact time did not change the conclusions from the adsorbability assessments. Therefore, it was concluded that the two hour contact time used for the adsorption experiments was sufficient.

Contamination from laboratory apparatus or procedures was monitored by processing a jar containing ultrapure water. Contamination of the GAC was checked by processing a jar containing ultrapure water and crushed GAC Figure 4-8 and Figure 4-9 show the TOC concentration of ultrapure water that was processed as a sample during experiments with the wood-based and coal-based GACs, respectively. The figures also show the TOC concentration of ultrapure water that was processed with GAC.

[107]Approximately 1.7 mg/L (6.9 mg/g GAC) of maltose was adsorbed by the GAC. The analyzer reported to the nearest 0.1 mg/L.

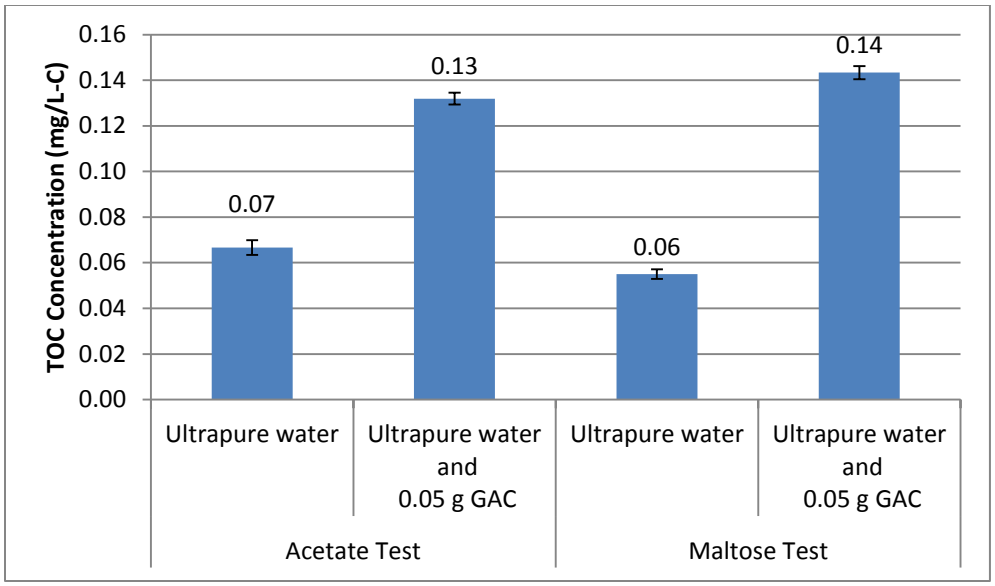

Figure 4-8: Average TOC concentration of ultrapure water processed through all laboratory procedures during adsorption experiments using the virgin wood-based GAC and TOC concentration of ultrapure water mixed with crushed GAC during experiments using the virgin wood-based GAC. (Error bars represent 99% confidence intervals. n=9 for all calculated values.)

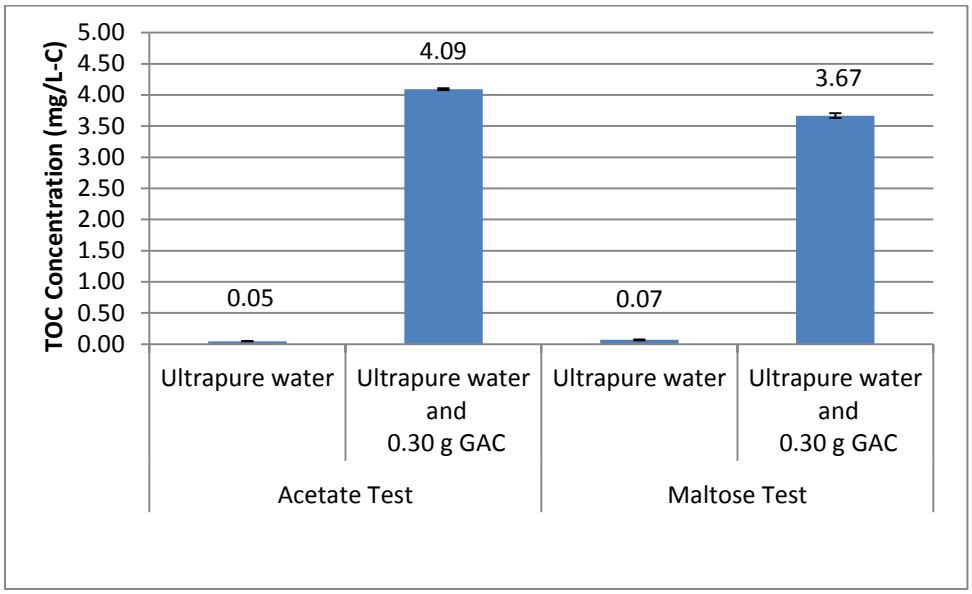

Figure 4-9: Average TOC concentrations of ultrapure water processed through all laboratory procedures during adsorption experiments using coal-based GAC taken from the UW pilot plant and average TOC concentrations of ultrapure water that was mixed with crushed GAC during the same experiments. (Error bars represent 99% confidence intervals. n=12 for all calculated values.)

It can be seen from Figure 4-8 and Figure 4-9 the TOC concentration of the ultrapure water that was not in contact with GAC and was processed through all laboratory procedures was quite low; therefore, there

was no systematic contamination from the laboratory apparatus or procedures. When the ultrapure water was contacted with the virgin wood-based GAC for two hours, the TOC concentration in the water increased but the increase was very small (only 0.06-0.08 mg/L); however, the TOC concentration increased significantly when the ultrapure water was contacted with the coal-based GAC that was taken from the UW pilot plant. The increase in TOC concentration indicated that GAC collected from the UW pilot plant was contaminated with organic matter, which was released into the ultrapure water.

The GAC from the UW pilot plant was taken out of the pilot plant after the spike experiments. Biomass grew on the GAC during pilot plant operations. The organic carbon contamination of the GAC could have been from dried biomass that remained on the GAC. Maltose was also passed through the pilot plant during the spike experiments and adsorbed to the GAC (see section 4.3.2). The GAC was collected from the UW pilot plant after these spike experiments. It is possible that some maltose desorbed from the GAC when the GAC was placed in contact with the ultrapure water. However, it is suspected that the increase in TOC concentration during the adsorption experiments came from dried biomass remaining on the GAC and not desorption of maltose because of the short duration of the spike experiments and, thus, the limited mass of adsorbed maltose. It is recommended that the GAC be well washed with filtered water prior to drying and crushing to minimize contamination by dried biomass or other materials in future adsorption experiments.

Replicate samples were analyzed during the adsorption experiment conducted with GAC taken from the UW pilot plant to confirm the reproducibility of the experimental results. Figure 4-10 shows a comparison of the average equilibrium TOC concentrations for replicate samples for both the acetate and maltose test solutions.

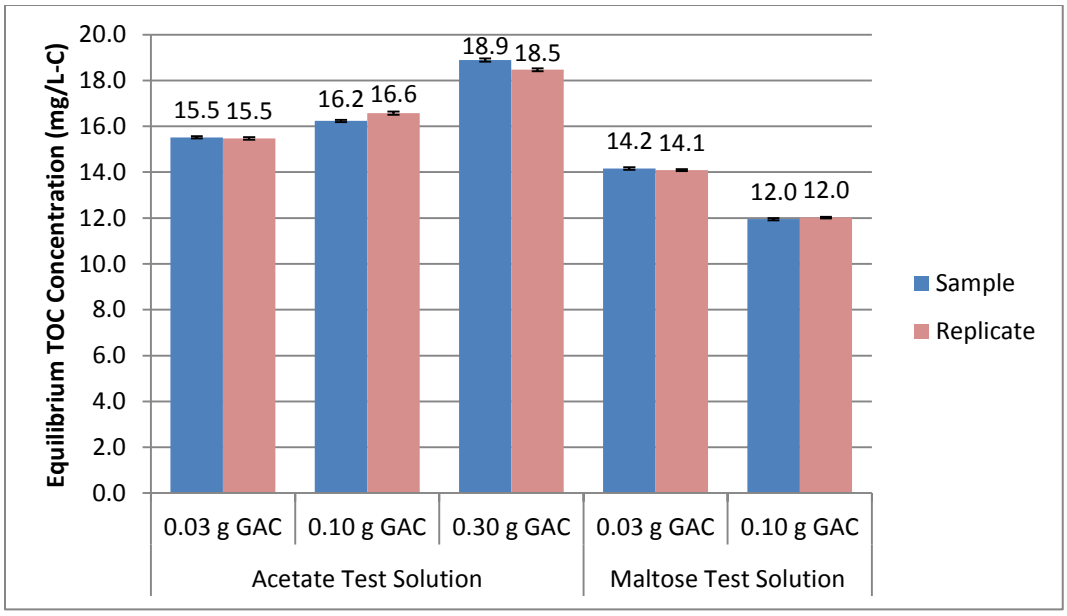

Figure 4-10: Average equilibrium TOC concentration for acetate and maltose test solutions after being in contact with various masses of GAC from the pilot plant. (Error bars represent 99% confidence intervals. n=12 for all calculated values.)

The equilibrium TOC concentrations of replicate samples were within 0 and 0.4 mg/L-C of each other. Therefore, the results were considered to be quite reproducible.

4.3.1.2.2 Adsorption Results

Figure 4-11 and Figure 4-12 show the concentration of acetate and maltose at equilibrium after two hours contact with virgin wood-based GAC and with the coal-based GAC from the UW pilot plant, respectively.

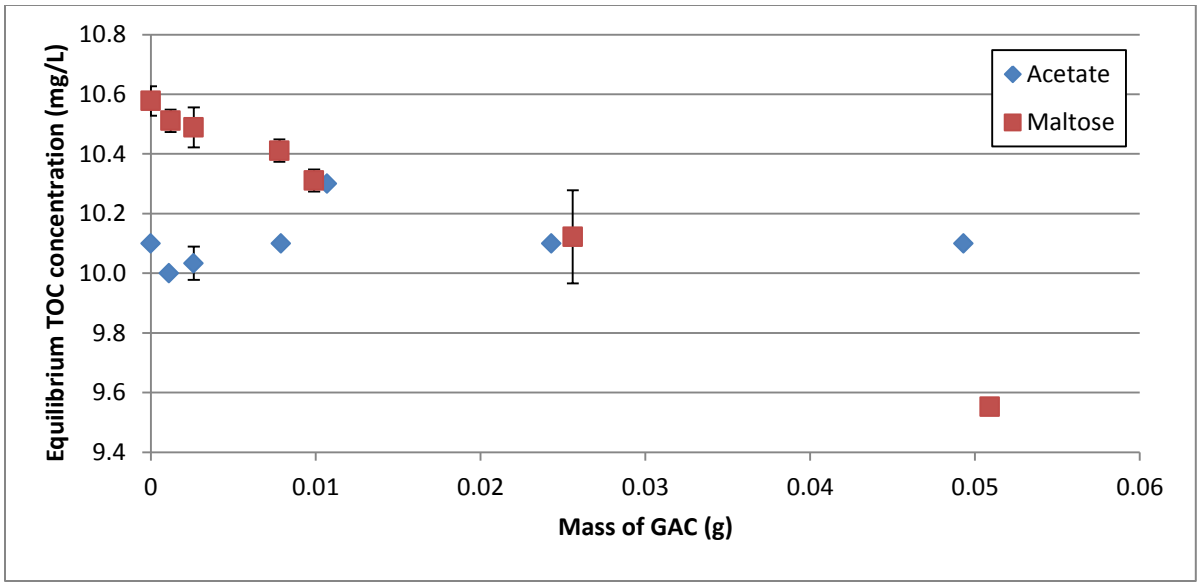

Figure 4-11: Average TOC concentrations at equilibrium after acetate and maltose test solutions were contacted with crushed virgin wood-based GAC for two hours. (Error bars indicate 99% confidence intervals. Error bars are plotted for all data points but are, in some cases, obscured by the data points. n=9 for all data points except 0.05 g of GAC with acetate: n=6 for this data point.)

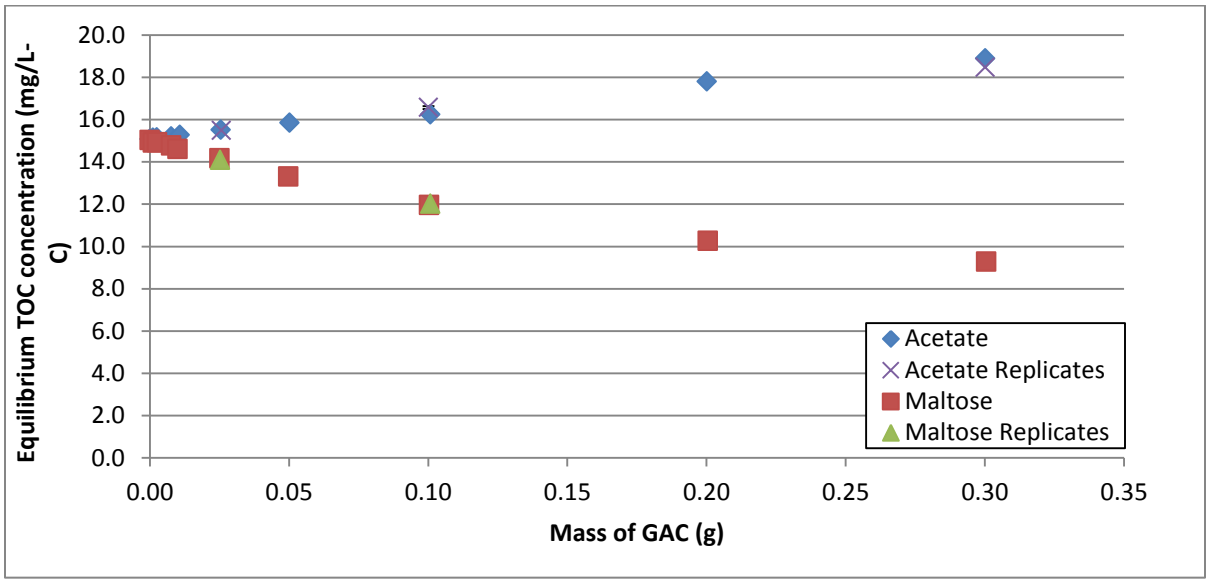

Figure 4-12: Average TOC concentrations at equilibrium after acetate and maltose test solutions were contacted with crushed coal-based GAC from the UW pilot plant for two hours. (Error bars indicate 99% confidence intervals. Error bars are plotted for all data points but are, in some cases, obscured by the data points. n=12 for all data points.)

In Figure 4-11 and Figure 4-12, a decrease in equilibrium maltose concentration with respect to an increase in the mass of GAC can be seen. The decrease in maltose concentration indicates that maltose

was adsorbed by both types of GAC; therefore, the experiments confirmed that the maltose is an absorbable organic compound.

In Figure 4-11, the concentration of acetate was essentially constant regardless of the mass of GAC used; therefore, the acetate did not adsorb to virgin wood-based GAC. However, in Figure 4-12, the equilibrium TOC concentration for the acetate test linearly increased as the mass of GAC increased. Contamination of the GAC with some form of organic carbon was identified in the quality control tests (see Figure 4-9).The linear increase in TOC concentration with the mass of GAC was, therefore, considered to be due to the contamination of the GAC.

Even though the equilibrium TOC concentration increased during the test with the acetate solution, it can still be concluded that the acetate is essentially nonadsorbable by the GAC from the pilot plant, at least in comparison to maltose. If the acetate was adsorbable by the GAC from the pilot plant, the TOC concentration would have been expected to decrease (as the TOC concentration did for the test with maltose) or at least remain constant with respect to the mass of GAC. Given that the TOC concentration increased substantially, the acetate did not adsorb to any substantial degree. Therefore, it was concluded that acetate is an essentially nonadsorbable organic compound.

4.3.2 UW Pilot Plant Experiments

4.3.2.1 TOC Analyzer Comparisons and Correction of Influent TOC Readings

The results from the comparisons of the TOC analyzers for each spike experiment are summarized in Table 4-8 and Table 4-9. The comparison presented in Table 4-8 was conducted on May 13, 2015, after the first spike experiment, and the comparisons presented in Table 4-9 was conducted on May 29, 2015, after the second experiment.

Table 4-8: Results from comparisons of the effluent and influent TOC analyzers on the same synthetic samples. Comparisons conducted on May 13, 2015, after the first spike experiment.

Analyte	Approximate concentration of sample (µg/L)	Average reading on: Effluent TOC analyzer (µg/L)	Average reading on: Influent TOC analyzer (µg/L)	Difference (Effluent-Influent) (µg/L)[1]
TOC	1000	1109	1074	35
	3000	3234	3041	193
	5000	5327	4971	356
	10000	10718	9866	852
	15000	15936	14886	1050
IC	1000	1082	1062	20
	3000	3076	3044	32
	5000	5015	5015	0
	10000	9954	9906	48
	15000	14807	14800	7

Table 4-9: Results from comparisons of the effluent and influent TOC analyzers on the same synthetic samples. Comparisons conducted on May 29, 2015, after the second spike experiment.

Analyte	Approximate concentration of sample (µg/L)	Average reading on: Effluent TOC analyzer (µg/L)	Average reading on: Influent TOC analyzer (µg/L)	Difference (Effluent-Influent) (µg/L)
TOC	1000	1084	1735	-651
	3000	3083	3487	-404
	5000	5081	5237	-156
	10000	9992	9697	295
	15000	14675	14092	583
IC	1000	1066	1057	9
	3000	3011	2989	22
	5000	4903	4872	31
	10000	9623	9598	25
	15000	14183	14175	8

There was essentially no difference in the inorganic carbon reading between the two analyzers. The IC readings were low but the readings were within approximately 0.13 mg/L of the approximate sample concentrations within the range of IC measurements made during the experiments[108]; therefore no correction was applied to the inorganic carbon measurements. There was, however, a difference in the TOC readings provided by the two analyzers. The difference in TOC reading was correlated to the TOC

[108] All observed IC readings were below 4000 ppb.

concentration: as the TOC concentration increased, the difference in TOC reading provided by the two analyzers also increased. Figure 4-13 shows a plot of the difference in TOC reading versus the reading measured on the influent analyzer.

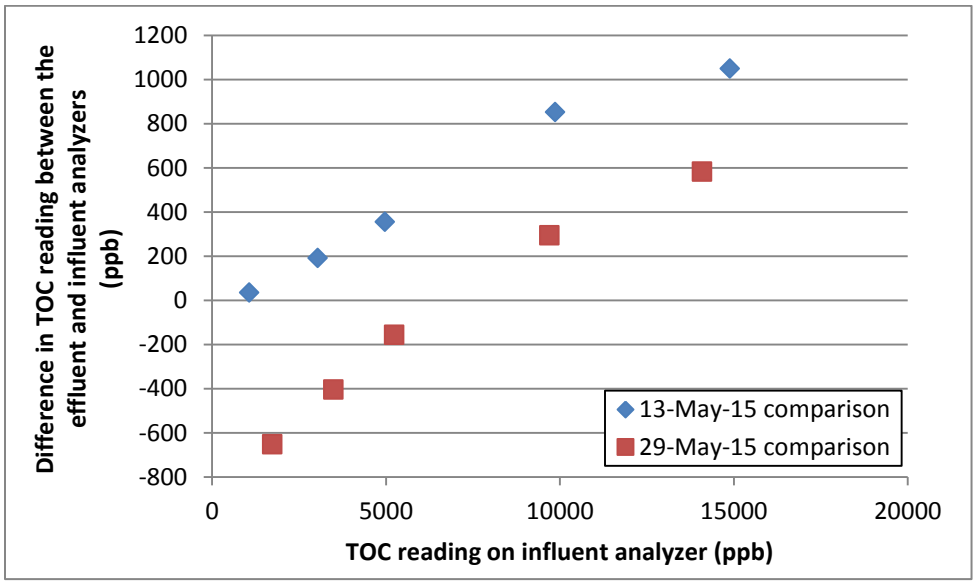

Figure 4-13: Difference in TOC reading between influent and effluent analyzers plotted versus reading on the influent TOC analyzer (May 13, 2015 and May 29, 2015 comparisons)

From Figure 4-13, it can be seen that the relationship between the difference in TOC reading and the reading measured on the influent analyzer was not linear and that the relationships were quite different. Investigation into the influent TOC analyzer performance indicated that there may have been a flow issue with the DI water module in the analyzer during the May 29, 2015 comparison[109]. Maintenance was performed on the analyzer[110] and an additional comparison was conducted on June 1, 2015. The results from the June 1, 2015 comparison are presented in Table 4-10. The difference in TOC concentration with respect to the reading on the influent TOC analyzer for the June 1, 2015 and the May 13, 2015 comparisons are plotted in Figure 4-14.

[109] This was determined based on conversations with GE Technical support.

[110] The restrictor tube on the DI water side of the TOC analyzer was replaced at the recommendation of GE technical support.

Table 4-10: Results from comparisons of the effluent and influent TOC analyzers on the same synthetic samples. Comparisons conducted on June 1, 2015, after the second spike experiment.

Analyte	Approximate concentration of standard (µg/L)	Average reading on: Effluent TOC analyzer (µg/L)	Influent TOC analyzer (µg/L)	Difference (Effluent-influent) (µg/L)
TOC	1000	1068	1105	-37
	3000	3029	3032	-3
	5000	4954	4775	179
	10000	9499	9005	494
	15000	14150	13185	965
IC	1000	1066	1043	23
	3000	2744	2694	50
	5000	4706	4643	63
	10000	9115	9045	70
	15000[1]	13406	13377	29

1. It is suspected that there was an error in making the 15000 ppb standard and that the true concentration was below 15000 ppb. All of the results follow a linear trend except the readings for the 15000 ppb sample. All IC readings were well below 15000 µg/L; therefore, this does not affect the results.

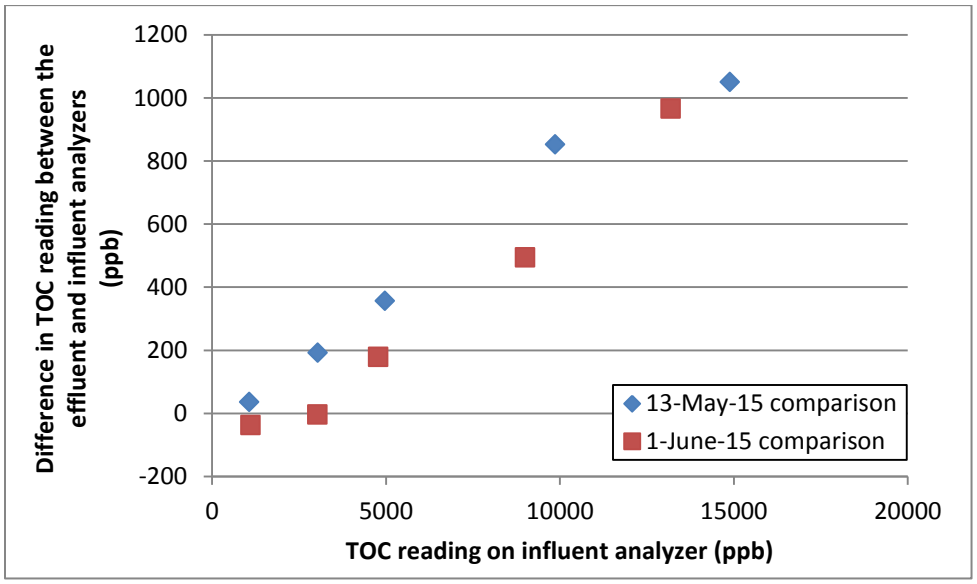

Figure 4-14: Difference in TOC reading between influent and effluent analyzers plotted versus reading on the influent TOC analyzer (May 13, 2015 and June 1, 2015 comparisons)

There was still a difference between the relationships from the June 1, 2015 and May 13, 2015 comparisons; however the relationships are much closer to each other than those from the May 29, 2015 and May 13, 2015 comparisons (see Figure 4-13). Therefore, it was suspected that there was an issue with the DI module in the influent TOC analyzer when the May 29, 2015 comparison was conducted. The

influent TOC readings would have been artificially during the second spike experiment high if there was an issue with the DI module during the experiment, based on the data from the May 29, 2015 comparison. Unfortunately, the time at which the issue with the DI module developed is unknown: it may have developed shortly before, during, or after the second spike experiment. The influent TOC data from the second spike experiment, therefore, was adjusted using corrections calculated from both the May 29, 2015 and the June 1, 2015 comparisons and data analysis for the second spike experiment was conducted twice: once using corrections from the May 29, 2015 comparisons and once using corrections from the June 1, 2015 comparisons.

The data presented in Figure 4-13 and Figure 4-14 were used to calculate corrections which matched the readings from the influent TOC analyzer to those of the effluent TOC analyzer. The difference in TOC reading between the two analyzers, for a given reading on the influent TOC analyzer, was calculated using point-to-point linear interpolation between the data points provided in the figures. The corrected influent TOC reading was then calculated by adding the difference in reading to the measured influent TOC value[111]. An example calculation illustrating the correction methods can be found in Appendix G.

4.3.2.2 Analysis of TOC Results Showing Significant Adsorption of Maltose Spikes

The influent and effluent TOC concentrations for both spike experiments were analyzed to determine whether adsorption of the maltose spike occurred. The influent and effluent organic carbon concentrations observed in the pilot plant were evaluated with respect to time. Figure 4-15 shows the influent and effluent TOC concentrations from the acetate and maltose spike from the first spike experiment. Figure 4-16 and Figure 4-17 show the influent and effluent TOC concentrations from the acetate and maltose spike from the second spike experiment, with the influent TOC concentrations corrected based on the May 29, 2015 and June 1, 2015 TOC analyzer comparisons, respectively. Table 4-11, Table 4-12, and Table 4-13 provide summary statistics for the influent and effluent TOC concentrations at the concentration plateaus observed during the spikes. The differences between average TOC concentrations observed during the acetate and maltose spikes are also presented in Table 4-11, Table 4-12, and Table 4-13.

[111] d=influent TOC-effluent TOC, where d is the difference in reading between the two analyzers, "influent TOC" is the average TOC measurement of a standard made by the influent TOC analyzer, and "effluent TOC" is the average TOC measurement of a standard made by the effluent TOC analyzer. Rearranging the equation, effluent TOC=influent TOC + d. Therefore, the difference in reading must be added to the influent TOC reading to provide a corrected effluent TOC reading.

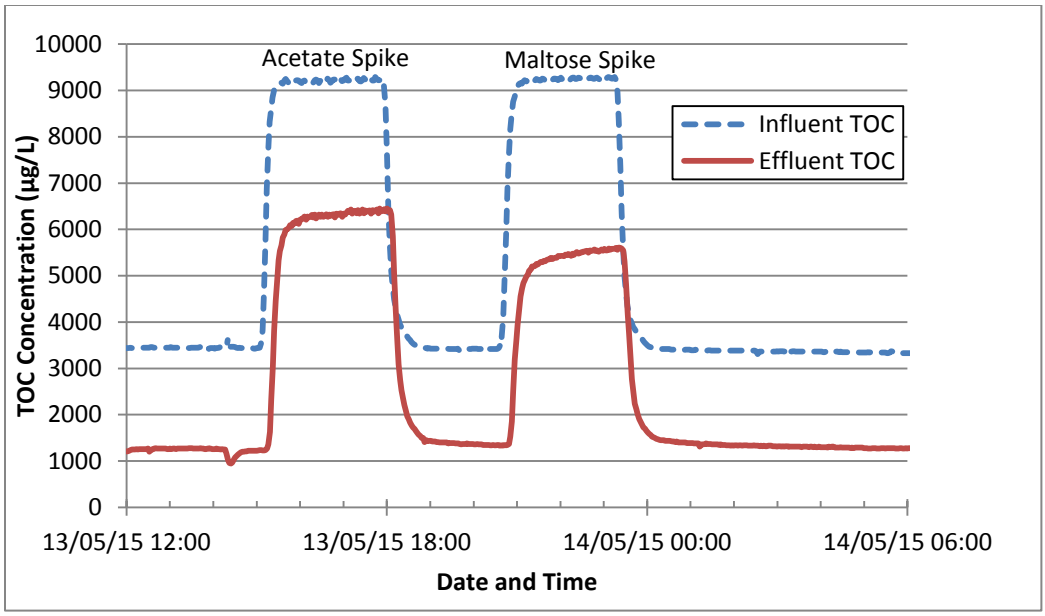

Figure 4-15: Influent and effluent TOC concentrations observed during the first experiment investigating biofilter response at the UW pilot plant to acetate and maltose spikes

Table 4-11: Summary statistics for the plateaus in TOC concentration observed during each spike during the first experiment investigating biofilter response at the UW pilot plant to acetate and maltose spikes

Spike	Biofilter Influent			Biofilter Effluent		
	Average (µg/L)	Standard deviation (µg/L)	n[1]	Average (µg/L)	Standard deviation (µg/L)	n[1]
Acetate spike	9216	32	71	6312	100	72
Maltose spike	9246	30	65	5464	108	62
Difference[2]	30	-	-	-848	-	-

1. Number of measurements
2. Difference was calculated as the average plateau concentration for the maltose spike minus the average plateau concentration for the acetate spike.

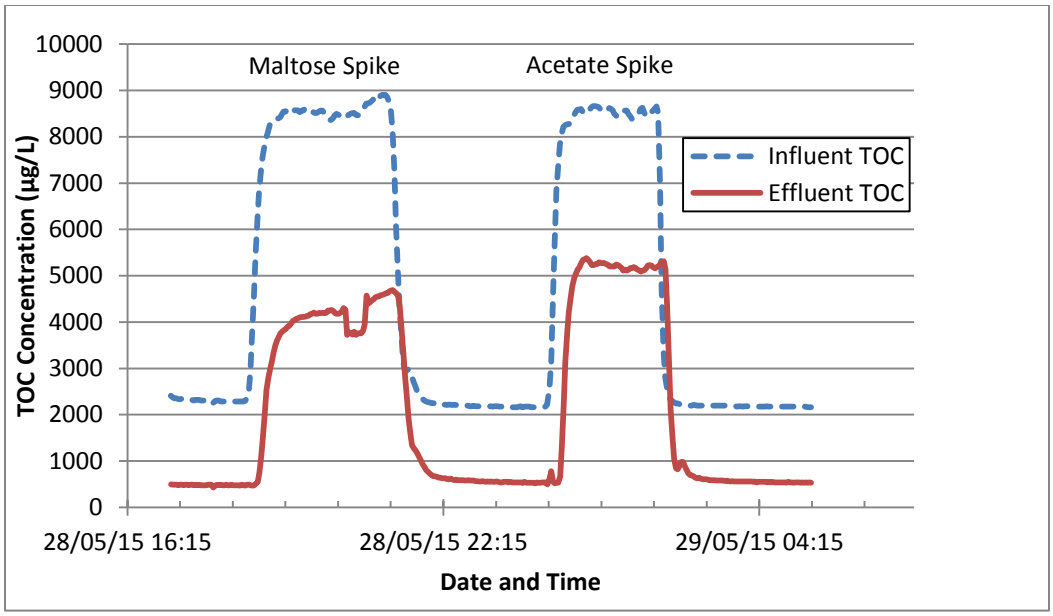

Figure 4-16: Influent and effluent TOC concentrations observed during the second experiment investigating biofilter response at the UW pilot plant to maltose and acetate spikes, using the May 29, 2015 corrections for influent TOC concentration

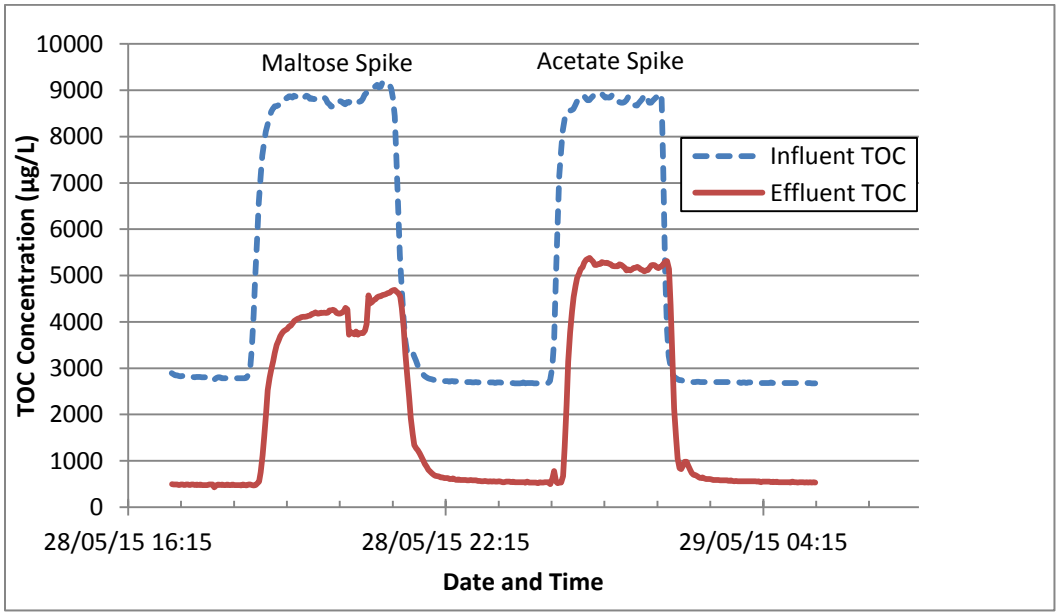

Figure 4-17: Influent and effluent TOC concentrations observed during the second experiment investigating biofilter response at the UW pilot plant to acetate and maltose spikes, using the June 1, 2015 corrections for influent TOC concentration

Table 4-12: Summary statistics, calculated using the May 29, 2015 corrections for influent TOC concentration, for the plateaus in TOC concentration observed during the second experiment investigating biofilter response to acetate and maltose spikes at the UW pilot plant

Spike	Biofilter Influent			Biofilter Effluent		
	Average (µg/L)	Standard deviation (µg/L)	n[1]	Average (µg/L)	Standard deviation (µg/L)	n[1]
Acetate spike	8521	96	52	5206	62	44
Maltose spike	8562	141	64	4245	237	49
Difference[2]	41	-	-	-961	-	-

1. Number of measurements
2. Difference was calculated as the average plateau concentration for the maltose spike minus the average plateau concentration for the acetate spike.

Table 4-13: Summary statistics, calculated using the June 1, 2015 corrections for influent TOC concentration, for the plateaus in TOC concentration observed during the second experiment investigating biofilter response to acetate and maltose spikes at the UW pilot plant

Spike	Biofilter Influent			Biofilter Effluent		
	Average (µg/L)	Standard deviation (µg/L)	n[1]	Average (µg/L)	Standard deviation (µg/L)	n[1]
Acetate spike	8807	94	52	5206	62	44
Maltose spike	8848	138	64	4245	237	49
Difference[2]	41	-	-	-961	-	-

1. Number of measurements
2. Difference was calculated as the average plateau concentration for the maltose spike minus the average plateau concentration for the acetate spike.

Data presented in Figure 4-16, Figure 4-17, Table 4-11, Table 4-12, and Table 4-13 indicate that that the effluent TOC concentration observed during the maltose spike was lower than the effluent TOC concentration observed during the acetate spike in both experiments. The influent TOC spikes observed during the maltose and acetate spikes were of a similar magnitude; therefore, there was greater removal of maltose than acetate.

Theoretically, additional removal of one organic compound versus another in a GAC biofilter can be attributed to differences in the rate of biodegradation between the two compounds or to adsorption of one the two compounds. The additional removal of maltose, in this case, was not due to differences in the biodegradation rate because maltose biodegrades at a slower rate than acetate (see section 4.3.1.1); the biofilter would have been expected to provide *worse* removal of maltose than acetate had the differences in removal been caused by differences in biodegradation rate, whereas the opposite was observed.

Furthermore, maltose was an adsorbable compound, whereas the acetate was not (see section 4.3.1.2). Therefore, the additional removal of maltose provided by the biofilter must have been due to adsorption of the maltose by the GAC.

The adsorption of maltose to the GAC resulted in effluent TOC concentrations during the maltose spikes were approximately 0.84-0.96 mg/L lower than those observed during the acetate spikes; this was a significant amount of additional TOC removal. To put this into perspective, DOC removals for biofilters containing different types of media that were observed during Phase I are summarized in Table 4-14 (note: raw data can be found in Appendix A).

Table 4-14: DOC removals observed during Phase I

Media Type	Average DOC removal (mg/L)	Range of Removals Observed (mg/L)
Coal-based GAC	0.610	0.245-1.680
Anthracite	0.470	0.177-0.844
Wood-based GAC	0.820	0.409-1.280

It can be seen that the ***additional*** TOC removal from adsorption of TOC onto used GAC seen during this phase of experiments was greater than the ***average*** DOC removal observed during Phase I. The additional TOC removal is also of a similar magnitude to the maximum DOC removals observed during Phase I. This comparison highlights just how substantial the additional removal of TOC provided by adsorption of spikes of organic matter onto used GAC can be, and demonstrates that the adsorption of organic matter spikes onto used GAC substantially improved the TOC removal during biofiltration. This additional adsorption of TOC may help account for differences in DOC removal observed, in some cases, between biofilters containing anthracite and GAC.

The GAC used in this study had been used in a full scale treatment plant for an extended period of time (approximately 25 months prior to this experiment being conducted). The results from the UW pilot plant, therefore, demonstrate that adsorption of organic matter spikes and substantial improvements in TOC removal due to this adsorption can occur with GAC that has been used for an extended period of time.

4.3.2.3 Analysis of TOC Removal and IC Production Providing Insight into Biofilter Mechanisms and providing evidence of bioregeneration/net decay of biomass

Figure 4-18 shows the TOC removal and IC production calculated for the first spike experiment.

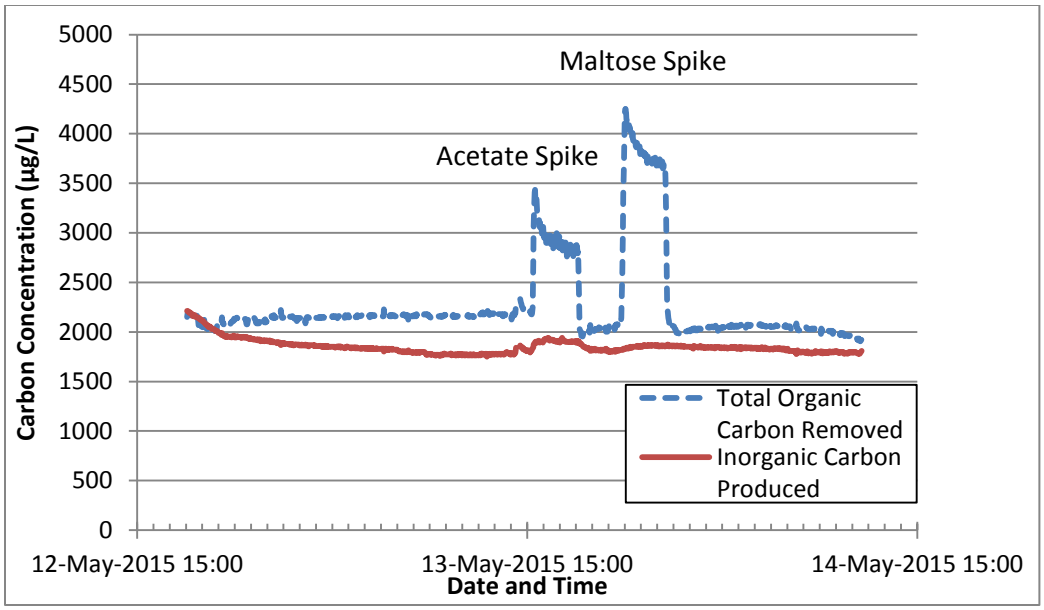

Figure 4-18: TOC Removed and IC produced during the first spike experiment at the UW pilot plant

During the first experiment, the filter was backwashed prior to starting the experiment. TOC and IC analysis was started approximately 2 hours after the filter was placed back into service. The filter had been in service for approximately 26 hours before the spike was conducted. TOC and IC monitoring was continued for an additional 11 hours after the last spike to monitor the response of the filters to the spike.

Initially, the amount of TOC removed was approximately equal to the amount of carbon produced; therefore, initially, there was no net storage of organic carbon in the biofilter. The amount of IC produced then decreased and was less than the amount of TOC removed for the rest of the monitoring period; therefore, for the rest of the monitoring period, organic carbon was stored in the filter. It should be noted that the carbon storage does not necessarily indicate that organic matter was adsorbed – organic carbon can be stored in a filter by being used by microorganisms to create biomass (e.g. cells and extracellular polymeric substances), which are then retained in the filter. It is speculated that the carbon stored in the filter prior to the spikes (where acetate was the sole carbonaceous substrate) and during the acetate spike was stored via microbial growth and the incorporation of the organic carbon into new biomass.

There was also a slight increase in the amount of IC produced by the biofilter during the two spikes and a large increase in the amount of carbon stored[112]. This increase in IC production indicated an increase in biological activity. There was a greater increase in IC production during the acetate spike than during the

[112] The amount of carbon stored is the difference between TOC removal and IC production.

maltose spike; this implies that there was greater biological activity during the acetate spike than the maltose spike, as would be expected given the higher biodegradability of acetate (section 4.2.2.1). The increased biological activity during the spikes, coupled with the increased carbon storage during the acetate spike, indicates that biofilters may be able to partially attenuate spikes of organic matter through biological action alone. Therefore, biofilters containing nonadsorptive media (e.g. anthracite or REC) may be able to provide some biological attenuation of spikes of organic matter. Use of adsorptive media will likely improve the removal of organic matter (assuming that adsorptive organic matter is present) but may not be necessary for some attenuation to be provided[113]. It is recommended that further research comparing the removal of spikes of organic matter, carbon fate, and biological activity between filters containing nonadsorptive and adsorptive media be conducted to further elucidate when and why one media type provides better removal of organic matter than another.

Figure 4-19 and Figure 4-20 show the TOC removal and IC production calculated for the second experiment using the corrections from the May 29, 2015 and June 1, 2015 TOC comparisons, respectively.

The pilot filter was backwashed prior to starting the second spike experiment. TOC and IC analysis were started approximately 15 minutes after the filters were placed back in service. TOC and IC analysis was continued for 3.3 hours, after which the analyzers were taken offline to allow other samples to be analyzed. The TOC analyzers were then placed back into operation 1.8 hours before the start of the first spike. TOC and IC monitoring was continued for an additional 2.5 hours after the last spike to monitor the response of the filters to the spike.

[113] It should be noted that it is theoretically possible that the microorganisms in the biofilter converted the acetate to an adsorbable form, which in turn was adsorbed to the GAC. Such a mechanism would also account for the improved TOC removal during the acetate spike. Whether such a mechanism exists or not is unknown but, if it exists, biofilters containing adsorptive media would be expected to provide better attenuation of spikes of *nonadsorptive organic matter*, in addition to providing better attenuation of spikes of adsorptive organic matter, than biofilters containing nonadsorptive media. Further research is needed to determine whether or not this is the case.

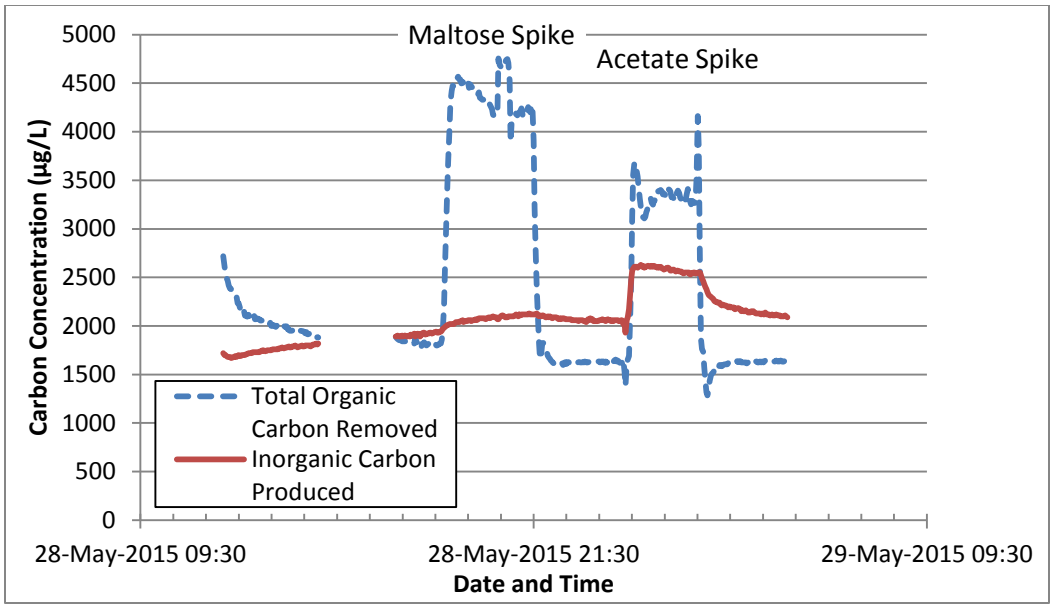

Figure 4-19: TOC Removed and IC produced during the second spike experiment at the UW pilot plant calculated using the May 29, 2015 corrections for influent TOC concentration

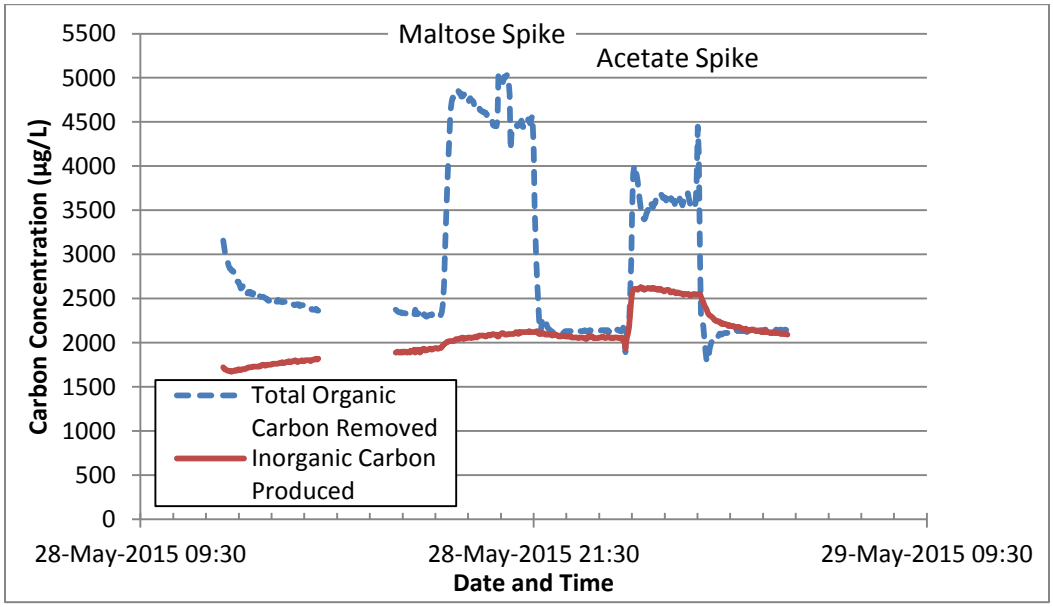

Figure 4-20: TOC Removed and IC produced during the second spike experiment at the UW pilot plant calculated using the June 1, 2015 corrections for influent TOC concentration

Comparison of Figure 4-19 to Figure 4-20 indicates that there is a clear difference in the TOC removal calculated using corrections from May 29, 2015 and June 1, 2015. There was no difference in the calculated IC production given that no correction was needed for the influent IC readings. It is suspected

that the results calculated using corrections from the June 1, 2015 TOC analyzer comparison are correct for the following reasons:

1. The spike influent TOC concentrations calculated using the June 1, 2015 correction are closer to the spike influent TOC concentrations for the first spike experiment than the spike influent TOC concentrations calculated using the May 29, 2015 corrections (see influent concentrations in Figure 4-15, Figure 4-16, and Figure 4-17 and in Table 4-11, Table 4-12 and Table 4-13). Theoretically, the spike influent TOC concentrations for the first and second spike experiment should be the same because the same procedures were used for both experiments.
2. It is unlikely that the IC production would be higher than the TOC removal before a spike was placed through the system. The results calculated using the May 29, 2015 TOC corrections show IC production that is higher than TOC removal before the first TOC spike was placed through the system (see Figure 4-19, TOC results between May 28, 2015 16:30 and May 28, 2015 17:30).

Therefore, discussion of the results from the second experiment will be focused mainly on the results calculated using the June 1, 2015 corrections (Figure 4-20).

Most trends seen in Figure 4-20 are similar to those observed in the first experiment: there was net carbon storage for most of the monitoring period (i.e. TOC removal was greater than IC production), during the spikes there was an increase in IC production indicating an increase in biological activity, and the increase in IC production was greater during the acetate spike than during the maltose spike. However, there were two differences observed in the second experiment: the TOC removal did not initially match the IC production and there was a 2 hour period after the acetate spike where the IC production ***exceeded*** the TOC removal.

The reason that the TOC removal did not initially match the IC production is unknown; however, it is speculated that it may have been related to the fact that the biologically active GAC biofilter had been transferred to the UW pilot filter shortly before the first experiment was conducted and the GAC had been installed for over two weeks by the time the second experiment was conducted. The microorganisms in the filter may have become more acclimatized to the operating conditions by the time the second experiment was conducted.

The 2 hour period after the acetate spike where IC production exceeded the TOC removal indicates that either bioregeneration or net decay of biomass occurred in the biofilter after the acetate spike[114]. The reason why bioregeneration or net decay of biomass was observed during the second experiment and not the first is unknown. Again, it may be that the microorganisms in the biofilter had acclimated further by the second experiment, resulting in a faster or stronger biological response that was detected in the second experiment but not the first. The order of the spikes may also have affected the results. In the first experiment the acetate spike was conducted first followed by the maltose spike, whereas in the second experiment the maltose spike was conducted first followed by the acetate spike. Biological activity could have been stimulated by conducting the acetate spike after the maltose spike, resulting in faster bioregeneration of adsorbed maltose during the second experiment. It is fully possible that bioregeneration did actually occur during the first experiment but that the rate of bioregeneration was not fast enough to result in a net loss of stored carbon, whereas in the second experiment the rate of bioregeneration was fast enough to cause a net loss of stored carbon. Further research is needed to elucidate the factors which cause bioregeneration (and/or net decay of biomass) to occur during biofiltration for drinking water treatment.

[114] This is based on the TOC removal results calculated using the June 1, 2015 corrections. It should be noted that if the May 29, 2015 corrections were used, the conclusion that bioregeneration and/or net decay of biomass occurred in the biofilter is still valid – in fact, if the May 29, 2015 corrections are taken as being correct, bioregeneration and/or net decay of biomass occurs after both the maltose and the acetate spikes.

4.3.3 Toronto Pilot Plant Experiments

4.3.3.1 TOC Analyzer Comparisons

Table 4-15 summarizes the results from the comparisons of the TOC analyzers.

Table 4-15: Results from comparisons of the TOC analyzers used to measure TOC in the effluent of the GAC and anthracite biofilters

Sample Set	Approximate concentration of sample (µg/L)	Average reading on: GAC effluent TOC analyzer (µg/L)	Average reading on: Anthracite effluent TOC analyzer (µg/L)	Difference (Effluent-Influent) (µg/L)
Full sample set[1]	1000	1039	1078	-39
	3000	3070	3100	-30
	5000	5071	5102	-31
	10000	10133	10100	33
	15000	15000	14982	18
5 mg/L-C standard[2]	5000	5019	5179	-160

1. Analyzed on-site, prior to the spikes being introduced to the filters
2. Analyzed on-site, after the last spike had passed through the filters

It can be seen that the two analyzers provided essentially the same readings on the samples before the spike experiments and that, though there was some drift, the readings were still within 0.16 mg/L of each other. Therefore, no correction of the TOC data was applied[115].

4.3.3.2 Spike Experiment Results

Figure 4-21 shows the effluent TOC concentrations from the anthracite and GAC filter effluents for the acetate and maltose spikes. Table 4-16 provides summary statistics for the plateau in the TOC concentration observed during each spike. Table 4-17 shows the difference in average plateau TOC concentrations between the GAC and anthracite biofilters for each spike.

[115] These results differ from those observed at UW because one of the analyzers was replaced between the experiments at UW and those conducted at Toronto. The replacement analyzer performed better than the original analyzer.

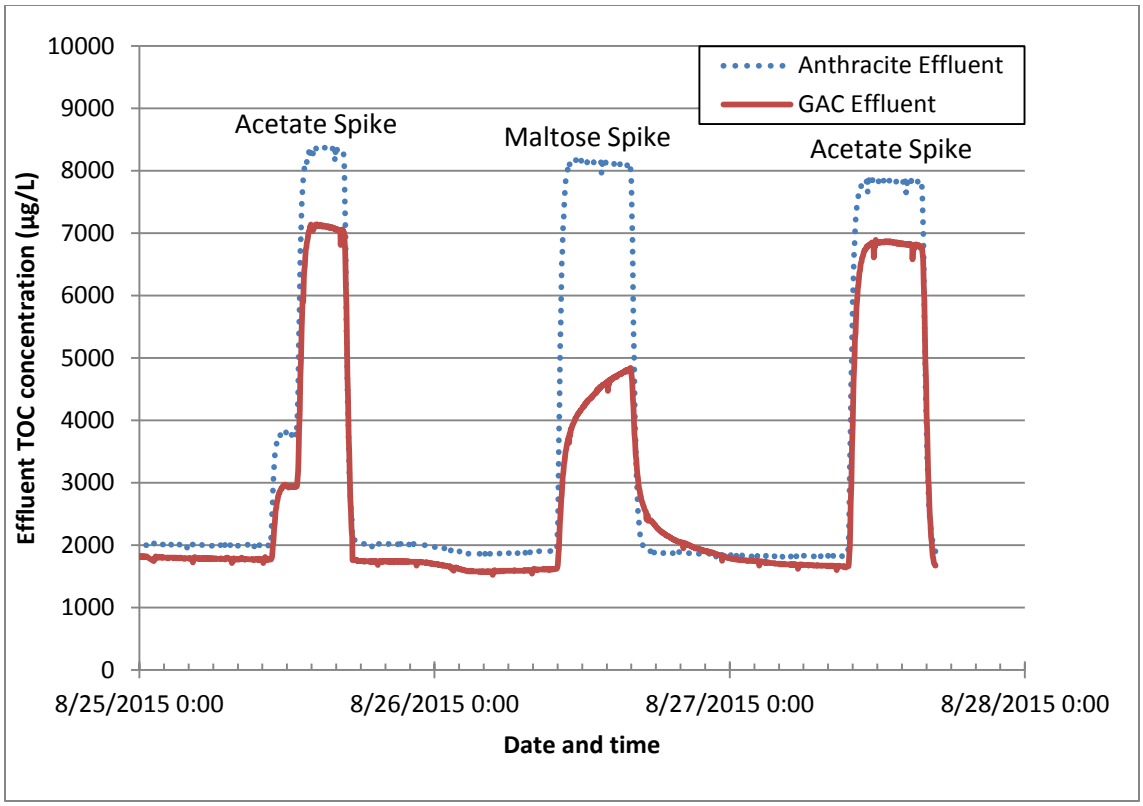

Figure 4-21: TOC concentration in the effluent of the anthracite and GAC biofilters during and between influent organic matter spikes at the Toronto pilot plant

Table 4-16: Summary statistics for the plateau in the effluent TOC concentration observed during each spike conducted at the Toronto pilot plant

Spike	GAC Biofilter Effluent			Anthracite Biofilter Effluent		
	Average (µg/L)	Standard deviation (µg/L)	n[1]	Average (µg/L)	Standard deviation (µg/L)	n[1]
Acetate spike 1	7079	47	81	8319	60	93
Maltose spike	4474	266	146	8124	28	147
Acetate spike 2	6822	43	141	7825	27	147

1. Number of measurements

Table 4-17: Difference in average effluent plateau TOC concentration between GAC and anthracite biofilters

Spike	Difference[1] (µg/L)
Acetate Spike 1	-1240
Maltose Spike	-3650
Acetate Spike 2	-1003

1. Average effluent plateau TOC concentration from the anthracite biofilter subtracted from the average effluent plateau TOC concentration from the GAC biofilter

The GAC biofilter attenuated both the acetate and maltose spikes to a greater degree than the anthracite biofilter: the average effluent concentration during the acetate and maltose spikes were, respectively ~1 mg/L and ~3.6 mg/L lower than those observed in the anthracite biofilter. It can be seen that, for both biofilters, the effluent plateau concentrations of the two acetate spikes were similar to each other. The effluent plateau concentration of the maltose spike was similar to that of the two acetate spikes for the anthracite biofilter but not for the GAC biofilter.

The additional attenuation of the acetate spike, provided by GAC, may have been due to greater bioactivity in the GAC filter. The GAC biofilter provided a slightly lower effluent TOC concentration between spikes, indicating greater bioactivity on the GAC. It is possible that previous experiments conducted on the anthracite biofilters and operational changes may have slightly impaired biological growth in the anthracite filters (Personal communication, Dave Scott, August, 2015).

The additional removal of the maltose spike provided by the GAC biofilter was due to adsorption of maltose onto the GAC. The effluent TOC concentration in the GAC filter during the maltose spike was much lower than both the effluent TOC concentration in the GAC filter during the acetate spikes and the effluent TOC concentration in the anthracite filter during the maltose spike. The lower effluent TOC concentration in the GAC filter during the maltose spikes was not caused by a lower influent concentration because the increase in influent TOC concentration was designed to be the same for all spikes: the stock solutions used for all spikes had the same carbon concentration and the same dosing rate was used for all solutions. The similar magnitude of all effluent TOC spikes in the anthracite filter provides additional evidence that the influent TOC spike concentrations were essentially the same. Differences in the rate of biological attenuation or the adsorption of the maltose, therefore, must have been the cause of the additional attenuation of the maltose spike in the GAC filter. Biodegradation testing, using microorganisms present in the filter influent as an inoculum, indicated that the rate of biodegradation of maltose was slower than that of acetate (see section 4.2.2.1); therefore, the lower effluent concentration observed for the maltose spike was not due to faster biodegradation of the maltose. Furthermore, maltose adsorbs onto GAC, whereas acetate does not adsorb (see section 4.2.2.2). The additional attenuation of the maltose spike, therefore, must have been due to adsorption of maltose onto the GAC because (a) maltose adsorbs onto GAC and (b) the lower effluent TOC concentration during the maltose spike was not due to faster biodegradation of the maltose. The similar magnitude of effluent TOC concentrations in the anthracite filter during the maltose and acetate spikes in comparison to the lower effluent TOC concentrations in the GAC filter during the maltose spikes, also implies that the additional

attenuation of the maltose spike was due to adsorption. Finally, it should also be noted that the slow increase in effluent TOC concentration during the maltose spike is indicative of adsorption.

It is difficult to quantify the exact amount of additional removal specifically provided by adsorption given that the GAC biofilter provided improved removal of a nonadsorptive compound (i.e. acetate); however the additional removal of maltose provided by GAC was three times higher than the additional removal of acetate (3.6 mg/L v.s. 1 to 1.2 mg/L). Therefore, the adsorption of maltose onto used GAC substantially improved TOC removal.

Initially, comparison of the decrease in effluent TOC concentration after the maltose spike was stopped, between the GAC and anthracite filter mplies that desorption of the adsorbed maltose may have occurred. There was a fast decrease in effluent TOC concentration in the anthracite filter after the maltose dosing was ceased. A similar rapid decrease in effluent TOC concentration was also seen in both the anthracite and GAC filters for the acetate spike, where adsorption would not have occurred. However, in the GAC filter there was a slower decrease in effluent TOC after the maltose dosing was ceased and there is clear "tailing". The anthracite and GAC filters were both operated at the same flow rate and tailing was not observed in the GAC filter for any of the other spike experiments; therefore, the slow decrease and "tailing" implies that some of the maltose, which had initially adsorbed to the GAC during the spike, slowly desorbed from the GAC after the influent spike was stopped.

The GAC in the biofilter used for this experiment had been in continuous use for a full three years (Personal communication, D. Scott, February 9, 2016); therefore, these results demonstrate that adsorption of spikes of organic matter as well as desorption of adsorbed organic matter can occur even in biofilters containing GAC that has been used for an extended period of time. The results also demonstrate that, while not the only possible mechanism, the adsorption of spikes of organic matter is a mechanism through which biofilters containing GAC can provide improved removal of organic matter compared to biofilters containing anthracite.

4.3.4 Final Discussion

In experiments conducted at both locations, it was shown that biofilters containing GAC attenuated spikes of an adsorbable organic compound (maltose) to a greater degree than they attenuated spikes of a nonadsorbable organic compound (acetate). The additional attenuation of the adsorbable organic compound was the result of adsorption onto the GAC and not due to differences biodegradation. This additional adsorption occurred despite the fact that GAC at both locations had been used for years prior to these experiments and resulted in substantially improved TOC removal. Therefore, the results from these

experiments demonstrated that organic matter spikes can adsorb onto GAC even after the GAC has been used in biofiltration for years and that this adsorption can substantially improve TOC removal during biofiltration. This additional adsorption during organic matter spikes may help explain why GAC biofilters sometimes provide better removal of organic matter than biofilters containing nonadsorptive media.

In one of the two experiments conducted at UW, TOC production was greater than IC removal after spikes of organic matter had been placed through the GAC biofilter. These results indicated that that either bioregeneration of adsorbed organic matter or net decay of biomass occurred after spikes of organic matter had been attenuated by the GAC biofilter. To the author's knowledge, this is the first direct evidence of either of these mechanisms occurring in a drinking water biofilter after the attenuation of an organic matter spike. Unfortunately, the results did not allow these two mechanisms to be differentiated from each other. Furthermore, it is unknown why evidence of these mechanisms was seen in only one of the two spike experiments. Further research is needed to differentiate between these two mechanisms and to elucidate the scenarios under which each of these mechanisms occur during drinking water treatment.

Finally, the results from the experiments conducted at UW and Toronto also implied that some fascinating dynamics may be occurring in biofilters. When a spike of organic matter is introduced to a biofilter, it can be attenuated through oxidation of the organic carbon and/or through storage of the organic carbon in the biofilter. Organic carbon is stored through either adsorption to the GAC or through incorporation into the biomass. Once stored, the organic carbon can then be oxidized to CO_2 through bioregeneration, oxidized to CO_2 from the decay of biomass, and/or desorbed from the GAC. Bioregeneration and desorption of adsorbed organic carbon frees-up adsorption capacity for the next spike of organic matter. Decay of excess biomass may free up space in the biofilter for future biomass growth. Preliminary evidence of almost all of these mechanisms was observed in this study:

1. Attenuation of spikes of organic matter was seen during both experiments conducted at UW and Toronto.
2. Increased oxidization of organic matter to CO_2 was seen when spikes of organic matter were introduced into biofilters at UW, indicating that spikes of organic matter can be partially attenuated by increased biologically-mediated oxidation of the organic carbon.
3. Storage of organic carbon (i.e. where TOC removal was greater than IC production) was seen during both experiments conducted at UW and the storage of organic carbon increased when spikes of organic matter were introduced to the biofilters. This indicated that spikes of organic

matter can be attenuated through storage of the organic carbon in the biofilter and not just through oxidation.

4. Adsorption of spikes of organic carbon was seen in two different pilot plants, at two different locations, indicating that the organic carbon can be stored via adsorption.
5. Increased storage of organic carbon was seen when a spike of a nonadsorptive organic compound was introduced to biofilters at UW. Because the compound was non-adsorptive, these results suggest that the increased storage of organic carbon was due to incorporation of the organic carbon into the biomass.
6. As mentioned previously, bioregeneration and/or net decay of biomass to CO_2 was indicated by the increase in IC production beyond the TOC removal observed during the second experiment conducted at UW.
7. Finally, evidence of desorption of adsorbed organic matter, after a spike of adsorbable organic matter had passed through a GAC biofilter, was seen at Toronto.

Understanding these mechanisms is practically important in that it may allow removal of organic matter by biofilters to be optimized, may explain when and why one media type should be used over another, and may allow the fate of specific compounds during biofiltration (e.g. pharmaceuticals or pesticides) to be understood. For example, it can be surmised from this research that biofilters containing GAC would provide improved removal of spikes of organic matter than biofilters containing anthracite *if* the organic matter present in the spike was adsorbable. This improved removal could be expected, even over the long-term, if the organic matter can desorb or be bioregenerated off of the GAC. Therefore, at a treatment plant that is exposed to spikes or changes in influent TOC and where that influent TOC is largely adsorbable, GAC would be expected to provide more reliable TOC removal via biofiltration than anthracite. Further research is needed to determine whether the mechanisms outlined above operate in all biofilters used for drinking water treatment and to determine which mechanisms operate under different operating conditions (i.e. with various media types, influent water qualities, and operational protocols).

4.4 Detailed Summary of Findings

The findings from Phase II are as follows.

1. Maltose biodegraded at a slower rate than acetate.
2. Maltose was an adsorbable organic compound whereas acetate was not adsorbable.

3. Spikes of maltose adsorbed to GAC in pilot-scale drinking water biofilters at two different locations, even though the GACs at both locations had been previously used for extended periods of time prior to conducting the spike experiments. Therefore, these results demonstrate that organic matter spikes can adsorb onto GAC that has been used for an extended period of time.

4. The adsorption of spikes of organic matter onto used GAC substantially improved TOC removal during organic matter spikes. At UW, this adsorption resulted in effluent concentrations that were 0.8-0.9 mg/L lower. At Toronto, it was difficult to quantify the additional TOC removal provided specifically by adsorption: the GAC biofilter being studied provided improved removal of acetate as well as maltose when compared to an anthracite biofilter. However, the GAC biofilter provided an average effluent TOC concentration that was 3.6 mg/L lower than the average effluent concentration from the anthracite biofilter during the maltose spike. Furthermore, the improved removal provided by the GAC during the maltose spike was approximately three times that observed during the acetate spikes (a 3.6 mg/L improvement vs. a 1.0~1.2 mg/L improvement). Therefore, it was concluded that substantial improvements of TOC removal during spikes were observed at both locations and that adsorption of organic matter spikes onto used GAC can substantially improve TOC removal during biofiltration.

5. The additional adsorption of organic matter during organic matter spikes may help explain why GAC biofilters provide better removal of organic matter than biofilters containing nonadsorptive media.

6. Evidence of bioregeneration and/or net decay of biomass to CO_2 was observed during the second experiment conducted at UW. It was not possible to differentiate between these two mechanisms.

7. Evidence of several mechanisms that may affect the removal of organic carbon during biofiltration was observed. The evidence suggested that the following can occur in drinking-water biofilters: (a) organic carbon can be removed through biologically-mediated oxidation of the organic carbon to CO_2 and storage of the organic carbon in the biofilters, (b) organic carbon can be stored in biofilters through adsorption of the organic carbon and/or through incorporation of organic carbon into biomass, (c) organic matter spikes can be attenuated through oxidation and storage of the organic carbon associated with the spike, (d) organic carbon that is stored in a biofilter can be removed through bioregeneration and/or decay of the biomass within which the carbon was incorporated, and (e) organic carbon adsorbed onto GAC during organic carbon spikes can desorb from the GAC. Understanding these mechanisms is important and may allow

the removal of organic matter during biofiltration to be optimized. Further research into the mechanisms impacting biofiltration is needed.

Chapter 5 Conclusions and Implications

The overall conclusions and implications from this work are as follows:

5.1 Matching Grain Size Distributions

1. The grain-size-distribution-matching method developed in this work allowed the grain size distributions of different types of media to be closely matched (i.e. effective sizes were within 0.06 mm (7%) and uniformity coefficients were within 0.06 (4.5%) of each other). Large amounts of media with matched grain size distributions were able to be prepared for piloting using this method.

5.2 Practical Conclusions and Implications

1. GAC generally removed organic matter better than REC or anthracite during biofiltration. This improved removal could be specifically attributed to the difference in media type and is not confounded by differences in grain size distribution.
2. Wood-based GAC generally provided better removal of DOC than coal-based GAC during biofiltration.
3. Even though GAC generally removed organic matter better than other biofiltration media (i.e. anthracite and REC), it did not necessarily provide better removal of all forms of organic matter (e.g., AOC, THMFP) simultaneously nor did it provide better removal in every sampling event.
4. Biofilters sometimes converted organic matter to less desirable forms. Specifically, dibromochloromethane formation potential increased slightly because of biofiltration, especially in GAC as compared to anthracite or REC filters.
5. Though not as adsorptive as the GACs used in this study, anthracite can adsorb some DOC when crushed to a powder.
6. Operation of biofilters in a declining-rate mode enhanced organic matter removal relative to operation at constant-rate. This additional removal could compensate for the differences in organic matter removal between coal-based and wood-based GAC.
7. REC and anthracite generally provided slower headloss development than GAC media during biofiltration. The specific medium that provided better (i.e. slower) headloss development within

adsorptive (coal-based vs. wood-based GAC) and non-adsorptive (REC vs. anthracite) media was seasonally dependent.

8. There may be a trade-off between choosing a media type that provides the greatest DOC removal and choosing a media type that provides the best headloss performance.
9. REC and wood-based GAC media could provide lower mean effluent turbidities and better turbidity dampening than anthracite and coal-based GAC. The media type that provided the best performance, between REC vs. wood-based GAC and between coal-based GAC vs. anthracite, was seasonally dependent.
10. The media types which provided the longest filter run time were seasonally dependent but, in general, REC provided longer filter run times than wood-based GAC and anthracite provided longer filter run times than coal-based GAC.

5.3 Mechanistic Conclusions and Implications

1. The results implied that media roughness is not a media property that significantly enhances DOC removal during biofiltration. Thus, mechanisms related to media roughness, such as biomass shielding, do not significantly contribute to increased DOC removal by GAC relative to other media during biofiltration at the conditions studied.
2. The adsorptive property of GAC is critical for enhancing DOC removal during biofiltration relative to other media over the long-term. This applies to new and spent GAC (i.e. media that have been used for many years). It also implies that mechanisms related to a medium's adsorptive properties (e.g. bioregeneration, adsorption of organic matter spikes) are significant to DOC removal during biofiltration in the long-term.
3. Organic matter spikes can adsorb onto GAC even after the GAC has been used in biofiltration for years. Adsorption of spikes of organic matter significantly improved DOC removal and may help explain why GAC biofilters can provide better removal of organic matter than biofilters containing nonadsorptive media.
4. Either bioregeneration of adsorbed organic matter and/or net decay of accumulated biomass can occur after spikes of organic matter have been attenuated by drinking water biofilters containing GAC media. Further research is needed to differentiate between these two mechanisms and to elucidate the scenarios under which each of these mechanisms occur during drinking water treatment.

5. Filter media roughness generally enhanced turbidity removal and turbidity dampening during biofiltration; however, elucidation of the exact mechanisms that enable this performance benefit in biofilters requires further research.

Chapter 6 Recommendations for Future Research

The following recommendations for future research and future researchers are offered based on the findings from this study:

1. The mechanisms that affect organic carbon removal should be further elucidated and confirmed, and studies into carbon fate and the dynamics of natural organic matter removal during drinking water biofiltration are sorely needed. Understanding these dynamics will greatly advance the understanding of organic matter removal during biofiltration and will aid in the development of design guidance for media selection. The research in this study has provided evidence of several mechanisms that affect the removal of organic matter. These mechanisms include the adsorption of organic matter spikes onto used GAC and bioregeneration/net decay of biomass. However, confirmation and further elucidation of these mechanisms is still needed.
2. The impact of biomass on turbidity removal should be investigated. "Crusts" on the surface of used GAC, presumably formed by microorganisms, were seen on the surface of used in this study. Such crusts have been seen in at least one other study (Lauderdale et al., 2012) and biomass may impact the removal of particles. It is possible that the presence of biomass in biofilters impacts the removal of particles and turbidity.
3. The role of media roughness on DOC removal should be confirmed. This research implied that media roughness does not positively impact the removal of DOC during biofiltration. The media types used in this study had several different morphologies; however, a systematic study of the impact of media roughness on DOC removal is still needed.

Chapter 7 Contributions

The unique contributions of this research to the field of drinking water treatment, in general, and the understanding biofiltration, in particular, are as follows:

1. A grain-size-distribution-matching method was developed that allows large amounts of media with matched grain size distributions to be created for pilot-scale biofiltration studies.
2. Differences in biofilter performance could be specifically attributed to the difference in media type and were not confounded by differences in grain size distribution.
3. The performance of REC during biofiltration was compared to other media types.
4. It was shown that media roughness was not a media property that significantly enhances DOC removal during biofiltration; this implies that mechanisms related to media roughness, such as biomass shielding, do not significantly contribute to increased DOC removal during biofiltration.
5. The adsorptive property of GAC was shown to be critical for enhancing DOC removal during biofiltration relative to other media, over the long-term.
6. Evidence that mechanisms related to a medium's adsorptive properties (e.g. bioregeneration, adsorption of organic matter spikes) are significant to DOC removal during biofiltration in the long-term was provided.
7. Adsorption of organic matter spikes was shown to be a mechanism that can help explain how GAC biofilters can provide better removal of organic matter than nonadsorptive media over the long-term.
8. Direct evidence that one or both of the following mechanisms occurs during biofiltration using GAC was provided: (a) bioregeneration of adsorbed organic matter and/or (b) net decay of accumulated biomass (after spikes of organic matter had been attenuated by drinking water biofilters containing GAC media).
9. Turbidity dampening was defined, and turbidity dampening provided by several media types during biofiltration was assessed.
10. It was shown that filter media roughness can generally enhance turbidity removal and turbidity dampening during biofiltration.

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Appendix A

Tables of Select Significant Interactions

This appendix contains tables of significant interactions found by Snider (2011) that were referenced throughout this document. These tables are not exhaustive and do not summarize all significant interactions found during the pilot experiments conducted by Snider (2011).

Table A-1: Significant Interactions between the Presence of Chlorine and other Backwash Factors

Interaction	Response Variables Affected (Removal of DOC/BDOC)	Number of Experiments where Interaction was Significant (per 3 Experiments)
Presence of chlorine and the use of collapse pulsing backwash	DOC; BDOC	DOC – 3/3 BDOC – 1/3
Presence of chlorine and the use of ETSW	DOC	DOC – 2/3
Presence of chlorine, the use of collapse pulsing backwash, and time after backwash	DOC	DOC – 2/3
Presence of chlorine, the use of ETSW , and the time after backwash	DOC	DOC – 2/3
Presence of chlorine, the use of ETSW, the use of collapse pulsing backwash, and the time after backwash	BDOC	BDOC – 1/3

Table A-2: Significant Interactions between the use of Collapse Pulsing Backwash and other Backwash Factors

Interaction	Response Variables Affected (Removal of DOC or BDOC)	Number of Experiments where Interaction was Significant (per 3 Experiments)
Collapse pulsing backwash and the use of ETSW	DOC	DOC – 2/3
Collapse pulsing backwash and the presence of chlorine	DOC; BDOC	DOC – 3/3 BDOC – 1/3
Collapse pulsing backwash, the presence of chlorine, and ETSW	DOC	DOC – 2/3
Collapse pulsing backwash, the presence of chlorine, and time after backwash	DOC	DOC – 2/3
Collapse pulsing backwash, ETSW, presence of chlorine and time after backwash	BDOC	BDOC – 1/3

Table A-3: Significant Interactions between Extended Terminal Subfluidization Wash [ETSW] and other Backwash Factors

Interaction	Response Variables Affected (Removal of DOC or BDOC)	Number of Experiments where Interaction was Significant (per 3 Experiments)
ETSW and collapse pulsing backwash	DOC	DOC – 2/3
ETSW, collapse pulsing backwash, and the presence of chlorine	DOC	DOC – 2/3
ETSW, presence of chlorine, and time after backwash	DOC	DOC – 2/3
ETSW, collapse pulsing, presence of chlorine, and time after backwash	BDOC	BDOC – 1/3

Appendix B

DOC Data

Contents

This appendix contains DOC data collected and information pertaining to the analysis of the DOC data.

Structure of the Appendix

A table listing the DOC data sets and information associated with each of the data sets is presented at the beginning of this appendix. After this table, a subsection is provided for each data set. Each subsection is further divided into "Raw Data" section and an "ANOVA results" sections.

In the raw data section for each data set, the following is provided: the raw DOC data, a list of data points excluded from further analysis (as appropriate), rationale for excluding these data points (as appropriate), and any other notes associated with the raw data.

In the ANOVA section for each data set, the following is provided: an ANOVA table summarizing univariate ANOVA results, a normal probability plot of the residuals from the ANOVA, a scatterplot of the residuals from the ANOVA versus the predicted values, a scatterplot of the residuals from the ANOVA versus the influent or filter number, the results from Levene's test of equality of variances, the results from multiple comparisons using Tukey's HSD test and Dunnett's T3 test, and a brief point-form analysis. The analysis in each of the ANOVA results sections indicates whether the main factor in the ANOVA (i.e. media type and influent) had a significant impact on the DOC concentrations, discusses the normality of the residuals from the ANOVA, discusses whether or not the data are heteroscedastic, and indicates whether Tukey's HSD or Dunnett's T3 test results were adopted for multiple comparisons. For three data sets, data sets 19, 27 and 28, potential outliers and data that contributed to the non-normality of the ANOVA residuals were identified. Additional analyses were conducted without the potential outliers and/or the data that contributed to the non-normality; results from the additional analyses are also summarized in the ANOVA results sections for these data sets.

At the end of the appendix, the results from the sign tests are provided.

Table B-1: List of data sets and associated information

Data Set	Collection Date (mm/dd/yyyy)	Analysis Date (mm/dd/yyyy)	Water Temperature (°C)	Temperature classification[1]	Sampling location[4]	Number of bottles of sample water collected per location	Number of aliquots analyzed per bottle
1	12/07/2011	12/09/2011	6.25	Cold	Influent	2	3
					F1	1	3
					F2	1	3
					F3	1	3
					F4	1	3
					F5	1	3
2	01/17/2012	01/19/2012	2.00	Cold	Influent	2	2
					F1	1	2
					F2	1	2
					F3	1	2
					F4	1	2
					F5	1	2
3	01/26/2012	02/02/2012	2.00	Cold	Influent	2	3
					F1	1	2
					F2	1	2
					F3	1	2
					F4	1	2
					F5	1	2
4	01/30/2012	02/02/2012	2.00	Cold	Influent	2	3
					F1	1	2
					F2	1	2
					F3	1	2
					F4	1	2
					F5	1	2
5[2]	03/01/2012	03/19/2012	3.30	Cold	Influent	2	2
					F1	2	2
					F2	2	2
					F3	2	2
					F4	2	2
					F5	2	2
6	03/05/2012	03/05/2012	2.80	Cold	Influent	2	2
					F1	2	2
					F2	2	2
					F3	2	2
					F4	2	2
					F5	2	2
7	03/15/2012	03/17/2012	4.35	Cold	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
8	03/21/2012	03/21/2012	9.50	Warm	Influent	2	2
					F1	2	2
					F2	2	2
					F3	2	2
					F4	2	2
					F5	2	2
9	04/02/2012	04/04/2012	9.25	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
10	04/12/2012	04/13/2012	9.80	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
11	04/24/2012	04/26/2012	12.95	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
12	06/07/2012	06/08/2012	17.90	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3

Data Set	Collection Date (mm/dd/yyyy)	Analysis Date (mm/dd/yyyy)	Water Temperature (°C)	Temperature classification[1]	Sampling location[4]	Number of bottles of sample water collected per location	Number of aliquots analyzed per bottle
13	06/09/2012	06/12/2012	21.10	Warm	Influent	2	2
					F1	2	2
					F2	2	2
					F3	2	2
					F4	2	2
					F5	2	2
14	06/19/2012	06/20/2012	24.60	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
15	06/21/2012	06/27/2012	27.40	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
16	06/27/2012	06/28/2012	24.30	Warm	Influent	2	3
					F1	1	3
					F2	1	3
					F3	1	3
					F4	1	3
					F5	1	3
17	07/17/2F012	07/23/2012	27.70	Warm	Influent	2	3
					F1	1	3
					F2	1	3
					F3	1	3
					F4	1	3
					F5	1	3
18	07/29/2012	07/30/2012	-[3]	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
19	07/31/2012	07/31/2012	26.95	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
20	08/14/2012	08/15/2012	24.50	Warm	Influent	2	3
					F1	1	3
					F2	1	3
					F3	1	3
					F4	1	3
					F5	1	3
21	08/16/2012	08/17/2012	24.65	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
22	08/20/2012	08/21/2012	24.05	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
23	09/25/2012	09/27/2012	16.90	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
24	10/09/2012	10/10/2012	15.20	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3

Data Set	Collection Date (mm/dd/yyyy)	Analysis Date (mm/dd/yyyy)	Water Temperature (°C)	Temperature classification[1]	Sampling location[4]	Number of bottles of sample water collected per location	Number of aliquots analyzed per bottle
25	10/11/2012	10/12/2012	12.90	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
26	10/13/2012	10/13/2012	11.60	Warm	Influent	2	3
					F1	2	3
					F2	2	3
					F3	2	3
					F4	2	3
					F5	2	3
27	06/10/2013	07/11/2013	-[3]	Warm	Influent	3	3
					F1	3	3
					F2	3	3
					F3	3	3
					F4	3	3
					F5	3	3
28	06/14/2013	07/12/2013	18.60	Warm	Influent	3	3
					F1	3	3
					F2	3	3
					F3	3	3
					F4	3	3
					F5	3	3

1. A temperature classification of “Cold” indicates cold water conditions, wherein the influent water temperature was less than 10°C. A temperature classification of “Warm” indicates warm water conditions, wherein the influent water temperature was greater than or equal to 10°C.
2. Samples preserved after collection by dropping the pH of the samples below 2, using hydrochloric acid.
3. Temperature not taken.
4. Sampling locations F1…F5 are the effluents of filters 1 through 5.F1 contained coal-based GAC. F2 contained anthracite. F3 contained rough engineered ceramic media. F4 contained wood-based GAC. F5 contained coal-based GAC and was operated in a constant-head-declining-rate mode. F1…F4 were all operated in a constant-head-constant-rate mode

Data Set 1: Collected December 7, 2011

Raw Data

Table B-2: Data Set 1 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	38.70*	3.891	3.906	3.852	3.554	3.972
		2	38.96*	3.906	3.92	3.852	3.56	3.861
		3	39.13*	3.922	3.97	3.889	3.543	3.836
		Average	38.93	3.906	3.932	3.864	3.552	3.890
	2	1	4.477	3.782	3.931	3.891	3.448	3.714
		2	4.395	3.83	3.994	3.975	3.47	3.773
		3	4.367	3.876	3.961	3.955	3.521	3.806
		Average	4.413	3.829	3.962	3.940	3.480	3.764
	3	1	4.167	3.814	3.942	3.884	3.501	3.744
		2	4.211	3.873	3.99	3.917	3.523	3.823
		3	4.261	3.913	3.957	3.948	3.573	3.865
		Average	4.213	3.867	3.963	3.916	3.532	3.811
	Average		4.313	3.867	3.952	3.907	3.521	3.822
	Standard Deviation		0.1191	0.0484	0.0302	0.0445	0.0420	0.0762
2	1	1	4.332	-	-	-	-	-
		2	4.363	-	-	-	-	-
		3	4.272	-	-	-	-	-
		Average	4.322					
	2	1	4.192	-	-	-	-	-
		2	4.229	-	-	-	-	-
		3	4.283	-	-	-	-	-
		Average	4.235					
	3	1	4.192	-	-	-	-	-
		2	4.242	-	-	-	-	-
		3	4.329	-	-	-	-	-
		Average	4.254					
	Average		4.270	-	-	-	-	-
	Standard Deviation		0.0620	-	-	-	-	-

* Data excluded from further analysis.

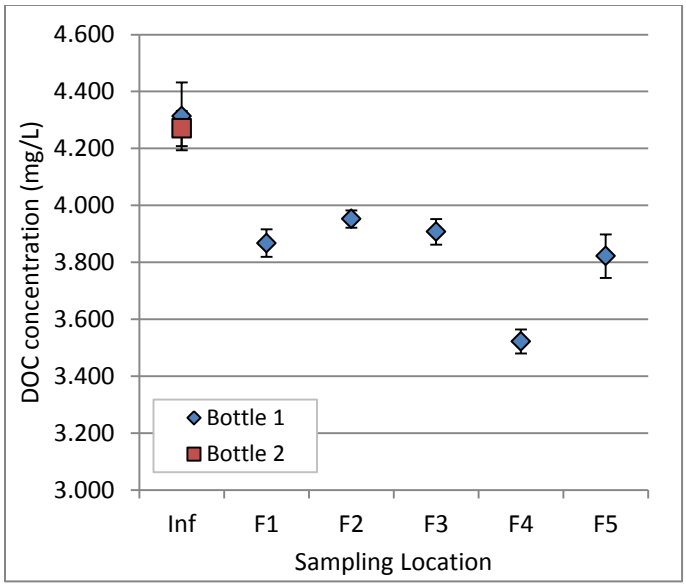

Figure B-1: Data Set 1 Plot of average DOC concentrations

List of Excluded Data from Data Set 1, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Aliquot 1 for influent bottle 1 excluded because the DOC concentration was substantially higher than the DOC concentrations for any of the other aliquots. QA/QC indicated that the higher values were due to a peculiarity of the TOC firmware and software programming that resulted in the vial not being sparged properly.

ANOVA Results

Table B-3: Data Set 1 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.190[a]	5	.238	75.947	1.220E-009
Intercept	292.265	1	292.265	93289.879	3.587E-028
filter#	1.190	5	.238	75.947	1.220E-009
Error	.044	14	.003		
Total	310.498	20			
Corrected Total	1.234	19			

a. R Squared = .964 (Adjusted R Squared = .952)

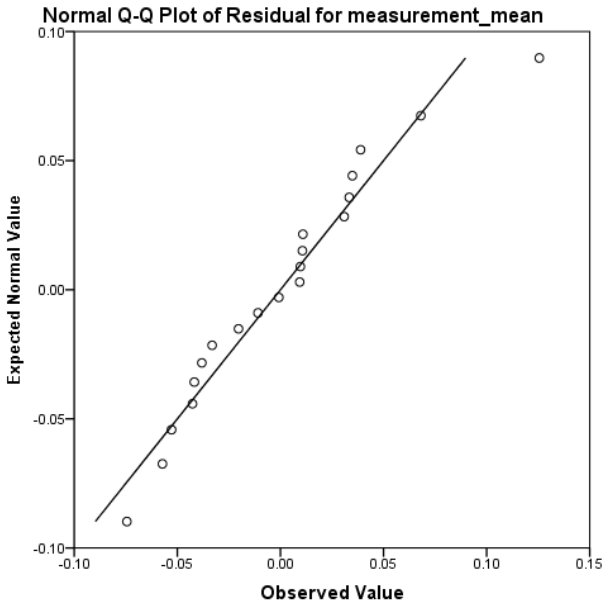

Figure B-2: Data Set 1 normal probability plot of residuals

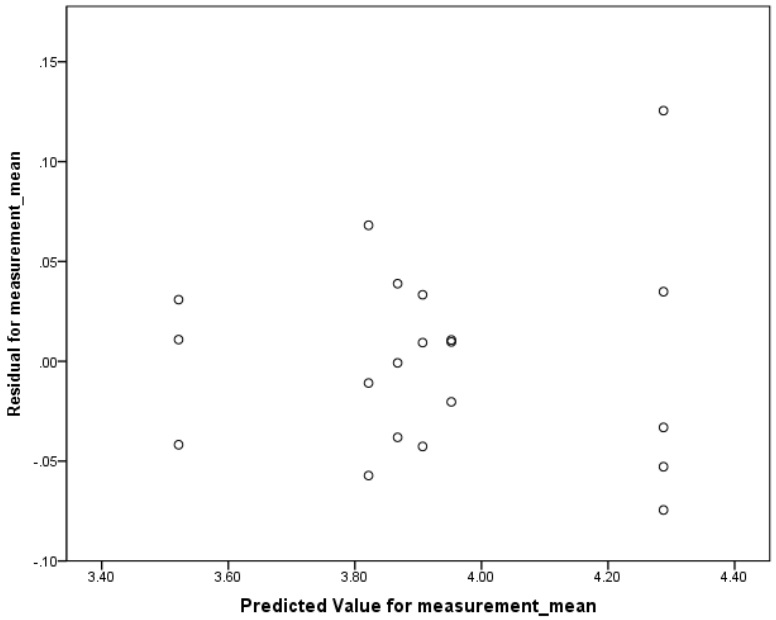

Figure B-3: Data Set 1 plot of residuals versus predicted values

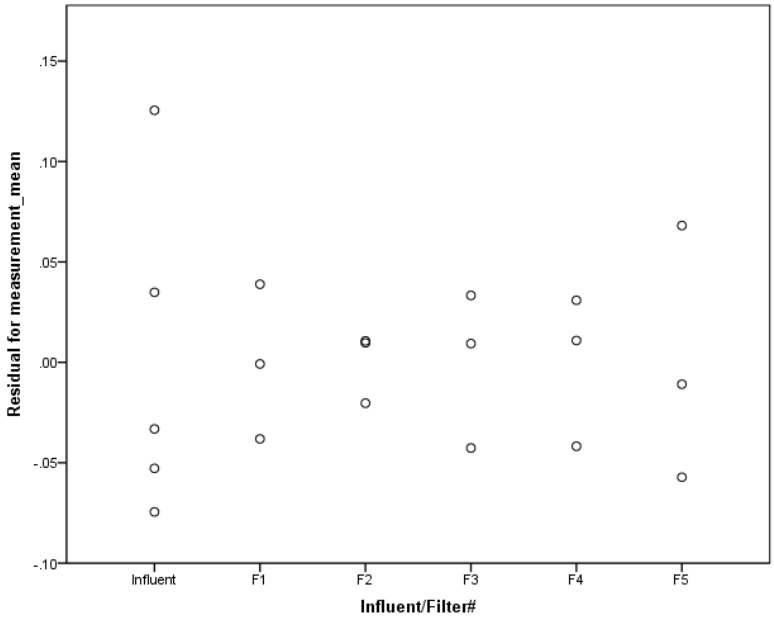

Figure B-4: Data Set 1 plot of residuals versus filter number

Table B-4: Data Set 1 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.830	5	14	1.713E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-5: Data Set 1 Multiple Comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.420*	0.0409	8.330E-007	0.286	0.554
		F2	0.335*	0.0409	1.258E-005	0.201	0.469
		F3	0.380*	0.0409	2.795E-006	0.246	0.515
		F4	0.766*	0.0409	3.334E-010	0.632	0.900
		F5	0.466*	0.0409	2.272E-007	0.332	0.600
	F1	Influent	-0.420*	0.0409	8.330E-007	-0.554	-0.286
		F2	-0.085	0.0457	4.639E-001	-0.235	0.065
		F3	-0.040	0.0457	9.488E-001	-0.189	0.110
		F4	0.346*	0.0457	3.132E-005	0.196	0.496
		F5	0.046	0.0457	9.090E-001	-0.104	0.196
	F2	Influent	-0.335*	0.0409	1.258E-005	-0.469	-0.201
		F1	0.085	0.0457	4.639E-001	-0.065	0.235
		F3	0.045	0.0457	9.131E-001	-0.105	0.195
		F4	0.431*	0.0457	2.392E-006	0.281	0.581
		F5	0.131	0.0457	1.042E-001	-0.019	0.281
	F3	Influent	-0.380*	0.0409	2.795E-006	-0.515	-0.246
		F1	0.040	0.0457	9.488E-001	-0.110	0.189
		F2	-0.045	0.0457	9.131E-001	-0.195	0.105
		F4	0.386*	0.0457	9.010E-006	0.236	0.535
		F5	0.085	0.0457	4.573E-001	-0.064	0.235
	F4	Influent	-0.766*	0.0409	3.334E-010	-0.900	-0.632
		F1	-0.346*	0.0457	3.132E-005	-0.496	-0.196
		F2	-0.431*	0.0457	2.392E-006	-0.581	-0.281
		F3	-0.386*	0.0457	9.010E-006	-0.535	-0.236
		F5	-0.300*	0.0457	1.487E-004	-0.450	-0.150
	F5	Influent	-0.466*	0.0409	2.272E-007	-0.600	-0.332
		F1	-0.046	0.0457	9.090E-001	-0.196	0.104
		F2	-0.131	0.0457	1.042E-001	-0.281	0.019
		F3	-0.085	0.0457	4.573E-001	-0.235	0.064
		F4	0.300*	0.0457	1.487E-004	0.150	0.450
Dunnett T3	Influent	F1	0.420*	0.0426	7.362E-004	0.237	0.603
		F2	0.335*	0.0377	4.063E-003	0.154	0.516
		F3	0.380*	0.0427	1.276E-003	0.197	0.564
		F4	0.766*	0.0423	2.432E-005	0.584	0.948
		F5	0.466*	0.0516	1.988E-003	0.234	0.697
	F1	Influent	-0.420*	0.0426	7.362E-004	-0.603	-0.237
		F2	-0.085	0.0244	2.338E-001	-0.247	0.077
		F3	-0.040	0.0316	9.152E-001	-0.203	0.124
		F4	0.346*	0.0310	2.963E-003	0.186	0.506
		F5	0.046	0.0428	9.573E-001	-0.204	0.296
	F2	Influent	-0.335*	0.0377	4.063E-003	-0.516	-0.154
		F1	0.085	0.0244	2.338E-001	-0.077	0.247
		F3	0.045	0.0246	6.718E-001	-0.118	0.209
		F4	0.431*	0.0239	3.109E-003	0.274	0.587
		F5	0.131	0.0380	2.741E-001	-0.170	0.431
	F3	Influent	-0.380*	0.0427	1.276E-003	-0.564	-0.197
		F1	0.040	0.0316	9.152E-001	-0.124	0.203
		F2	-0.045	0.0246	6.718E-001	-0.209	0.118
		F4	0.386*	0.0312	1.989E-003	0.224	0.547
		F5	0.085	0.0429	6.025E-001	-0.164	0.335
	F4	Influent	-0.766*	0.0423	2.432E-005	-0.948	-0.584
		F1	-0.346*	0.0310	2.963E-003	-0.506	-0.186
		F2	-0.431*	0.0239	3.109E-003	-0.587	-0.274
		F3	-0.386*	0.0312	1.989E-003	-0.547	-0.224
		F5	-0.300*	0.0425	2.938E-002	-0.551	-0.049
	F5	Influent	-0.466*	0.0516	1.988E-003	-0.697	-0.234
		F1	-0.046	0.0428	9.573E-001	-0.296	0.204
		F2	-0.131	0.0380	2.741E-001	-0.431	0.170
		F3	-0.085	0.0429	6.025E-001	-0.335	0.164
		F4	0.300*	0.0425	2.938E-002	0.049	0.551

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) is a factor that has a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals is broadly OK, indicating that the residuals were relatively normally distributed.
3. The plot of residuals versus influent/filter # indicates some potential heteroscedasticity between the influent and the filter effluents but little to no heteroscedasticity between residuals from filter effluent DOC concentrations.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit significant heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 2: Collected January17, 2012

Raw Data

Table B-6: Data Set 2 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.827	3.297	3.410	3.336	3.142	3.369
		2	3.812	3.311	3.379	3.309	3.237	3.425
		3	3.829	3.404	3.414	3.458	3.235	3.357
		Average	3.823	3.337	3.401	3.368	3.205	3.384
	2	1	3.600	3.247	3.369	3.371	3.123	3.200
		2	3.641	3.284	3.427	3.421	3.177	3.249
		3	3.658	3.338	3.464	3.435	3.165	3.257
		Average	3.633	3.290	3.420	3.409	3.155	3.235
	3	1						
		2						
		3						
		Average						
	Average		3.728	3.314	3.411	3.388	3.180	3.310
	Standard Deviation		0.1057	0.0536	0.0342	0.0590	0.0473	0.0867
2	1	1	3.693					
		2	3.734					
		3	3.647					
		Average	3.691					
	2	1	3.569					
		2	3.652					
		3	3.678					
		Average	3.633					
	3	1						
		2						
		3						
		Average						
	Average		3.662					
	Standard Deviation		0.0555					

* Data excluded from further analysis.

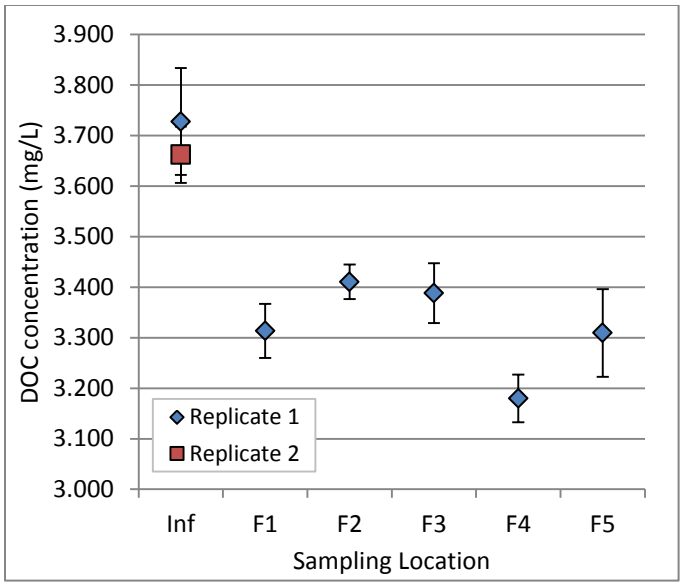

Figure B-5: Data Set 2 Plot of average DOC concentrations

List of Excluded Data from Data Set 2, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded

ANOVA Results

Table B-7: Data Set 2 ANOVA Table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.466[a]	5	0.093	19.430	2.752E-004
Intercept	149.802	1	149.802	31203.993	1.180E-015
filter#	0.466	5	0.093	19.430	2.752E-004
Error	0.038	8	0.005		
Total	164.962	14			
Corrected Total	0.505	13			

a. R Squared = .924 (Adjusted R Squared = .876)

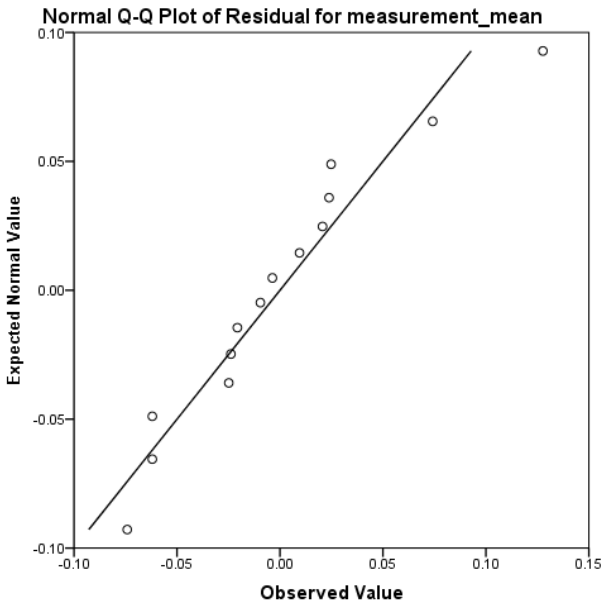

Figure B-6: Data Set 2 normal probability plot of residuals

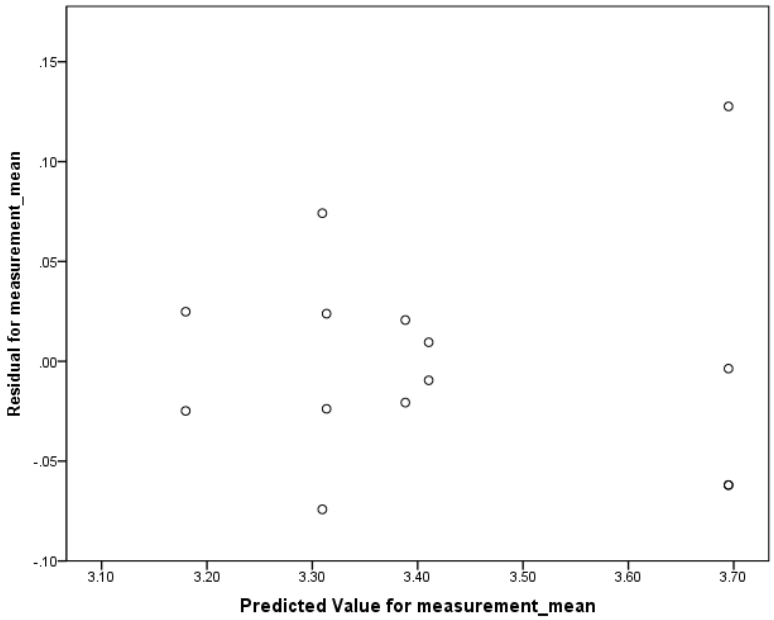

Figure B-7: Data Set 2 plot of residuals versus predicted values

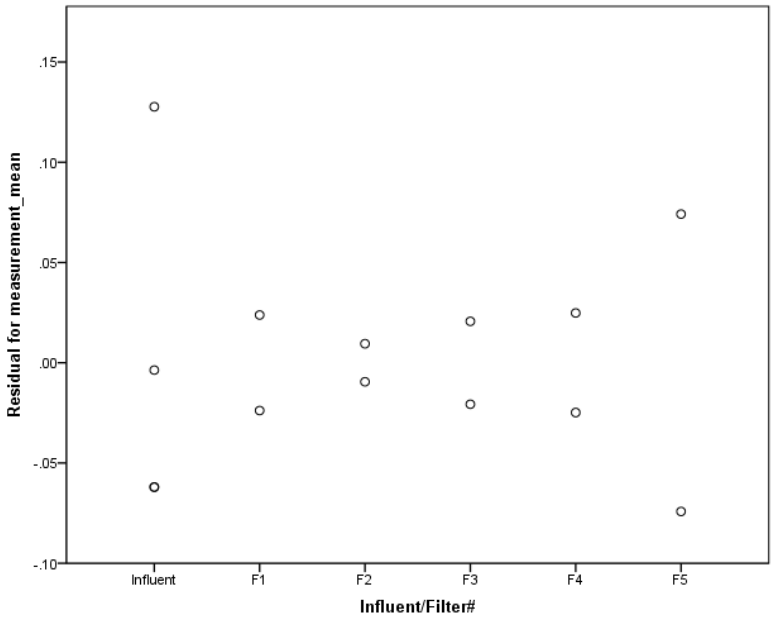

Figure B-8: Data Set 2 plot of residuals versus filter number

Table B-8: Data Set 2 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.703	5	8	2.396E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-9: Data Set 2 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.381*	0.0600	1.991E-003	0.162	0.601
		F2	0.285*	0.0600	1.244E-002	0.065	0.504
		F3	0.307*	0.0600	7.973E-003	0.087	0.526
		F4	0.515*	0.0600	2.479E-004	0.296	0.734
		F5	0.385*	0.0600	1.858E-003	0.166	0.605
	F1	Influent	-0.381*	0.0600	1.991E-003	-0.601	-0.162
		F2	-0.097	0.0693	7.273E-001	-0.350	0.156
		F3	-0.075	0.0693	8.765E-001	-0.328	0.178
		F4	0.134	0.0693	4.495E-001	-0.119	0.387
		F5	0.004	0.0693	1.000E+000	-0.249	0.257
	F2	Influent	-0.285*	0.0600	1.244E-002	-0.504	-0.065
		F1	0.097	0.0693	7.273E-001	-0.156	0.350
		F3	0.022	0.0693	9.994E-001	-0.231	0.275
		F4	0.231	0.0693	7.699E-002	-0.022	0.484
		F5	0.101	0.0693	6.967E-001	-0.152	0.354
	F3	Influent	-0.307*	0.0600	7.973E-003	-0.526	-0.087
		F1	0.075	0.0693	8.765E-001	-0.178	0.328
		F2	-0.022	0.0693	9.994E-001	-0.275	0.231
		F4	0.209	0.0693	1.179E-001	-0.045	0.462
		F5	0.079	0.0693	8.531E-001	-0.174	0.332
	F4	Influent	-0.515*	0.0600	2.479E-004	-0.734	-0.296
		F1	-0.134	0.0693	4.495E-001	-0.387	0.119
		F2	-0.231	0.0693	7.699E-002	-0.484	0.022
		F3	-0.209	0.0693	1.179E-001	-0.462	0.045
		F5	-0.130	0.0693	4.777E-001	-0.383	0.123
	F5	Influent	-0.385*	0.0600	1.858E-003	-0.605	-0.166
		F1	-0.004	0.0693	1.000E+000	-0.257	0.249
		F2	-0.101	0.0693	6.967E-001	-0.354	0.152
		F3	-0.079	0.0693	8.531E-001	-0.332	0.174
		F4	0.130	0.0693	4.777E-001	-0.123	0.383
Dunnett T3	Influent	F1	0.381*	0.0507	1.325E-002	0.119	0.644
		F2	0.285*	0.0457	4.253E-002	0.015	0.554
		F3	0.307*	0.0493	2.805E-002	0.048	0.565
		F4	0.515*	0.0512	4.381E-003	0.251	0.780
		F5	0.385	0.0866	2.204E-001	-0.547	1.318
	F1	Influent	-0.381*	0.0507	1.325E-002	-0.644	-0.119
		F2	-0.097	0.0257	3.493E-001	-0.553	0.359
		F3	-0.075	0.0315	5.186E-001	-0.375	0.225
		F4	0.134	0.0344	2.483E-001	-0.186	0.454
		F5	0.004	0.0779	1.000E+000	-1.639	1.647
	F2	Influent	-0.285*	0.0457	4.253E-002	-0.554	-0.015
		F1	0.097	0.0257	3.493E-001	-0.359	0.553
		F3	0.022	0.0227	9.527E-001	-0.333	0.378
		F4	0.231	0.0266	1.301E-001	-0.259	0.721
		F5	0.101	0.0748	8.481E-001	-2.150	2.352
	F3	Influent	-0.307*	0.0493	2.805E-002	-0.565	-0.048
		F1	0.075	0.0315	5.186E-001	-0.225	0.375
		F2	-0.022	0.0227	9.527E-001	-0.378	0.333
		F4	0.209	0.0323	1.055E-001	-0.103	0.520
		F5	0.079	0.0770	9.361E-001	-1.702	1.859
	F4	Influent	-0.515*	0.0512	4.381E-003	-0.780	-0.251
		F1	-0.134	0.0344	2.483E-001	-0.454	0.186
		F2	-0.231	0.0266	1.301E-001	-0.721	0.259
		F3	-0.209	0.0323	1.055E-001	-0.520	0.103
		F5	-0.130	0.0782	7.588E-001	-1.731	1.472
	F5	Influent	-0.385	0.0866	2.204E-001	-1.318	0.547
		F1	-0.004	0.0779	1.000E+000	-1.647	1.639
		F2	-0.101	0.0748	8.481E-001	-2.352	2.150
		F3	-0.079	0.0770	9.361E-001	-1.859	1.702
		F4	0.130	0.0782	7.588E-001	-1.472	1.731

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) is a factor that has a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals is broadly OK, indicating that the residuals were relatively normally distributed.
3. The plot of residuals versus influent/filter # indicates some potential heteroscedasticity but this seems to be minimal for F1-F5.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit significant heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 3: Collected January 26, 2012

Raw Data

Table B-10: Data Set 3 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.699	3.300	3.359	-	3.052	3.369
		2	3.895	3.238	3.254	-	3.02	3.369
		3	3.751	3.331	3.386	-	2.961	3.358
		Average	3.782	3.290	3.333	-	3.011	3.365
	2	1	3.544	3.450	3.324	-	3.016	3.361
		2	3.657	3.399	3.341	-	2.971	3.382
		3	3.613	3.345	3.250	-	2.979	3.252
		Average	3.605	3.398	3.305	-	2.989	3.332
	3	1	3.481	-	-	-	-	-
		2	3.445	-	-	-	-	-
		3	3.486	-	-	-	-	-
		Average	3.471	-	-	-	-	-
	Average		3.619	3.344	3.319	-	3.000	3.349
	Standard Deviation		0.1475	0.0743	0.0558	-	0.0351	0.0480
2	1	1	3.530	-	-	-	-	-
		2	3.599	-	-	-	-	-
		3	3.541	-	-	-	-	-
		Average	3.557	-	-	-	-	-
	2	1	3.693	-	-	-	-	-
		2	3.614	-	-	-	-	-
		3	3.690	-	-	-	-	-
		Average	3.666	-	-	-	-	-
	3	1	3.436	-	-	-	-	-
		2	3.486	-	-	-	-	-
		3	3.448	-	-	-	-	-
		Average	3.457	-	-	-	-	-
	Average		3.560	-	-	-	-	-
	Standard Deviation		0.0960	-	-	-	-	-

* Data excluded from further analysis.

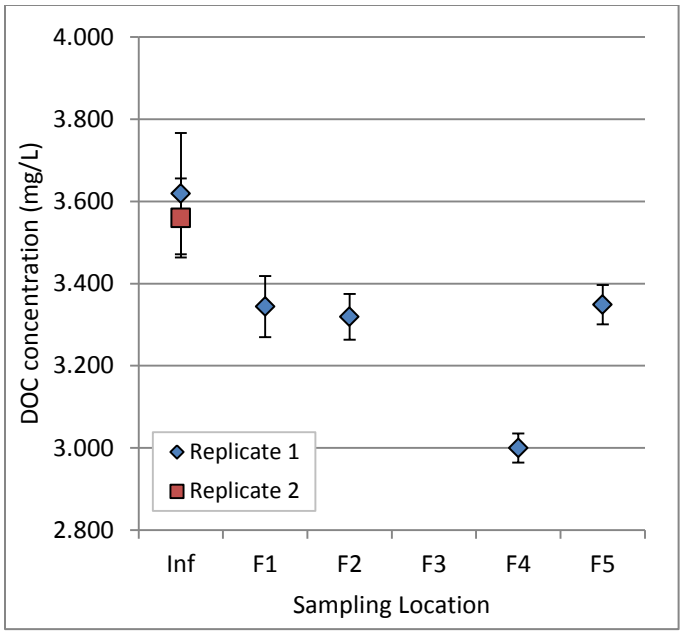

Figure B-9: Data Set 3 plot of average DOC concentrations

List of Excluded Data from Data Set 3, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Bottle containing Filter 3 effluent broke in transport. No data was available for this bottle.

ANOVA Results

Table B-11: Data Set 3 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.560[a]	4	0.140	15.202	4.881E-004
Intercept	127.189	1	127.189	13811.652	1.187E-015
filter#	0.560	4	0.140	15.202	4.881E-004
Error	0.083	9	0.009		
Total	162.200	14			
Corrected Total	0.643	13			

a. R Squared = .871 (Adjusted R Squared = .814)

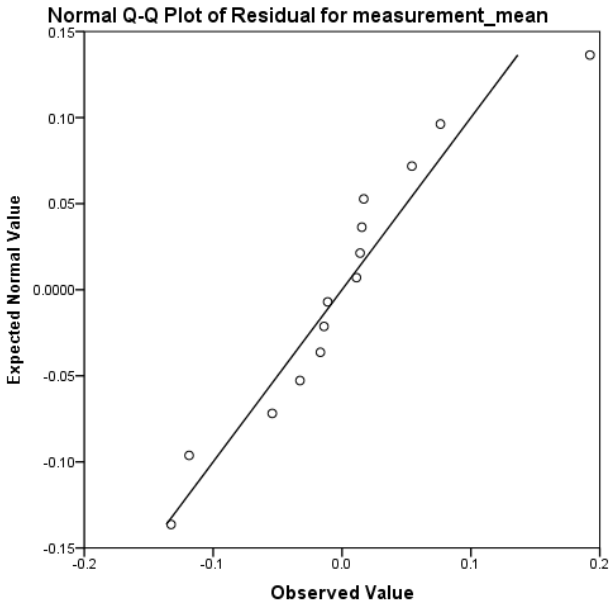

Figure B-10: Data Set 3 normal probability plot of residuals

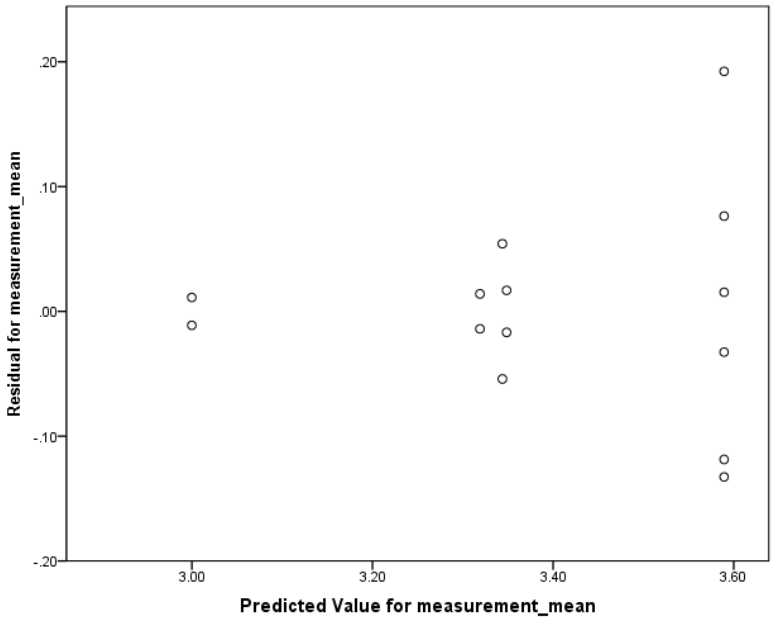

Figure B-11: Data Set 3 plot of residuals versus predicted values

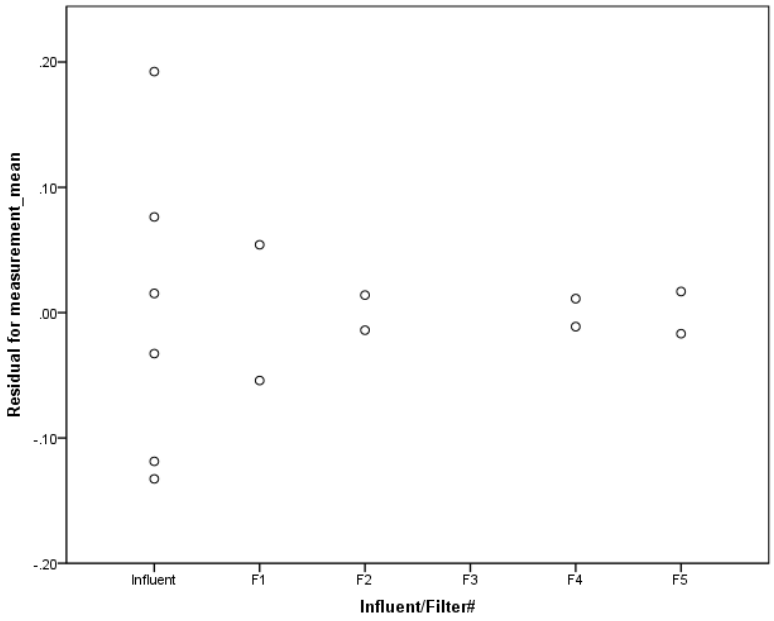

Figure B-12: Data Set 3 plot of residuals versus filter number

Table B-12: Data Set 3 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.997	4	9	1.787E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-13: Data Set 3 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.245	0.0784	6.994E-002	-0.018	0.509
		F2	0.270*	0.0784	4.399E-002	0.007	0.534
		F4	0.590*	0.0784	2.604E-004	0.326	0.853
		F5	0.241	0.0784	7.630E-002	-0.023	0.504
	F1	Influent	-0.245	0.0784	6.994E-002	-0.509	0.018
		F2	0.025	0.0960	9.988E-001	-0.298	0.348
		F4	0.344*	0.0960	3.615E-002	0.021	0.667
		F5	-0.005	0.0960	1.000E+000	-0.327	0.318
	F2	Influent	-0.270*	0.0784	4.399E-002	-0.534	-0.007
		F1	-0.025	0.0960	9.988E-001	-0.348	0.298
		F4	0.319	0.0960	5.275E-002	-0.004	0.642
		F5	-0.030	0.0960	9.977E-001	-0.352	0.293
	F4	Influent	-0.590*	0.0784	2.604E-004	-0.853	-0.326
		F1	-0.344*	0.0960	3.615E-002	-0.667	-0.021
		F2	-0.319	0.0960	5.275E-002	-0.642	0.004
		F5	-0.349*	0.0960	3.368E-002	-0.671	-0.026
	F5	Influent	-0.241	0.0784	7.630E-002	-0.504	0.023
		F1	0.005	0.0960	1.000E+000	-0.318	0.327
		F2	0.030	0.0960	9.977E-001	-0.293	0.352
		F4	0.349*	0.0960	3.368E-002	0.026	0.671
Dunnett T3**	Influent	F1	0.245	0.0739	2.037E-001	-0.182	0.673
		F2	0.270*	0.0522	1.783E-002	0.056	0.484
		F4	0.590*	0.0515	3.874E-004	0.375	0.804
		F5	0.241*	0.0530	3.032E-002	0.026	0.456
	F1	Influent	-0.245	0.0739	2.037E-001	-0.673	0.182
		F2	0.025	0.0559	9.981E-001	-1.214	1.264
		F4	0.344	0.0553	2.167E-001	-1.010	1.698
		F5	-0.005	0.0567	1.000E+000	-1.129	1.120
	F2	Influent	-0.270*	0.0522	1.783E-002	-0.484	-0.056
		F1	-0.025	0.0559	9.981E-001	-1.264	1.214
		F4	0.319*	0.0179	1.415E-002	0.156	0.482
		F5	-0.030	0.0219	8.066E-001	-0.225	0.166
	F4	Influent	-0.590*	0.0515	3.874E-004	-0.804	-0.375
		F1	-0.344	0.0553	2.167E-001	-1.698	1.010
		F2	-0.319*	0.0179	1.415E-002	-0.482	-0.156
		F5	-0.349*	0.0202	2.057E-002	-0.556	-0.141
	F5	Influent	-0.241*	0.0530	3.032E-002	-0.456	-0.026
		F1	0.005	0.0567	1.000E+000	-1.120	1.129
		F2	0.030	0.0219	8.066E-001	-0.166	0.225
		F4	0.349*	0.0202	2.057E-002	0.141	0.556

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) is a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals is broadly OK, indicating that the residuals were relatively normally distributed.
3. The plot of residuals versus influent/filter # indicates heteroscedasticity
4. Results from Levene's test of equality of variance do not provide a strong indication of heteroscedasticity.
5. As a result of the clear heteroscedasticity observed in the plot of residuals, the data were considered to be heteroscedastic; therefore, results from Dunnett's T3 test were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 4: Collected January 30, 2012

Raw Data

Table B-14: Data Set 4 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.587*	3.710*	3.938*	3.883*	3.595*	3.857*
		2	4.456*	3.633*	3.942*	3.861*	3.562*	3.831*
		3	4.427*	3.663*	3.952*	3.835*	3.587*	3.810*
		Average	4.490	3.669	3.944	3.860	3.581	3.833
	2	1	4.357*	3.579*	3.988*	3.865*	3.623*	3.974*
		2	4.363*	3.550*	4.109*	3.867*	3.718*	3.887*
		3	4.431*	3.589*	3.980*	3.907*	3.762*	3.915*
		Average	4.384	3.573	4.026	3.880	3.701	3.925
	3	1	4.081*	-	-	-	-	-
		2	4.048*	-	-	-	-	-
		3	4.028*	-	-	-	-	-
		Average	4.052	-	-	-	-	-
	Average		4.309	3.621	3.985	3.870	3.641	3.879
	Standard Deviation		0.2037	0.0594	0.0641	0.0240	0.0802	0.0599
2	1	1	4.677*	-	-	-	-	-
		2	4.694*	-	-	-	-	-
		3	4.647*	-	-	-	-	-
		Average	4.673	-	-	-	-	-
	2	1	4.502*	-	-	-	-	-
		2	4.476*	-	-	-	-	-
		3	4.450*	-	-	-	-	-
		Average	4.476	-	-	-	-	-
	3	1	4.409*	-	-	-	-	-
		2	4.377*	-	-	-	-	-
		3	4.397*	-	-	-	-	-
		Average	4.394	-	-	-	-	-
	Average		4.514	-	-	-	-	-
	Standard Deviation		0.1254	-	-	-	-	-

* Data excluded from further analysis.

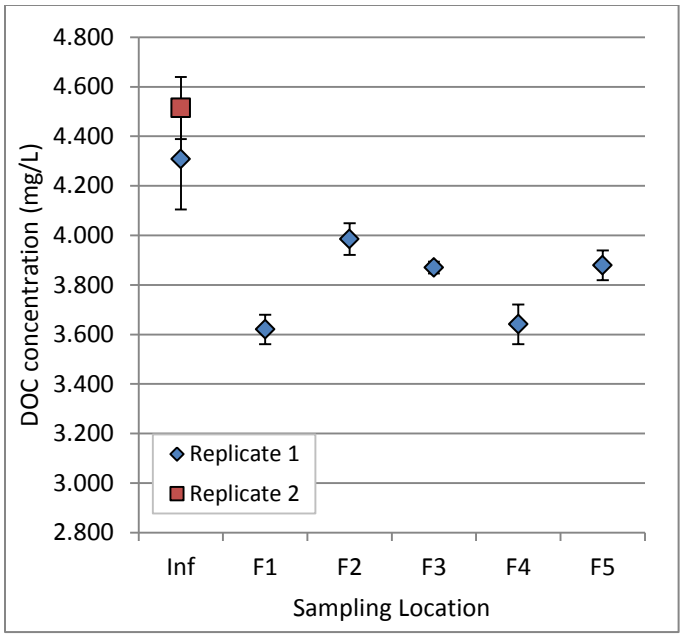

Figure B-13: Data Set 4 plot of average DOC concentrations

List of Excluded Data from Data Set 4, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. All data from data set four excluded from analysis because residuals from the ANOVA were non-normal. See the ANOVA results section for more detail.

ANOVA Results

Table B-15: Data Set 4 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.364[a]	5	0.273	76.363	1.561E-006
Intercept	199.646	1	199.646	55870.086	1.149E-016
filter#	1.364	5	0.273	76.363	1.561E-006
Error	0.029	8	0.004		
Total	223.275	14			
Corrected Total	1.393	13			

a. R Squared = .979 (Adjusted R Squared = .967)

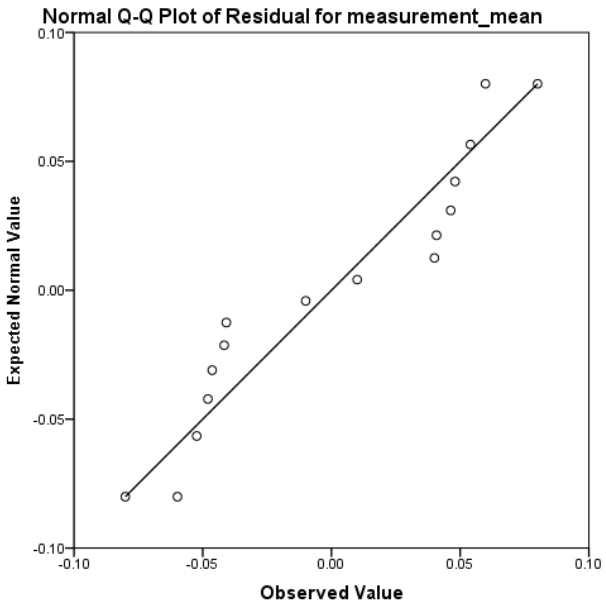

Figure B-14: Data Set 4 normal probability plot of residuals

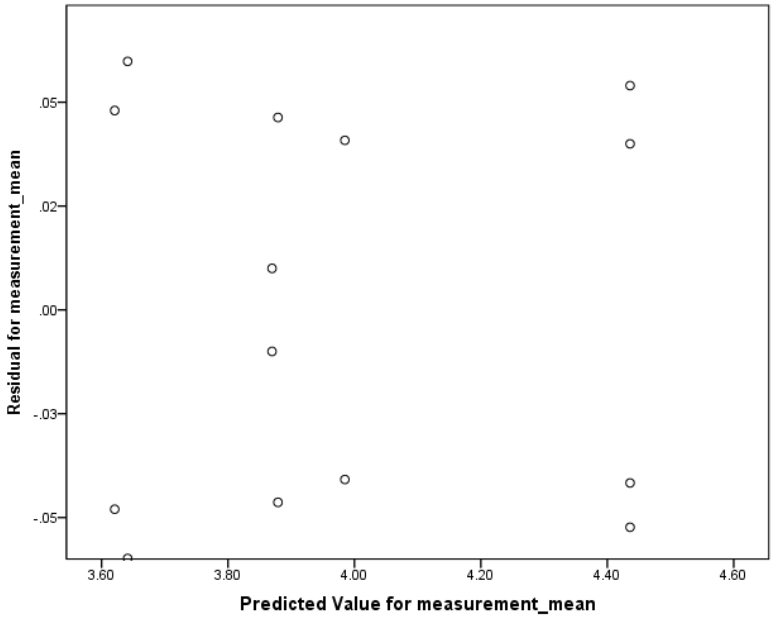

Figure B-15: Data Set 4 plot of residuals versus predicted values

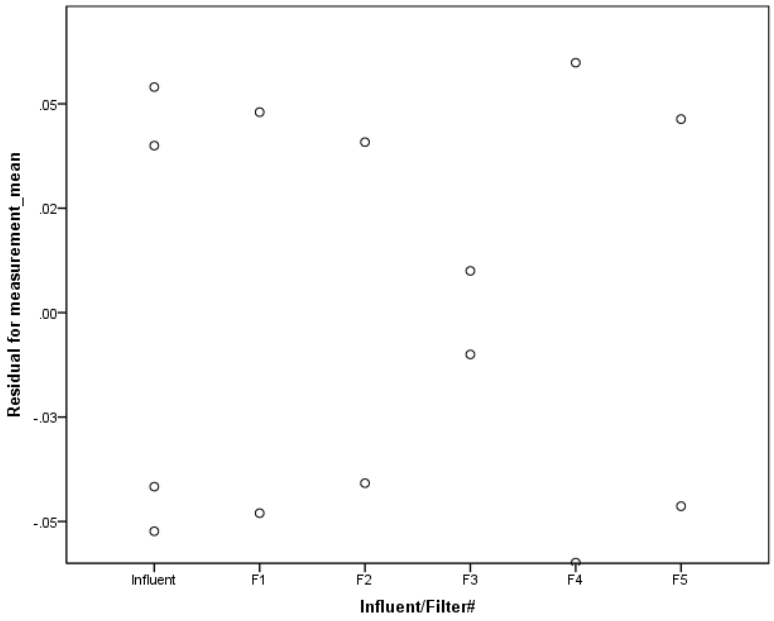

Figure B-16: Data Set 4 plot of residuals versus filter number

Table B-16: Data Set 4 results from Levene's test of equality of variances

F	df1	df2	Sig.
29.845	5	8	5.683E-005

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-17: Data Set 4 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.815*	0.0518	2.588E-006	0.626	1.004
		F2	0.451*	0.0518	2.225E-004	0.262	0.640
		F3	0.566*	0.0518	4.174E-005	0.377	0.755
		F4	0.795*	0.0518	3.152E-006	0.606	0.984
		F5	0.557*	0.0518	4.727E-005	0.368	0.746
	F1	Influent	-0.815*	0.0518	2.588E-006	-1.004	-0.626
		F2	-0.364*	0.0598	2.638E-003	-0.583	-0.146
		F3	-0.249*	0.0598	2.564E-002	-0.467	-0.031
		F4	-0.021	0.0598	9.991E-001	-0.239	0.198
		F5	-0.258*	0.0598	2.100E-002	-0.477	-0.040
	F2	Influent	-0.451*	0.0518	2.225E-004	-0.640	-0.262
		F1	0.364*	0.0598	2.638E-003	0.146	0.583
		F3	0.115	0.0598	4.508E-001	-0.103	0.334
		F4	0.344*	0.0598	3.835E-003	0.125	0.562
		F5	0.106	0.0598	5.292E-001	-0.113	0.324
	F3	Influent	-0.566*	0.0518	4.174E-005	-0.755	-0.377
		F1	0.249*	0.0598	2.564E-002	0.031	0.467
		F2	-0.115	0.0598	4.508E-001	-0.334	0.103
		F4	0.228*	0.0598	4.003E-002	0.010	0.447
		F5	-0.009	0.0598	1.000E+000	-0.228	0.209
	F4	Influent	-0.795*	0.0518	3.152E-006	-0.984	-0.606
		F1	0.021	0.0598	9.991E-001	-0.198	0.239
		F2	-0.344*	0.0598	3.835E-003	-0.562	-0.125
		F3	-0.228*	0.0598	4.003E-002	-0.447	-0.010
		F5	-0.238*	0.0598	3.264E-002	-0.456	-0.019
	F5	Influent	-0.557*	0.0518	4.727E-005	-0.746	-0.368
		F1	0.258*	0.0598	2.100E-002	0.040	0.477
		F2	-0.106	0.0598	5.292E-001	-0.324	0.113
		F3	0.009	0.0598	1.000E+000	-0.209	0.228
		F4	0.238*	0.0598	3.264E-002	0.019	0.456
Dunnett T3	Influent	F1	0.815*	0.0553	3.312E-002	0.178	1.453
		F2	0.451	0.0492	5.300E-002	-0.014	0.916
		F3	0.566*	0.0291	5.988E-004	0.408	0.725
		F4	0.795	0.0658	6.763E-002	-0.188	1.777
		F5	0.557	0.0538	5.588E-002	-0.037	1.151
	F1	Influent	-0.815*	0.0553	3.312E-002	-1.453	-0.178
		F2	-0.364	0.0630	1.274E-001	-0.967	0.239
		F3	-0.249	0.0490	2.917E-001	-1.552	1.054
		F4	-0.021	0.0767	1.000E+000	-0.774	0.733
		F5	-0.258	0.0667	2.494E-001	-0.878	0.362
	F2	Influent	-0.451	0.0492	5.300E-002	-0.916	0.014
		F1	0.364	0.0630	1.274E-001	-0.239	0.967
		F3	0.115	0.0420	5.203E-001	-0.927	1.157
		F4	0.344	0.0724	2.011E-001	-0.446	1.133
		F5	0.106	0.0618	7.293E-001	-0.478	0.690
	F3	Influent	-0.566*	0.0291	5.988E-004	-0.725	-0.408
		F1	0.249	0.0490	2.917E-001	-1.054	1.552
		F2	-0.115	0.0420	5.203E-001	-1.157	0.927
		F4	0.228	0.0607	3.986E-001	-1.500	1.957
		F5	-0.009	0.0474	1.000E+000	-1.252	1.233
	F4	Influent	-0.795	0.0658	6.763E-002	-1.777	0.188
		F1	0.021	0.0767	1.000E+000	-0.733	0.774
		F2	-0.344	0.0724	2.011E-001	-1.133	0.446
		F3	-0.228	0.0607	3.986E-001	-1.957	1.500
		F5	-0.238	0.0757	3.595E-001	-0.995	0.520
	F5	Influent	-0.557	0.0538	5.588E-002	-1.151	0.037
		F1	0.258	0.0667	2.494E-001	-0.362	0.878
		F2	-0.106	0.0618	7.293E-001	-0.690	0.478
		F3	0.009	0.0474	1.000E+000	-1.233	1.252
		F4	0.238	0.0757	3.595E-001	-0.520	0.995

Based on observed means.
*. The mean difference is significant at the .05 level.

Brief Analysis of ANOVA Results:

1. Based on the ANOVA, filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. However, the normal probability plot of residuals shows non-normality. The ANOVA used is based on the assumption of normal residuals and is not valid if the residuals are not normally distributed. The reason for the non-normality is unknown. The non-normality was not due to a one or two outlier values that could be excluded, and the majority of the other data sets had normal data; therefore, the data were considered to be questionable and were excluded from consideration.

Data Set 5: Collected March 1, 2012

Raw Data

Table B-18: Data Set 5 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.019	3.267	3.965*	3.270	3.226	3.125*
		2	3.770	3.276	3.831*	3.483	3.353	3.280*
		3	4.006	3.261	3.824*	3.290	3.230	3.171*
		Average	3.932	3.268	3.873	3.348	3.270	3.192
	2	1	3.879	3.406	3.826*	3.661	3.418	3.169*
		2	3.958	3.339	3.812*	3.699	3.288	3.171*
		3	3.950	3.357	3.937*	3.519	3.232	3.148*
		Average	3.929	3.367	3.858	3.626	3.313	3.163
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		3.930	3.318	3.866	3.487	3.291	3.177
	Standard Deviation		0.0928	0.0589	0.0669	0.1801	0.0793	0.0535
2	1	1	4.121	3.224	3.349*	3.313	3.127	4.371*
		2	4.019	3.295	3.360*	3.508	3.403	4.130*
		3	3.956	3.251	3.368*	3.320	3.058	4.092*
		Average	4.032	3.257	3.359	3.380	3.196	4.198
	2	1	3.789	3.491	3.546*	3.860	3.188	4.253*
		2	3.676	3.506	3.527*	3.730	3.052	4.174*
		3	3.784	3.533	3.604*	3.784	3.064	4.172*
		Average	3.750	3.510	3.559	3.791	3.101	4.200
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		3.891	3.383	3.459	3.586	3.149	4.199
	Standard Deviation		0.1683	0.1412	0.1126	0.2393	0.1352	0.1001

* Data excluded from further analysis.

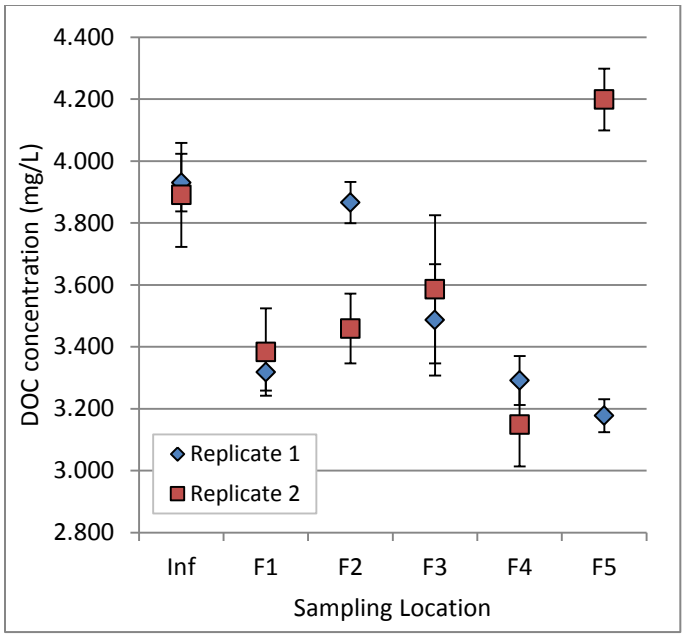

Figure B-17: Data Set 5 plot of average DOC concentrations

List of Excluded Data from Data Set 5, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data associated with Filters 2 and 5 excluded from further analysis because the DOC readings from bottles collected at the same time were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 2 and at least one of the bottles used to collect samples from Filter 5 was contaminated.

ANOVA Results

Table B-19: Data Set 5 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.083[a]	3	0.361	17.928	9.923E-005
Intercept	196.488	1	196.488	9762.482	7.728E-019
filter#	1.083	3	0.361	17.928	9.923E-005
Error	0.242	12	0.020		
Total	197.812	16			
Corrected Total	1.324	15			

a. R Squared = .818 (Adjusted R Squared = .772)

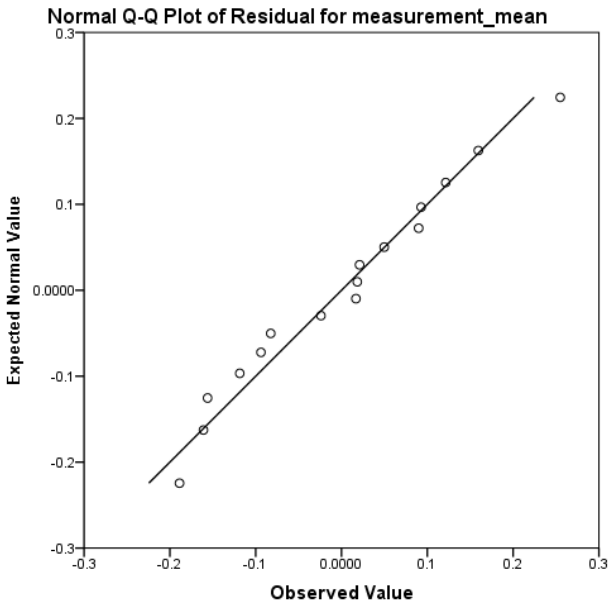

Figure B-18: Data Set 5 normal probability plot of residuals

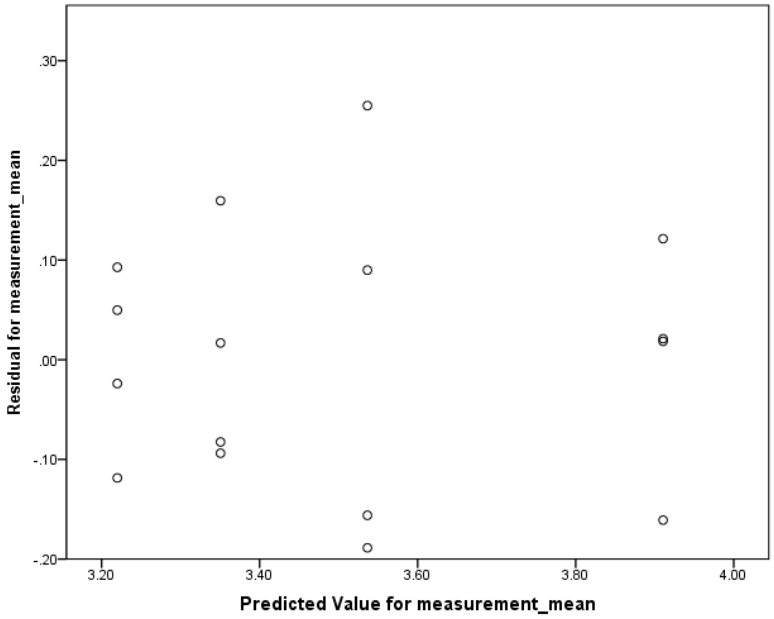

Figure B-19: Data Set 5 plot of residuals versus predicted values

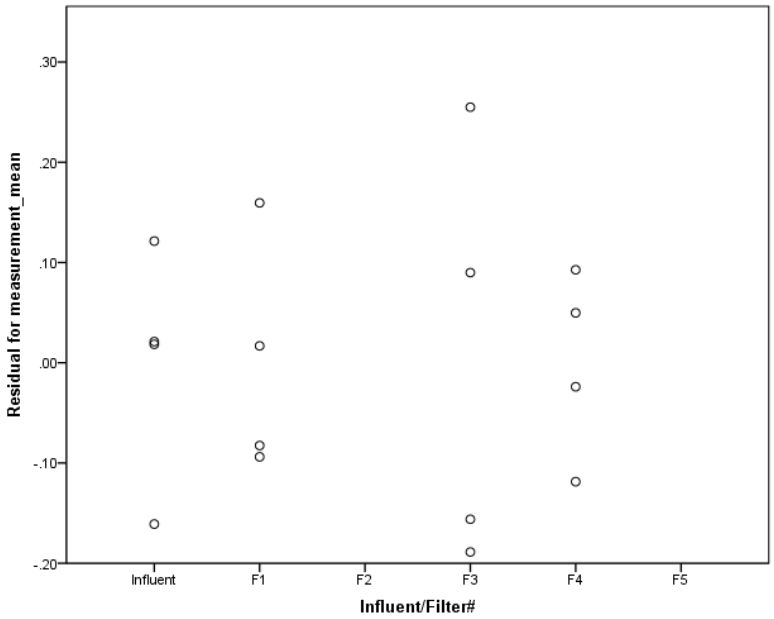

Figure B-20: Data Set 5 plot of residuals versus filter number

Table B-20: Data Set 5 results from Levene's test of equality of variances

F	df1	df2	Sig.
2.314	3	12	1.277E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-21: Data Set 5 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.560*	0.1003	5.961E-004	0.262	0.858
		F3	0.374*	0.1003	1.323E-002	0.076	0.672
		F4	0.691*	0.1003	8.634E-005	0.393	0.988
	F1	Influent	-0.560*	0.1003	5.961E-004	-0.858	-0.262
		F3	-0.186	0.1003	2.973E-001	-0.484	0.112
		F4	0.131	0.1003	5.791E-001	-0.167	0.428
	F3	Influent	-0.374*	0.1003	1.323E-002	-0.672	-0.076
		F1	0.186	0.1003	2.973E-001	-0.112	0.484
		F4	0.316*	0.1003	3.620E-002	0.019	0.614
	F4	Influent	-0.691*	0.1003	8.634E-005	-0.988	-0.393
		F1	-0.131	0.1003	5.791E-001	-0.428	0.167
		F3	-0.316*	0.1003	3.620E-002	-0.614	-0.019
Dunnett T3	Influent	F1	0.560*	0.0830	2.622E-003	0.256	0.864
		F3	0.374	0.1206	1.223E-001	-0.112	0.860
		F4	0.691*	0.0748	6.223E-004	0.411	0.970
	F1	Influent	-0.560*	0.0830	2.622E-003	-0.864	-0.256
		F3	-0.186	0.1206	5.978E-001	-0.672	0.300
		F4	0.131	0.0748	4.826E-001	-0.148	0.410
	F3	Influent	-0.374	0.1206	1.223E-001	-0.860	0.112
		F1	0.186	0.1206	5.978E-001	-0.300	0.672
		F4	0.316	0.1150	1.929E-001	-0.178	0.811
	F4	Influent	-0.691*	0.0748	6.223E-004	-0.970	-0.411
		F1	-0.131	0.0748	4.826E-001	-0.410	0.148
		F3	-0.316	0.1150	1.929E-001	-0.811	0.178

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) is a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals is OK, indicating that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the data are not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 6: Collected March 5, 2012

Raw Data

Table B-22: Data Set 6 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.503	3.288	3.842*	3.360	3.139	3.303
		2	3.541	3.249	3.881*	3.389	3.196	3.222
		3	3.602	3.281	3.885*	3.398	3.196	3.236
		Average	3.549	3.273	3.869	3.382	3.177	3.254
	2	1	3.576	3.224	3.365	3.446	3.121	3.298
		2	3.635	3.267	3.446	3.458	3.157	3.377
		3	3.686	3.307	3.430	3.482	3.191	3.374
		Average	3.632	3.266	3.414	3.462	3.156	3.350
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		3.591	3.269	3.642	3.422	3.167	3.302
	Standard Deviation		0.0656	0.0296	0.2515	0.0469	0.0324	0.0657
2	1	1	3.616	3.267	3.418	3.316	3.129	3.193
		2	3.678	3.328	3.455	3.340	3.151	3.222
		3	3.687	3.334	3.476	3.374	3.152	3.245
		Average	3.660	3.310	3.450	3.343	3.144	3.220
	2	1	3.559	3.245	3.433	3.358	3.096	3.221
		2	3.623	3.295	3.437	3.398	3.138	3.227
		3	3.650	3.318	3.467	3.434	3.141	3.243
		Average	3.611	3.286	3.446	3.397	3.125	3.230
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		3.636	3.298	3.448	3.370	3.135	3.225
	Standard Deviation		0.0470	0.0357	0.0221	0.0421	0.0207	0.0189

* Data excluded from further analysis.

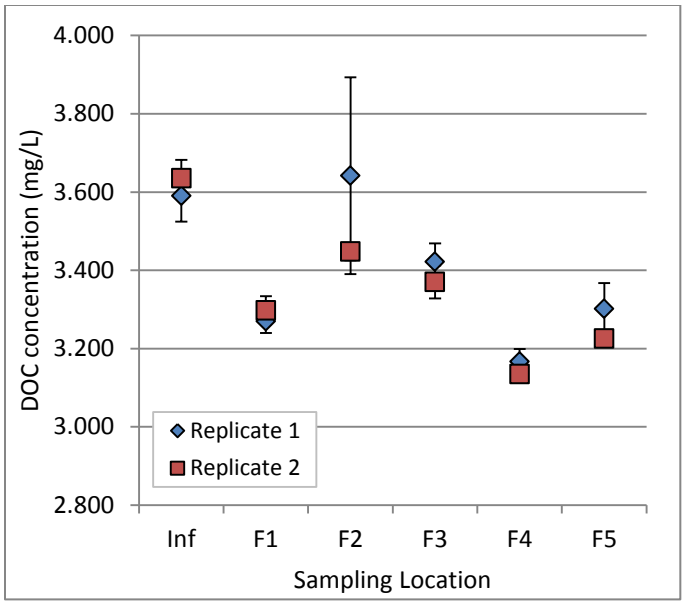

Figure B-21: Data Set 6 plot of average DOC concentrations

List of Excluded Data from Data Set 6, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Aliquot 1 for Filter 2, bottle 1, excluded because the DOC concentration was higher than the DOC concentrations for the other aliquots.

ANOVA Results

Table B-23: Data Set 6 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.514[a]	5	.103	62.603	2.399E-010
Intercept	256.257	1	256.257	156080.797	3.938E-035
filter#	.514	5	.103	62.603	2.399E-010
Error	.028	17	.002		
Total	259.234	23			
Corrected Total	.542	22			

a. R Squared = .948 (Adjusted R Squared = .933)

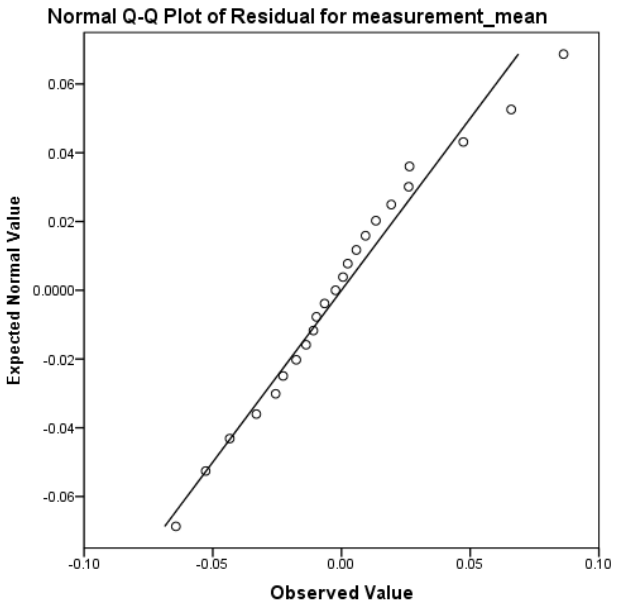

Figure B-22: Data Set 6 normal probability plot of residuals

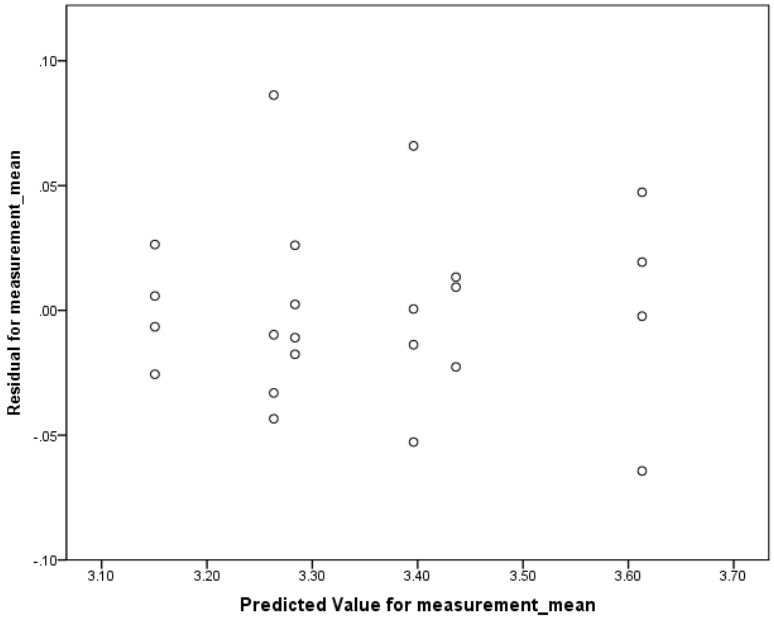

Figure B-23: Data Set 6 plot of residuals versus predicted values

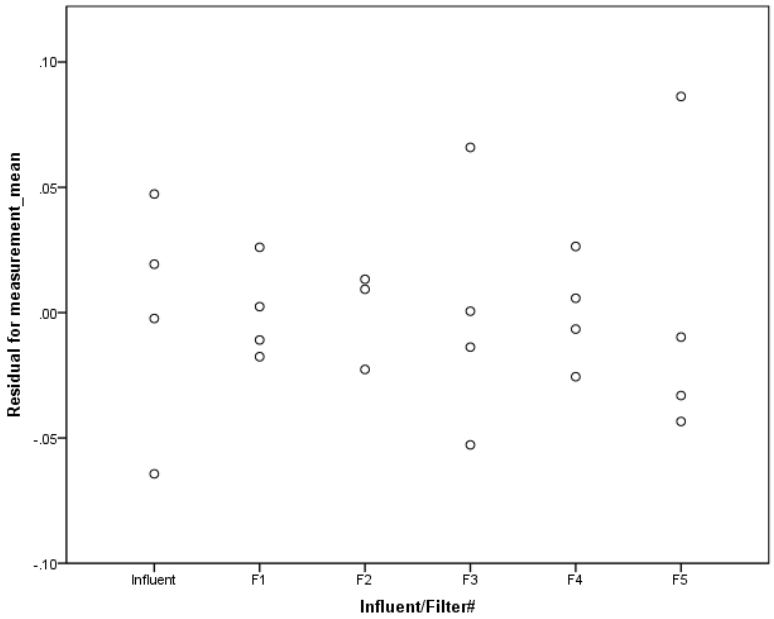

Figure B-24: Data Set 6 plot of residuals versus filter number

Table B-24: Data Set 6 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.086	5	17	4.033E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-25: Data Set 6 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.329*	0.0287	2.579E-008	0.238	0.421
		F2	0.177*	0.0309	3.133E-004	0.078	0.276
		F3	0.217*	0.0287	9.874E-006	0.125	0.309
		F4	0.462*	0.0287	1.314E-010	0.371	0.554
		F5	0.350*	0.0287	1.045E-008	0.258	0.441
	F1	Influent	-0.329*	0.0287	2.579E-008	-0.421	-0.238
		F2	-0.153*	0.0309	1.473E-003	-0.252	-0.054
		F3	-0.113*	0.0287	1.165E-002	-0.204	-0.021
		F4	0.133*	0.0287	2.684E-003	0.041	0.225
		F5	0.020	0.0287	9.789E-001	-0.071	0.112
	F2	Influent	-0.177*	0.0309	3.133E-004	-0.276	-0.078
		F1	0.153*	0.0309	1.473E-003	0.054	0.252
		F3	0.040	0.0309	7.808E-001	-0.059	0.139
		F4	0.286*	0.0309	6.470E-007	0.187	0.385
		F5	0.173*	0.0309	3.978E-004	0.074	0.272
	F3	Influent	-0.217*	0.0287	9.874E-006	-0.309	-0.125
		F1	0.113*	0.0287	1.165E-002	0.021	0.204
		F2	-0.040	0.0309	7.808E-001	-0.139	0.059
		F4	0.245*	0.0287	1.850E-006	0.154	0.337
		F5	0.133*	0.0287	2.748E-003	0.041	0.224
	F4	Influent	-0.462*	0.0287	1.314E-010	-0.554	-0.371
		F1	-0.133*	0.0287	2.684E-003	-0.225	-0.041
		F2	-0.286*	0.0309	6.470E-007	-0.385	-0.187
		F3	-0.245*	0.0287	1.850E-006	-0.337	-0.154
		F5	-0.113*	0.0287	1.138E-002	-0.204	-0.021
	F5	Influent	-0.350*	0.0287	1.045E-008	-0.441	-0.258
		F1	-0.020	0.0287	9.789E-001	-0.112	0.071
		F2	-0.173*	0.0309	3.978E-004	-0.272	-0.074
		F3	-0.133*	0.0287	2.748E-003	-0.224	-0.041
		F4	0.113*	0.0287	1.138E-002	0.021	0.204
Dunnett T3	Influent	F1	0.329*	0.0256	1.778E-003	0.196	0.462
		F2	0.177*	0.0263	1.726E-002	0.044	0.309
		F3	0.217*	0.0342	7.513E-003	0.070	0.363
		F4	0.462*	0.0261	3.447E-004	0.331	0.594
		F5	0.350*	0.0379	1.243E-003	0.184	0.515
	F1	Influent	-0.329*	0.0256	1.778E-003	-0.462	-0.196
		F2	-0.153*	0.0149	2.715E-003	-0.226	-0.079
		F3	-0.113	0.0265	9.893E-002	-0.252	0.027
		F4	0.133*	0.0146	1.114E-003	0.070	0.196
		F5	0.020	0.0311	9.990E-001	-0.150	0.191
	F2	Influent	-0.177*	0.0263	1.726E-002	-0.309	-0.044
		F1	0.153*	0.0149	2.715E-003	0.079	0.226
		F3	0.040	0.0272	8.295E-001	-0.098	0.178
		F4	0.286*	0.0158	1.427E-004	0.211	0.361
		F5	0.173*	0.0317	4.554E-002	0.005	0.341
	F3	Influent	-0.217*	0.0342	7.513E-003	-0.363	-0.070
		F1	0.113	0.0265	9.893E-002	-0.027	0.252
		F2	-0.040	0.0272	8.295E-001	-0.178	0.098
		F4	0.245*	0.0270	5.688E-003	0.108	0.383
		F5	0.133	0.0385	1.260E-001	-0.034	0.299
	F4	Influent	-0.462*	0.0261	3.447E-004	-0.594	-0.331
		F1	-0.133*	0.0146	1.114E-003	-0.196	-0.070
		F2	-0.286*	0.0158	1.427E-004	-0.361	-0.211
		F3	-0.245*	0.0270	5.688E-003	-0.383	-0.108
		F5	-0.113	0.0315	1.678E-001	-0.281	0.055
	F5	Influent	-0.350*	0.0379	1.243E-003	-0.515	-0.184
		F1	-0.020	0.0311	9.990E-001	-0.191	0.150
		F2	-0.173*	0.0317	4.554E-002	-0.341	-0.005
		F3	-0.133	0.0385	1.260E-001	-0.299	0.034
		F4	0.113	0.0315	1.678E-001	-0.055	0.281

Based on observed means.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals is OK, indicating that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the data are not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 7: Collected March 15, 2012

Raw Data

Table B-26: Data Set 7 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.454	3.139	3.106	3.287	3.026	3.267*
		2	3.549	3.150	3.239	3.245	3.006	3.347*
		3	3.480	3.130	3.163	3.230	2.949	3.321*
		Average	3.494	3.140	3.169	3.254	2.994	3.312
	2	1	3.343	3.075	3.076	3.026	2.934	3.236*
		2	3.419	3.082	3.147	3.125	3.034	3.287*
		3	3.456	3.086	3.163	3.136	3.041	3.317*
		Average	3.406	3.081	3.129	3.096	3.003	3.280
	3	1	3.373	3.024	3.134	3.123	2.993	3.265*
		2	3.438	3.062	3.230	3.187	3.021	3.293*
		3	3.460	3.063	3.199	3.204	3.028	3.315*
		Average	3.424	3.050	3.188	3.171	3.014	3.291
	Average		3.441	3.090	3.162	3.174	3.004	3.294
	Standard Deviation		0.0599	0.0415	0.0542	0.0793	0.0382	0.0344
2	1	1	3.365	2.963	3.156	3.121	3.047	2.924*
		2	3.434	3.030	3.193	3.182	2.991	2.986*
		3	3.458	3.036	3.213	3.184	3.082	2.980*
		Average	3.419	3.010	3.187	3.162	3.040	2.963
	2	1	3.615	3.071	3.065	3.121	3.132	2.982*
		2	3.576	3.095	3.110	3.195	3.141	3.012*
		3	3.563	3.078	3.136	3.219	3.184	3.017*
		Average	3.585	3.081	3.104	3.178	3.152	3.004
	3	1	3.330	2.960	3.162	3.191	3.024	3.180*
		2	3.412	3.012	3.178	3.306	3.060	3.197*
		3	3.412	3.037	3.215	3.297	3.075	3.156*
		Average	3.385	3.003	3.185	3.265	3.053	3.178
	Average		3.463	3.031	3.159	3.202	3.082	3.048
	Standard Deviation		0.0995	0.0474	0.0492	0.0653	0.0610	0.1011

* Data excluded from further analysis.

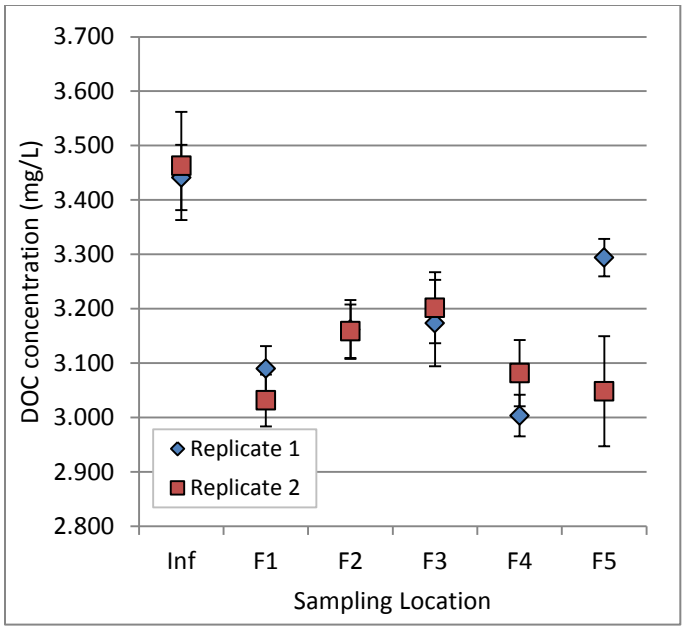

Figure B-25: Data Set 7 plot of average DOC concentrations

List of Excluded Data from Data Set 7, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from Filter 5 excluded because readings from bottles containing sample water from the same location were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 5 was contaminated.

ANOVA Results

Table B-27: Data Set 7 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.645[a]	4	0.161	47.917	2.281E-011
Intercept	303.503	1	303.503	90147.954	5.426E-046
filter#	0.645	4	0.161	47.917	2.281E-011
Error	0.084	25	0.003		
Total	304.233	30			
Corrected Total	0.729	29			

a. R Squared = .885 (Adjusted R Squared = .866)

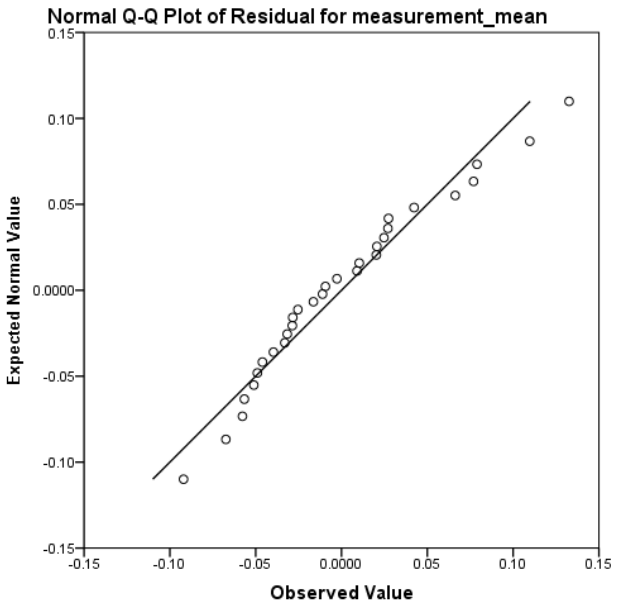

Figure B-26: Data Set 7 normal probability plot of residuals

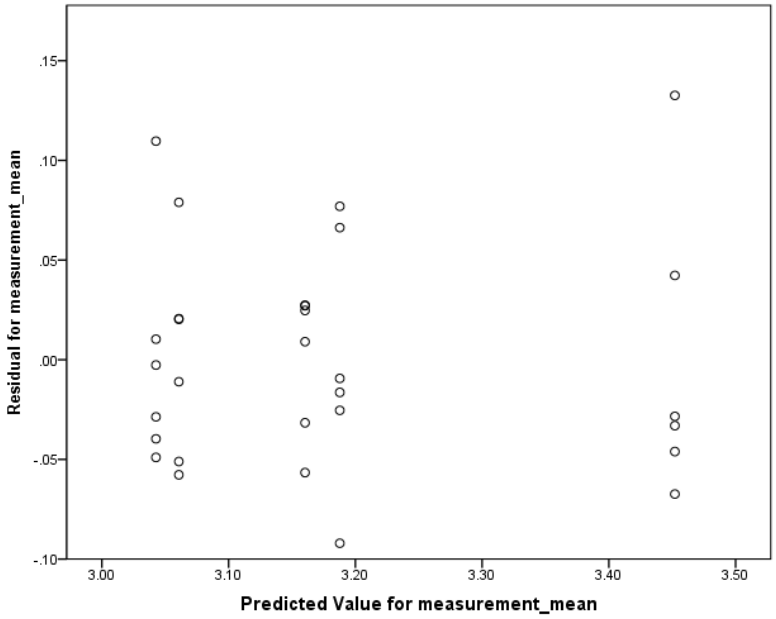

Figure B-27: Data Set 7 plot of residuals versus predicted values

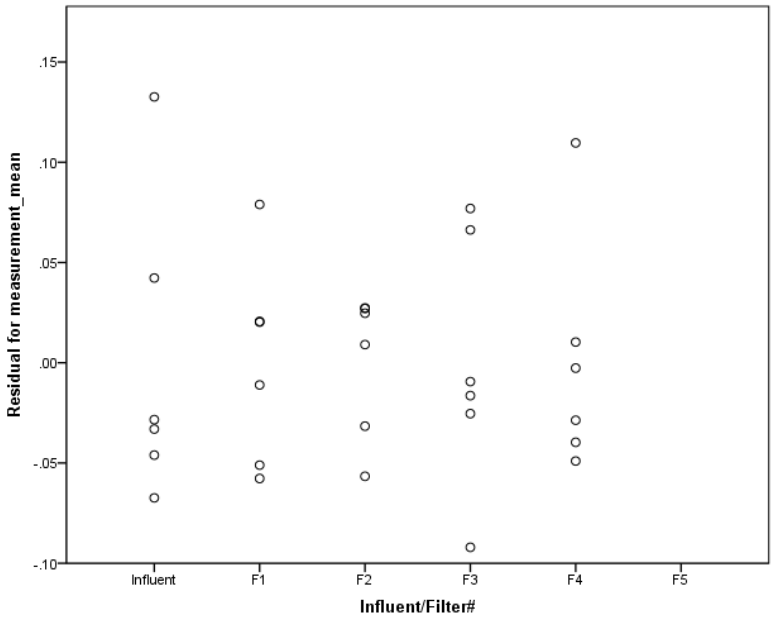

Figure B-28: Data Set 7 plot of residuals versus filter number

Table B-28: Data Set 7 results from Levene's test of equality of variances

F	df1	df2	Sig.
0.669	4	25	0.619

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-29: Data Set 7 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.391*	0.0335	1.243E-010	0.293	0.490
		F2	0.292*	0.0335	4.609E-008	0.193	0.390
		F3	0.264*	0.0335	2.866E-007	0.166	0.363
		F4	0.409*	0.0335	4.788E-011	0.311	0.508
	F1	Influent	-0.391*	0.0335	1.243E-010	-0.490	-0.293
		F2	-0.100*	0.0335	4.634E-002	-0.198	-0.001
		F3	-0.127*	0.0335	6.892E-003	-0.225	-0.029
		F4	0.018	0.0335	9.823E-001	-0.080	0.116
	F2	Influent	-0.292*	0.0335	4.609E-008	-0.390	-0.193
		F1	0.100*	0.0335	4.634E-002	0.001	0.198
		F3	-0.027	0.0335	9.222E-001	-0.126	0.071
		F4	0.118*	0.0335	1.353E-002	0.019	0.216
	F3	Influent	-0.264*	0.0335	2.866E-007	-0.363	-0.166
		F1	0.127*	0.0335	6.892E-003	0.029	0.225
		F2	0.027	0.0335	9.222E-001	-0.071	0.126
		F4	0.145*	0.0335	1.811E-003	0.047	0.243
	F4	Influent	-0.409*	0.0335	4.788E-011	-0.508	-0.311
		F1	-0.018	0.0335	9.823E-001	-0.116	0.080
		F2	-0.118*	0.0335	1.353E-002	-0.216	-0.019
		F3	-0.145*	0.0335	1.811E-003	-0.243	-0.047
Dunnett T3	Influent	F1	0.391*	0.0370	2.325E-005	0.259	0.523
		F2	0.292*	0.0338	4.099E-004	0.164	0.420
		F3	0.264*	0.0399	6.126E-004	0.125	0.404
		F4	0.409*	0.0387	1.407E-005	0.274	0.545
	F1	Influent	-0.391*	0.0370	2.325E-005	-0.523	-0.259
		F2	-0.100*	0.0255	3.013E-002	-0.190	-0.009
		F3	-0.127*	0.0331	2.982E-002	-0.243	-0.011
		F4	0.018	0.0317	9.993E-001	-0.092	0.128
	F2	Influent	-0.292*	0.0338	4.099E-004	-0.420	-0.164
		F1	0.100*	0.0255	3.013E-002	0.009	0.190
		F3	-0.027	0.0295	9.733E-001	-0.136	0.081
		F4	0.118*	0.0279	2.205E-002	0.017	0.219
	F3	Influent	-0.264*	0.0399	6.126E-004	-0.404	-0.125
		F1	0.127*	0.0331	2.982E-002	0.011	0.243
		F2	0.027	0.0295	9.733E-001	-0.081	0.136
		F4	0.145*	0.0350	1.744E-002	0.024	0.267
	F4	Influent	-0.409*	0.0387	1.407E-005	-0.545	-0.274
		F1	-0.018	0.0317	9.993E-001	-0.128	0.092
		F2	-0.118*	0.0279	2.205E-002	-0.219	-0.017
		F3	-0.145*	0.0350	1.744E-002	-0.267	-0.024

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the data are not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 8: Collected March 21, 2012

Raw Data

Table B-30: Data Set 8 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.751	3.481	3.422	3.414	3.237	3.244
		2	3.816	3.493	3.474	3.443	3.277	3.290
		3	3.871	3.577	3.508	3.485	3.298	3.307
		Average	3.813	3.517	3.468	3.447	3.271	3.280
	2	1	3.705	3.464	3.533	3.489	3.227	3.327
		2	3.778	3.537	3.659	3.562	3.292	3.428
		3	3.829	3.525	3.682	3.567	3.311	3.349
		Average	3.771	3.509	3.625	3.539	3.277	3.368
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		3.792	3.513	3.546	3.493	3.274	3.324
	Standard Deviation		0.0594	0.0416	0.1034	0.0617	0.0342	0.0621
2	1	1	3.759	3.460	3.445	3.514	3.262	3.298
		2	3.818	3.386	3.468	3.476	3.390	3.359
		3	3.902	3.430	3.508	3.430	3.332	3.357
		Average	3.826	3.425	3.474	3.473	3.328	3.338
	2	1	3.980	3.279	3.414	3.474	3.323	3.286
		2	4.020	3.393	3.470	3.522	3.380	3.372
		3	4.036	3.336	3.479	3.544	3.422	3.378
		Average	4.012	3.336	3.454	3.513	3.375	3.345
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		3.919	3.381	3.464	3.493	3.352	3.342
	Standard Deviation		0.1129	0.0652	0.0319	0.0412	0.0574	0.0394

* Data excluded from further analysis.

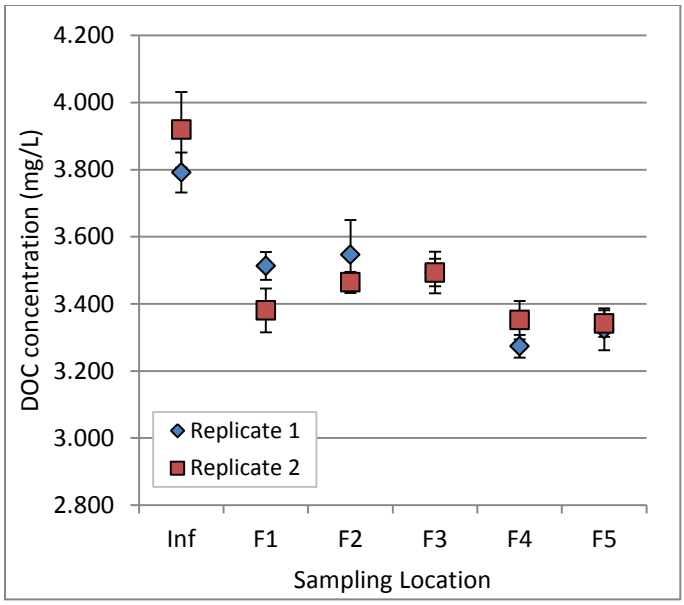

Figure B-29: Data Set 8 plot of average DOC concentrations

List of Excluded Data from Data Set 8, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded.

ANOVA Results

Table B-31: Data Set 8 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.767[a]	5	0.153	30.185	3.756E-008
Intercept	292.495	1	292.495	57543.974	5.304E-033
filter#	0.767	5	0.153	30.185	3.756E-008
Error	0.091	18	0.005		
Total	293.353	24			
Corrected Total	0.859	23			

a. R Squared = .893 (Adjusted R Squared = .864)

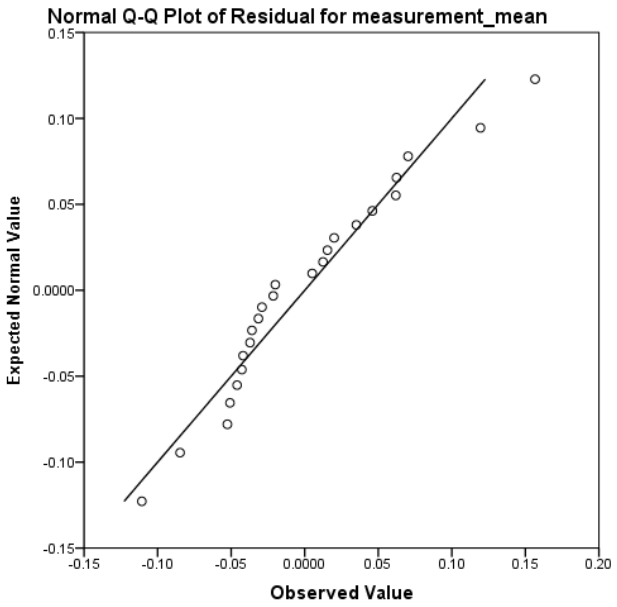

Figure B-30: Data Set 8 normal probability plot of residuals

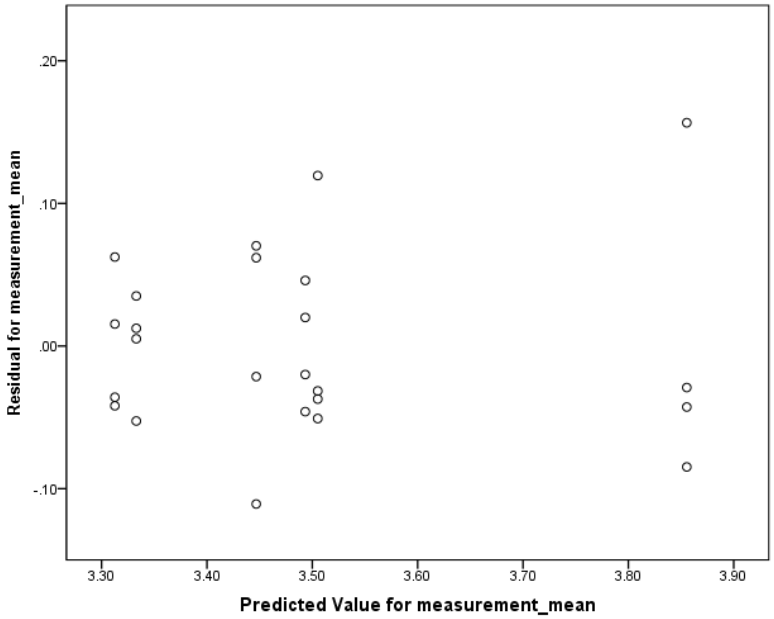

Figure B-31: Data Set 8 plot of residuals versus predicted values

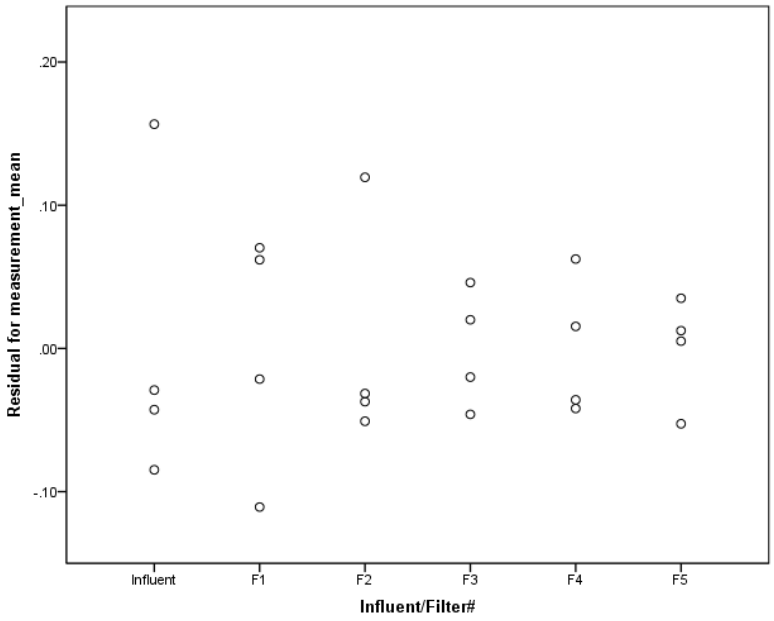

Figure B-32: Data Set 8 plot of residuals versus filter number

Table B-32: Data Set 8 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.389	5	18	2.749E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-33: Data Set 8 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.409*	0.0504	2.676E-006	0.248	0.569
		F2	0.350*	0.0504	2.219E-005	0.190	0.510
		F3	0.362*	0.0504	1.426E-005	0.202	0.522
		F4	0.543*	0.0504	3.818E-008	0.383	0.703
		F5	0.523*	0.0504	6.915E-008	0.362	0.683
	F1	Influent	-0.409*	0.0504	2.676E-006	-0.569	-0.248
		F2	-0.058	0.0504	8.501E-001	-0.219	0.102
		F3	-0.047	0.0504	9.351E-001	-0.207	0.114
		F4	0.134	0.0504	1.327E-001	-0.026	0.294
		F5	0.114	0.0504	2.607E-001	-0.046	0.274
	F2	Influent	-0.350*	0.0504	2.219E-005	-0.510	-0.190
		F1	0.058	0.0504	8.501E-001	-0.102	0.219
		F3	0.012	0.0504	9.999E-001	-0.148	0.172
		F4	0.193*	0.0504	1.346E-002	0.032	0.353
		F5	0.172*	0.0504	3.097E-002	0.012	0.332
	F3	Influent	-0.362*	0.0504	1.426E-005	-0.522	-0.202
		F1	0.047	0.0504	9.351E-001	-0.114	0.207
		F2	-0.012	0.0504	9.999E-001	-0.172	0.148
		F4	0.181*	0.0504	2.193E-002	0.021	0.341
		F5	0.160*	0.0504	4.961E-002	0.000	0.321
	F4	Influent	-0.543*	0.0504	3.818E-008	-0.703	-0.383
		F1	-0.134	0.0504	1.327E-001	-0.294	0.026
		F2	-0.193*	0.0504	1.346E-002	-0.353	-0.032
		F3	-0.181*	0.0504	2.193E-002	-0.341	-0.021
		F5	-0.020	0.0504	9.984E-001	-0.181	0.140
	F5	Influent	-0.523*	0.0504	6.915E-008	-0.683	-0.362
		F1	-0.114	0.0504	2.607E-001	-0.274	0.046
		F2	-0.172*	0.0504	3.097E-002	-0.332	-0.012
		F3	-0.160*	0.0504	4.961E-002	-0.321	0.000
		F4	0.020	0.0504	9.984E-001	-0.140	0.181
Dunnett T3	Influent	F1	0.409*	0.0682	1.163E-002	0.111	0.706
		F2	0.350*	0.0668	2.333E-002	0.056	0.645
		F3	0.362*	0.0573	2.709E-002	0.060	0.664
		F4	0.543*	0.0588	5.016E-003	0.247	0.839
		F5	0.523*	0.0567	8.065E-003	0.217	0.828
	F1	Influent	-0.409*	0.0682	1.163E-002	-0.706	-0.111
		F2	-0.058	0.0583	9.821E-001	-0.308	0.191
		F3	-0.047	0.0470	9.783E-001	-0.279	0.186
		F4	0.134	0.0489	2.939E-001	-0.095	0.364
		F5	0.114	0.0463	4.022E-001	-0.121	0.349
	F2	Influent	-0.350*	0.0668	2.333E-002	-0.645	-0.056
		F1	0.058	0.0583	9.821E-001	-0.191	0.308
		F3	0.012	0.0450	1.000E+000	-0.207	0.231
		F4	0.193	0.0469	7.893E-002	-0.024	0.410
		F5	0.172	0.0442	1.155E-001	-0.049	0.393
	F3	Influent	-0.362*	0.0573	2.709E-002	-0.664	-0.060
		F1	0.047	0.0470	9.783E-001	-0.186	0.279
		F2	-0.012	0.0450	1.000E+000	-0.231	0.207
		F4	0.181*	0.0319	1.435E-002	0.043	0.319
		F5	0.160*	0.0277	1.212E-002	0.042	0.279
	F4	Influent	-0.543*	0.0588	5.016E-003	-0.839	-0.247
		F1	-0.134	0.0489	2.939E-001	-0.364	0.095
		F2	-0.193	0.0469	7.893E-002	-0.410	0.024
		F3	-0.181*	0.0319	1.435E-002	-0.319	-0.043
		F5	-0.020	0.0308	9.994E-001	-0.155	0.115
	F5	Influent	-0.523*	0.0567	8.065E-003	-0.828	-0.217
		F1	-0.114	0.0463	4.022E-001	-0.349	0.121
		F2	-0.172	0.0442	1.155E-001	-0.393	0.049
		F3	-0.160*	0.0277	1.212E-002	-0.279	-0.042
		F4	0.020	0.0308	9.994E-001	-0.115	0.155

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals are not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity and, therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 9: Collected April 2, 2012

Raw Data

Table B-34: Data Set 9 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.604	3.219	3.353	3.284	3.060	3.111
		2	3.679	3.260	3.405	3.395	3.108	3.135
		3	3.689	3.284	3.432	3.368	3.150	3.164
		Average	3.657	3.254	3.397	3.349	3.106	3.137
	2	1	3.626	3.252	3.390	3.558	3.269	3.143
		2	3.670	3.258	3.439	3.516	3.170	3.185
		3	3.725	3.311	3.449	3.547	3.274	3.219
		Average	3.674	3.274	3.426	3.540	3.238	3.182
	3	1	3.775	3.223	-	3.452	-	-
		2	3.826	3.337	-	3.582	-	-
		3	3.855	3.267	-	3.564	-	-
		Average	3.819	3.276	-	3.533	-	-
	Average		3.717	3.268	3.411	3.474	3.172	3.160
	Standard Deviation		0.0865	0.0383	0.0361	0.1049	0.0860	0.0386
2	1	1	3.722	3.229	3.372	3.326	3.318	3.185
		2	3.769	3.274	3.406	3.381	3.372	3.251
		3	3.788	3.285	3.359	3.405	3.403	3.273
		Average	3.760	3.263	3.379	3.371	3.364	3.236
	2	1	3.740	3.225	3.357	3.604	3.197	3.164
		2	3.700	3.234	3.403	3.628	3.252	3.227
		3	3.729	3.313	3.412	3.615	3.249	3.230
		Average	3.723	3.257	3.391	3.616	3.233	3.207
	3	1	3.725	3.306	-	3.445	-	-
		2	3.848	3.236	-	3.434	-	-
		3	3.817	3.351	-	3.458	-	-
		Average	3.797	3.298	-	3.446	-	-
	Average		3.760	3.273	3.385	3.477	3.299	3.222
	Standard Deviation		0.0494	0.0448	0.0250	0.1109	0.0795	0.0407

* Data excluded from further analysis.

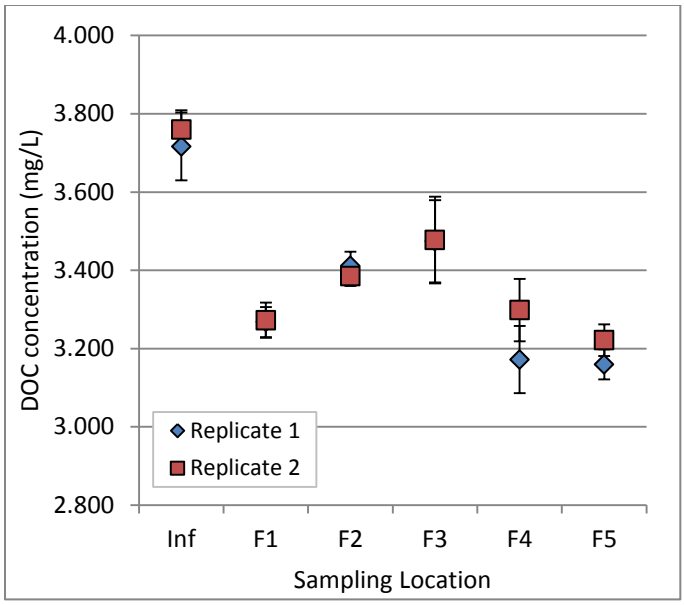

Figure B-33: Data Set 9 plot of average DOC concentrations

List of Excluded Data from Data Set 9, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. There was not enough sample water available to analyze a third aliquot from bottles collected from filters 2, 4, and 5.

ANOVA Results

Table B-35: Data Set 9 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.104[a]	5	0.221	45.122	1.970E-011
Intercept	329.928	1	329.928	67402.014	6.668E-043
filter#	1.104	5	0.221	45.122	1.970E-011
Error	0.117	24	0.005		
Total	349.381	30			
Corrected Total	1.222	29			

a. R Squared = .904 (Adjusted R Squared = .884)

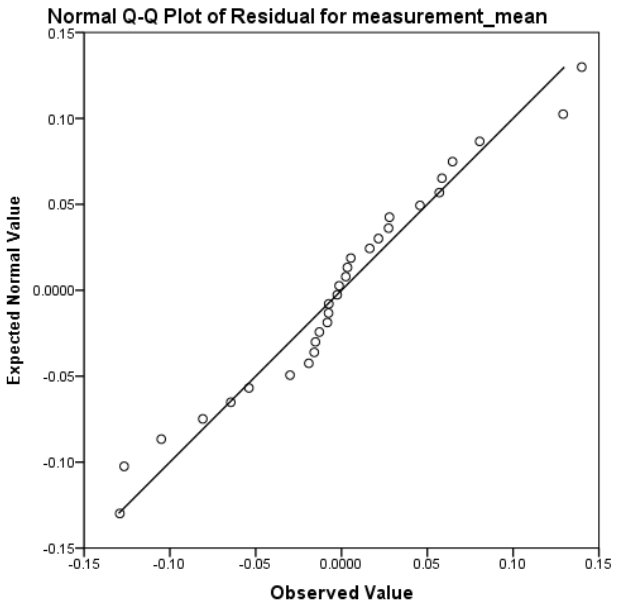

Figure B-34: Data Set 9 normal probability plot of residuals

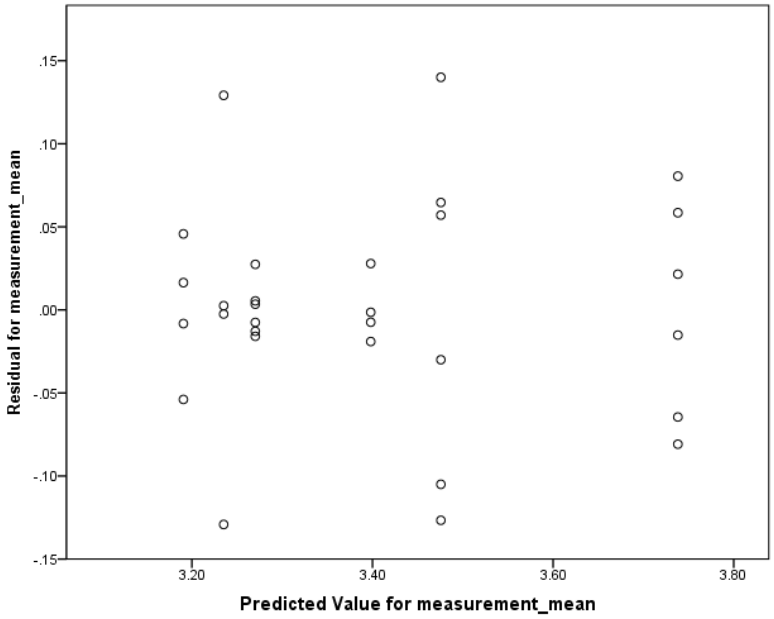

Figure B-35: Data Set 9 plot of residuals versus predicted values

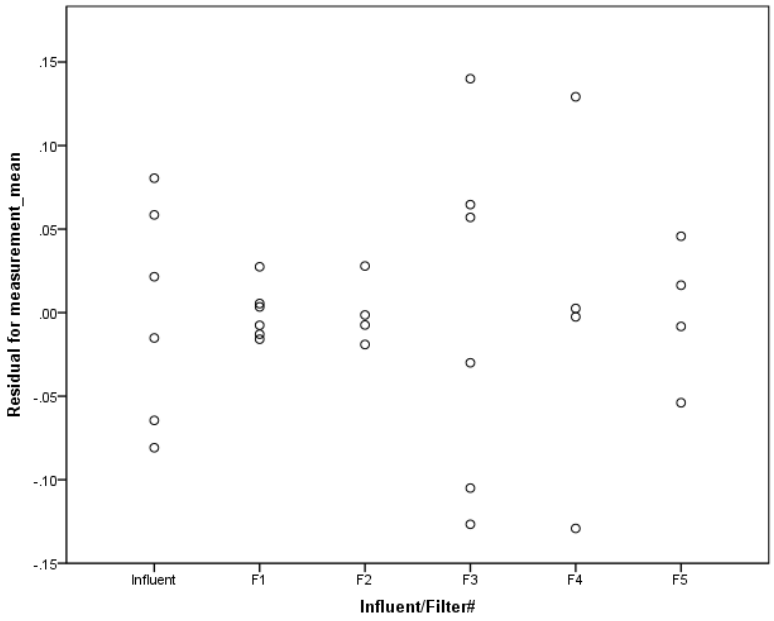

Figure B-36: Data Set 9 plot of residuals versus filter number

Table B-36: Data Set 9 results from Levene's test of equality of variances

F	df1	df2	Sig.
3.620	5	24	1.397E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-37: Data Set 9 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.468*	0.0404	3.701E-010	0.343	0.593
		F2	0.340*	0.0452	1.256E-006	0.200	0.480
		F3	0.263*	0.0404	1.378E-005	0.138	0.387
		F4	0.503*	0.0452	8.225E-010	0.363	0.643
		F5	0.548*	0.0452	1.452E-010	0.408	0.687
	F1	Influent	-0.468*	0.0404	3.701E-010	-0.593	-0.343
		F2	-0.128	0.0452	8.629E-002	-0.267	0.012
		F3	-0.205*	0.0404	4.307E-004	-0.330	-0.081
		F4	0.035	0.0452	9.690E-001	-0.105	0.175
		F5	0.080	0.0452	5.062E-001	-0.060	0.219
	F2	Influent	-0.340*	0.0452	1.256E-006	-0.480	-0.200
		F1	0.128	0.0452	8.629E-002	-0.012	0.267
		F3	-0.078	0.0452	5.339E-001	-0.217	0.062
		F4	0.163*	0.0495	3.216E-002	0.010	0.316
		F5	0.208*	0.0495	3.872E-003	0.055	0.360
	F3	Influent	-0.263*	0.0404	1.378E-005	-0.387	-0.138
		F1	0.205*	0.0404	4.307E-004	0.081	0.330
		F2	0.078	0.0452	5.339E-001	-0.062	0.217
		F4	0.240*	0.0452	2.385E-004	0.101	0.380
		F5	0.285*	0.0452	2.149E-005	0.145	0.425
	F4	Influent	-0.503*	0.0452	8.225E-010	-0.643	-0.363
		F1	-0.035	0.0452	9.690E-001	-0.175	0.105
		F2	-0.163*	0.0495	3.216E-002	-0.316	-0.010
		F3	-0.240*	0.0452	2.385E-004	-0.380	-0.101
		F5	0.045	0.0495	9.424E-001	-0.108	0.198
	F5	Influent	-0.548*	0.0452	1.452E-010	-0.687	-0.408
		F1	-0.080	0.0452	5.062E-001	-0.219	0.060
		F2	-0.208*	0.0495	3.872E-003	-0.360	-0.055
		F3	-0.285*	0.0452	2.149E-005	-0.425	-0.145
		F4	-0.045	0.0495	9.424E-001	-0.198	0.108
Dunnett T3**	Influent	F1	0.468*	0.0274	5.073E-005	0.347	0.588
		F2	0.340*	0.0285	1.621E-004	0.221	0.460
		F3	0.263*	0.0504	8.462E-003	0.069	0.456
		F4	0.503*	0.0591	5.080E-003	0.218	0.788
		F5	0.548*	0.0340	2.816E-006	0.415	0.680
	F1	Influent	-0.468*	0.0274	5.073E-005	-0.588	-0.347
		F2	-0.128*	0.0119	7.035E-004	-0.181	-0.075
		F3	-0.205*	0.0433	4.096E-002	-0.401	-0.010
		F4	0.035	0.0531	9.984E-001	-0.290	0.360
		F5	0.080	0.0221	1.733E-001	-0.042	0.202
	F2	Influent	-0.340*	0.0285	1.621E-004	-0.460	-0.221
		F1	0.128*	0.0119	7.035E-004	0.075	0.181
		F3	-0.078	0.0440	6.961E-001	-0.272	0.116
		F4	0.163	0.0537	2.847E-001	-0.156	0.482
		F5	0.208*	0.0233	5.377E-003	0.091	0.324
	F3	Influent	-0.263*	0.0504	8.462E-003	-0.456	-0.069
		F1	0.205*	0.0433	4.096E-002	0.010	0.401
		F2	0.078	0.0440	6.961E-001	-0.116	0.272
		F4	0.240	0.0679	9.970E-002	-0.041	0.522
		F5	0.285*	0.0477	6.150E-003	0.092	0.478
	F4	Influent	-0.503*	0.0591	5.080E-003	-0.788	-0.218
		F1	-0.035	0.0531	9.984E-001	-0.360	0.290
		F2	-0.163	0.0537	2.847E-001	-0.482	0.156
		F3	-0.240	0.0679	9.970E-002	-0.522	0.041
		F5	0.045	0.0568	9.955E-001	-0.252	0.341
	F5	Influent	-0.548*	0.0340	2.816E-006	-0.680	-0.415
		F1	-0.080	0.0221	1.733E-001	-0.202	0.042
		F2	-0.208*	0.0233	5.377E-003	-0.324	-0.091
		F3	-0.285*	0.0477	6.150E-003	-0.478	-0.092
		F4	-0.045	0.0568	9.955E-001	-0.341	0.252

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed. There were a few data points that may deviate from normality but the majority of the points were close to the line that represents normality.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # exhibit some heteroscedasticity in the residuals.
4. Results from Levene's test of equality of variance indicate that the residuals were heteroscedastic.
5. As a result of points 3&4, the residuals and the data were considered to exhibit heteroscedasticity; therefore, results from Dunnett's T3 test were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 10: Collected April 12, 2012

Raw Data

Table B-38: Data Set 10 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.800	-	-	3.326	3.006*	3.302
		2	3.986	-	-	3.442	3.038*	3.308
		3	3.936	-	-	3.393	3.067*	3.198
		Average	3.907	-	-	3.387	3.037	3.269
	2	1	4.081	-	-	3.410	3.011*	3.343
		2	4.005	-	-	3.429	3.071*	3.338
		3	4.007	-	-	3.483	3.108*	3.31
		Average	4.031	-	-	3.441	3.063	3.330
	3	1	3.947	-	-	-	-	-
		2	3.997	-	-	-	-	-
		3	4.007	-	-	-	-	-
		Average	3.984	-	-	-	-	-
	Average		3.974	-	-	3.414	3.050	3.300
	Standard Deviation		0.0772	-	-	0.0529	0.0392	0.0527
2	1	1	3.746	3.377*	3.513	3.360	3.013*	3.125
		2	3.755	3.405*	3.557	3.395	3.028*	3.174
		3	3.88	3.451*	3.569	3.412	3.024*	3.159
		Average	3.794	3.411	3.546	3.389	3.022	3.153
	2	1	3.885	3.190*	3.643	3.440	3.058*	3.254
		2	3.872	3.211*	3.721	3.362	3.090*	3.263
		3	3.870	3.218*	3.682	3.354	3.134*	3.295
		Average	3.876	3.206	3.682	3.385	3.094	3.271
	3	1	3.671	-	-	-	-	-
		2	3.803	-	-	-	-	-
		3	3.734	-	-	-	-	-
		Average	3.736	-	-	-	-	-
	Average		3.802	3.309	3.614	3.387	3.058	3.212
	Standard Deviation		0.0788	0.1149	0.0805	0.0345	0.0466	0.0679

* Data excluded from further analysis.

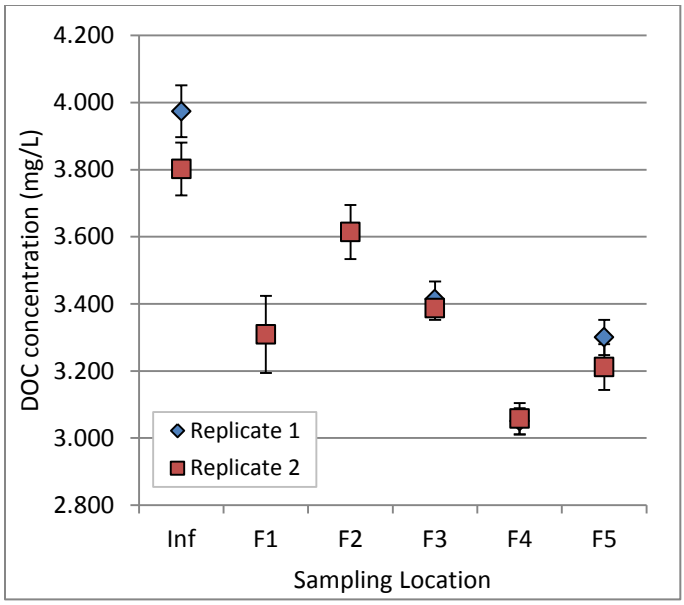

Figure B-37: Data Set 10 plot of average DOC concentrations

List of Excluded Data from Data Set 10, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Sample water was collected for AOC analysis. There was not enough water available to do full DOC analysis on water collected in all bottles.
2. Data from Filter 1 and Filter 4 were excluded because the flow rate in these filters had dropped off due to excessive (i.e. terminal) headloss; as a result the flow rates and, thus, EBCTs of these filters did not match the flow rates or EBCTs of the other filters. The flow rate through Filter 1, at the time of collection, had dropped to 2.2 L/min from a target of 3.0 L/min and the flow rate through Filter 4 had dropped to 1.5 L/min from a target of 3.0 L/min.

ANOVA Results

Table B-39: Data Set 10 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.120[a]	3	.373	49.727	4.832E-007
Intercept	171.821	1	171.821	22887.527	4.672E-021
filter#	1.120	3	.373	49.727	4.832E-007
Error	.090	12	.008		
Total	205.562	16			
Corrected Total	1.210	15			

a. R Squared = .926 (Adjusted R Squared = .907)

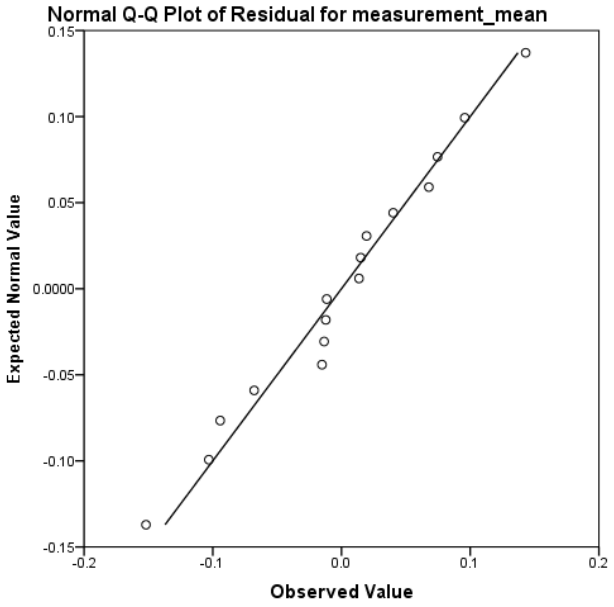

Figure B-38: Data Set 10 normal probability plot of residuals

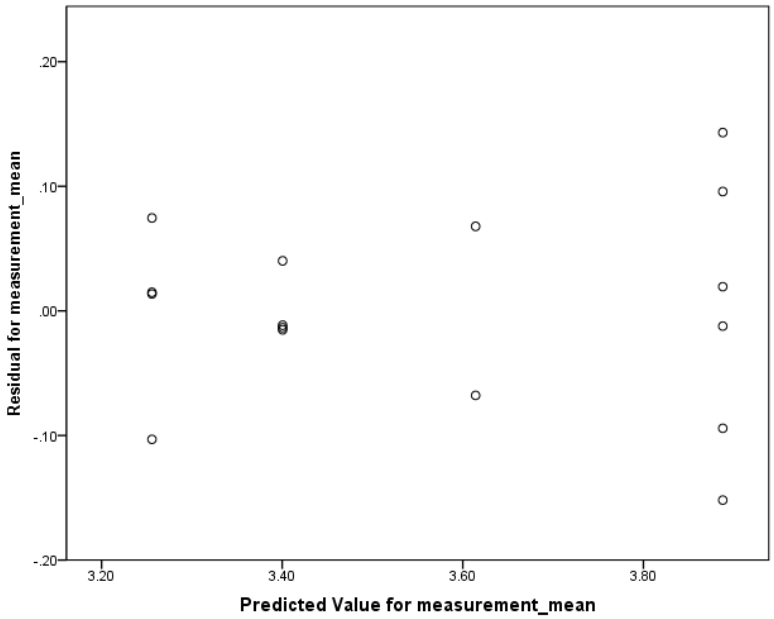

Figure B-39: Data Set 10 plot of residuals versus predicted values

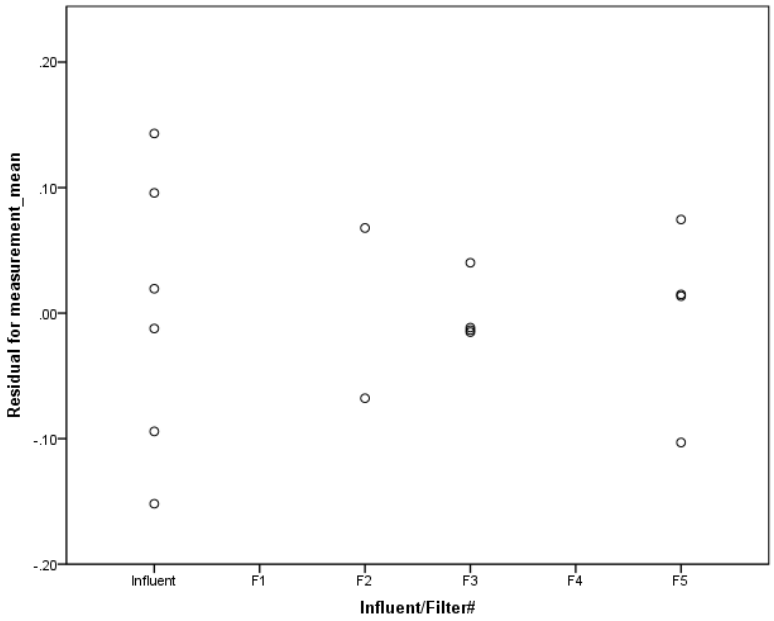

Figure B-40: Data Set 10 plot of residuals versus filter number

Table B-40: Data Set 10 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.796	3	12	2.015E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-41: Data Set 10 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F2	.274*	.0707	1.037E-002	.064	.484
		F3	.487*	.0559	8.073E-006	.321	.653
		F5	.632*	.0559	4.953E-007	.466	.798
	F2	Influent	-.274*	.0707	1.037E-002	-.484	-.064
		F3	.214	.0750	6.160E-002	-.009	.436
		F5	.358*	.0750	2.199E-003	.136	.581
	F3	Influent	-.487*	.0559	8.073E-006	-.653	-.321
		F2	-.214	.0750	6.160E-002	-.436	.009
		F5	.145	.0613	1.381E-001	-.037	.327
	F5	Influent	-.632*	.0559	4.953E-007	-.798	-.466
		F2	-.358*	.0750	2.199E-003	-.581	-.136
		F3	-.145	.0613	1.381E-001	-.327	.037
Dunnett T3**	Influent	F2	.274	.0817	2.233E-001	-.343	.891
		F3	.487*	.0474	3.025E-004	.312	.663
		F5	.632*	.0588	2.788E-005	.434	.830
	F2	Influent	-.274	.0817	2.233E-001	-.891	.343
		F3	.214	.0691	3.850E-001	-1.296	1.723
		F5	.358	.0774	1.650E-001	-.408	1.124
	F3	Influent	-.487*	.0474	3.025E-004	-.663	-.312
		F2	-.214	.0691	3.850E-001	-1.723	1.296
		F5	.145	.0395	9.470E-002	-.034	.323
	F5	Influent	-.632*	.0588	2.788E-005	-.830	-.434
		F2	-.358	.0774	1.650E-001	-1.124	.408
		F3	-.145	.0395	9.470E-002	-.323	.034

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed. There are a few data points that may deviate from normality but the majority of the points are close to the line that represents normality.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # exhibit some heteroscedasticity in the residuals.
4. Results from Levene's test of equality of variance do not indicate that the residuals are heteroscedastic.
5. While Levene's test did not indicate heteroscedasticity, the residuals and the data were considered to exhibit some heteroscedasticity based on the plots of residuals; to ensure that the multiple comparison results were correct, Dunnett's T3 test was used because this test can accommodate heteroscedasticity.

Data Set 11: Collected April 24, 2012

Raw Data

Table B-42: Data Set 11 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.743	3.396	3.661*	3.667	3.271*	3.388
		2	3.859	3.485	3.680*	3.788	3.323*	3.433
		3	3.823	3.506	3.685*	3.745	3.332*	3.478
		Average	3.808	3.462	3.675	3.733	3.309	3.433
	2	1	3.797	3.517	3.622*	3.515	3.272*	3.345
		2	3.883	3.566	3.665*	3.627	3.304*	3.418
		3	3.922	3.583	3.696*	3.657	3.342*	3.450
		Average	3.867	3.555	3.661	3.600	3.306	3.404
	3	1	3.781	3.485	3.616*	3.678	3.261*	3.450
		2	3.835	3.526	3.588*	3.732	3.310*	3.476
		3	3.859	3.556	3.605*	3.726	3.323*	3.545
		Average	3.825	3.522	3.603	3.712	3.298	3.490
	Average		3.834	3.513	3.646	3.682	3.304	3.443
	Standard Deviation		0.0547	0.0560	0.0392	0.0802	0.0295	0.0572
2	1	1	3.724	3.424	4.304*	3.558	3.495*	3.467
		2	3.769	3.452	4.339*	3.668	3.517*	3.476
		3	3.803	3.482	4.360*	3.691	3.504*	3.498
		Average	3.765	3.453	4.334	3.639	3.505	3.480
	2	1	3.883	3.446	4.354*	3.573	3.530*	3.398
		2	3.911	3.510	4.425*	3.612	3.566*	3.431
		3	3.889	3.551	4.442*	3.661	3.497*	3.467
		Average	3.894	3.502	4.407	3.615	3.531	3.432
	3	1	3.837	3.489	4.294*	3.693	3.581*	3.420
		2	3.896	3.513	4.315*	3.739	3.627*	3.519
		3	3.930	3.549	4.373*	3.683	3.678*	3.547
		Average	3.888	3.517	4.327	3.705	3.629	3.495
	Average		3.849	3.491	4.356	3.653	3.555	3.469
	Standard Deviation		0.0704	0.0446	0.0512	0.0599	0.0640	0.0479

* Data excluded from further analysis.

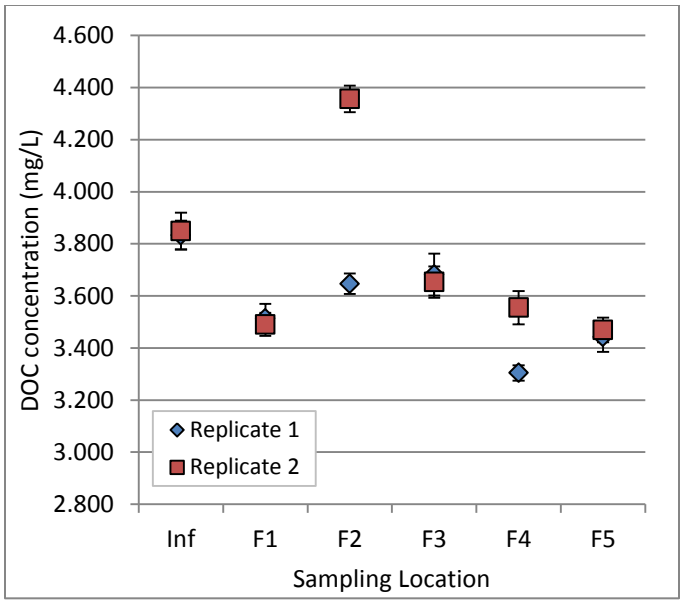

Figure B-41: Data Set 11 plot of average DOC concentrations

List of Excluded Data from Data Set 11, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from Filter 2 and Filter 4 excluded because readings from bottles containing sample water from the same location were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 2 and at least one of the bottles used to collect samples from Filter 4 was contaminated.

ANOVA Results

Table B-43: Data Set 11 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.552[a]	3	0.184	85.224	1.445E-011
Intercept	313.924	1	313.924	145330.008	4.287E-040
filter#	0.552	3	0.184	85.224	1.445E-011
Error	0.043	20	0.002		
Total	314.520	24			
Corrected Total	0.595	23			

a. R Squared = .927 (Adjusted R Squared = .917)

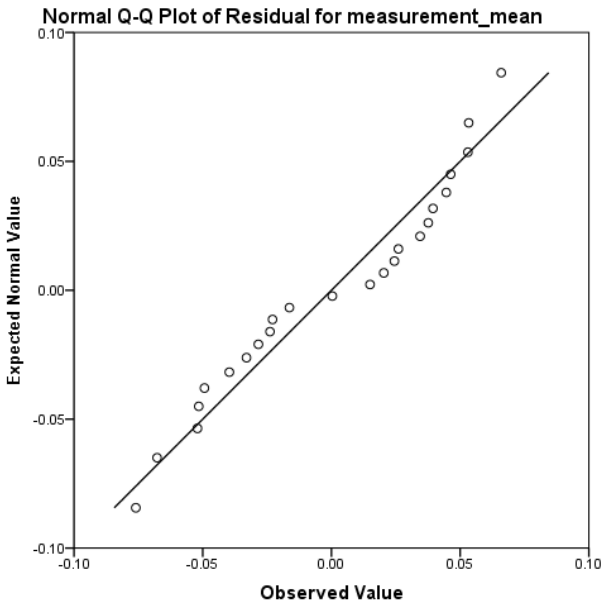

Figure B-42: Data Set 11 normal probability plot of residuals

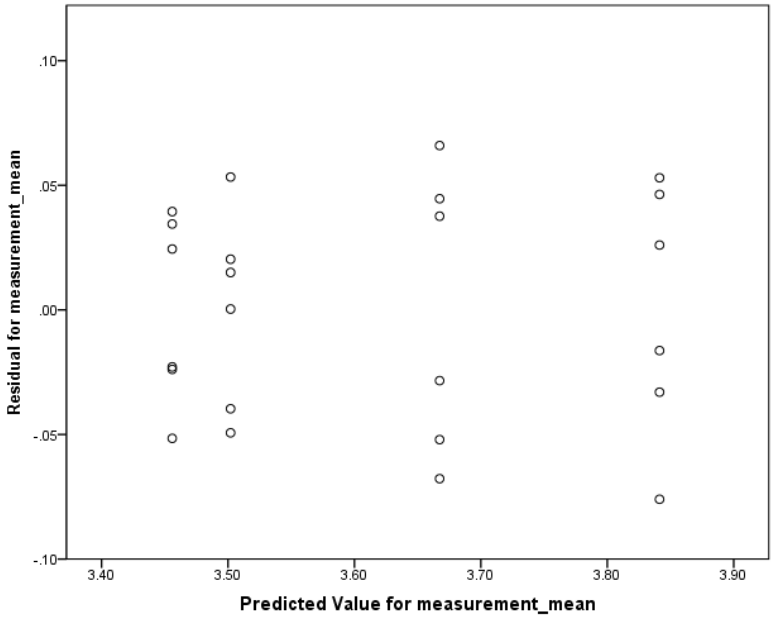

Figure B-43: Data Set 11 plot of residuals versus predicted values

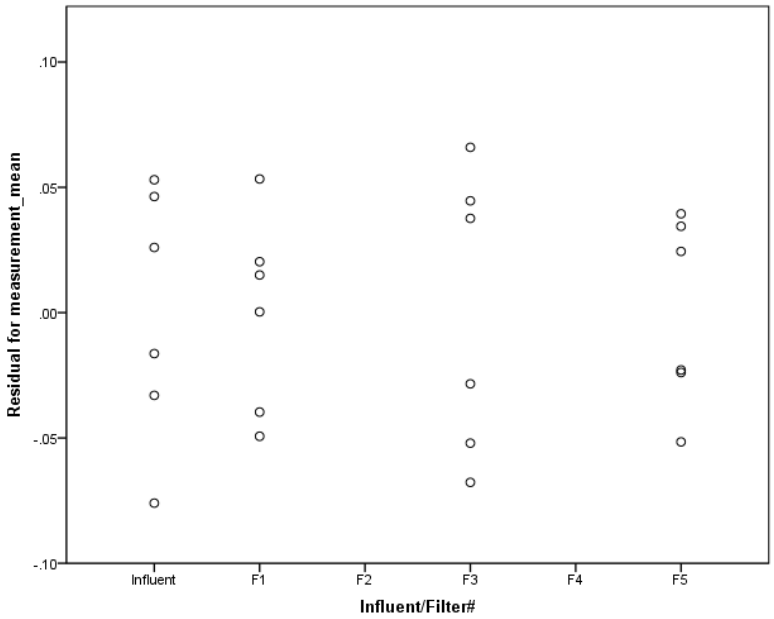

Figure B-44: Data Set 11 plot of residuals versus filter number

Table B-44: Data Set 11 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.508	3	20	2.430E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-45: Data Set 11 multiple comparisons

Tests	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.339*	0.0268	3.094E-010	0.264	0.414
		F3	0.174*	0.0268	1.422E-005	0.099	0.249
		F5	0.385*	0.0268	3.157E-011	0.310	0.461
	F1	Influent	-0.339*	0.0268	3.094E-010	-0.414	-0.264
		F3	-0.165*	0.0268	2.812E-005	-0.240	-0.090
		F5	0.046	0.0268	3.407E-001	-0.029	0.121
	F3	Influent	-0.174*	0.0268	1.422E-005	-0.249	-0.099
		F1	0.165*	0.0268	2.812E-005	0.090	0.240
		F5	0.211*	0.0268	8.299E-007	0.136	0.287
	F5	Influent	-0.385*	0.0268	3.157E-011	-0.461	-0.310
		F1	-0.046	0.0268	3.407E-001	-0.121	0.029
		F3	-0.211*	0.0268	8.299E-007	-0.287	-0.136
Dunnett T3	Influent	F1	0.339*	0.0260	1.452E-006	0.255	0.424
		F3	0.174*	0.0309	1.283E-003	0.075	0.273
		F5	0.385*	0.0257	4.873E-007	0.302	0.469
	F1	Influent	-0.339*	0.0260	1.452E-006	-0.424	-0.255
		F3	-0.165*	0.0279	1.305E-003	-0.257	-0.074
		F5	0.046	0.0220	2.847E-001	-0.024	0.117
	F3	Influent	-0.174*	0.0309	1.283E-003	-0.273	-0.075
		F1	0.165*	0.0279	1.305E-003	0.074	0.257
		F5	0.211*	0.0277	2.106E-004	0.120	0.303
	F5	Influent	-0.385*	0.0257	4.873E-007	-0.469	-0.302
		F1	-0.046	0.0220	2.847E-001	-0.117	0.024
		F3	-0.211*	0.0277	2.106E-004	-0.303	-0.120

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals are not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 12: Collected June 7, 2012

Raw Data

Table B-46: Data Set 12 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.781	3.835	4.035	4.043	3.634	3.696
		2	4.722	3.837	4.073	4.059	3.682	3.617
		3	4.741	3.882	4.079	3.988	3.666	3.740
		Average	4.748	3.851	4.062	4.030	3.661	3.684
	2	1	4.860	3.930	4.097	4.017	3.488	3.898
		2	4.854	3.962	4.164	4.061	3.904	3.908
		3	4.839	3.960	4.218	4.113	3.833	3.962
		Average	4.851	3.951	4.160	4.064	3.742	3.923
	3	1	4.646	4.035	4.162	4.148	3.857	3.831
		2	4.716	4.033	4.210	4.037	3.865	3.926
		3	4.785	4.063	4.261	4.065	3.946	3.950
		Average	4.716	4.044	4.211	4.083	3.889	3.902
	Average		4.772	3.949	4.144	4.059	3.764	3.836
	Standard Deviation		0.0722	0.0852	0.0771	0.0480	0.1524	0.1239
2	1	1	4.864	4.011	4.214	4.134	3.591	3.726
		2	4.886	4.095	4.170	4.146	3.599	3.716
		3	4.948	4.126	4.200	4.174	3.634	3.795
		Average	4.899	4.077	4.195	4.151	3.608	3.746
	2	1	5.001	3.922	4.275	4.057	3.749	3.817
		2	5.035	3.938	4.317	4.055	3.809	3.811
		3	5.079	3.974	4.364	4.114	3.777	3.872
		Average	5.038	3.945	4.319	4.075	3.778	3.833
	3	1	5.471*	3.938	4.476	4.075	3.807	3.833
		2	5.537*	3.999	4.567	4.339	3.813	3.843
		3	5.511*	4.025	4.571	4.325	3.831	3.912
		Average	5.506	3.987	4.538	4.246	3.817	3.863
	Average		4.969	4.003	4.350	4.158	3.734	3.814
	Standard Deviation		0.0847	0.0707	0.1550	0.1068	0.0983	0.0631

* Data excluded from further analysis.

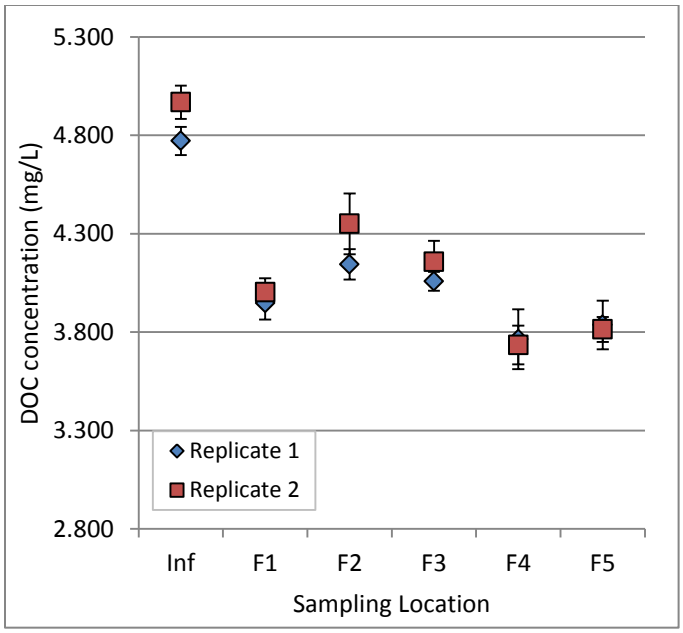

Figure B-45: Data Set 12 plot of average DOC concentrations

List of Excluded Data from Data Set 12, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Aliquot 3 for Influent, bottle 2, was excluded because the DOC concentration was higher than the DOC concentrations for the other aliquots.

ANOVA Results

Table B-47: Data Set 12 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.230[a]	5	0.846	67.995	4.033E-015
Intercept	593.107	1	593.107	47670.144	3.416E-048
filter#	4.230	5	0.846	67.995	4.033E-015
Error	0.361	29	0.012		
Total	594.481	35			
Corrected Total	4.591	34			

a. R Squared = .921 (Adjusted R Squared = .908)

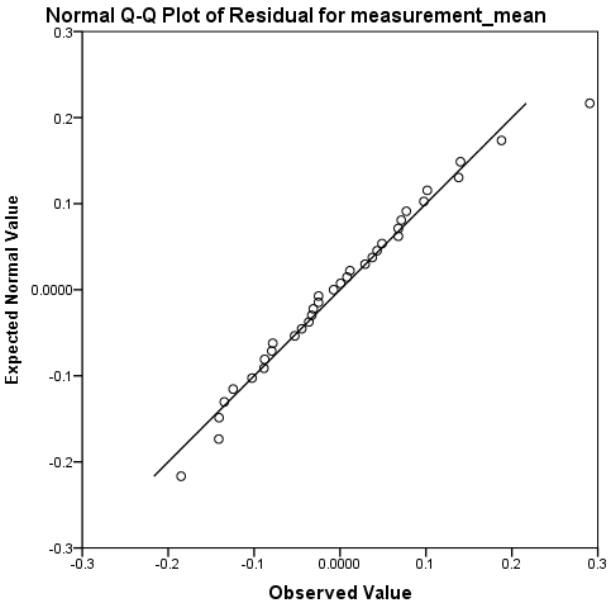

Figure B-46: Data Set 12 normal probability plot of residuals

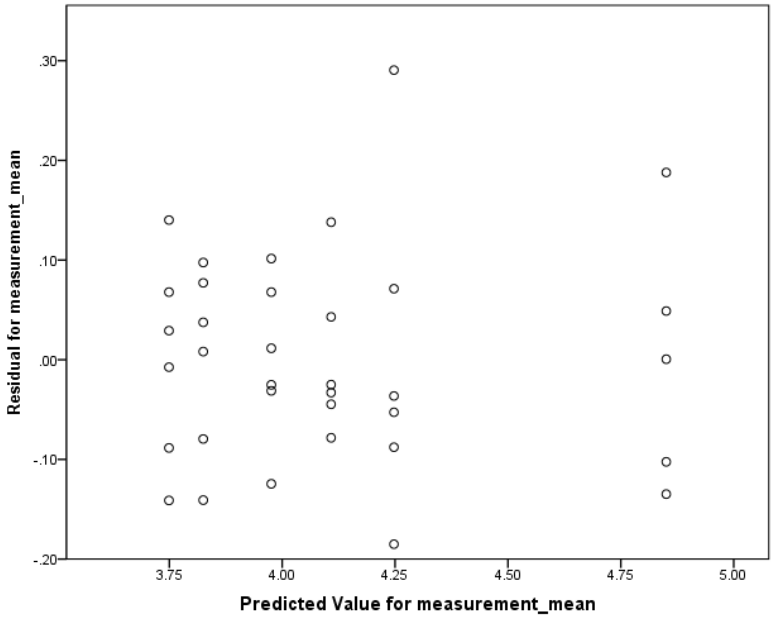

Figure B-47: Data Set 12 plot of residuals versus predicted values

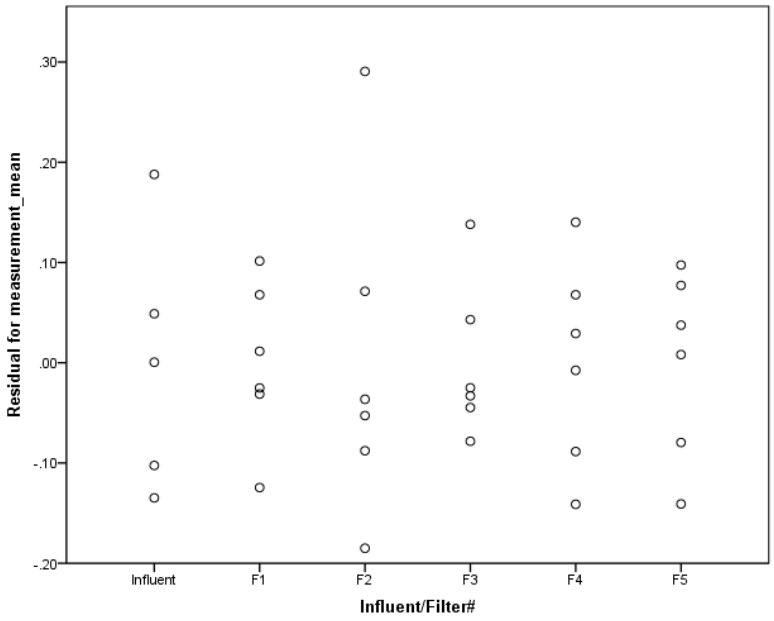

Figure B-48: Data Set 12 plot of residuals versus filter number

Table B-48: Data Set 12 results from Levene's test of equality of variances

F	df1	df2	Sig.
.802	5	29	5.575E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-49: Data Set 12 multiple comparisons

Tests	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.875*	0.0675	2.826E-012	0.669	1.081
		F2	0.603*	0.0675	1.167E-008	0.397	0.809
		F3	0.742*	0.0675	1.096E-010	0.536	0.948
		F4	1.101*	0.0675	8.431E-013	0.895	1.307
		F5	1.025*	0.0675	8.690E-013	0.819	1.231
	F1	Influent	-0.875*	0.0675	2.826E-012	-1.081	-0.669
		F2	-0.272*	0.0644	2.762E-003	-0.468	-0.075
		F3	-0.132	0.0644	3.365E-001	-0.329	0.064
		F4	0.227*	0.0644	1.644E-002	0.030	0.423
		F5	0.151	0.0644	2.112E-001	-0.046	0.347
	F2	Influent	-0.603*	0.0675	1.167E-008	-0.809	-0.397
		F1	0.272*	0.0644	2.762E-003	0.075	0.468
		F3	0.139	0.0644	2.869E-001	-0.057	0.335
		F4	0.498*	0.0644	2.239E-007	0.302	0.695
		F5	0.422*	0.0644	4.912E-006	0.226	0.619
	F3	Influent	-0.742*	0.0675	1.096E-010	-0.948	-0.536
		F1	0.132	0.0644	3.365E-001	-0.064	0.329
		F2	-0.139	0.0644	2.869E-001	-0.335	0.057
		F4	0.359*	0.0644	6.958E-005	0.163	0.555
		F5	0.283*	0.0644	1.712E-003	0.087	0.479
	F4	Influent	-1.101*	0.0675	8.431E-013	-1.307	-0.895
		F1	-0.227*	0.0644	1.644E-002	-0.423	-0.030
		F2	-0.498*	0.0644	2.239E-007	-0.695	-0.302
		F3	-0.359*	0.0644	6.958E-005	-0.555	-0.163
		F5	-0.076	0.0644	8.426E-001	-0.272	0.120
	F5	Influent	-1.025*	0.0675	8.690E-013	-1.231	-0.819
		F1	-0.151	0.0644	2.112E-001	-0.347	0.046
		F2	-0.422*	0.0644	4.912E-006	-0.619	-0.226
		F3	-0.283*	0.0644	1.712E-003	-0.479	-0.087
		F4	0.076	0.0644	8.426E-001	-0.120	0.272
Dunnett T3	Influent	F1	0.875*	0.0662	7.353E-005	0.599	1.150
		F2	0.603*	0.0885	1.005E-003	0.269	0.937
		F3	0.742*	0.0659	2.166E-004	0.466	1.018
		F4	1.101*	0.0713	5.983E-006	0.820	1.382
		F5	1.025*	0.0689	1.486E-005	0.748	1.303
	F1	Influent	-0.875*	0.0662	7.353E-005	-1.150	-0.599
		F2	-0.272	0.0748	7.954E-002	-0.571	0.028
		F3	-0.132	0.0458	1.665E-001	-0.301	0.036
		F4	0.227*	0.0532	2.287E-002	0.028	0.425
		F5	0.151	0.0501	1.421E-001	-0.034	0.336
	F2	Influent	-0.603*	0.0885	1.005E-003	-0.937	-0.269
		F1	0.272	0.0748	7.954E-002	-0.028	0.571
		F3	0.139	0.0745	6.372E-001	-0.160	0.439
		F4	0.498*	0.0793	2.387E-003	0.194	0.803
		F5	0.422*	0.0772	7.315E-003	0.121	0.724
	F3	Influent	-0.742*	0.0659	2.166E-004	-1.018	-0.466
		F1	0.132	0.0458	1.665E-001	-0.036	0.301
		F2	-0.139	0.0745	6.372E-001	-0.439	0.160
		F4	0.359*	0.0528	8.545E-004	0.162	0.556
		F5	0.283*	0.0496	2.804E-003	0.100	0.467
	F4	Influent	-1.101*	0.0713	5.983E-006	-1.382	-0.820
		F1	-0.227*	0.0532	2.287E-002	-0.425	-0.028
		F2	-0.498*	0.0793	2.387E-003	-0.803	-0.194
		F3	-0.359*	0.0528	8.545E-004	-0.556	-0.162
		F5	-0.076	0.0566	9.123E-001	-0.284	0.132
	F5	Influent	-1.025*	0.0689	1.486E-005	-1.303	-0.748
		F1	-0.151	0.0501	1.421E-001	-0.336	0.034
		F2	-0.422*	0.0772	7.315E-003	-0.724	-0.121
		F3	-0.283*	0.0496	2.804E-003	-0.467	-0.100
		F4	0.076	0.0566	9.123E-001	-0.132	0.284

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 13: Collected June 9, 2012

Raw Data

Table B-50: Data Set 13 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	5.269	4.149*	4.440	4.271	3.991	4.188*
		2	5.431	4.230*	4.489	4.373	4.017	4.174*
		3	5.274	4.239*	4.526	4.366	4.049	4.186*
		Average	5.325	4.206	4.485	4.337	4.019	4.183
	2	1	5.061	4.239*	4.357	4.327	4.135	4.142*
		2	5.179	4.276*	4.410	4.362	4.153	4.177*
		3	5.218	4.320*	4.438	4.385	4.114	4.221*
		Average	5.153	4.278	4.402	4.358	4.134	4.180
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		5.239	4.242	4.443	4.347	4.077	4.181
	Standard Deviation		0.1222	0.0567	0.0592	0.0421	0.0668	0.0255
2	1	1	5.172	4.373*	4.346	4.295	3.964	4.461*
		2	5.274	4.473*	4.385	4.357	4.014	4.487*
		3	5.325	4.489*	4.420	4.387	3.970	4.568*
		Average	5.257	4.445	4.384	4.346	3.983	4.505
	2	1	5.017	4.475*	4.401	4.232	4.135	4.359*
		2	5.144	4.512*	4.447	4.262	4.160	4.399*
		3	5.172	4.572*	4.464	4.306	4.126	4.461*
		Average	5.111	4.520	4.437	4.267	4.140	4.406
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		5.184	4.482	4.411	4.307	4.062	4.456
	Standard Deviation		0.1075	0.0649	0.0429	0.0578	0.0888	0.0724

* Data excluded from further analysis.

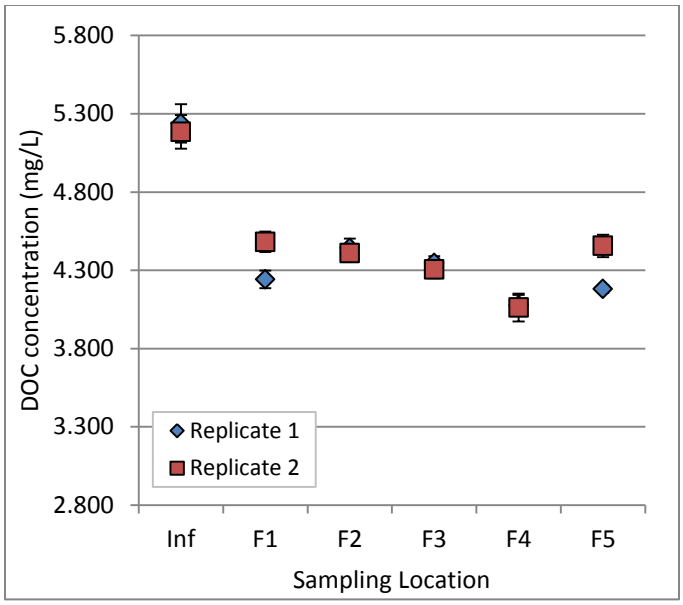

Figure B-49: Data Set 13 plot of average DOC concentrations

List of Excluded Data from Data Set 13, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from Filter 1 and Filter 5 excluded because readings from bottles containing sample water from the same location were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 1 and at least one of the bottles used to collect samples from Filter 5 was contaminated.

ANOVA Results

Table B-51: Data Set 13 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.907[a]	3	.969	197.880	1.759E-010
Intercept	325.231	1	325.231	66414.432	7.841E-024
filter#	2.907	3	.969	197.880	1.759E-010
Error	.059	12	.005		
Total	328.197	16			
Corrected Total	2.966	15			

a. R Squared = .980 (Adjusted R Squared = .975)

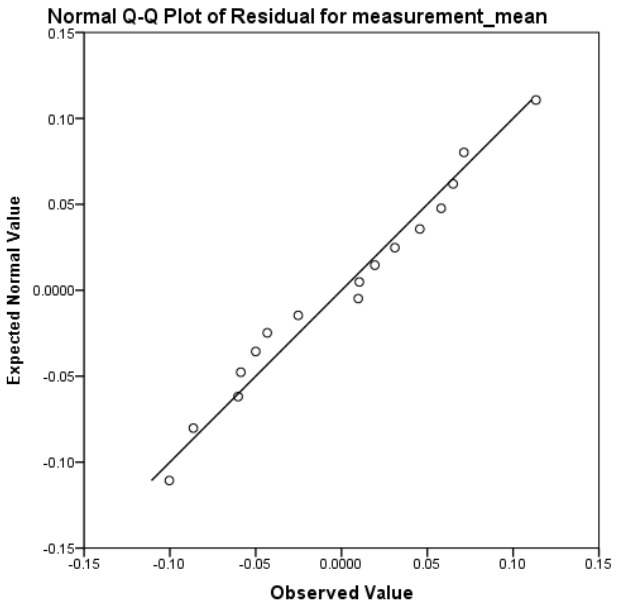

Figure B-50: Data Set 13 normal probability plot of residuals

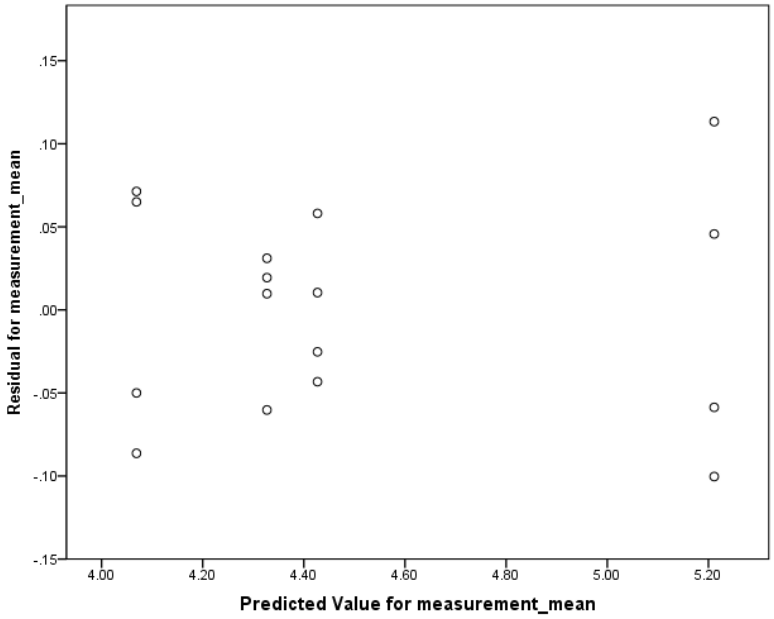

Figure B-51: Data Set 13 plot of residuals versus predicted values

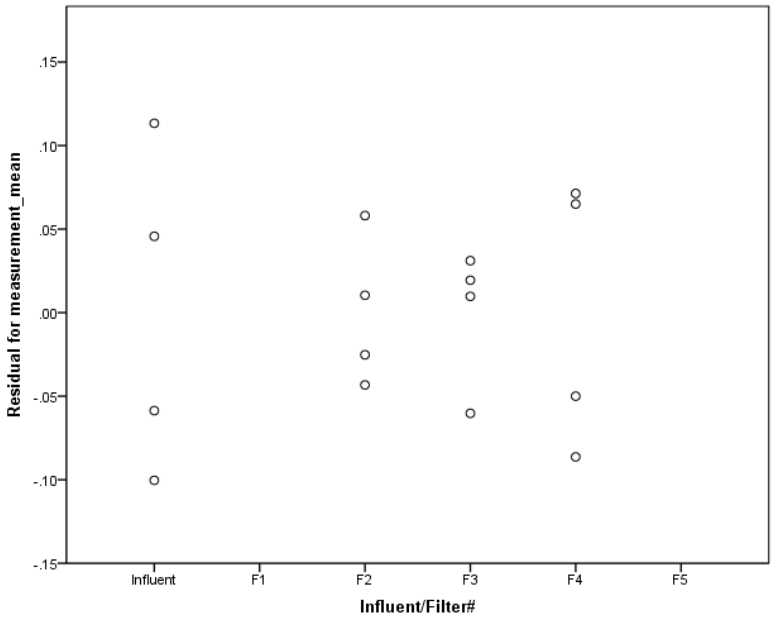

Figure B-52: Data Set 13 plot of residuals versus filter number

Table B-52: Data Set 13 results from Levene's test of equality of variances

F	df1	df2	Sig.
4.398	3	12	2.630E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-53: Data Set 13 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F2	0.784*	0.0495	1.097E-008	0.638	0.931
		F3	0.884*	0.0495	2.750E-009	0.738	1.031
		F4	1.142*	0.0495	1.397E-010	0.995	1.289
	F2	Influent	-0.784*	0.0495	1.097E-008	-0.931	-0.638
		F3	0.100	0.0495	2.339E-001	-0.047	0.247
		F4	0.358*	0.0495	5.337E-005	0.211	0.505
	F3	Influent	-0.884*	0.0495	2.750E-009	-1.031	-0.738
		F2	-0.100	0.0495	2.339E-001	-0.247	0.047
		F4	0.258*	0.0495	1.076E-003	0.111	0.405
	F4	Influent	-1.142*	0.0495	1.397E-010	-1.289	-0.995
		F2	-0.358*	0.0495	5.337E-005	-0.505	-0.211
		F3	-0.258*	0.0495	1.076E-003	-0.405	-0.111
Dunnett T3**	Influent	F2	0.784*	0.0536	4.067E-004	0.557	1.012
		F3	0.884*	0.0528	3.098E-004	0.655	1.114
		F4	1.142*	0.0631	1.314E-005	0.908	1.376
	F2	Influent	-0.784*	0.0536	4.067E-004	-1.012	-0.557
		F3	0.100	0.0304	7.750E-002	-0.012	0.212
		F4	0.358*	0.0459	3.406E-003	0.173	0.543
	F3	Influent	-0.884*	0.0528	3.098E-004	-1.114	-0.655
		F2	-0.100	0.0304	7.750E-002	-0.212	0.012
		F4	0.258*	0.0450	1.455E-002	0.072	0.444
	F4	Influent	-1.142*	0.0631	1.314E-005	-1.376	-0.908
		F2	-0.358*	0.0459	3.406E-003	-0.543	-0.173
		F3	-0.258*	0.0450	1.455E-002	-0.444	-0.072

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # exhibit some heteroscedasticity in the residuals.
4. Results from Levene's test of equality of variance indicate that the residuals were heteroscedastic.
5. As a result of points 3&4, the residuals and the data were considered to exhibit heteroscedasticity; therefore, results from Dunnett's T3 test were used for multiple comparisons between the filter effluent DOC concentration

Data Set 14: Collected June 19, 2012

Raw Data

Table B-54: Data Set 14 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.487	3.916	3.950	3.905	3.468	3.621
		2	4.488	3.978	3.982	3.884	3.449	3.587
		3	4.452	3.917	3.982	3.886	3.470	3.640
		Average	4.476	3.937	3.971	3.892	3.462	3.616
	2	1	4.379	3.693	4.044	3.881	3.654	3.797
		2	4.351	3.726	4.154	3.923	3.637	3.849
		3	4.476	3.689	4.114	4.017	3.607	3.813
		Average	4.402	3.703	4.104	3.940	3.633	3.820
	3	1	4.304	3.670	3.768	3.773	3.484	3.587
		2	4.241	3.771	3.759	3.748	3.390	3.625
		3	4.279	3.656	3.785	3.717	3.430	3.538
		Average	4.275	3.699	3.771	3.746	3.435	3.583
	Average		4.384	3.780	3.949	3.859	3.510	3.673
	Standard Deviation		0.0959	0.1239	0.1484	0.0955	0.0967	0.1146
2	1	1	4.398	3.797	3.966	4.046	3.496	3.583
		2	4.361	3.860	4.093	4.069	3.529	3.580
		3	4.384	3.823	3.957	4.050	3.557	3.682
		Average	4.381	3.827	4.005	4.055	3.527	3.615
	2	1	4.447	3.701	3.860	4.255*	3.466	3.634
		2	4.497	3.658	3.879	4.274*	3.524	3.614
		3	4.459	3.696	3.902	4.283*	3.550	3.607
		Average	4.468	3.685	3.880	4.271	3.513	3.618
	3	1	4.711*	4.027*	4.387*	3.813	3.538	3.529
		2	4.645*	4.039*	4.387*	3.771	3.520	3.515
		3	4.650*	4.051*	4.344*	3.797	3.470	3.543
		Average	4.669	4.039	4.373	3.794	3.509	3.529
	Average		4.424	3.756	3.943	3.924	3.517	3.587
	Standard Deviation		0.0516	0.0815	0.0847	0.1440	0.0328	0.0535

* Data excluded from further analysis.

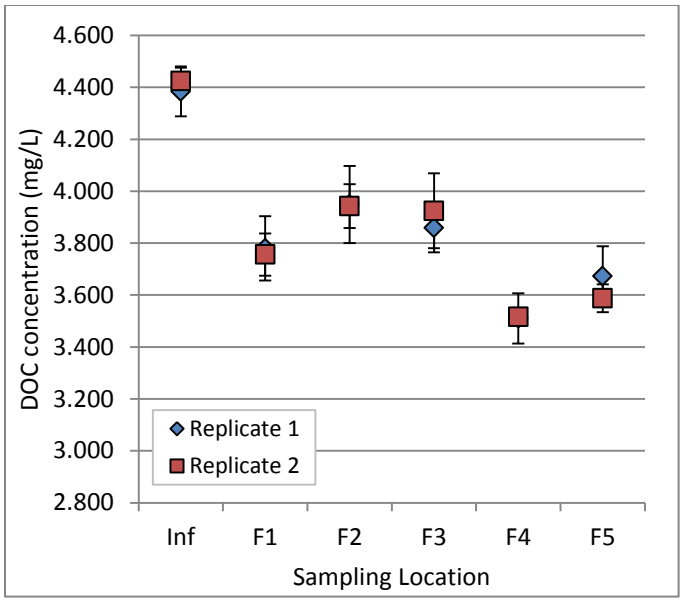

Figure B-53: Data Set 14 plot of average DOC concentrations

List of Excluded Data from Data Set 14, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from aliquot 3 for Influent bottle 2, aliquot 3 for Filter 1 bottle 2, aliquot 3 for Filter 2 bottle 2, and aliquot 2 for Filter 3 bottle 2 were excluded because the DOC concentration for each of these aliquots was higher than the DOC concentrations for other aliquots associated with the same bottle; it is suspected that the vials containing these aliquots were contaminated.

ANOVA Results

Table B-55: Data Set 14 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.565[a]	5	.513	49.348	1.890E-012
Intercept	472.686	1	472.686	45471.413	1.075E-043
filter#	2.565	5	.513	49.348	1.890E-012
Error	.270	26	.010		
Total	474.623	32			
Corrected Total	2.835	31			

a. R Squared = .905 (Adjusted R Squared = .886)

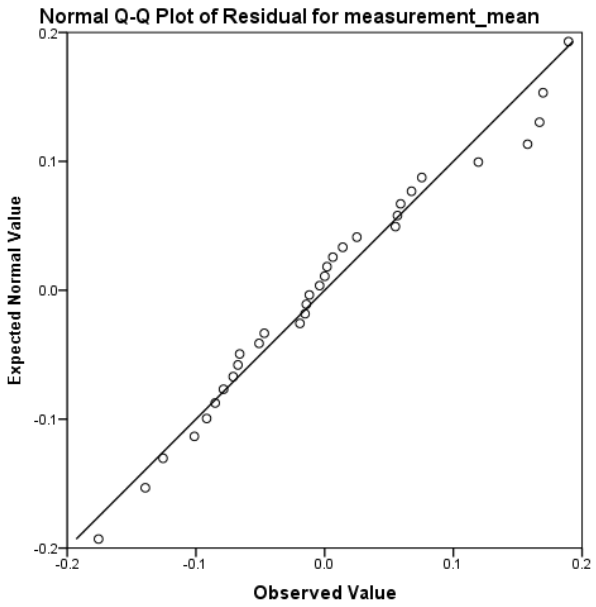

Figure B-54: Data Set 14 normal probability plot of residuals

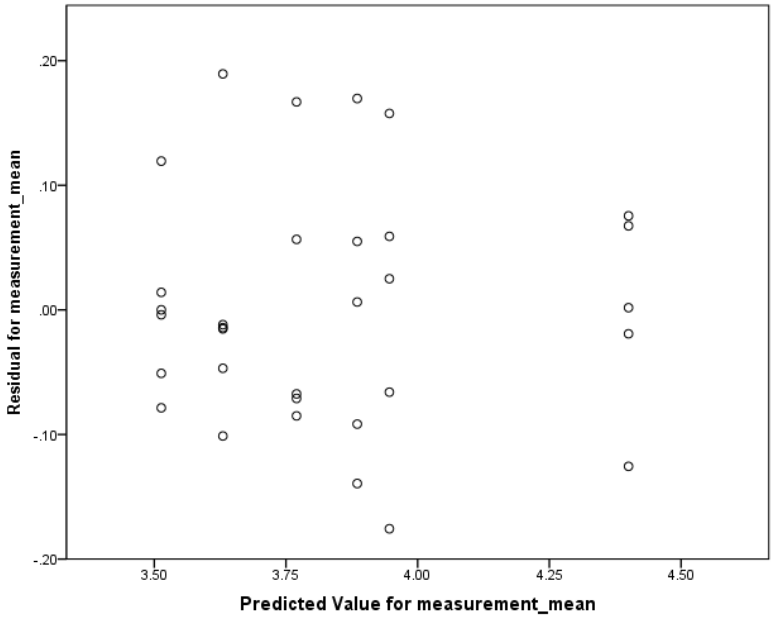

Figure B-55: Data Set 14 plot of residuals versus predicted values

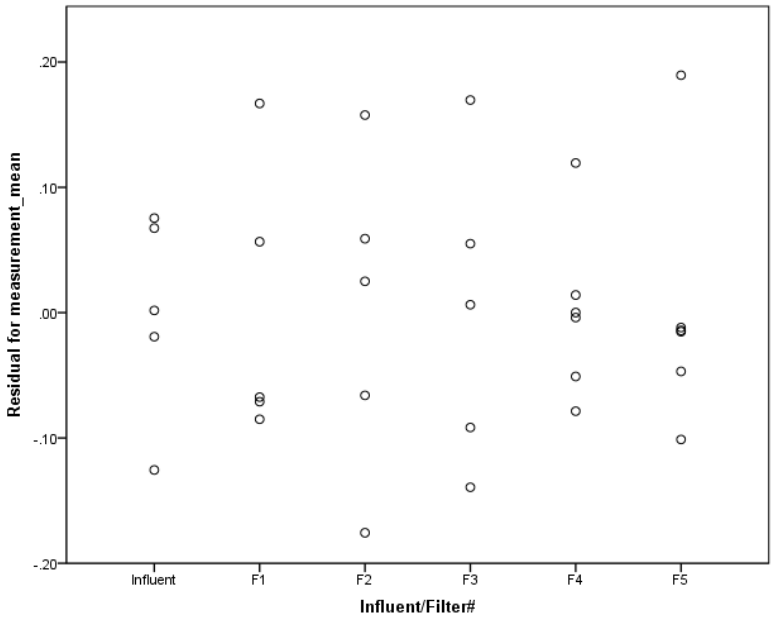

Figure B-56: Data Set 14 plot of residuals versus filter number

Table B-56: Data Set 14 results from Levene's test of equality of variances

F	df1	df2	Sig.
.743	5	26	5.982E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-57: Data Set 14 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.630*	0.0645	4.902E-009	0.432	0.828
		F2	0.454*	0.0645	2.492E-006	0.256	0.652
		F3	0.515*	0.0645	2.592E-007	0.317	0.713
		F4	0.887*	0.0617	1.821E-012	0.697	1.077
		F5	0.770*	0.0617	2.649E-011	0.580	0.960
	F1	Influent	-0.630*	0.0645	4.902E-009	-0.828	-0.432
		F2	-0.176	0.0645	1.022E-001	-0.374	0.022
		F3	-0.115	0.0645	4.905E-001	-0.313	0.083
		F4	0.257*	0.0617	3.749E-003	0.067	0.446
		F5	0.140	0.0617	2.439E-001	-0.050	0.330
	F2	Influent	-0.454*	0.0645	2.492E-006	-0.652	-0.256
		F1	0.176	0.0645	1.022E-001	-0.022	0.374
		F3	0.061	0.0645	9.305E-001	-0.137	0.259
		F4	0.433*	0.0617	2.643E-006	0.243	0.623
		F5	0.316*	0.0617	3.207E-004	0.126	0.506
	F3	Influent	-0.515*	0.0645	2.592E-007	-0.713	-0.317
		F1	0.115	0.0645	4.905E-001	-0.083	0.313
		F2	-0.061	0.0645	9.305E-001	-0.259	0.137
		F4	0.372*	0.0617	3.129E-005	0.182	0.562
		F5	0.255*	0.0617	4.014E-003	0.065	0.445
	F4	Influent	-0.887*	0.0617	1.821E-012	-1.077	-0.697
		F1	-0.257*	0.0617	3.749E-003	-0.446	-0.067
		F2	-0.433*	0.0617	2.643E-006	-0.623	-0.243
		F3	-0.372*	0.0617	3.129E-005	-0.562	-0.182
		F5	-0.117	0.0589	3.764E-001	-0.298	0.064
	F5	Influent	-0.770*	0.0617	2.649E-011	-0.960	-0.580
		F1	-0.140	0.0617	2.439E-001	-0.330	0.050
		F2	-0.316*	0.0617	3.207E-004	-0.506	-0.126
		F3	-0.255*	0.0617	4.014E-003	-0.445	-0.065
		F4	0.117	0.0589	3.764E-001	-0.064	0.298
Dunnett T3	Influent	F1	0.630*	0.0609	1.430E-004	0.387	0.873
		F2	0.454*	0.0673	3.361E-003	0.179	0.729
		F3	0.515*	0.0656	1.221E-003	0.249	0.781
		F4	0.887*	0.0458	7.685E-007	0.708	1.066
		F5	0.770*	0.0543	2.442E-006	0.565	0.975
	F1	Influent	-0.630*	0.0609	1.430E-004	-0.873	-0.387
		F2	-0.176	0.0749	3.787E-001	-0.469	0.117
		F3	-0.115	0.0733	8.024E-001	-0.402	0.171
		F4	0.257*	0.0563	3.237E-002	0.023	0.491
		F5	0.140	0.0634	4.470E-001	-0.105	0.385
	F2	Influent	-0.454*	0.0673	3.361E-003	-0.729	-0.179
		F1	0.176	0.0749	3.787E-001	-0.117	0.469
		F3	0.061	0.0787	9.985E-001	-0.245	0.367
		F4	0.433*	0.0631	5.257E-003	0.161	0.705
		F5	0.316*	0.0696	2.426E-002	0.041	0.591
	F3	Influent	-0.515*	0.0656	1.221E-003	-0.781	-0.249
		F1	0.115	0.0733	8.024E-001	-0.171	0.402
		F2	-0.061	0.0787	9.985E-001	-0.367	0.245
		F4	0.372*	0.0613	9.207E-003	0.110	0.634
		F5	0.255	0.0679	6.268E-002	-0.012	0.522
	F4	Influent	-0.887*	0.0458	7.685E-007	-1.066	-0.708
		F1	-0.257*	0.0563	3.237E-002	-0.491	-0.023
		F2	-0.433*	0.0631	5.257E-003	-0.705	-0.161
		F3	-0.372*	0.0613	9.207E-003	-0.634	-0.110
		F5	-0.117	0.0490	3.545E-001	-0.302	0.069
	F5	Influent	-0.770*	0.0543	2.442E-006	-0.975	-0.565
		F1	-0.140	0.0634	4.470E-001	-0.385	0.105
		F2	-0.316*	0.0696	2.426E-002	-0.591	-0.041
		F3	-0.255	0.0679	6.268E-002	-0.522	0.012
		F4	0.117	0.0490	3.545E-001	-0.069	0.302

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the data were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 15: Collected June 21, 2012

Raw Data

Table B-58: Data Set 15 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.327	3.608	3.799	3.756	3.372	3.538
		2	4.375	3.615	3.769	3.792	3.382	3.545
		3	4.371	3.673	3.781	3.859	3.428	3.553
		Average	4.358	3.632	3.783	3.802	3.394	3.545
	2	1	4.318	3.571	3.743	3.670	3.439	3.394
		2	4.391	3.602	3.769	3.726	3.454	3.436
		3	4.396	3.621	3.815	3.739	3.464	3.441
		Average	4.368	3.598	3.776	3.712	3.452	3.424
	3	1	4.336	3.540	3.765	3.673	3.381	3.390
		2	4.321	3.506	3.818	3.586	3.377	3.394
		3	4.373	3.608	3.766	3.628	3.415	3.441
		Average	4.343	3.551	3.783	3.629	3.391	3.408
	Average		4.356	3.594	3.781	3.714	3.412	3.459
	Standard Deviation		0.0308	0.0488	0.0252	0.0844	0.0356	0.0679
2	1	1	4.383	3.473	3.711	3.737	3.363	3.379
		2	4.498	3.579	3.752	3.763	3.304	3.423
		3	4.443	3.517	3.778	3.776	3.438	3.439
		Average	4.441	3.523	3.747	3.759	3.368	3.414
	2	1	4.510	3.504	3.787	3.708	3.490	3.381
		2	4.571	3.530	3.818	3.753	3.558	3.416
		3	4.581	3.540	3.838	3.742	3.550	3.429
		Average	4.554	3.525	3.814	3.734	3.533	3.409
	3	1	4.487	3.477	3.872	3.709	3.394	3.421
		2	4.524	3.508	3.870	3.600	3.465	3.454
		3	4.567	3.521	3.852	3.722	3.355	3.483
		Average	4.526	3.502	3.865	3.677	3.405	3.453
	Average		4.507	3.517	3.809	3.723	3.435	3.425
	Standard Deviation		0.0646	0.0323	0.0556	0.0517	0.0885	0.0327

* Data excluded from further analysis.

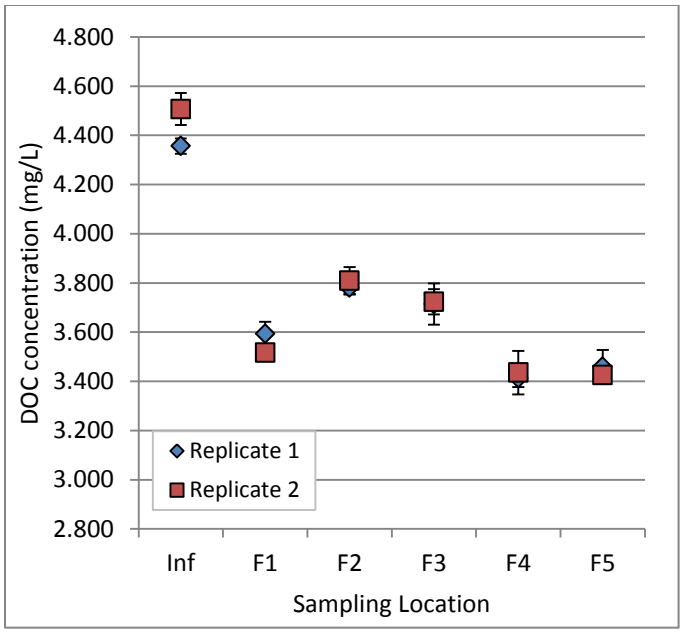

Figure B-57: Data Set 15 plot of average DOC concentrations

List of Excluded Data from Data Set 15, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded

ANOVA Results

Table B-59: Data Set 15 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.224[a]	5	0.845	224.470	8.118E-023
Intercept	500.250	1	500.250	132924.920	2.891E-056
filter#	4.224	5	0.845	224.470	8.118E-023
Error	0.113	30	0.004		
Total	504.587	36			
Corrected Total	4.337	35			

a. R Squared = .974 (Adjusted R Squared = .970)

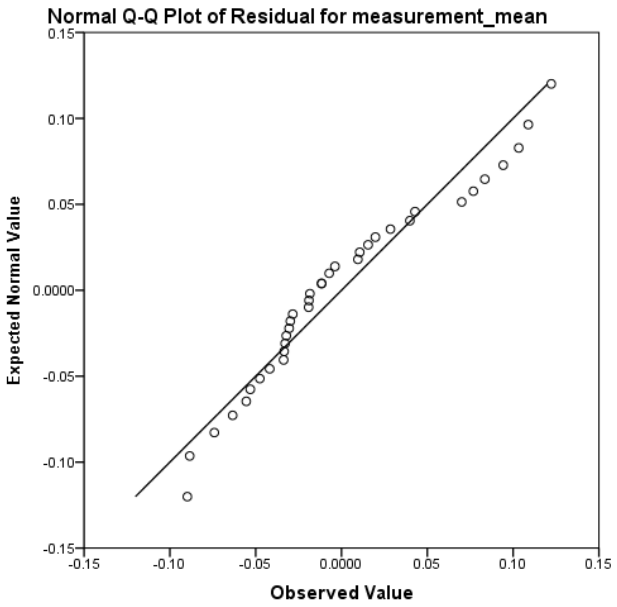

Figure B-58: Data Set 15 normal probability plot of residuals

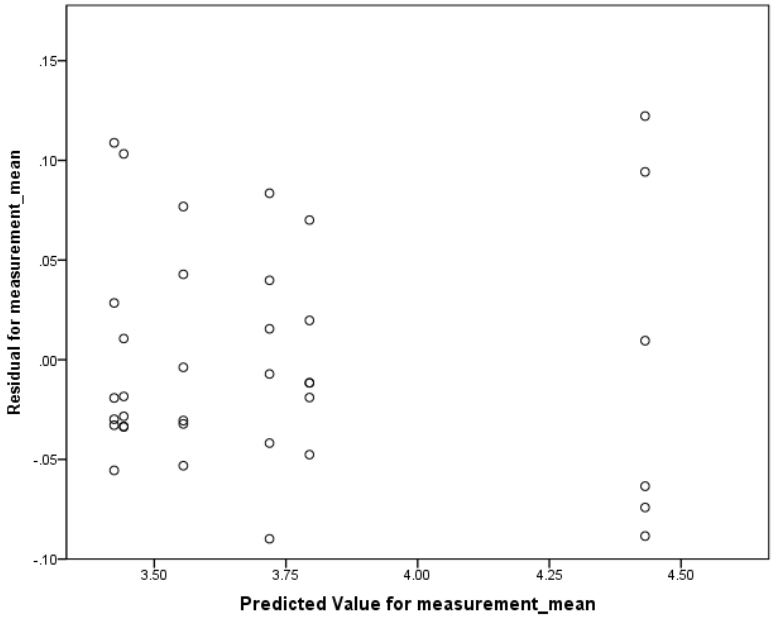

Figure B-59: Data Set 15 plot of residuals versus predicted values

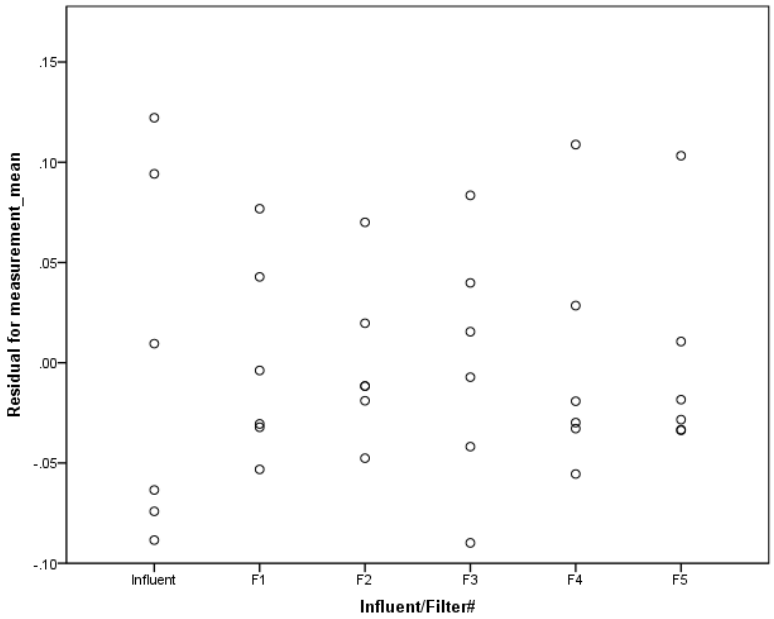

Figure B-60: Data Set 15 plot of residuals versus filter number

Table B-60: Data Set 15 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.472	5	30	2.283E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-61: Data Set 15 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.877*	0.0354	8.280E-013	0.769	0.984
		F2	0.637*	0.0354	8.281E-013	0.529	0.745
		F3	0.713*	0.0354	8.280E-013	0.605	0.821
		F4	1.008*	0.0354	8.280E-013	0.900	1.116
		F5	0.990*	0.0354	8.280E-013	0.882	1.097
	F1	Influent	-0.877*	0.0354	8.280E-013	-0.984	-0.769
		F2	-0.239*	0.0354	2.405E-006	-0.347	-0.132
		F3	-0.164*	0.0354	8.808E-004	-0.271	-0.056
		F4	0.131*	0.0354	9.961E-003	0.024	0.239
		F5	0.113*	0.0354	3.521E-002	0.005	0.221
	F2	Influent	-0.637*	0.0354	8.281E-013	-0.745	-0.529
		F1	0.239*	0.0354	2.405E-006	0.132	0.347
		F3	0.076	0.0354	2.952E-001	-0.032	0.184
		F4	0.371*	0.0354	2.281E-010	0.263	0.479
		F5	0.353*	0.0354	7.425E-010	0.245	0.460
	F3	Influent	-0.713*	0.0354	8.280E-013	-0.821	-0.605
		F1	0.164*	0.0354	8.808E-004	0.056	0.271
		F2	-0.076	0.0354	2.952E-001	-0.184	0.032
		F4	0.295*	0.0354	3.881E-008	0.187	0.403
		F5	0.277*	0.0354	1.457E-007	0.169	0.385
	F4	Influent	-1.008*	0.0354	8.280E-013	-1.116	-0.900
		F1	-0.131*	0.0354	9.961E-003	-0.239	-0.024
		F2	-0.371*	0.0354	2.281E-010	-0.479	-0.263
		F3	-0.295*	0.0354	3.881E-008	-0.403	-0.187
		F5	-0.018	0.0354	9.952E-001	-0.126	0.090
	F5	Influent	-0.990*	0.0354	8.280E-013	-1.097	-0.882
		F1	-0.113*	0.0354	3.521E-002	-0.221	-0.005
		F2	-0.353*	0.0354	7.425E-010	-0.460	-0.245
		F3	-0.277*	0.0354	1.457E-007	-0.385	-0.169
		F4	0.018	0.0354	9.952E-001	-0.090	0.126
Dunnett T3	Influent	F1	0.877*	0.0423	5.499E-007	0.711	1.043
		F2	0.637*	0.0406	1.379E-005	0.472	0.802
		F3	0.713*	0.0447	1.183E-006	0.543	0.883
		F4	1.008*	0.0445	6.653E-008	0.839	1.177
		F5	0.990*	0.0430	1.522E-007	0.823	1.157
	F1	Influent	-0.877*	0.0423	5.499E-007	-1.043	-0.711
		F2	-0.239*	0.0263	6.733E-005	-0.337	-0.142
		F3	-0.164*	0.0323	6.828E-003	-0.283	-0.044
		F4	0.131*	0.0319	2.707E-002	0.013	0.250
		F5	0.113*	0.0298	4.217E-002	0.003	0.223
	F2	Influent	-0.637*	0.0406	1.379E-005	-0.802	-0.472
		F1	0.239*	0.0263	6.733E-005	0.142	0.337
		F3	0.076	0.0299	2.950E-001	-0.038	0.190
		F4	0.371*	0.0296	8.950E-006	0.258	0.483
		F5	0.353*	0.0273	3.894E-006	0.251	0.455
	F3	Influent	-0.713*	0.0447	1.183E-006	-0.883	-0.543
		F1	0.164*	0.0323	6.828E-003	0.044	0.283
		F2	-0.076	0.0299	2.950E-001	-0.190	0.038
		F4	0.295*	0.0350	1.003E-004	0.166	0.424
		F5	0.277*	0.0331	1.201E-004	0.155	0.399
	F4	Influent	-1.008*	0.0445	6.653E-008	-1.177	-0.839
		F1	-0.131*	0.0319	2.707E-002	-0.250	-0.013
		F2	-0.371*	0.0296	8.950E-006	-0.483	-0.258
		F3	-0.295*	0.0350	1.003E-004	-0.424	-0.166
		F5	-0.018	0.0328	1.000E+000	-0.139	0.103
	F5	Influent	-0.990*	0.0430	1.522E-007	-1.157	-0.823
		F1	-0.113*	0.0298	4.217E-002	-0.223	-0.003
		F2	-0.353*	0.0273	3.894E-006	-0.455	-0.251
		F3	-0.277*	0.0331	1.201E-004	-0.399	-0.155
		F4	0.018	0.0328	1.000E+000	-0.103	0.139

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the data were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 16: Collected June 27, 2012

Raw Data

Table B-62: Data Set 16 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	5.005	4.154	4.499	4.374	3.910	3.996
		2	5.047	4.120	4.455	4.412	4.041	4.045
		3	5.088	4.210	4.514	4.435	4.050	4.089
		Average	5.047	4.161	4.489	4.407	4.000	4.043
	2	1	5.107	4.206	4.447	4.468	3.994	4.025
		2	5.190	4.277	4.549	4.526	4.027	4.068
		3	5.255	4.258	4.616	4.555	3.956	4.091
		Average	5.184	4.247	4.537	4.516	3.992	4.061
	3	1	5.126	4.358	4.485	4.476	4.021	4.041
		2	5.171	4.410	4.562	4.518	4.070	4.106
		3	5.186	4.403	4.570	4.580	4.116	4.112
		Average	5.161	4.390	4.539	4.525	4.069	4.086
	Average		5.131	4.266	4.522	4.483	4.021	4.064
	Standard Deviation		0.0782	0.1053	0.0565	0.0682	0.0612	0.0395
2	1	1	5.053	-	-	-	-	-
		2	5.159	-	-	-	-	-
		3	5.161	-	-	-	-	-
		Average	5.124	-	-	-	-	-
	2	1	5.082	-	-	-	-	-
		2	5.250	-	-	-	-	-
		3	5.192	-	-	-	-	-
		Average	5.175	-	-	-	-	-
	3	1	5.294	-	-	-	-	-
		2	5.292	-	-	-	-	-
		3	5.215	-	-	-	-	-
		Average	5.267	-	-	-	-	-
	Average		5.189	-	-	-	-	-
	Standard Deviation		0.0849	-	-	-	-	-

* Data excluded from further analysis.

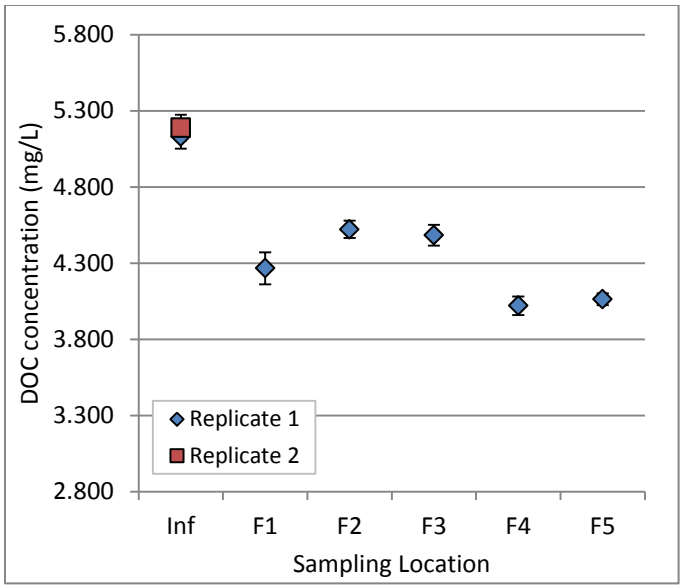

Figure B-61: Data Set 16 plot of average DOC concentrations

List of Excluded Data from Data Set 16, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded
2. AOC analysis also conducted on the same day. There was only enough sample water to allow one bottle from each filter effluent to be analyzed for DOC.

ANOVA Results

Table B-63: Data Set 16 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.025[a]	5	.805	177.998	8.418E-013
Intercept	383.468	1	383.468	84799.852	1.458E-029
filter#	4.025	5	.805	177.998	8.418E-013
Error	.068	15	.005		
Total	434.059	21			
Corrected Total	4.092	20			

a. R Squared = .983 (Adjusted R Squared = .978)

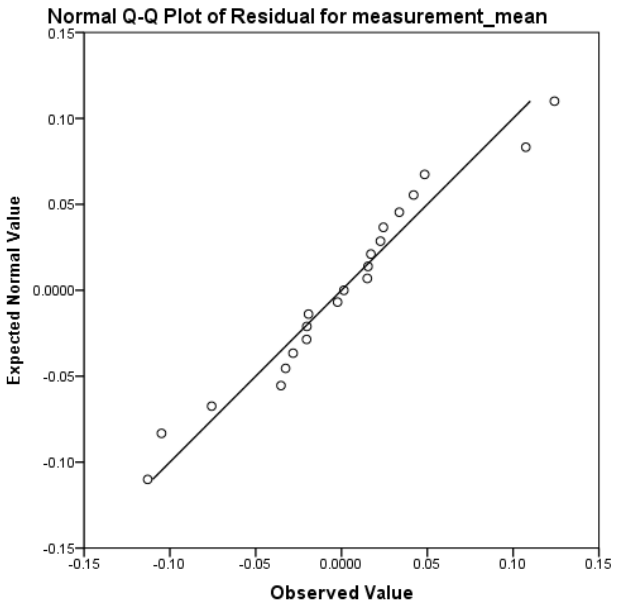

Figure B-62: Data Set 16 normal probability plot of residuals

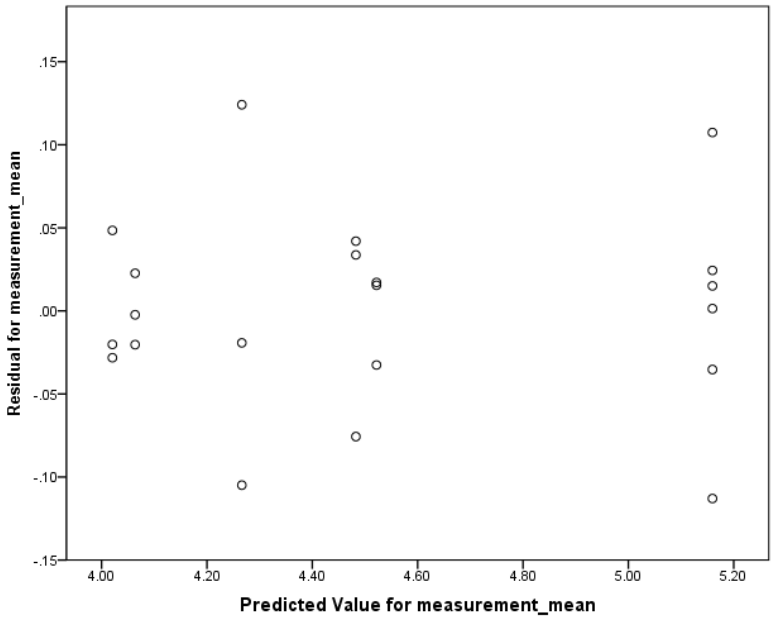

Figure B-63: Data Set 16 plot of residuals versus predicted values

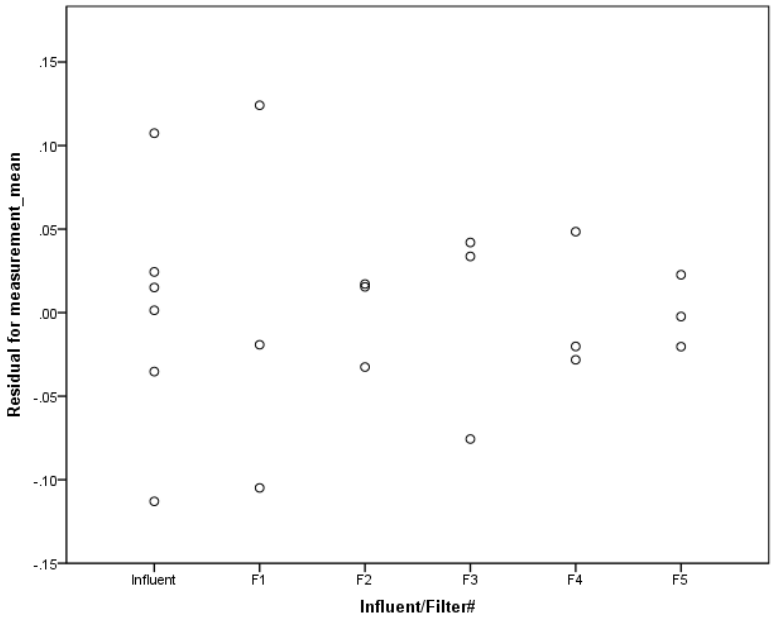

Figure B-64: Data Set 16 plot of residuals versus filter number

Table B-64: Data Set 16 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.393	5	15	2.821E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept + filter#

Table B-65: Data Set 16 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.893*	0.0476	1.030E-010	0.739	1.048
		F2	0.638*	0.0476	1.210E-008	0.483	0.792
		F3	0.677*	0.0476	5.270E-009	0.522	0.831
		F4	1.139*	0.0476	4.020E-012	0.985	1.294
		F5	1.096*	0.0476	6.273E-012	0.941	1.250
	F1	Influent	-0.893*	0.0476	1.030E-010	-1.048	-0.739
		F2	-0.256*	0.0549	3.439E-003	-0.434	-0.077
		F3	-0.216*	0.0549	1.349E-002	-0.395	-0.038
		F4	0.246*	0.0549	4.865E-003	0.067	0.424
		F5	0.203*	0.0549	2.186E-002	0.024	0.381
	F2	Influent	-0.638*	0.0476	1.210E-008	-0.792	-0.483
		F1	0.256*	0.0549	3.439E-003	0.077	0.434
		F3	0.039	0.0549	9.772E-001	-0.139	0.218
		F4	0.501*	0.0549	2.065E-006	0.323	0.680
		F5	0.458*	0.0549	6.395E-006	0.280	0.637
	F3	Influent	-0.677*	0.0476	5.270E-009	-0.831	-0.522
		F1	0.216*	0.0549	1.349E-002	0.038	0.395
		F2	-0.039	0.0549	9.772E-001	-0.218	0.139
		F4	0.462*	0.0549	5.759E-006	0.284	0.640
		F5	0.419*	0.0549	1.902E-005	0.241	0.597
	F4	Influent	-1.139*	0.0476	4.020E-012	-1.294	-0.985
		F1	-0.246*	0.0549	4.865E-003	-0.424	-0.067
		F2	-0.501*	0.0549	2.065E-006	-0.680	-0.323
		F3	-0.462*	0.0549	5.759E-006	-0.640	-0.284
		F5	-0.043	0.0549	9.659E-001	-0.221	0.135
	F5	Influent	-1.096*	0.0476	6.273E-012	-1.250	-0.941
		F1	-0.203*	0.0549	2.186E-002	-0.381	-0.024
		F2	-0.458*	0.0549	6.395E-006	-0.637	-0.280
		F3	-0.419*	0.0549	1.902E-005	-0.597	-0.241
		F4	0.043	0.0549	9.659E-001	-0.135	0.221
Dunnett T3	Influent	F1	0.893*	0.0731	9.397E-003	0.413	1.374
		F2	0.638*	0.0338	4.047E-006	0.500	0.775
		F3	0.677*	0.0481	5.927E-004	0.444	0.910
		F4	1.139*	0.0383	3.535E-007	0.980	1.298
		F5	1.096*	0.0322	1.921E-007	0.962	1.230
	F1	Influent	-0.893*	0.0731	9.397E-003	-1.374	-0.413
		F2	-0.256	0.0688	2.442E-001	-0.818	0.306
		F3	-0.216	0.0768	3.353E-001	-0.678	0.245
		F4	0.246	0.0711	2.556E-001	-0.270	0.761
		F5	0.203	0.0680	3.652E-001	-0.381	0.786
	F2	Influent	-0.638*	0.0338	4.047E-006	-0.775	-0.500
		F1	0.256	0.0688	2.442E-001	-0.306	0.818
		F3	0.039	0.0413	9.746E-001	-0.241	0.319
		F4	0.501*	0.0293	1.234E-003	0.337	0.666
		F5	0.458*	0.0205	3.080E-004	0.348	0.568
	F3	Influent	-0.677*	0.0481	5.927E-004	-0.910	-0.444
		F1	0.216	0.0768	3.353E-001	-0.245	0.678
		F2	-0.039	0.0413	9.746E-001	-0.319	0.241
		F4	0.462*	0.0450	7.767E-003	0.205	0.719
		F5	0.419*	0.0399	2.298E-002	0.119	0.719
	F4	Influent	-1.139*	0.0383	3.535E-007	-1.298	-0.980
		F1	-0.246	0.0711	2.556E-001	-0.761	0.270
		F2	-0.501*	0.0293	1.234E-003	-0.666	-0.337
		F3	-0.462*	0.0450	7.767E-003	-0.719	-0.205
		F5	-0.043	0.0273	7.815E-001	-0.215	0.129
	F5	Influent	-1.096*	0.0322	1.921E-007	-1.230	-0.962
		F1	-0.203	0.0680	3.652E-001	-0.786	0.381
		F2	-0.458*	0.0205	3.080E-004	-0.568	-0.348
		F3	-0.419*	0.0399	2.298E-002	-0.719	-0.119
		F4	0.043	0.0273	7.815E-001	-0.129	0.215

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted did not show any heteroscedasticity in the data.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. The plot of residuals versus the influent/Filter # shows some possible heteroscedasticity but because the plot of residuals versus the predicted values and Levene's test did not indicate heteroscedasticity, the data was considered to not be heteroscedastic; therefore, Tukey's HSD test was used for multiple comparisons.

Data Set 17: Collected July 17, 2012

Raw Data

Table B-66: Data Set 17 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.959	3.973	4.133	4.491	3.911	3.748
		2	5.047	4.073	4.243	4.411	3.969	3.808
		3	5.014	4.076	4.283	4.367	4.001	3.866
		Average	5.007	4.041	4.220	4.423	3.960	3.807
	2	1	5.079	4.121	4.320	4.388	3.958	3.761
		2	5.147	4.189	4.411	4.443	3.994	3.828
		3	5.205	4.195	4.418	4.482	4.039	3.817
		Average	5.144	4.168	4.383	4.438	3.997	3.802
	3	1	4.871	4.351	4.351	4.249	3.967	3.753
		2	4.912	4.292	4.292	4.336	4.012	3.77
		3	4.972	4.334	4.334	4.377	3.986	3.808
		Average	4.918	4.326	4.326	4.321	3.988	3.777
	Average		5.023	4.178	4.309	4.394	3.982	3.795
	Standard Deviation		0.1086	0.1296	0.0874	0.0752	0.0365	0.0399
2	1	1	5.012	-	-	-	-	-
		2	5.094	-	-	-	-	-
		3	5.143	-	-	-	-	-
		Average	5.083	-	-	-	-	-
	2	1	4.989	-	-	-	-	-
		2	5.072	-	-	-	-	-
		3	5.134	-	-	-	-	-
		Average	5.065	-	-	-	-	-
	3	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
		3	-	-	-	-	-	-
		Average	-	-	-	-	-	-
	Average		5.074	-	-	-	-	-
	Standard Deviation		0.0630	-	-	-	-	-

* Data excluded from further analysis.

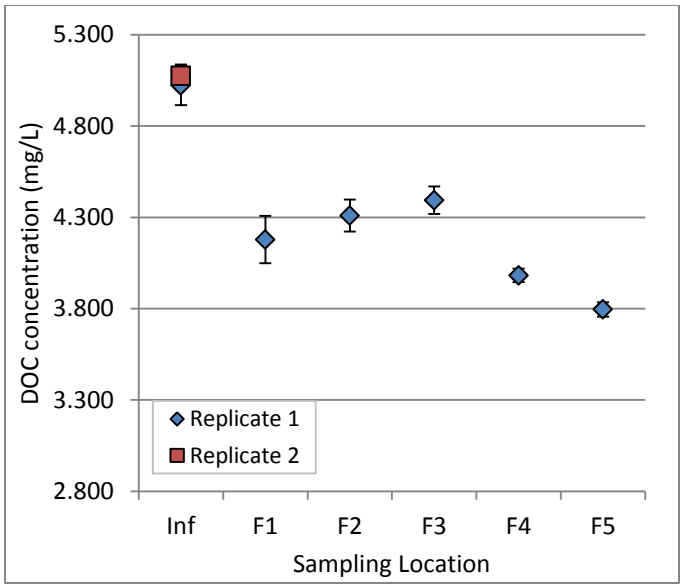

Figure B-65: Data Set 17 plot of average DOC concentrations

List of Excluded Data from Data Set 17, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded
2. AOC analysis also conducted on the same day. There was only enough sample water to allow one bottle from each filter effluent to be analyzed for DOC.

ANOVA Results

Table B-67: Data Set 17 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.830[a]	5	.766	115.366	7.237E-011
Intercept	353.892	1	353.892	53299.078	1.804E-026
filter#	3.830	5	.766	115.366	7.237E-011
Error	.093	14	.007		
Total	384.054	20			
Corrected Total	3.923	19			

a. R Squared = .976 (Adjusted R Squared = .968)

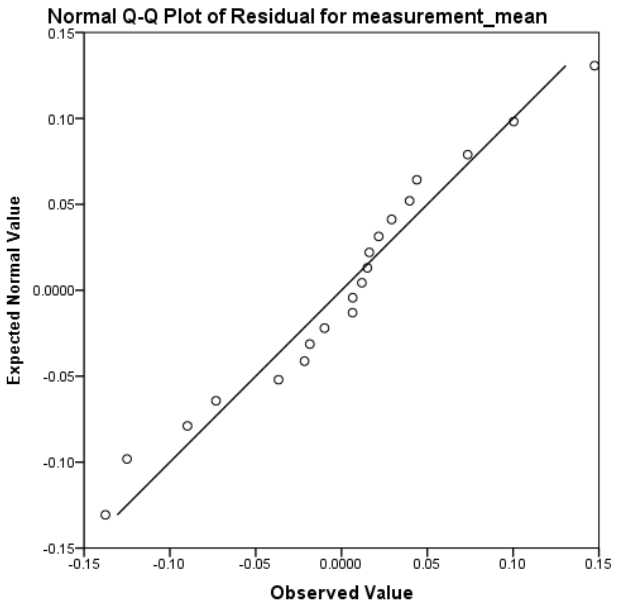

Figure B-66: Data Set 17 normal probability plot of residuals

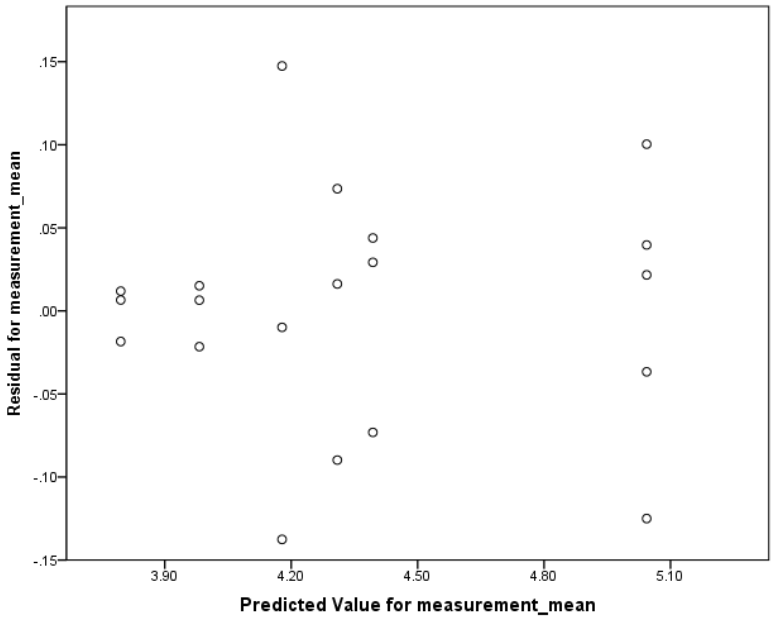

Figure B-67: Data Set 17 plot of residuals versus predicted values

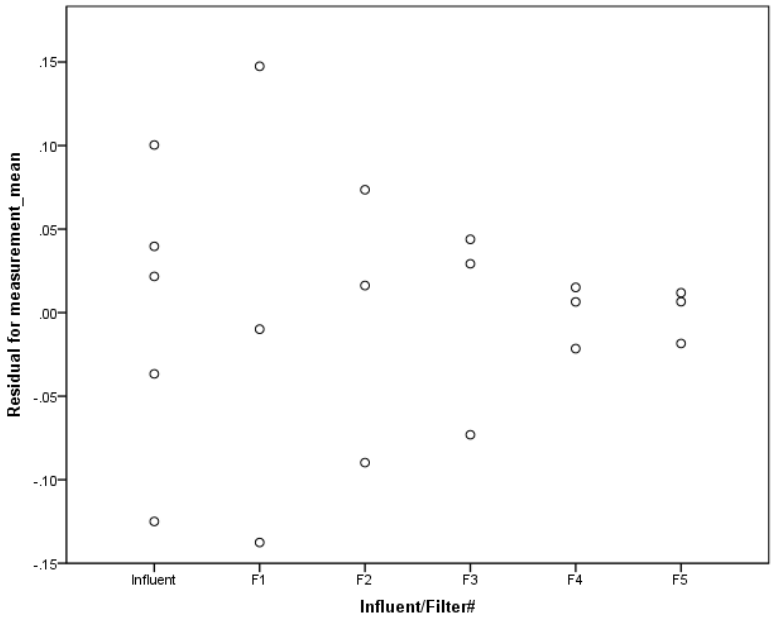

Figure B-68: Data Set 17 plot of residuals versus filter number

Table B-68: Data Set 17 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.906	5	14	.157

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-69: Data Set 17 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.865*	0.0595	9.799E-009	0.670	1.060
		F2	0.734*	0.0595	8.318E-008	0.539	0.929
		F3	0.650*	0.0595	3.921E-007	0.454	0.845
		F4	1.061*	0.0595	6.470E-010	0.866	1.257
		F5	1.248*	0.0595	7.354E-011	1.053	1.443
	F1	Influent	-0.865*	0.0595	9.799E-009	-1.060	-0.670
		F2	-0.131	0.0665	4.030E-001	-0.349	0.087
		F3	-0.216	0.0665	5.372E-002	-0.434	0.003
		F4	0.196	0.0665	8.939E-002	-0.022	0.415
		F5	0.383*	0.0665	5.754E-004	0.165	0.601
	F2	Influent	-0.734*	0.0595	8.318E-008	-0.929	-0.539
		F1	0.131	0.0665	4.030E-001	-0.087	0.349
		F3	-0.084	0.0665	7.970E-001	-0.303	0.134
		F4	0.328*	0.0665	2.475E-003	0.109	0.546
		F5	0.514*	0.0665	2.491E-005	0.296	0.732
	F3	Influent	-0.650*	0.0595	3.921E-007	-0.845	-0.454
		F1	0.216	0.0665	5.372E-002	-0.003	0.434
		F2	0.084	0.0665	7.970E-001	-0.134	0.303
		F4	0.412*	0.0665	2.751E-004	0.194	0.630
		F5	0.598*	0.0665	4.226E-006	0.380	0.817
	F4	Influent	-1.061*	0.0595	6.470E-010	-1.257	-0.866
		F1	-0.196	0.0665	8.939E-002	-0.415	0.022
		F2	-0.328*	0.0665	2.475E-003	-0.546	-0.109
		F3	-0.412*	0.0665	2.751E-004	-0.630	-0.194
		F5	0.186	0.0665	1.153E-001	-0.032	0.405
	F5	Influent	-1.248*	0.0595	7.354E-011	-1.443	-1.053
		F1	-0.383*	0.0665	5.754E-004	-0.601	-0.165
		F2	-0.514*	0.0665	2.491E-005	-0.732	-0.296
		F3	-0.598*	0.0665	4.226E-006	-0.817	-0.380
		F4	-0.186	0.0665	1.153E-001	-0.405	0.032
Dunnett T3**	Influent	F1	0.865*	0.0908	1.741E-002	0.278	1.452
		F2	0.734*	0.0612	1.292E-003	0.436	1.032
		F3	0.650*	0.0530	3.598E-004	0.414	0.885
		F4	1.061*	0.0397	2.688E-005	0.872	1.251
		F5	1.248*	0.0393	1.751E-005	1.057	1.439
	F1	Influent	-0.865*	0.0908	1.741E-002	-1.452	-0.278
		F2	-0.131	0.0953	8.638E-001	-0.698	0.436
		F3	-0.216	0.0903	4.730E-001	-0.819	0.388
		F4	0.196	0.0832	5.151E-001	-0.544	0.936
		F5	0.383	0.0829	1.793E-001	-0.364	1.130
	F2	Influent	-0.734*	0.0612	1.292E-003	-1.032	-0.436
		F1	0.131	0.0953	8.638E-001	-0.436	0.698
		F3	-0.084	0.0604	8.609E-001	-0.408	0.239
		F4	0.328	0.0491	7.846E-002	-0.078	0.734
		F5	0.514*	0.0487	3.210E-002	0.098	0.930
	F3	Influent	-0.650*	0.0530	3.598E-004	-0.885	-0.414
		F1	0.216	0.0903	4.730E-001	-0.388	0.819
		F2	0.084	0.0604	8.609E-001	-0.239	0.408
		F4	0.412*	0.0384	2.387E-002	0.114	0.709
		F5	0.598*	0.0380	1.155E-002	0.291	0.906
	F4	Influent	-1.061*	0.0397	2.688E-005	-1.251	-0.872
		F1	-0.196	0.0832	5.151E-001	-0.936	0.544
		F2	-0.328	0.0491	7.846E-002	-0.734	0.078
		F3	-0.412*	0.0384	2.387E-002	-0.709	-0.114
		F5	0.186*	0.0145	1.944E-003	0.110	0.262
	F5	Influent	-1.248*	0.0393	1.751E-005	-1.439	-1.057
		F1	-0.383	0.0829	1.793E-001	-1.130	0.364
		F2	-0.514*	0.0487	3.210E-002	-0.930	-0.098
		F3	-0.598*	0.0380	1.155E-002	-0.906	-0.291
		F4	-0.186*	0.0145	1.944E-003	-0.262	-0.110

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plot of residuals versus influent/filter # indicates that the residuals were heteroscedastic.
4. Results from Levene's test of equality of variance do not provide a strong indication of heteroscedasticity
5. While Levene's test does not provide a strong indication of heteroscedasticity, the plot of residuals versus influent/filter # shows clear heteroscedasticity; therefore, results from Dunnett's T3 test will be used for multiple comparisons.

Data Set 18: Collected July 29, 2012

Raw Data

Table B-70: Data Set 18 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	5.263	4.012	4.146	4.337	3.847	4.536*
		2	5.294	4.072	4.165	4.388	3.892	4.585*
		3	5.293	4.133	4.206	4.397	3.912	4.630*
		Average	5.283	4.072	4.172	4.374	3.884	4.584
	2	1	5.191	3.965	4.244	4.233	3.987	4.399*
		2	5.246	4.013	4.334	4.349	4.010	4.470*
		3	5.291	4.036	4.360	4.339	3.997	4.536*
		Average	5.243	4.005	4.313	4.307	3.998	4.468
	3	1	5.083	3.884	4.291	4.201	3.736	5.720*
		2	5.178	3.912	4.345	4.285	3.766	5.856*
		3	5.203	3.967	4.336	4.304	3.774	5.913*
		Average	5.155	3.921	4.324	4.263	3.759	5.830
	Average		5.227	3.999	4.270	4.315	3.880	4.961
	Standard Deviation		0.0704	0.0775	0.0820	0.0662	0.1056	0.6569
2	1	1	5.047	3.789	4.352	4.336	3.802	4.113*
		2	5.075	3.815	4.240	4.394	3.869	4.199*
		3	5.105	3.828	4.246	4.412	3.903	4.178*
		Average	5.076	3.811	4.279	4.381	3.858	4.163
	2	1	5.062	4.085	4.309	4.306	3.907	4.210*
		2	5.113	4.118	4.358	4.371	3.880	4.272*
		3	5.147	4.180	4.384	4.433	3.888	4.294*
		Average	5.107	4.128	4.350	4.370	3.892	4.259
	3	1	4.972	3.875	4.313	4.249	3.761	4.075*
		2	4.950	3.894	4.321	4.300	3.809	4.204*
		3	5.017	3.927	4.382	4.336	3.746	4.218*
		Average	4.980	3.899	4.339	4.295	3.772	4.166
	Average		5.054	3.946	4.323	4.349	3.841	4.196
	Standard Deviation		0.0654	0.1447	0.0529	0.0593	0.0619	0.0689

* Data excluded from further analysis.

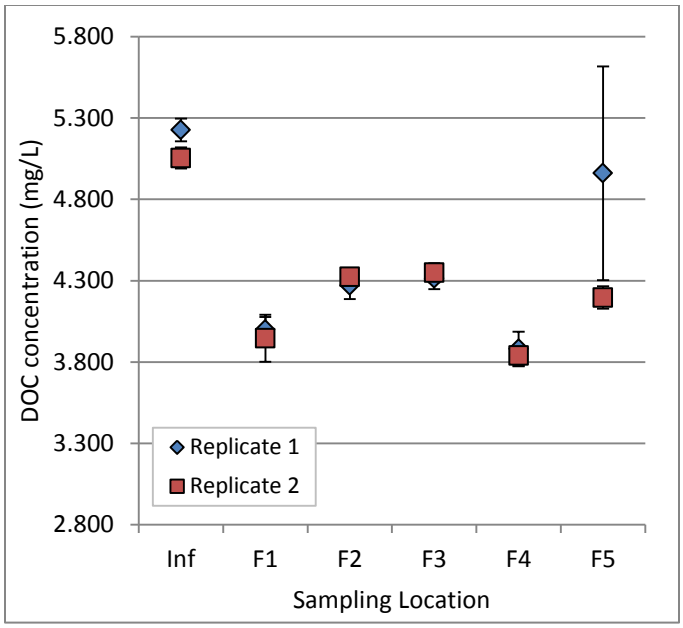

Figure B-69: Data Set 18 plot of average DOC concentrations

List of Excluded Data from Data Set 18, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from Filter 5 was excluded because readings from bottles containing sample water from the same location were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 5 was contaminated.

ANOVA Results

Table B-71: Data Set 18 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.036[a]	4	1.509	185.033	3.504E-018
Intercept	559.938	1	559.938	68655.101	1.631E-044
filter#	6.036	4	1.509	185.033	3.504E-018
Error	.204	25	.008		
Total	566.179	30			
Corrected Total	6.240	29			

a. R Squared = .967 (Adjusted R Squared = .962)

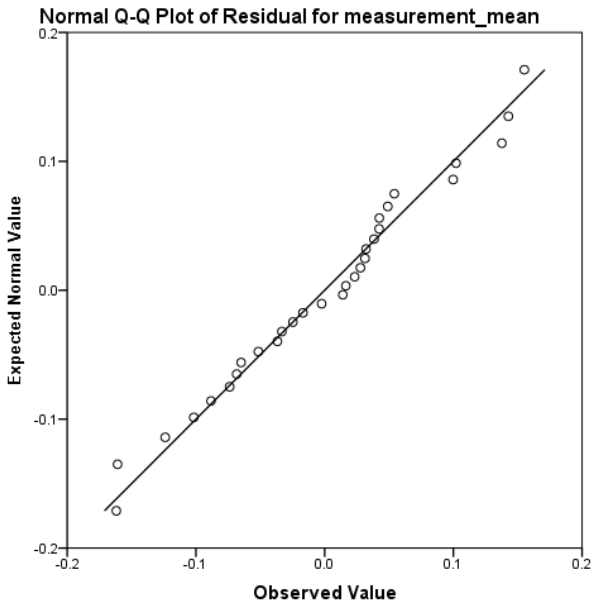

Figure B-70: Data Set 18 normal probability plot of residuals

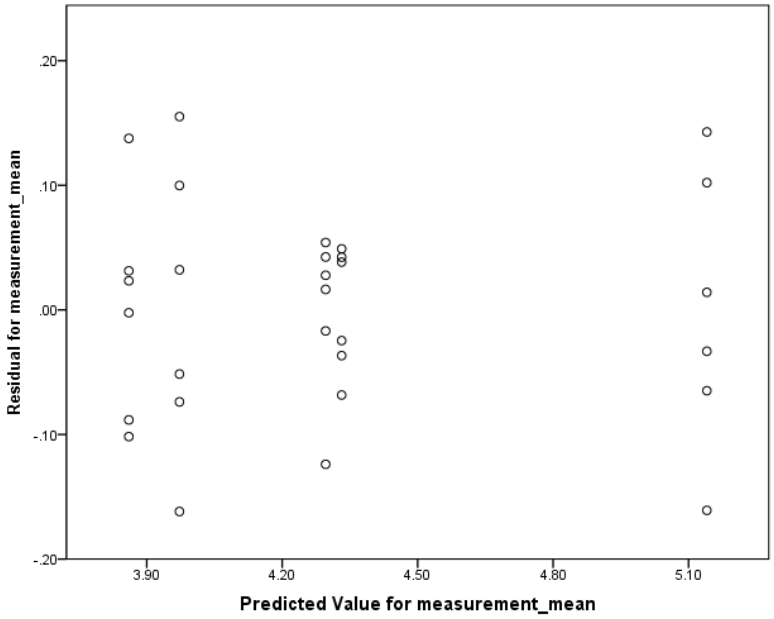

Figure B-71: Data Set 18 plot of residuals versus predicted values

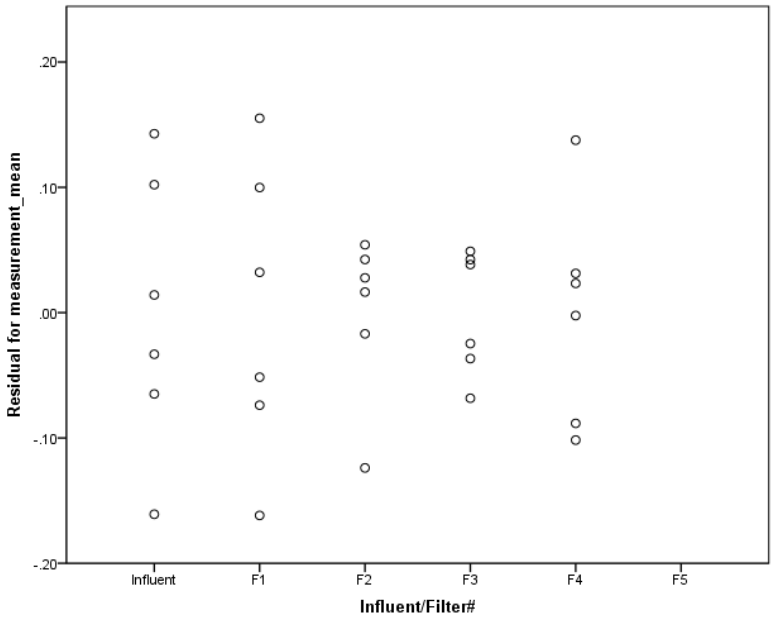

Figure B-72: Data Set 18 plot of residuals versus filter number

Table B-72: Data Set 18 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.480	4	25	2.382E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-73: Data Set 18 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	1.168*	0.0521	9.349E-013	1.015	1.321
		F2	0.844*	0.0521	1.010E-012	0.691	0.997
		F3	0.809*	0.0521	1.149E-012	0.656	0.962
		F4	1.280*	0.0521	9.349E-013	1.127	1.433
	F1	Influent	-1.168*	0.0521	9.349E-013	-1.321	-1.015
		F2	-0.324*	0.0521	1.583E-005	-0.477	-0.171
		F3	-0.359*	0.0521	3.009E-006	-0.512	-0.206
		F4	0.112	0.0521	2.308E-001	-0.041	0.265
	F2	Influent	-0.844*	0.0521	1.010E-012	-0.997	-0.691
		F1	0.324*	0.0521	1.583E-005	0.171	0.477
		F3	-0.035	0.0521	9.590E-001	-0.189	0.118
		F4	0.436*	0.0521	9.953E-008	0.283	0.589
	F3	Influent	-0.809*	0.0521	1.149E-012	-0.962	-0.656
		F1	0.359*	0.0521	3.009E-006	0.206	0.512
		F2	0.035	0.0521	9.590E-001	-0.118	0.189
		F4	0.471*	0.0521	2.263E-008	0.318	0.624
	F4	Influent	-1.280*	0.0521	9.349E-013	-1.433	-1.127
		F1	-0.112	0.0521	2.308E-001	-0.265	0.041
		F2	-0.436*	0.0521	9.953E-008	-0.589	-0.283
		F3	-0.471*	0.0521	2.263E-008	-0.624	-0.318
Dunnett T3	Influent	F1	1.168*	0.0662	7.160E-008	0.938	1.398
		F2	0.844*	0.0528	1.889E-006	0.652	1.037
		F3	0.809*	0.0498	7.948E-006	0.618	0.999
		F4	1.280*	0.0580	1.675E-008	1.077	1.484
	F1	Influent	-1.168*	0.0662	7.160E-008	-1.398	-0.938
		F2	-0.324*	0.0550	3.391E-003	-0.526	-0.121
		F3	-0.359*	0.0522	2.279E-003	-0.560	-0.158
		F4	0.112	0.0600	5.247E-001	-0.100	0.324
	F2	Influent	-0.844*	0.0528	1.889E-006	-1.037	-0.652
		F1	0.324*	0.0550	3.391E-003	0.121	0.526
		F3	-0.035	0.0335	9.474E-001	-0.153	0.083
		F4	0.436*	0.0447	3.351E-005	0.278	0.594
	F3	Influent	-0.809*	0.0498	7.948E-006	-0.999	-0.618
		F1	0.359*	0.0522	2.279E-003	0.158	0.560
		F2	0.035	0.0335	9.474E-001	-0.083	0.153
		F4	0.471*	0.0412	3.033E-005	0.320	0.623
	F4	Influent	-1.280*	0.0580	1.675E-008	-1.484	-1.077
		F1	-0.112	0.0600	5.247E-001	-0.324	0.100
		F2	-0.436*	0.0447	3.351E-005	-0.594	-0.278
		F3	-0.471*	0.0412	3.033E-005	-0.623	-0.320

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # show some possible heteroscedasticity: the spread of the residuals for Filter 2 effluent and Filter 3 effluent is slightly smaller than for the other filter effluents and the influent; however, Levene's test of equality of variances does not provide strong evidence of heteroscedasticity. Results from Tukey's HSD were used for multiple comparisons because Levene's test did not provide strong evidence of heteroscedasticity and because the heteroscedasticity seen in the plots was minimal. It should be noted that at a significance level of 0.05, the same comparisons will be considered significant regardless of whether results from Tukey's test or Dunnett's T3 test are used; therefore, using Tukey's test does not result in a different conclusions than using Dunnett's T3.

Data Set 19: Collected July 31, 2012

Raw Data

Table B-74: Data Set 19 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	5.136	3.868*	4.242	4.385	4.073	3.922*
		2	5.136	3.853*	4.368	4.496	4.118	3.971*
		3	5.225	3.964*	4.367	4.532	4.176	4.007*
		Average	5.166	3.895	4.326	4.471	4.122	3.967
	2	1	5.095	3.943*	4.430	4.367	4.175	3.896*
		2	5.206	4.031*	4.506	4.414	4.212	3.996*
		3	5.276	4.065*	4.491	4.444	4.214	4.011*
		Average	5.192	4.013	4.476	4.408	4.200	3.968
	3	1	4.971	3.890*	4.496	4.346	3.947	3.808*
		2	5.040	3.907*	4.562	4.378	4.052	3.887*
		3	5.129	3.920*	4.664	4.468	4.033	3.924*
		Average	5.047	3.906	4.574	4.397	4.011	3.873
	Average		5.135	3.938	4.458	4.426	4.111	3.936
	Standard Deviation		0.0939	0.0718	0.1234	0.0635	0.0916	0.0673
2	1	1	5.129	3.883*	4.372	4.500	4.037	4.193*
		2	5.212	3.919*	4.476	4.558	4.082	4.308*
		3	5.229	3.967*	4.481	4.592	4.107	4.319*
		Average	5.190	3.923	4.443	4.550	4.075	4.273
	2	1	5.174	3.924*	4.398	4.506	3.983	4.190*
		2	5.298	3.954*	4.476	4.555	4.079	4.318*
		3	5.321	4.030*	4.519	4.600	4.114	4.310*
		Average	5.264	3.969	4.464	4.554	4.059	4.273
	3	1	5.127	4.003*	4.306	4.353	3.935	4.231*
		2	5.195	4.088*	4.350	4.459	3.949	4.304*
		3	5.212	4.095*	4.440	4.481	3.979	4.327*
		Average	5.178	4.062	4.365	4.431	3.954	4.287
	Average		5.211	3.985	4.424	4.512	4.029	4.278
	Standard Deviation		0.0665	0.0749	0.0713	0.0769	0.0694	0.0564

* Data excluded from further analysis.

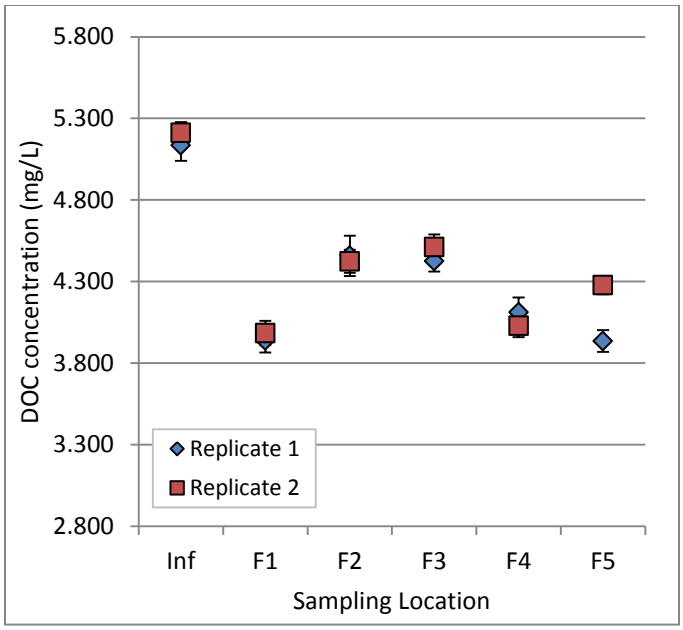

Figure B-73: Data Set 19 plot of average DOC concentrations

List of Excluded Data from Data Set 19, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from Filter 5 was excluded because readings from bottles containing sample water from the same location were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 5 was contaminated.
2. Data from Filter 1 was excluded because the flow rate in these filters had dropped off due to excessive (i.e. terminal) headloss; as a result the flow rates and, thus, EBCTs of these filters did not match the flow rates or EBCTs of the other filters. The flow rate through Filter 1, at the time of collection, had dropped to 1.5 L/min from a target of 3.0 L/min.

ANOVA Results

Table B-75: Data Set 19 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.816[a]	3	1.272	204.676	3.557E-015
Intercept	494.297	1	494.297	79543.754	1.775E-037
filter#	3.816	3	1.272	204.676	3.557E-015
Error	.124	20	.006		
Total	498.237	24			
Corrected Total	3.940	23			

a. R Squared = .968 (Adjusted R Squared = .964)

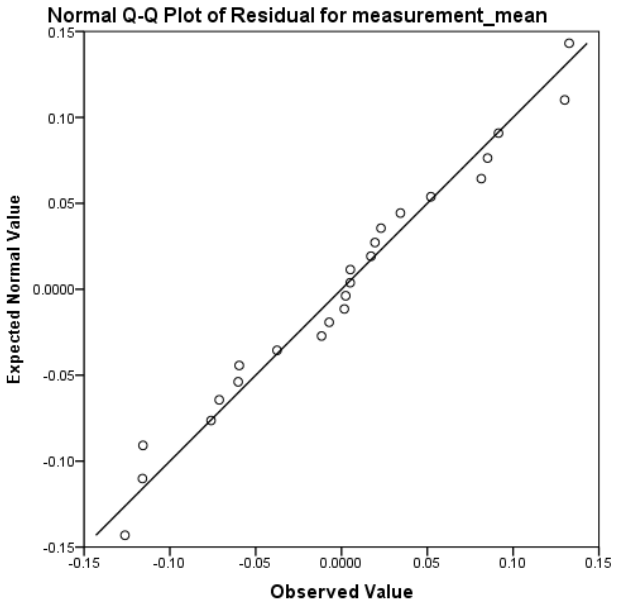

Figure B-74: Data Set 19 normal probability plot of residuals

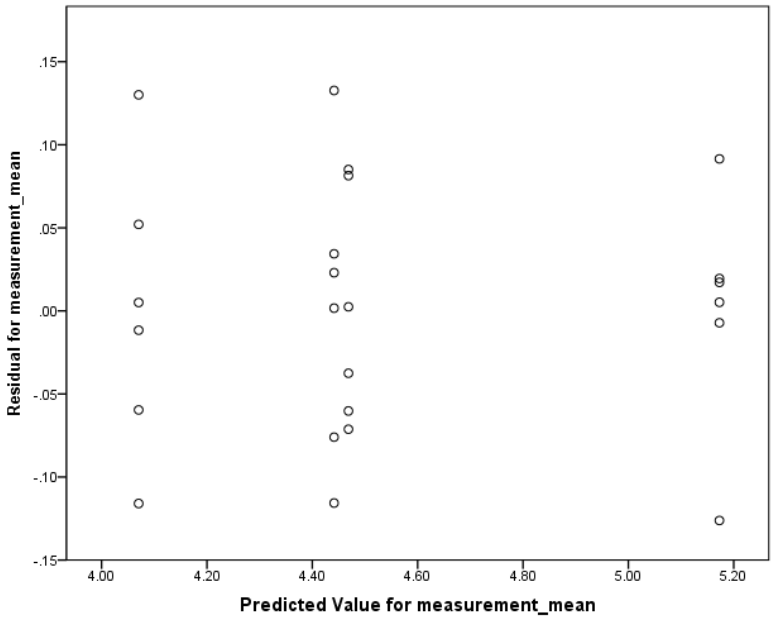

Figure B-75: Data Set 19 plot of residuals versus predicted values

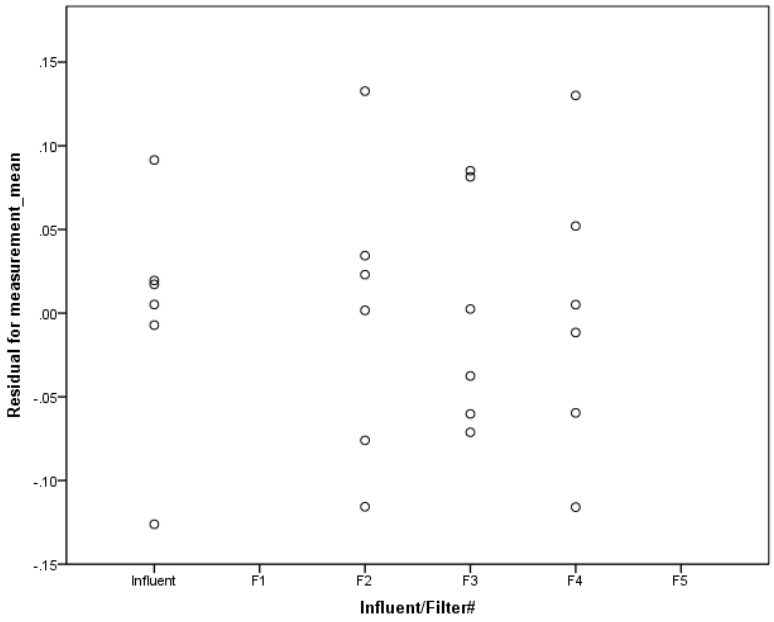

Figure B-76: Data Set 19 plot of residuals versus filter number

Table B-76: Data Set 19 results from Levene's test of equality of variances

F	df1	df2	Sig.
.206	3	20	8.911E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-77: Data Set 19 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F2	0.732*	0.0455	4.677E-012	0.604	0.859
		F3	0.704*	0.0455	8.627E-012	0.577	0.832
		F4	1.103*	0.0455	8.464E-013	0.975	1.230
	F2	Influent	-0.732*	0.0455	4.677E-012	-0.859	-0.604
		F3	-0.027	0.0455	9.314E-001	-0.155	0.100
		F4	0.371*	0.0455	4.932E-007	0.244	0.498
	F3	Influent	-0.704*	0.0455	8.627E-012	-0.832	-0.577
		F2	0.027	0.0455	9.314E-001	-0.100	0.155
		F4	0.398*	0.0455	1.616E-007	0.271	0.526
	F4	Influent	-1.103*	0.0455	8.464E-013	-1.230	-0.975
		F2	-0.371*	0.0455	4.932E-007	-0.498	-0.244
		F3	-0.398*	0.0455	1.616E-007	-0.526	-0.271
Dunnett T3	Influent	F2	0.732*	0.0460	1.929E-007	0.583	0.880
		F3	0.704*	0.0404	4.806E-008	0.575	0.834
		F4	1.103*	0.0454	3.229E-009	0.956	1.249
	F2	Influent	-0.732*	0.0460	1.929E-007	-0.880	-0.583
		F3	-0.027	0.0456	9.883E-001	-0.175	0.120
		F4	0.371*	0.0501	1.315E-004	0.211	0.531
	F3	Influent	-0.704*	0.0404	4.806E-008	-0.834	-0.575
		F2	0.027	0.0456	9.883E-001	-0.120	0.175
		F4	0.398*	0.0450	3.700E-005	0.253	0.544
	F4	Influent	-1.103*	0.0454	3.229E-009	-1.249	-0.956
		F2	-0.371*	0.0501	1.315E-004	-0.531	-0.211
		F3	-0.398*	0.0450	3.700E-005	-0.544	-0.253

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 20: Collected August 14, 2012

Raw Data

Table B-78: Data Set 20 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.975	3.159*	-	3.460	3.147	3.148
		2	4.061	3.195*	-	3.505	3.162	3.214
		3	4.079	3.204*	-	3.529	3.192	3.223
		Average	4.038	3.186	-	3.498	3.167	3.195
	2	1	4.039	3.136*	-	3.431	3.121	3.166
		2	4.070	3.190*	-	3.515	3.169	3.212
		3	4.068	3.185*	-	3.522	3.190	3.224
		Average	4.059	3.170	-	3.489	3.160	3.201
	3	1	4.111	3.135*	-	3.479	3.114	3.162
		2	4.135	3.202*	-	3.527	3.179	3.210
		3	4.087	3.207*	-	3.536	3.193	3.248
		Average	4.111	3.181	-	3.514	3.162	3.207
	Average		4.069	3.179	-	3.500	3.163	3.201
	Standard Deviation		0.0452	0.0286	-	0.0361	0.0300	0.0338
2	1	1	4.180	-	-	-	-	-
		2	4.211	-	-	-	-	-
		3	4.266	-	-	-	-	-
		Average	4.219	-	-	-	-	-
	2	1	4.144	-	-	-	-	-
		2	4.234	-	-	-	-	-
		3	4.237	-	-	-	-	-
		Average	4.205	-	-	-	-	-
	3	1	4.184	-	-	-	-	-
		2	4.230	-	-	-	-	-
		3	4.239	-	-	-	-	-
		Average	4.218	-	-	-	-	-
	Average		4.214	-	-	-	-	-
	Standard Deviation		0.0379	-	-	-	-	-

* Data excluded from further analysis.

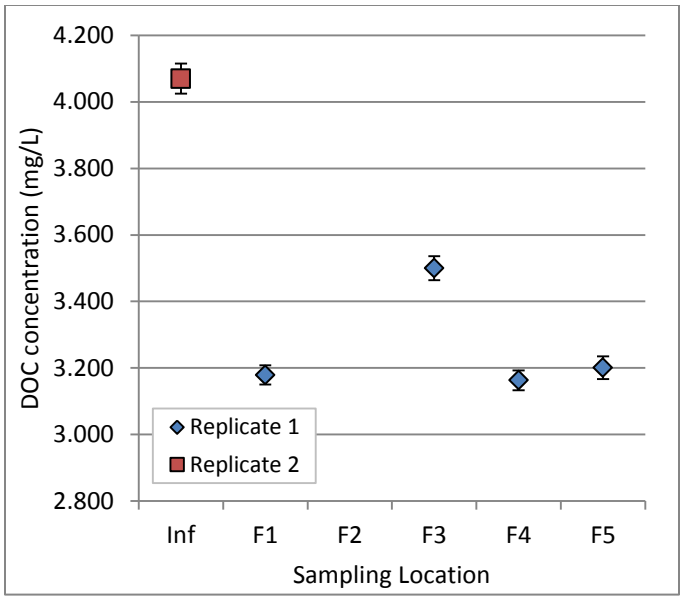

Figure B-77: Data Set 20 plot of average DOC concentrations

List of Excluded Data from Data Set 20, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. AOC analysis also conducted on the same day. There was only enough sample water to allow one bottle from each filter effluent to be analyzed for DOC.
2. Bottle containing sample water from Filter 2 for DOC analysis broke in transport
3. Data from Filter 1 was excluded because the flow rate in these filters had dropped off due to excessive (i.e. terminal) headloss; as a result the flow rates and, thus, EBCTs of these filters did not match the flow rates or EBCTs of the other filters. The flow rate through Filter 1, at the time of collection, had dropped to 1.8 L/min from a target of 3.0 L/min.

ANOVA Results (Including Data from Influent, F3 Effluent, F4 Effluent, F5 Effluent)

Table B-79: Data Set 20 ANOVA table for DOC concentration (including data from Inf., F3, F4, & F5)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.828[a]	3	.943	299.473	7.994E-011
Intercept	168.141	1	168.141	53413.951	1.249E-021
filter#	2.828	3	.943	299.473	7.994E-011
Error	.035	11	.003		
Total	200.463	15			
Corrected Total	2.863	14			

a. R Squared = .988 (Adjusted R Squared = .985)

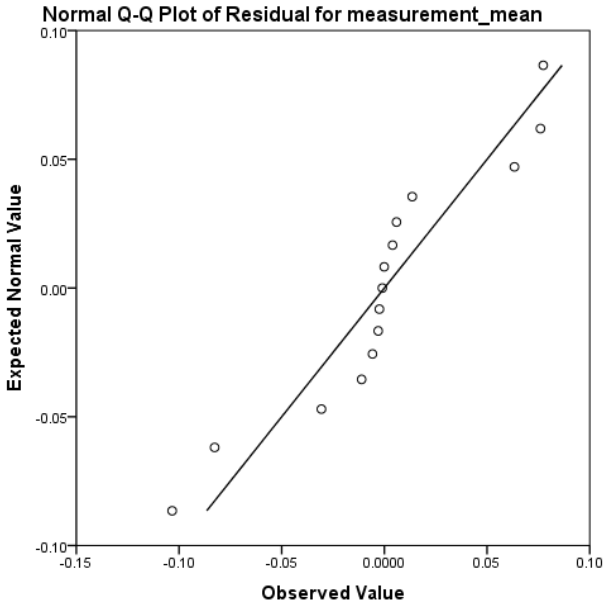

Figure B-78: Data Set 20 normal probability plot of residuals (including data from Inf., F3, F4, & F5)

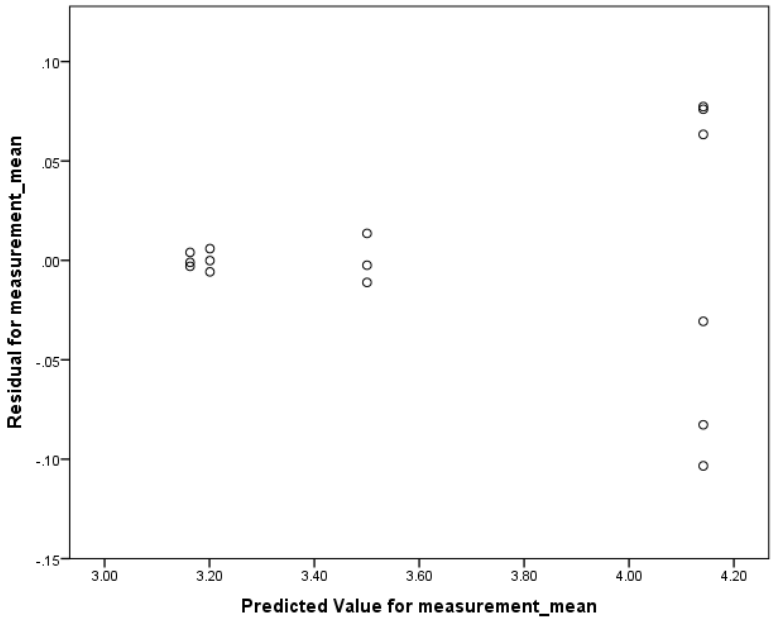

Figure B-79: Data Set 20 plot of residuals versus predicted values (including data from Inf., F3, F4, & F5)

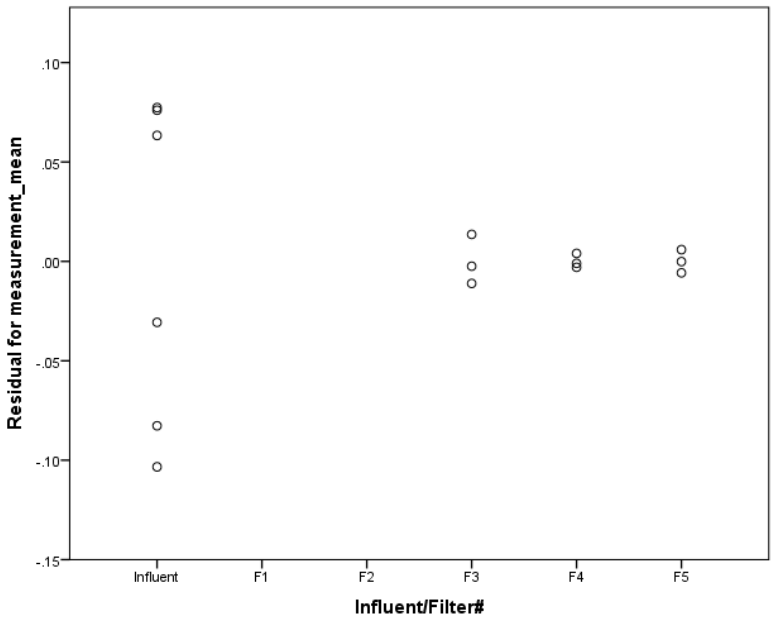

Figure B-80: Data Set 20 plot of residuals versus filter number (including data from Inf., F3, F4, & F5)

Table B-80: Data Set 20 results from Levene's test of equality of variances (including data from Inf., F3, F4, & F5)

F	df1	df2	Sig.
19.724	3	11	9.848E-005

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-81: Data Set 20 multiple comparisons (including data from Inf., F3, F4, & F5)

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F3	0.641*	0.0397	2.697E-008	0.522	0.761
		F4	0.979*	0.0397	2.924E-010	0.859	1.098
		F5	0.941*	0.0397	4.469E-010	0.821	1.060
	F3	Influent	-0.641*	0.0397	2.697E-008	-0.761	-0.522
		F4	0.337*	0.0458	7.150E-005	0.200	0.475
		F5	0.300*	0.0458	2.085E-004	0.162	0.438
	F4	Influent	-0.979*	0.0397	2.924E-010	-1.098	-0.859
		F3	-0.337*	0.0458	7.150E-005	-0.475	-0.200
		F5	-0.038	0.0458	8.417E-001	-0.176	0.100
	F5	Influent	-0.941*	0.0397	4.469E-010	-1.060	-0.821
		F3	-0.300*	0.0458	2.085E-004	-0.438	-0.162
		F4	0.038	0.0458	8.417E-001	-0.100	0.176
Dunnett T3	Influent	F3	0.641*	0.0345	1.985E-005	0.510	0.772
		F4	0.979*	0.0338	4.165E-006	0.846	1.111
		F5	0.941*	0.0339	4.553E-006	0.809	1.073
	F3	Influent	-0.641*	0.0345	1.985E-005	-0.772	-0.510
		F4	0.337*	0.0075	5.904E-004	0.289	0.386
		F5	0.300*	0.0080	2.434E-004	0.256	0.343
	F4	Influent	-0.979*	0.0338	4.165E-006	-1.111	-0.846
		F3	-0.337*	0.0075	5.904E-004	-0.386	-0.289
		F5	-0.038*	0.0040	6.228E-003	-0.057	-0.019
	F5	Influent	-0.941*	0.0339	4.553E-006	-1.073	-0.809
		F3	-0.300*	0.0080	2.434E-004	-0.343	-0.256
		F4	0.038*	0.0040	6.228E-003	0.019	0.057

Based on observed means.

*. The mean difference is significant at the .05 level.

Initial Brief Analysis of ANOVA Results:

1. ANOVA initially conducted on the influent, F3 effluent, F4 effluent, and F5 effluent DOC data.
2. The normal probability plot of the residuals indicated that the residuals from the ANOVA were not normally distributed.
3. Investigation indicated that the influent data contributed to the non-normality of the residuals
4. The influent DOC data were excluded and the ANOVA was re-done on the F3 effluent, F4 effluent and F5 effluent DOC data.

ANOVA Results with Influent Data Excluded

Table B-82: Data Set 20 ANOVA table for DOC concentration (Influent data excluded)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.205[a]	2	.103	1510.802	7.783E-009
Intercept	97.303	1	97.303	1433527.334	2.291E-017
filter#	.205	2	.103	1510.802	7.783E-009
Error	.000	6	6.788E-5		
Total	97.508	9			
Corrected Total	.206	8			

a. R Squared = .998 (Adjusted R Squared = .997)

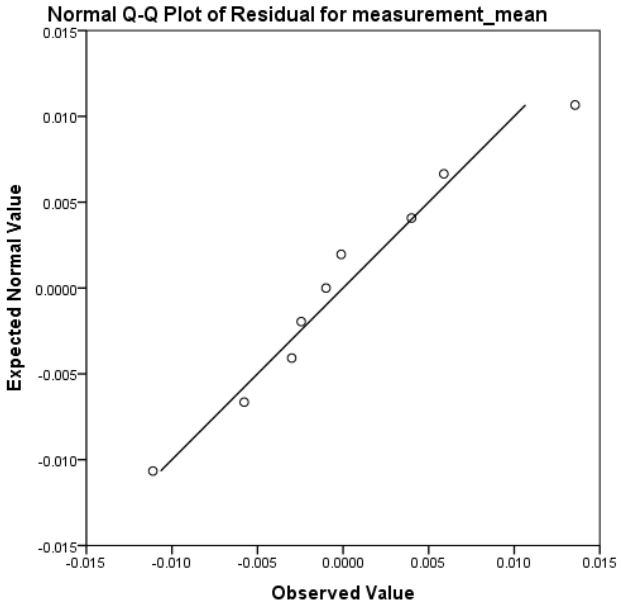

Figure B-81: Data Set 20 normal probability plot of residuals (Influent data excluded)

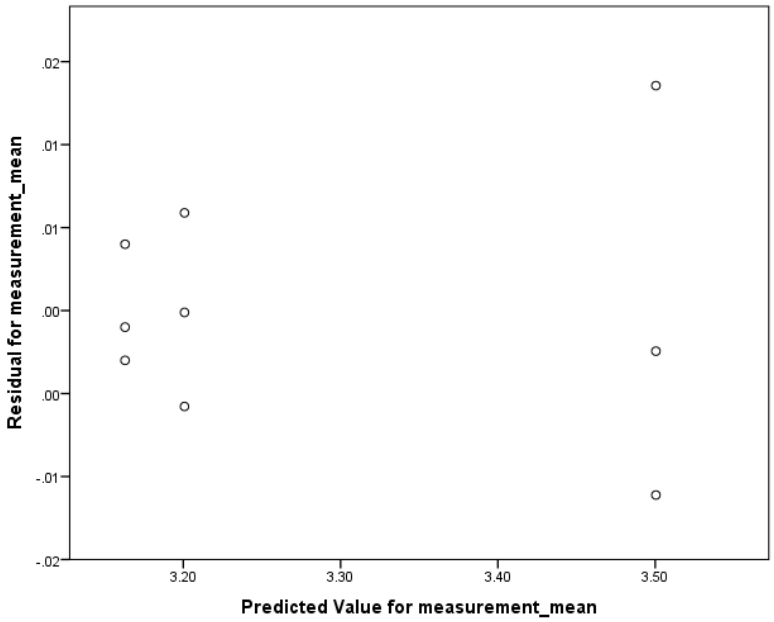

Figure B-82: Data Set 20 plot of residuals versus predicted values (Influent data excluded)

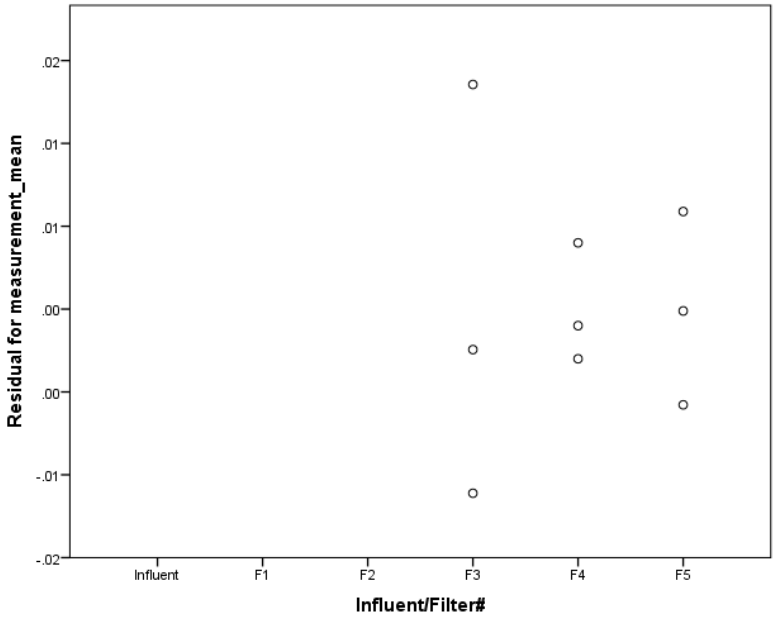

Figure B-83: Data Set 20 plot of residuals versus filter number (Influent data excluded)

Table B-83: Data Set 20 results from Levene's test of equality of variances (Influent data excluded)

F	df1	df2	Sig.
2.164	2	6	1.961E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-84: Data Set 20 multiple comparisons (Influent data excluded)

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	F3	F4	0.337*	0.0067	2.499E-007	0.317	0.358
		F5	0.300*	0.0067	2.536E-007	0.279	0.320
	F4	F3	-0.337*	0.0067	2.499E-007	-0.358	-0.317
		F5	-0.038*	0.0067	3.285E-003	-0.058	-0.017
	F5	F3	-0.300*	0.0067	2.536E-007	-0.320	-0.279
		F4	0.038*	0.0067	3.285E-003	0.017	0.058
Dunnett T3	F3	F4	0.337*	0.0075	3.947E-004	0.297	0.378
		F5	0.300*	0.0080	1.551E-004	0.263	0.336
	F4	F3	-0.337*	0.0075	3.947E-004	-0.378	-0.297
		F5	-0.038*	0.0040	3.835E-003	-0.054	-0.021
	F5	F3	-0.300*	0.0080	1.551E-004	-0.336	-0.263
		F4	0.038*	0.0040	3.835E-003	0.021	0.054

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. It was found that the residuals were relatively normally distributed for the ANOVA that excluded the influent data. Results from this ANOVA were used.
2. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
3. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
4. As a result of points 2&3, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations

Data Set 21: Collected August 16, 2012

Raw Data

Table B-85: Data Set 21 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.474	3.707	3.963	3.776	3.438	3.481
		2	4.519	3.782	3.902	3.840	3.483	3.547
		3	4.540	3.795	3.944	3.859	3.483	3.558
		Average	4.511	3.761	3.936	3.825	3.468	3.529
	2	1	4.403	3.791	3.823	3.769	3.449	3.453
		2	4.549	3.788	3.934	3.857	3.470	3.528
		3	4.557	3.814	3.964	3.874	3.509	3.577
		Average	4.503	3.798	3.907	3.833	3.476	3.519
	3	1	4.472	3.712	3.852	3.761	3.438	3.583
		2	4.551	3.729	3.912	3.846	3.502	3.586
		3	4.515	3.793	3.919	3.863	3.524	3.549
		Average	4.513	3.745	3.894	3.823	3.488	3.573
	Average		4.509	3.768	3.913	3.829	3.477	3.540
	Standard Deviation		0.0507	0.0403	0.0481	0.0453	0.0312	0.0461
2	1	1	4.463	3.554	4.042	3.852	3.447	3.568
		2	4.564	3.665	4.064	3.923	3.521	3.596
		3	4.568	3.677	4.092	3.946	3.504	3.654
		Average	4.532	3.632	4.066	3.907	3.491	3.606
	2	1	4.508	3.637	4.149	3.852	3.440	3.583
		2	4.534	3.703	4.085	3.910	3.506	3.598
		3	4.547	3.720	4.075	3.940	3.519	3.616
		Average	4.530	3.687	4.103	3.901	3.488	3.599
	3	1	4.467	3.618	3.953	3.868	3.451	3.581
		2	4.530	3.658	4.068	3.916	3.502	3.639
		3	4.564	3.726	4.053	3.919	3.553	3.628
		Average	4.520	3.667	4.025	3.901	3.502	3.616
	Average		4.527	3.662	4.065	3.904	3.494	3.607
	Standard Deviation		0.0402	0.0543	0.0519	0.0421	0.0389	0.0290

* Data excluded from further analysis.

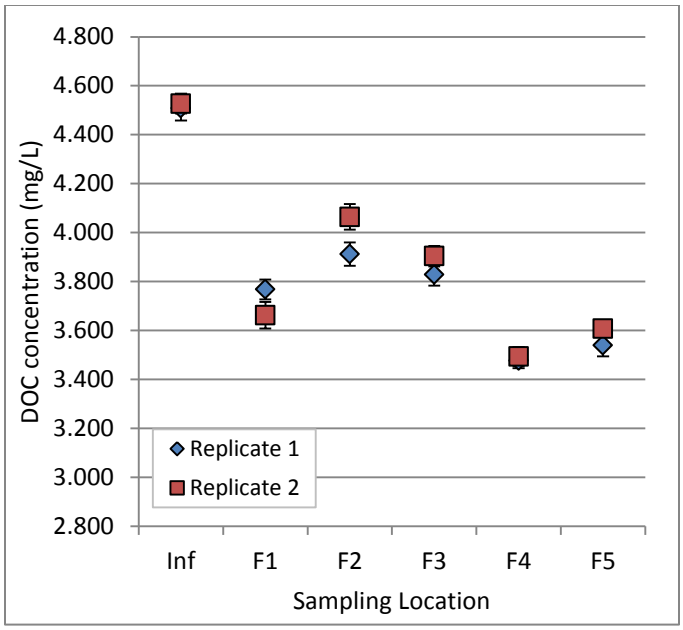

Figure B-84: Data Set 21 plot of average DOC concentrations

List of Excluded Data from Data Set 21, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded

ANOVA Results

Table B-86: Data Set 21 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.157[a]	5	0.831	324.152	3.740E-025
Intercept	535.724	1	535.724	208862.403	3.294E-059
filter#	4.157	5	0.831	324.152	3.740E-025
Error	0.077	30	0.003		
Total	539.959	36			
Corrected Total	4.234	35			

a. R Squared = .982 (Adjusted R Squared = .979)

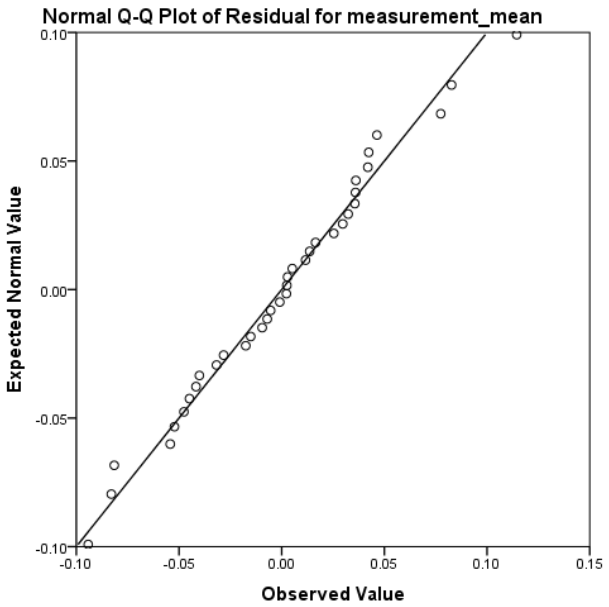

Figure B-85: Data Set 21 normal probability plot of residuals

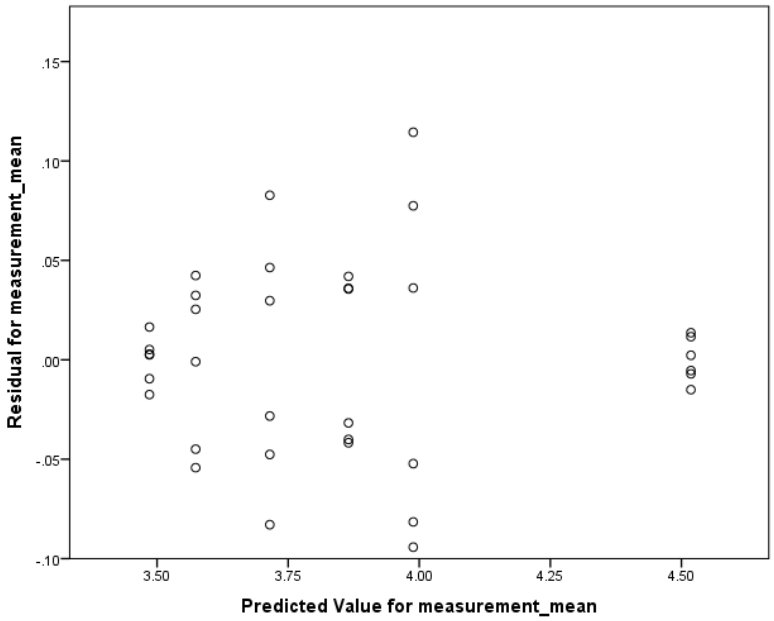

Figure B-86: Data Set 21 plot of residuals versus predicted values

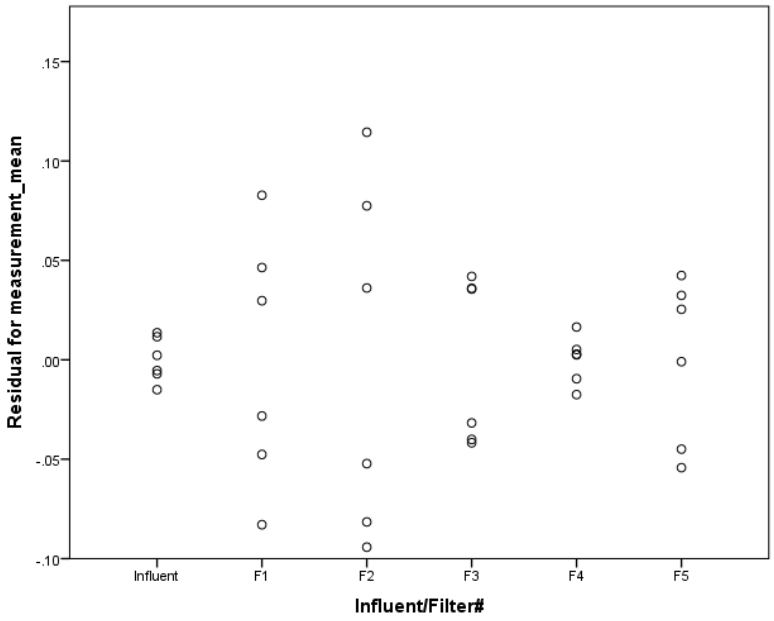

Figure B-87: Data Set 21 plot of residuals versus filter number

Table B-87: Data Set 21 results from Levene's test of equality of variances

F	df1	df2	Sig.
13.081	5	30	8.480E-007

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-88: Data Set 21 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.803*	0.0292	8.280E-013	0.714	0.892
		F2	0.530*	0.0292	8.281E-013	0.441	0.618
		F3	0.653*	0.0292	8.280E-013	0.564	0.742
		F4	1.033*	0.0292	8.280E-013	0.944	1.121
		F5	0.944*	0.0292	8.280E-013	0.856	1.033
	F1	Influent	-0.803*	0.0292	8.280E-013	-0.892	-0.714
		F2	-0.274*	0.0292	3.049E-009	-0.363	-0.185
		F3	-0.150*	0.0292	2.142E-004	-0.239	-0.061
		F4	0.229*	0.0292	1.339E-007	0.141	0.318
		F5	0.141*	0.0292	4.913E-004	0.052	0.230
	F2	Influent	-0.530*	0.0292	8.281E-013	-0.618	-0.441
		F1	0.274*	0.0292	3.049E-009	0.185	0.363
		F3	0.123*	0.0292	2.583E-003	0.035	0.212
		F4	0.503*	0.0292	8.281E-013	0.414	0.592
		F5	0.415*	0.0292	9.265E-013	0.326	0.504
	F3	Influent	-0.653*	0.0292	8.280E-013	-0.742	-0.564
		F1	0.150*	0.0292	2.142E-004	0.061	0.239
		F2	-0.123*	0.0292	2.583E-003	-0.212	-0.035
		F4	0.380*	0.0292	1.912E-012	0.291	0.468
		F5	0.291*	0.0292	7.199E-010	0.203	0.380
	F4	Influent	-1.033*	0.0292	8.280E-013	-1.121	-0.944
		F1	-0.229*	0.0292	1.339E-007	-0.318	-0.141
		F2	-0.503*	0.0292	8.281E-013	-0.592	-0.414
		F3	-0.380*	0.0292	1.912E-012	-0.468	-0.291
		F5	-0.088	0.0292	5.330E-002	-0.177	0.001
	F5	Influent	-0.944*	0.0292	8.280E-013	-1.033	-0.856
		F1	-0.141*	0.0292	4.913E-004	-0.230	-0.052
		F2	-0.415*	0.0292	9.265E-013	-0.504	-0.326
		F3	-0.291*	0.0292	7.199E-010	-0.380	-0.203
		F4	0.088	0.0292	5.330E-002	-0.001	0.177
Dunnett T3**	Influent	F1	0.803*	0.0261	3.433E-006	0.686	0.920
		F2	0.530*	0.0362	2.079E-004	0.365	0.694
		F3	0.653*	0.0176	5.177E-007	0.576	0.730
		F4	1.033*	0.0067	1.332E-015	1.008	1.057
		F5	0.944*	0.0174	5.612E-008	0.869	1.020
	F1	Influent	-0.803*	0.0261	3.433E-006	-0.920	-0.686
		F2	-0.274*	0.0442	1.966E-003	-0.440	-0.107
		F3	-0.150*	0.0308	1.177E-002	-0.267	-0.033
		F4	0.229*	0.0262	2.211E-003	0.112	0.346
		F5	0.141*	0.0307	1.702E-002	0.024	0.258
	F2	Influent	-0.530*	0.0362	2.079E-004	-0.694	-0.365
		F1	0.274*	0.0442	1.966E-003	0.107	0.440
		F3	0.123	0.0397	1.553E-001	-0.036	0.283
		F4	0.503*	0.0362	2.633E-004	0.339	0.667
		F5	0.415*	0.0396	1.711E-004	0.255	0.575
	F3	Influent	-0.653*	0.0176	5.177E-007	-0.730	-0.576
		F1	0.150*	0.0308	1.177E-002	0.033	0.267
		F2	-0.123	0.0397	1.553E-001	-0.283	0.036
		F4	0.380*	0.0177	9.955E-006	0.303	0.456
		F5	0.291*	0.0239	3.435E-006	0.204	0.379
	F4	Influent	-1.033*	0.0067	1.332E-015	-1.057	-1.008
		F1	-0.229*	0.0262	2.211E-003	-0.346	-0.112
		F2	-0.503*	0.0362	2.633E-004	-0.667	-0.339
		F3	-0.380*	0.0177	9.955E-006	-0.456	-0.303
		F5	-0.088*	0.0175	2.495E-002	-0.164	-0.013
	F5	Influent	-0.944*	0.0174	5.612E-008	-1.020	-0.869
		F1	-0.141*	0.0307	1.702E-002	-0.258	-0.024
		F2	-0.415*	0.0396	1.711E-004	-0.575	-0.255
		F3	-0.291*	0.0239	3.435E-006	-0.379	-0.204
		F4	0.088*	0.0175	2.495E-002	0.013	0.164

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plot of residuals versus predicted values and the plot of residuals versus influent/filter # indicate that the residuals were heteroscedastic.
4. Results from Levene's test of equality of variance provides a strong indication of heteroscedasticity
5. Given points 3 and 4, the residuals were considered to be heteroscedastic; therefore, results from Dunnett's T3 test were used for multiple comparisons.

Data Set 22: Collected August 20, 2012

Raw Data

Table B-89: Data Set 22 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.844	3.992	4.120	4.129	3.746	3.759
		2	4.924	4.013	4.253	4.184	3.806	3.793
		3	4.973	4.058	4.242	4.195	3.838	3.767
		Average	4.914	4.021	4.205	4.169	3.797	3.773
	2	1	4.825	3.981	4.150	4.129	3.740	3.876
		2	4.892	4.020	4.178	4.18	3.789	3.861
		3	4.941	4.035	4.221	4.186	3.870	3.866
		Average	4.886	4.012	4.183	4.165	3.800	3.868
	3	1	5.013	3.947	4.142	4.131	3.721	3.789
		2	5.092	3.977	4.242	4.154	3.789	3.838
		3	5.052	4.020	4.212	4.221	3.767	3.877
		Average	5.052	3.981	4.199	4.169	3.759	3.835
	Average		4.951	4.005	4.196	4.167	3.785	3.825
	Standard Deviation		0.0909	0.0338	0.0494	0.0300	0.0481	0.0481
2	1	1	4.797	3.939	4.146	4.107	3.691	3.996
		2	4.881	4.015	4.274	4.199	3.721	3.990
		3	4.907	4.079	4.261	4.191	3.761	3.909
		Average	4.862	4.011	4.227	4.166	3.724	3.965
	2	1	4.765	3.988	4.236	4.135	3.748	3.808
		2	4.862	3.973	4.225	4.154	3.847	3.847
		3	4.830	4.058	4.251	4.216	3.838	3.904
		Average	4.819	4.006	4.237	4.168	3.811	3.853
	3	1	4.819	3.994	4.152	4.111	3.708	3.845
		2	4.872	3.986	4.212	4.174	3.691	3.830
		3	4.860	4.003	4.272	4.184	3.806	3.829
		Average	4.850	3.994	4.212	4.156	3.735	3.835
	Average		4.844	4.004	4.225	4.167	3.757	3.884
	Standard Deviation		0.0447	0.0426	0.0480	0.0419	0.0608	0.0702

* Data excluded from further analysis.

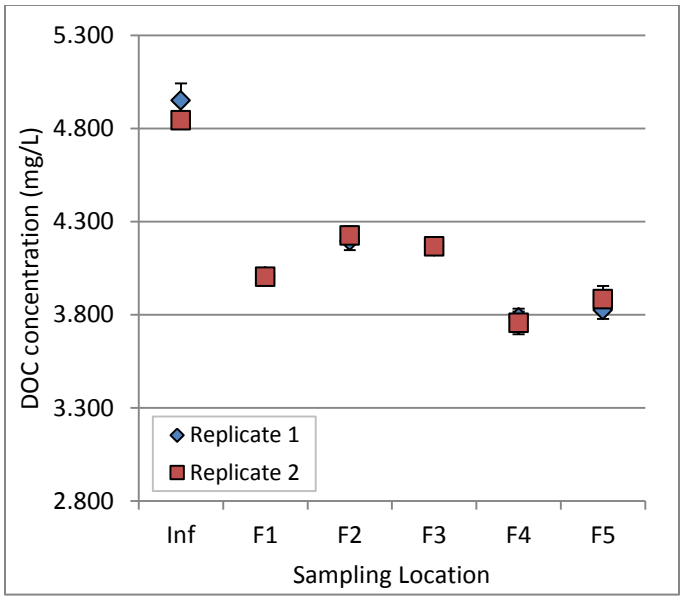

Figure B-88: Data Set 22 plot of average DOC concentrations

List of Excluded Data from Data Set 22, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded

ANOVA Results

Table B-90: Data Set 22 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.066[a]	5	0.813	1132.813	2.161E-031
Intercept	578.930	1	578.930	806382.612	5.532E-064
filter#	4.066	5	0.813	1132.813	2.161E-031
Error	0.020	28	0.001		
Total	583.870	34			
Corrected Total	4.087	33			

a. R Squared = .995 (Adjusted R Squared = .994)

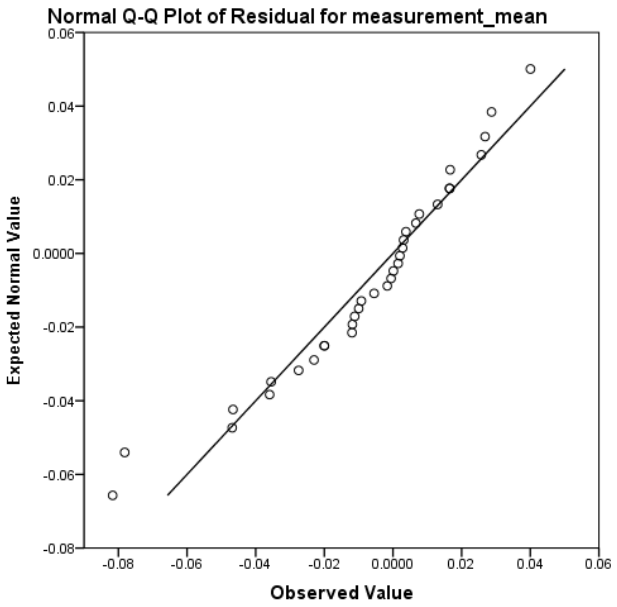

Figure B-89: Data Set 22 normal probability plot of residuals

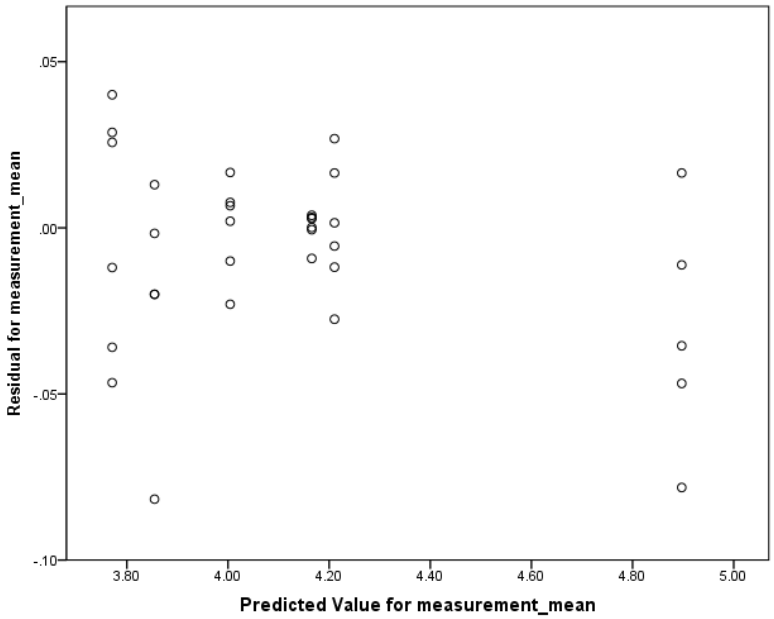

Figure B-90: Data Set 22 plot of residuals versus predicted values

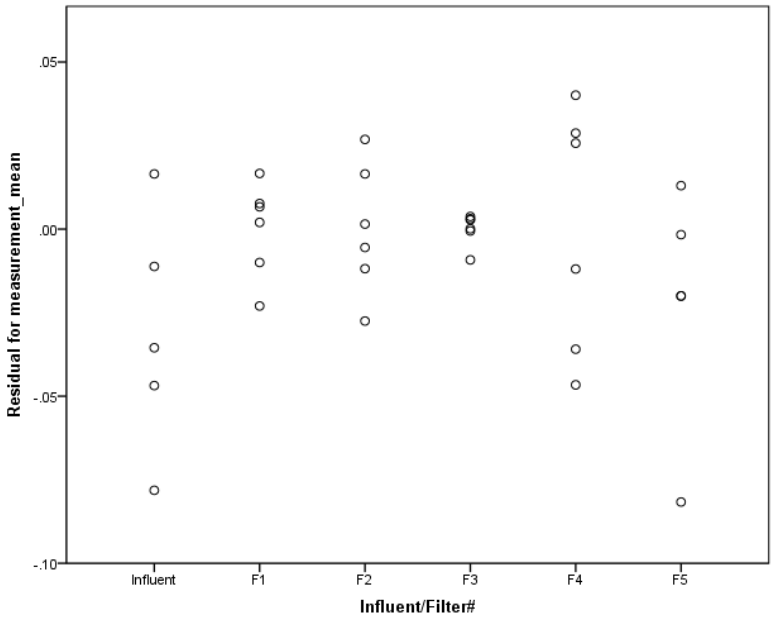

Figure B-91: Data Set 22 plot of residuals versus filter number

Table B-91: Data Set 22 results from Levene's test of equality of variances

F	df1	df2	Sig.
3.352	5	28	1.694E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-92: Data Set 22 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.862*	0.0162	8.863E-013	0.812	0.911
		F2	0.656*	0.0162	8.863E-013	0.606	0.705
		F3	0.701*	0.0162	8.863E-013	0.651	0.750
		F4	1.095*	0.0162	8.863E-013	1.046	1.145
		F5	1.034*	0.0169	8.863E-013	0.982	1.085
	F1	Influent	-0.862*	0.0162	8.863E-013	-0.911	-0.812
		F2	-0.206*	0.0155	2.608E-012	-0.253	-0.159
		F3	-0.161*	0.0155	5.569E-010	-0.208	-0.114
		F4	0.233*	0.0155	9.563E-013	0.186	0.281
		F5	0.172*	0.0162	3.933E-010	0.122	0.221
	F2	Influent	-0.656*	0.0162	8.863E-013	-0.705	-0.606
		F1	0.206*	0.0155	2.608E-012	0.159	0.253
		F3	0.045	0.0155	6.958E-002	-0.002	0.092
		F4	0.440*	0.0155	8.863E-013	0.392	0.487
		F5	0.378*	0.0162	8.863E-013	0.328	0.427
	F3	Influent	-0.701*	0.0162	8.863E-013	-0.750	-0.651
		F1	0.161*	0.0155	5.569E-010	0.114	0.208
		F2	-0.045	0.0155	6.958E-002	-0.092	0.002
		F4	0.395*	0.0155	8.863E-013	0.347	0.442
		F5	0.333*	0.0162	8.863E-013	0.283	0.383
	F4	Influent	-1.095*	0.0162	8.863E-013	-1.145	-1.046
		F1	-0.233*	0.0155	9.563E-013	-0.281	-0.186
		F2	-0.440*	0.0155	8.863E-013	-0.487	-0.392
		F3	-0.395*	0.0155	8.863E-013	-0.442	-0.347
		F5	-0.062*	0.0162	8.449E-003	-0.111	-0.012
	F5	Influent	-1.034*	0.0169	8.863E-013	-1.085	-0.982
		F1	-0.172*	0.0162	3.933E-010	-0.221	-0.122
		F2	-0.378*	0.0162	8.863E-013	-0.427	-0.328
		F3	-0.333*	0.0162	8.863E-013	-0.383	-0.283
		F4	0.062*	0.0162	8.449E-003	0.012	0.111
Dunnett T3**	Influent	F1	0.862*	0.0171	4.893E-007	0.783	0.940
		F2	0.656*	0.0179	3.453E-007	0.579	0.733
		F3	0.701*	0.0162	1.021E-005	0.618	0.783
		F4	1.095*	0.0219	6.865E-011	1.012	1.179
		F5	1.034*	0.0228	7.807E-010	0.945	1.122
	F1	Influent	-0.862*	0.0171	4.893E-007	-0.940	-0.783
		F2	-0.206*	0.0099	6.976E-008	-0.243	-0.169
		F3	-0.161*	0.0061	1.707E-006	-0.187	-0.135
		F4	0.233*	0.0160	3.904E-005	0.167	0.300
		F5	0.172*	0.0172	1.549E-003	0.093	0.251
	F2	Influent	-0.656*	0.0179	3.453E-007	-0.733	-0.579
		F1	0.206*	0.0099	6.976E-008	0.169	0.243
		F3	0.045*	0.0082	1.900E-002	0.009	0.081
		F4	0.440*	0.0170	1.233E-007	0.373	0.506
		F5	0.378*	0.0180	9.467E-006	0.301	0.455
	F3	Influent	-0.701*	0.0162	1.021E-005	-0.783	-0.618
		F1	0.161*	0.0061	1.707E-006	0.135	0.187
		F2	-0.045*	0.0082	1.900E-002	-0.081	-0.009
		F4	0.395*	0.0151	1.054E-005	0.326	0.463
		F5	0.333*	0.0163	2.210E-004	0.250	0.416
	F4	Influent	-1.095*	0.0219	6.865E-011	-1.179	-1.012
		F1	-0.233*	0.0160	3.904E-005	-0.300	-0.167
		F2	-0.440*	0.0170	1.233E-007	-0.506	-0.373
		F3	-0.395*	0.0151	1.054E-005	-0.463	-0.326
		F5	-0.062	0.0220	2.048E-001	-0.145	0.022
	F5	Influent	-1.034*	0.0228	7.807E-010	-1.122	-0.945
		F1	-0.172*	0.0172	1.549E-003	-0.251	-0.093
		F2	-0.378*	0.0180	9.467E-006	-0.455	-0.301
		F3	-0.333*	0.0163	2.210E-004	-0.416	-0.250
		F4	0.062	0.0220	2.048E-001	-0.022	0.145

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed. There are a few data points that may deviate from normality but the majority of the points are close to the line that represents normality.
3. The plot of residuals versus predicted values and the plot of residuals versus influent/filter # indicate that the residuals were heteroscedastic.
4. Results from Levene's test of equality of variance provide a strong indication of heteroscedasticity
5. Given points 3 and 4, the residuals were considered to be heteroscedastic; therefore, results from Dunnett's T3 test were be used for multiple comparisons.

Data Set 23: Collected September 25, 2012

Raw Data

Table B-93: Data Set 23 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.221	-	9.665*	3.837	3.443	3.469
		2	4.268	-	9.828*	3.835	3.497	3.503
		3	4.317	-	9.875*	3.855	3.535	3.529
		Average	4.269	-	9.665	3.842	3.492	3.500
	2	1	4.336	-	3.818	3.767	3.479	3.398
		2	4.332	-	3.870	3.799	3.492	3.452
		3	4.276	-	3.893	3.807	3.479	3.473
		Average	4.315	-	3.860	3.791	3.483	3.441
	3	1	4.244	-	3.681	3.824	3.445	3.473
		2	4.289	-	3.765	3.859	3.516	3.507
		3	4.396	-	3.786	3.878	3.505	3.490
		Average	4.310	-	3.744	3.854	3.489	3.490
	Average		4.298	-	3.802	3.817	3.488	3.477
	Standard Deviation		0.0535	-	0.0767	0.0319	0.0304	0.0378
2	1	1	4.647	0.086*	3.865	3.704	3.865	3.447
		2	4.568	0.091*	3.874	3.822	3.951	3.507
		3	4.482	0.130*	3.874	3.822	3.949	3.516
		Average	4.566	0.086	3.871	3.783	3.922	3.490
	2	1	4.281	3.657	3.797	3.818	3.737	3.458
		2	4.351	3.692	3.854	3.848	3.827	3.377
		3	4.345	3.674	3.852	3.854	3.805	3.499
		Average	4.326	3.674	3.834	3.840	3.790	3.445
	3	1	4.289	3.717	3.764	3.818	3.833	3.467
		2	4.386	3.713	3.820	3.882	3.855	3.548
		3	4.352	3.715	3.835	3.904	3.899	3.509
		Average	4.342	3.715	3.806	3.868	3.862	3.508
	Average		4.411	3.695	3.837	3.811	3.858	3.481
	Standard Deviation		0.1271	0.0249	0.0375	0.0547	0.0687	0.0502

* Data excluded from further analysis.

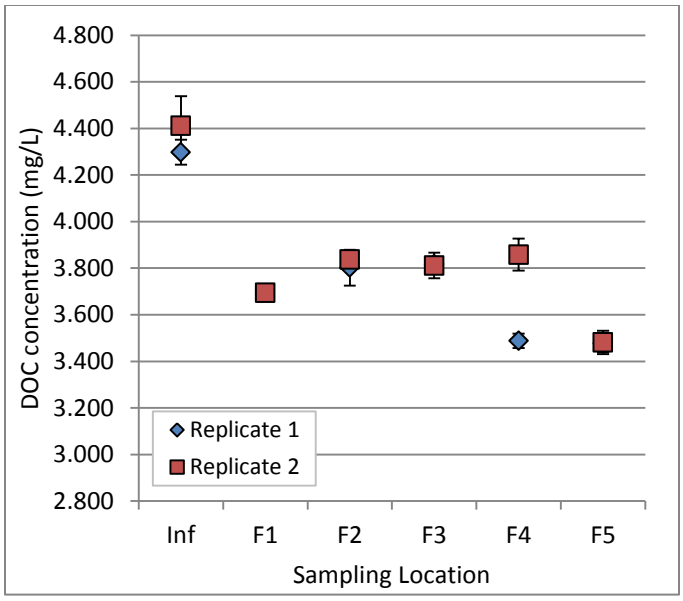

Figure B-92: Data Set 23 plot of average DOC concentrations

List of Excluded Data from Data Set 23, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data from Filter 1 bottle 1 because bottle broke
2. Aliquot 1 for Filter 1, bottle 2, excluded because the DOC concentration was significantly lower than the DOC concentrations for the other aliquots. It is suspected that there was an analytical error when this aliquot was analyzed.
3. Aliquot 1 for Filter 2, bottle 1, excluded because the DOC concentration was significantly higher than the DOC concentrations for the other aliquots. It is suspected that either the vial containing this aliquot was contaminated or that there was an analytical error.

ANOVA Results

Table B-94: Data Set 23 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.695[a]	5	0.539	462.870	4.886E-023
Intercept	363.911	1	363.911	312478.665	6.786E-051
filter#	2.695	5	0.539	462.870	4.886E-023
Error	0.028	24	0.001		
Total	424.713	30			
Corrected Total	2.723	29			

a. R Squared = .990 (Adjusted R Squared = .988)

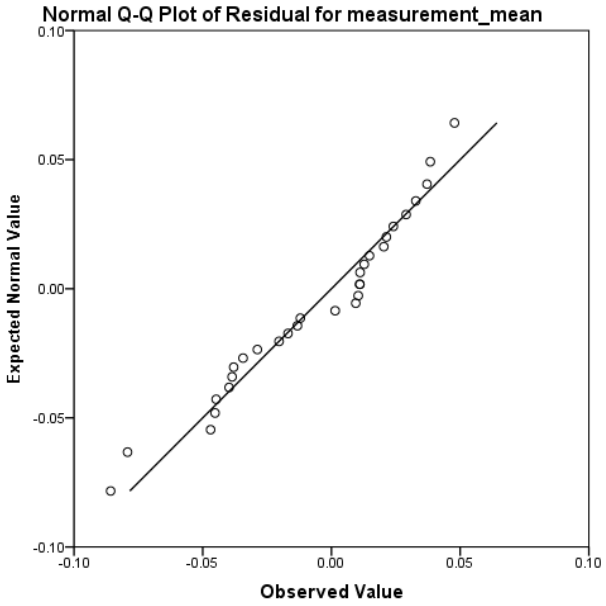

Figure B-93: Data Set 23 normal probability plot of residuals

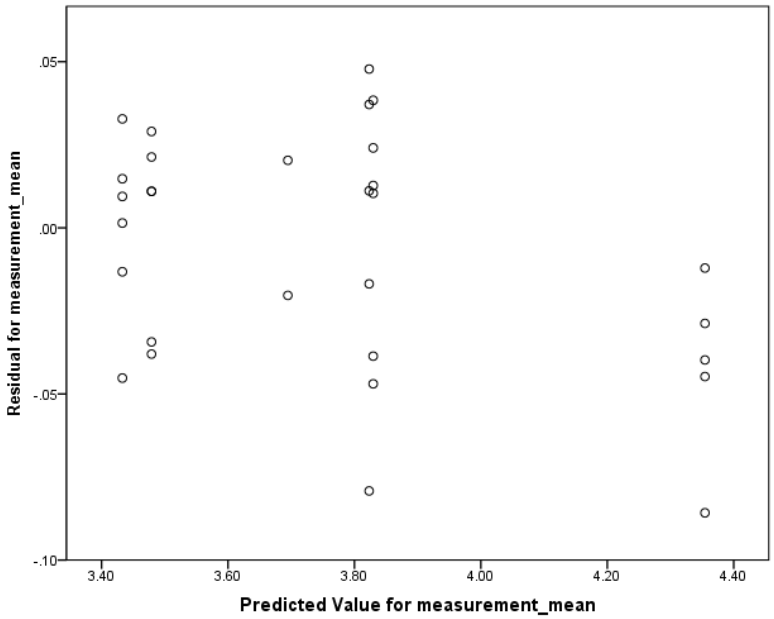

Figure B-94: Data Set 23 plot of residuals versus predicted values

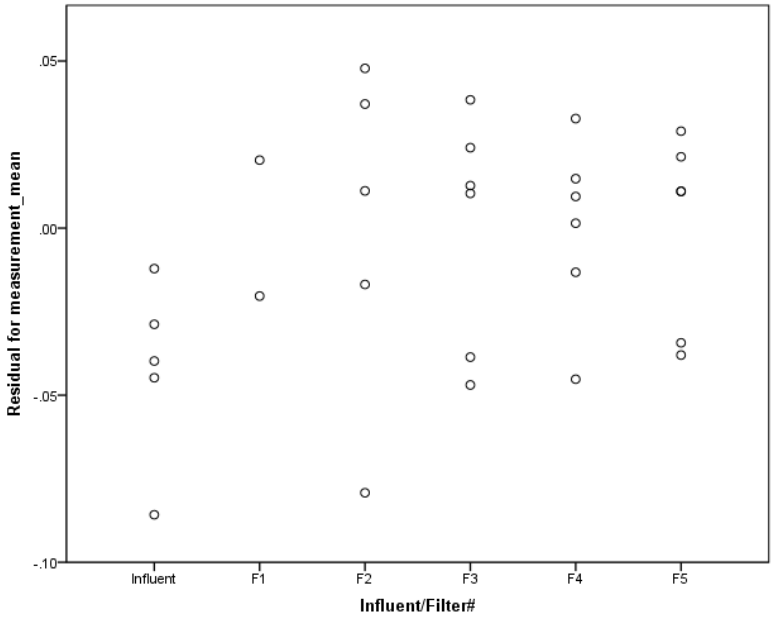

Figure B-95: Data Set 23 plot of residuals versus filter number

Table B-95: Data Set 23 results from Levene's test of equality of variances

F	df1	df2	Sig.
.922	5	24	4.839E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-96: Data Set 23 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.618*	0.0286	9.058E-013	0.529	0.706
		F2	0.489*	0.0216	9.057E-013	0.422	0.556
		F3	0.483*	0.0207	9.057E-013	0.419	0.546
		F4	0.879*	0.0207	9.057E-013	0.815	0.943
		F5	0.833*	0.0207	9.057E-013	0.769	0.897
	F1	Influent	-0.618*	0.0286	9.058E-013	-0.706	-0.529
		F2	-0.129*	0.0286	1.824E-003	-0.217	-0.040
		F3	-0.135*	0.0279	7.858E-004	-0.221	-0.049
		F4	0.262*	0.0279	2.320E-008	0.176	0.348
		F5	0.216*	0.0279	7.842E-007	0.130	0.302
	F2	Influent	-0.489*	0.0216	9.057E-013	-0.556	-0.422
		F1	0.129*	0.0286	1.824E-003	0.040	0.217
		F3	-0.006	0.0207	9.996E-001	-0.070	0.057
		F4	0.390*	0.0207	9.106E-013	0.326	0.454
		F5	0.344*	0.0207	1.037E-012	0.280	0.408
	F3	Influent	-0.483*	0.0207	9.057E-013	-0.546	-0.419
		F1	0.135*	0.0279	7.858E-004	0.049	0.221
		F2	0.006	0.0207	9.996E-001	-0.057	0.070
		F4	0.397*	0.0197	9.065E-013	0.336	0.458
		F5	0.351*	0.0197	9.311E-013	0.290	0.412
	F4	Influent	-0.879*	0.0207	9.057E-013	-0.943	-0.815
		F1	-0.262*	0.0279	2.320E-008	-0.348	-0.176
		F2	-0.390*	0.0207	9.106E-013	-0.454	-0.326
		F3	-0.397*	0.0197	9.065E-013	-0.458	-0.336
		F5	-0.046	0.0197	2.172E-001	-0.107	0.015
	F5	Influent	-0.833*	0.0207	9.057E-013	-0.897	-0.769
		F1	-0.216*	0.0279	7.842E-007	-0.302	-0.130
		F2	-0.344*	0.0207	1.037E-012	-0.408	-0.280
		F3	-0.351*	0.0197	9.311E-013	-0.412	-0.290
		F4	0.046	0.0197	2.172E-001	-0.015	0.107
Dunnett T3	Influent	F1	0.618*	0.0237	1.019E-002	0.365	0.870
		F2	0.489*	0.0258	1.241E-005	0.380	0.598
		F3	0.483*	0.0187	1.304E-008	0.412	0.553
		F4	0.879*	0.0164	5.216E-011	0.817	0.942
		F5	0.833*	0.0170	6.506E-011	0.769	0.898
	F1	Influent	-0.618*	0.0237	1.019E-002	-0.870	-0.365
		F2	-0.129	0.0305	1.105E-001	-0.295	0.038
		F3	-0.135	0.0248	1.274E-001	-0.351	0.081
		F4	0.262	0.0231	5.590E-002	-0.019	0.542
		F5	0.216	0.0235	6.896E-002	-0.045	0.476
	F2	Influent	-0.489*	0.0258	1.241E-005	-0.598	-0.380
		F1	0.129	0.0305	1.105E-001	-0.038	0.295
		F3	-0.006	0.0268	1.000E+000	-0.116	0.103
		F4	0.390*	0.0252	6.397E-005	0.281	0.499
		F5	0.344*	0.0256	1.032E-004	0.235	0.453
	F3	Influent	-0.483*	0.0187	1.304E-008	-0.553	-0.412
		F1	0.135	0.0248	1.274E-001	-0.081	0.351
		F2	0.006	0.0268	1.000E+000	-0.103	0.116
		F4	0.397*	0.0179	2.642E-008	0.330	0.464
		F5	0.351*	0.0184	7.400E-008	0.282	0.419
	F4	Influent	-0.879*	0.0164	5.216E-011	-0.942	-0.817
		F1	-0.262	0.0231	5.590E-002	-0.542	0.019
		F2	-0.390*	0.0252	6.397E-005	-0.499	-0.281
		F3	-0.397*	0.0179	2.642E-008	-0.464	-0.330
		F5	-0.046	0.0161	1.741E-001	-0.105	0.013
	F5	Influent	-0.833*	0.0170	6.506E-011	-0.898	-0.769
		F1	-0.216	0.0235	6.896E-002	-0.476	0.045
		F2	-0.344*	0.0256	1.032E-004	-0.453	-0.235
		F3	-0.351*	0.0184	7.400E-008	-0.419	-0.282
		F4	0.046	0.0161	1.741E-001	-0.013	0.105

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were relatively normally distributed. There were a few data points that deviate from normality but the majority of the points were close to the line that represents normality.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 24: Collected October 9, 2012

Raw Data

Table B-97: Data Set 24 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.538	3.812	4.177	4.129	3.698	3.654
		2	4.589	3.902	4.238	4.089	3.703	3.688
		3	4.612	3.898	4.265	4.158	3.720	3.713
		Average	4.580	3.871	4.227	4.125	3.707	3.685
	2	1	4.561	3.846	4.177	4.089	3.621	3.795
		2	4.631	3.913	4.219	4.123	3.738	3.816
		3	4.666	3.942	4.230	4.173	3.713	3.774
		Average	4.619	3.900	4.209	4.128	3.691	3.795
	3	1	4.582	3.885	4.198	4.045	3.659	3.619
		2	4.652	3.929	4.251	4.183	3.686	3.680
		3	4.689	3.913	4.282	4.150	3.701	3.732
		Average	4.641	3.909	4.244	4.126	3.682	3.677
	Average		4.613	3.893	4.226	4.127	3.693	3.719
	Standard Deviation		0.0504	0.0410	0.0372	0.0346	0.0349	0.0663
2	1	1	4.528	3.906	4.070	4.037	3.707	17.550*
		2	4.605	3.973	4.116	4.068	3.764	17.800*
		3	4.662	3.994	4.179	4.093	3.768	18.030*
		Average	4.598	3.958	4.122	4.066	3.746	17.550
	2	1	4.677	3.953	3.986	4.053	3.673	3.730
		2	4.756	3.965	4.137	4.089	3.753	3.772
		3	4.738	3.915	4.143	4.123	3.789	3.829
		Average	4.724	3.944	4.089	4.088	3.738	3.777
	3	1	4.559	3.892	4.095	4.078	3.711	3.720
		2	4.624	3.919	4.165	4.097	3.770	3.774
		3	4.675	3.950	4.179	4.148	3.801	3.803
		Average	4.619	3.920	4.146	4.108	3.761	3.766
	Average		4.647	3.941	4.119	4.077	3.748	3.771
	Standard Deviation		0.0761	0.0343	0.0621	0.0309	0.0423	0.0417

* Data excluded from further analysis.

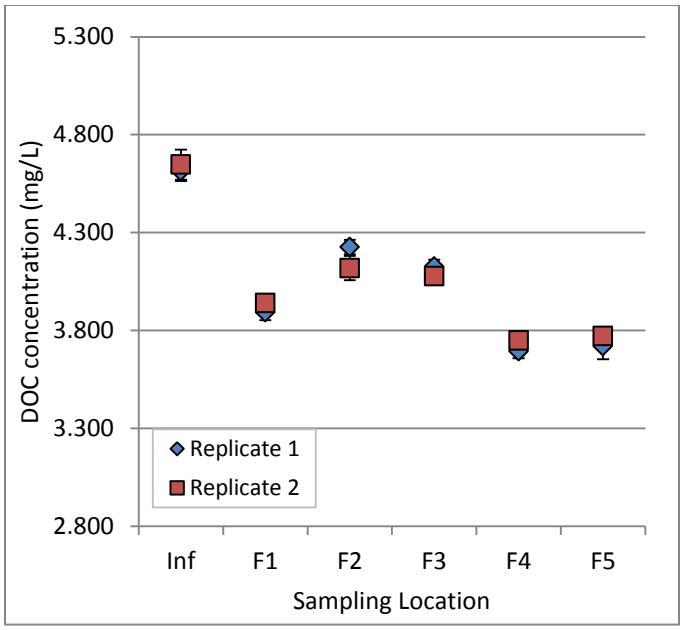

Figure B-96: Data Set 24 plot of average DOC concentrations

List of Excluded Data from Data Set 24, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Aliquot 1 for Filter 5, bottle 2, excluded because the DOC concentration was higher than the DOC concentrations for the other aliquots. It is suspected that the vial containing this aliquot was contaminated.

ANOVA Results

Table B-98: Data Set 24 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.365[a]	5	.673	339.158	8.589E-025
Intercept	570.859	1	570.859	287694.550	1.647E-059
filter#	3.365	5	0.673	339.158	8.589E-025
Error	.058	29	0.002		
Total	579.420	35			
Corrected Total	3.422	34			

a. R Squared = .983 (Adjusted R Squared = .980)

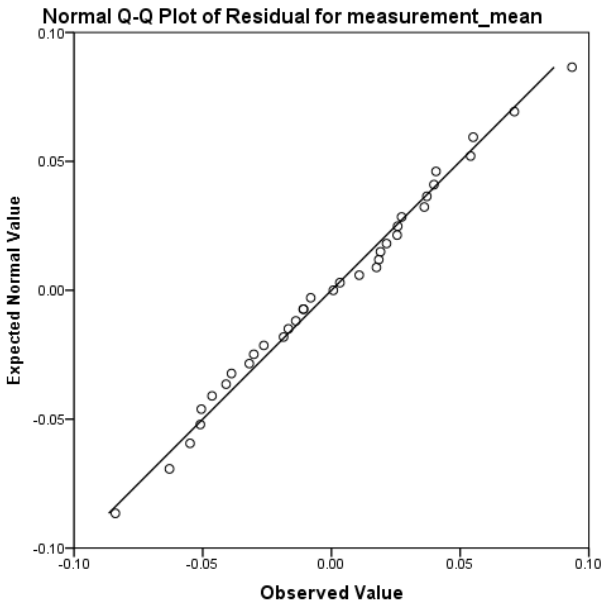

Figure B-97: Data Set 24 normal probability plot of residuals

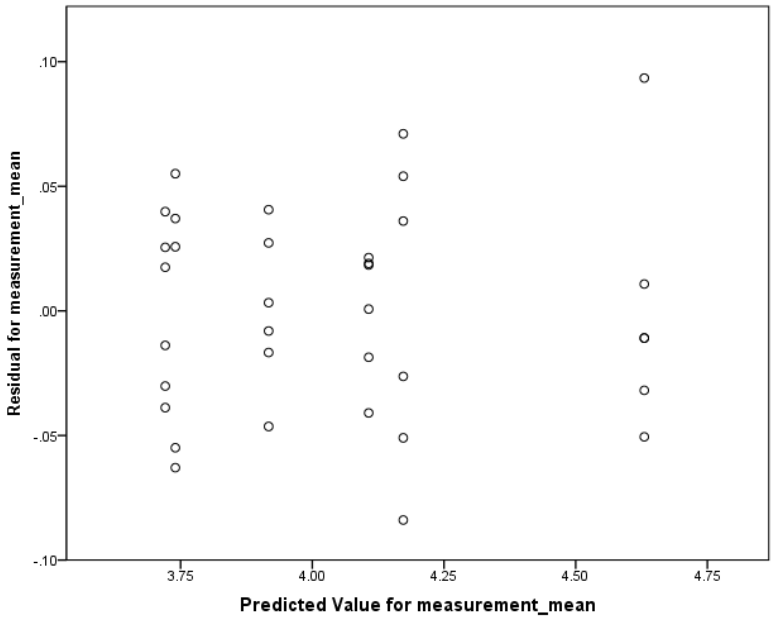

Figure B-98: Data Set 24 plot of residuals versus predicted values

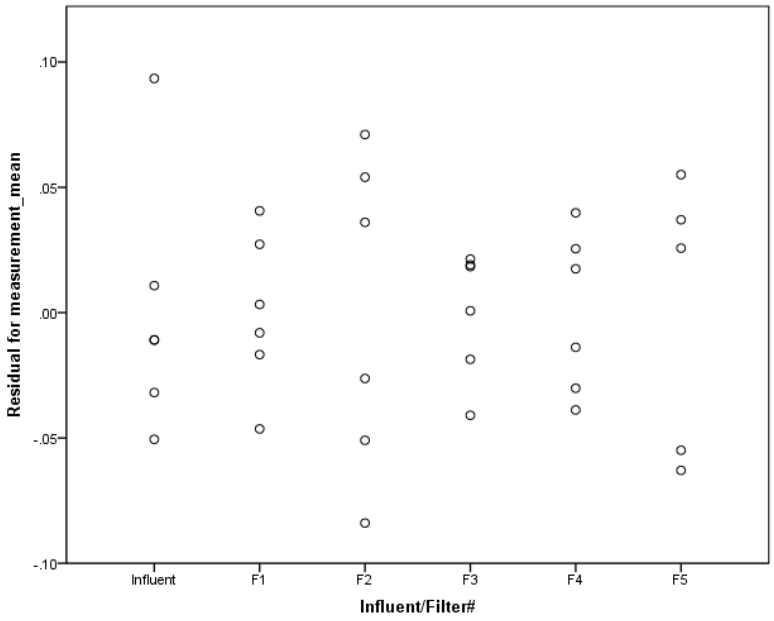

Figure B-99: Data Set 24 plot of residuals versus filter number

Table B-99: Data Set 24 results from Levene's test of equality of variances

F	df1	df2	Sig.
2.650	5	29	4.315E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-100: Data Set 24 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.713*	0.0257	8.399E-013	0.635	0.792
		F2	0.458*	0.0257	8.400E-013	0.379	0.536
		F3	0.523*	0.0257	8.399E-013	0.445	0.602
		F4	0.909*	0.0257	8.399E-013	0.831	0.988
		F5	0.890*	0.0270	8.399E-013	0.808	0.973
	F1	Influent	-0.713*	0.0257	8.399E-013	-0.792	-0.635
		F2	-0.256*	0.0257	1.107E-009	-0.334	-0.177
		F3	-0.190*	0.0257	5.551E-007	-0.268	-0.111
		F4	0.196*	0.0257	2.942E-007	0.118	0.275
		F5	0.177*	0.0270	4.779E-006	0.095	0.259
	F2	Influent	-0.458*	0.0257	8.400E-013	-0.536	-0.379
		F1	0.256*	0.0257	1.107E-009	0.177	0.334
		F3	0.066	0.0257	1.419E-001	-0.013	0.144
		F4	0.452*	0.0257	8.400E-013	0.373	0.530
		F5	0.433*	0.0270	8.457E-013	0.350	0.515
	F3	Influent	-0.523*	0.0257	8.399E-013	-0.602	-0.445
		F1	0.190*	0.0257	5.551E-007	0.111	0.268
		F2	-0.066	0.0257	1.419E-001	-0.144	0.013
		F4	0.386*	0.0257	8.793E-013	0.308	0.465
		F5	0.367*	0.0270	1.399E-012	0.285	0.449
	F4	Influent	-0.909*	0.0257	8.399E-013	-0.988	-0.831
		F1	-0.196*	0.0257	2.942E-007	-0.275	-0.118
		F2	-0.452*	0.0257	8.400E-013	-0.530	-0.373
		F3	-0.386*	0.0257	8.793E-013	-0.465	-0.308
		F5	-0.019	0.0270	9.794E-001	-0.101	0.063
	F5	Influent	-0.890*	0.0270	8.399E-013	-0.973	-0.808
		F1	-0.177*	0.0270	4.779E-006	-0.259	-0.095
		F2	-0.433*	0.0270	8.457E-013	-0.515	-0.350
		F3	-0.367*	0.0270	1.399E-012	-0.449	-0.285
		F4	0.019	0.0270	9.794E-001	-0.063	0.101
Dunnett T3**	Influent	F1	0.713*	0.0242	1.234E-008	0.620	0.806
		F2	0.458*	0.0328	1.534E-006	0.336	0.579
		F3	0.523*	0.0230	5.239E-007	0.432	0.615
		F4	0.909*	0.0244	1.342E-009	0.816	10.003
		F5	0.890*	0.0320	2.223E-008	0.767	1.014
	F1	Influent	-0.713*	0.0242	1.234E-008	-0.806	-0.620
		F2	-0.256*	0.0286	3.942E-004	-0.370	-0.142
		F3	-0.190*	0.0164	8.277E-006	-0.251	-0.129
		F4	0.196*	0.0183	1.149E-005	0.129	0.264
		F5	0.177*	0.0277	6.678E-003	0.060	0.295
	F2	Influent	-0.458*	0.0328	1.534E-006	-0.579	-0.336
		F1	0.256*	0.0286	3.942E-004	0.142	0.370
		F3	0.066	0.0276	3.824E-001	-0.048	0.180
		F4	0.452*	0.0287	6.714E-006	0.338	0.566
		F5	0.433*	0.0354	9.179E-006	0.299	0.566
	F3	Influent	-0.523*	0.0230	5.239E-007	-0.615	-0.432
		F1	0.190*	0.0164	8.277E-006	0.129	0.251
		F2	-0.066	0.0276	3.824E-001	-0.180	0.048
		F4	0.386*	0.0167	1.587E-008	0.324	0.448
		F5	0.367*	0.0266	2.076E-004	0.248	0.486
	F4	Influent	-0.909*	0.0244	1.342E-009	-1.003	-0.816
		F1	-0.196*	0.0183	1.149E-005	-0.264	-0.129
		F2	-0.452*	0.0287	6.714E-006	-0.566	-0.338
		F3	-0.386*	0.0167	1.587E-008	-0.448	-0.324
		F5	-0.019	0.0278	9.993E-001	-0.137	0.098
	F5	Influent	-0.890*	0.0320	2.223E-008	-1.014	-0.767
		F1	-0.177*	0.0277	6.678E-003	-0.295	-0.060
		F2	-0.433*	0.0354	9.179E-006	-0.566	-0.299
		F3	-0.367*	0.0266	2.076E-004	-0.486	-0.248
		F4	0.019	0.0278	9.993E-001	-0.098	0.137

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # do not indicate that the residuals were heteroscedastic.
4. Results from Levene's test of equality of variance indicated heteroscedasticity.
5. Given that the Levene's test indicated heteroscedasticity, the residuals were considered to be heteroscedastic; therefore, results from Dunnett's T3 test were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 25: Collected October 11, 2012

Raw Data

Table B-101: Data Set 25 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.558	3.915	4.132	4.048	3.786	3.719
		2	4.633	3.878	4.156	4.096	3.846	3.757
		3	4.698	3.965	4.181	4.109	3.865	3.792
		Average	4.630	3.919	4.156	4.084	3.832	3.756
	2	1	4.571	3.973	4.002	4.055	3.769	3.615
		2	4.690	3.915	4.059	4.042	3.852	3.728
		3	4.725	3.984	4.069	4.044	3.921	3.728
		Average	4.662	3.957	4.043	4.047	3.847	3.690
	3	1	4.592	3.938	4.104	4.067	3.850	3.686
		2	4.663	4.079	4.121	4.121	3.888	3.759
		3	4.742	4.071	4.156	4.148	3.873	3.778
		Average	4.666	4.029	4.127	4.112	3.870	3.741
	Average		4.652	3.969	4.109	4.066	3.850	3.729
	Standard Deviation		0.0675	0.0688	0.0568	0.0292	0.0473	0.0536
2	1	1	4.596	3.890	4.002	4.063	3.736	3.788
		2	4.665	3.977	4.121	4.136	3.807	3.846
		3	4.717	4.019	4.140	4.175	3.809	3.855
		Average	4.659	3.962	4.088	4.125	3.784	3.830
	2	1	4.673	3.900	4.119	4.084	3.800	3.792
		2	4.735	3.936	4.184	4.150	3.809	3.832
		3	4.792	3.994	4.194	4.167	3.834	3.892
		Average	4.733	3.943	4.166	4.134	3.814	3.839
	3	1	4.629	3.905	4.136	4.242	3.738	3.817
		2	4.606	3.984	4.156	4.179	3.817	3.853
		3	4.733	3.980	4.173	4.138	3.853	3.911
		Average	4.656	3.956	4.155	4.186	3.803	3.860
	Average		4.683	3.954	4.136	4.129	3.800	3.843
	Standard Deviation		0.0662	0.0470	0.0569	0.0457	0.0394	0.0414

* Data excluded from further analysis.

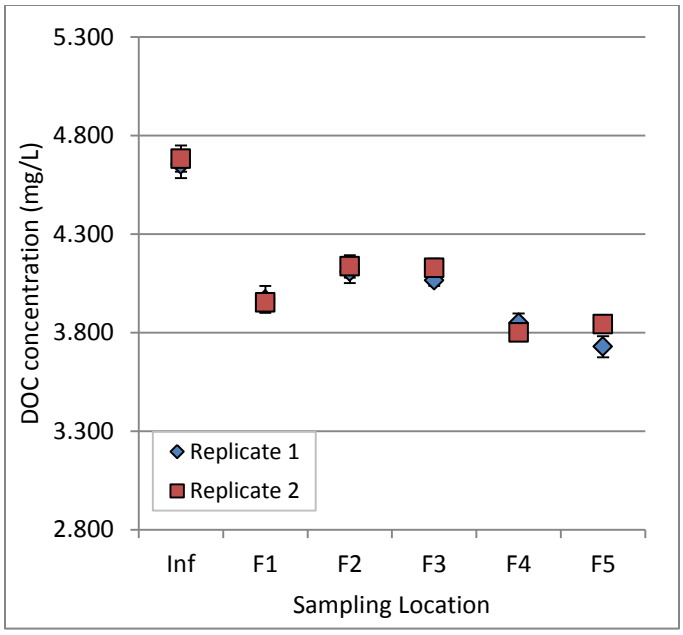

Figure B-100: Data Set 25 plot of average DOC concentrations

List of Excluded Data from Data Set 25, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded

ANOVA Results

Table B-102: Data Set 25 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.083[a]	5	0.617	295.475	1.458E-024
Intercept	599.137	1	599.137	287109.177	2.787E-061
filter#	3.083	5	0.617	295.475	1.458E-024
Error	0.063	30	0.002		
Total	602.283	36			
Corrected Total	3.146	35			

a. R Squared = .980 (Adjusted R Squared = .977)

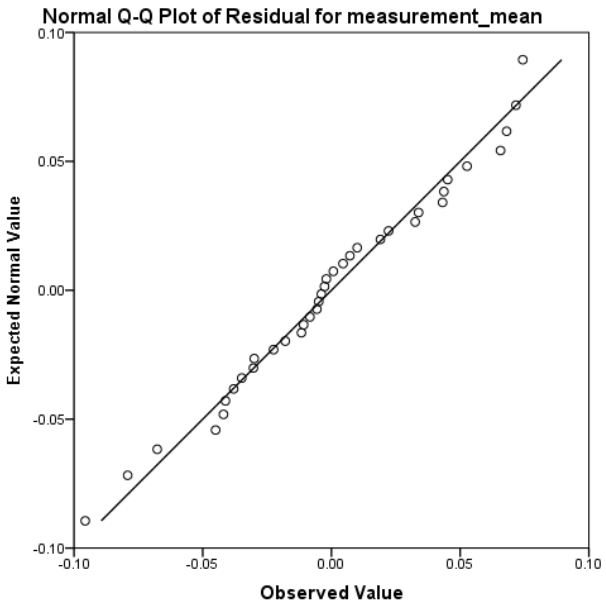

Figure B-101: Data Set 25 normal probability plot of residuals

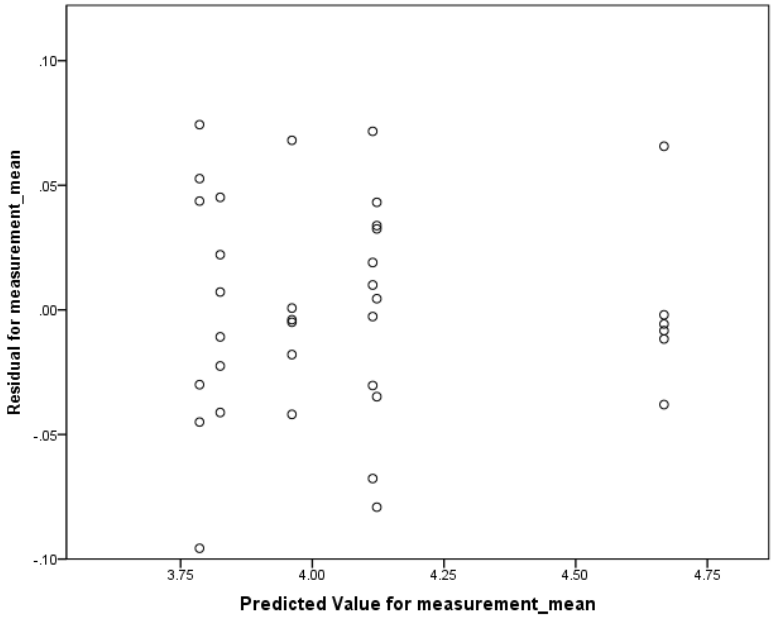

Figure B-102: Data Set 25 plot of residuals versus predicted values

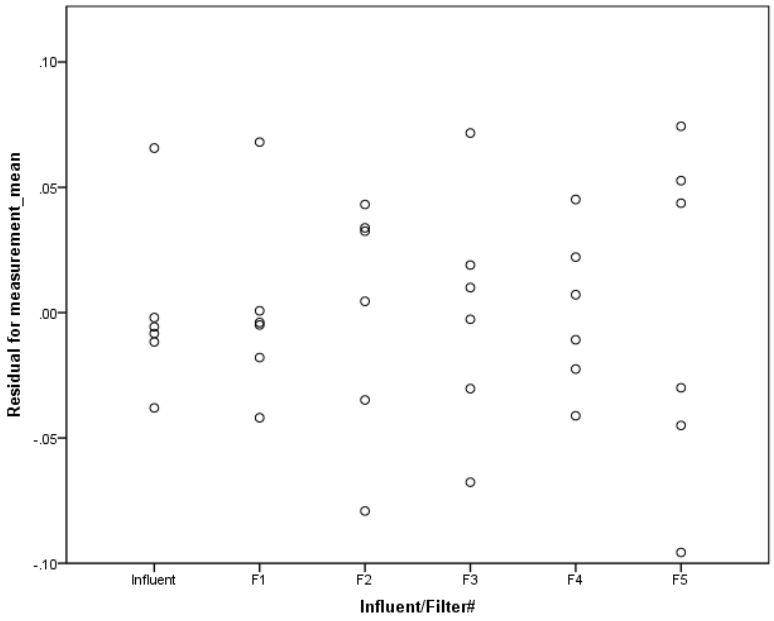

Figure B-103: Data Set 25 plot of residuals versus filter number

Table B-103: Data Set 25 results from Levene's test of equality of variances

F	df1	df2	Sig.
1.772	5	30	1.490E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-104: Data Set 25 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.706*	0.0264	8.280E-013	0.626	0.787
		F2	0.545*	0.0264	8.280E-013	0.465	0.625
		F3	0.553*	0.0264	8.280E-013	0.473	0.633
		F4	0.842*	0.0264	8.280E-013	0.762	0.923
		F5	0.882*	0.0264	8.280E-013	0.801	0.962
	F1	Influent	-0.706*	0.0264	8.280E-013	-0.787	-0.626
		F2	-0.161*	0.0264	1.417E-005	-0.241	-0.081
		F3	-0.153*	0.0264	3.223E-005	-0.234	-0.073
		F4	0.136*	0.0264	1.987E-004	0.056	0.216
		F5	0.175*	0.0264	3.284E-006	0.095	0.255
	F2	Influent	-0.545*	0.0264	8.280E-013	-0.625	-0.465
		F1	0.161*	0.0264	1.417E-005	0.081	0.241
		F3	0.008	0.0264	9.997E-001	-0.072	0.088
		F4	0.297*	0.0264	3.897E-011	0.217	0.378
		F5	0.336*	0.0264	2.525E-012	0.256	0.417
	F3	Influent	-0.553*	0.0264	8.280E-013	-0.633	-0.473
		F1	0.153*	0.0264	3.223E-005	0.073	0.234
		F2	-0.008	0.0264	9.997E-001	-0.088	0.072
		F4	0.289*	0.0264	7.383E-011	0.209	0.370
		F5	0.329*	0.0264	3.938E-012	0.248	0.409
	F4	Influent	-0.842*	0.0264	8.280E-013	-0.923	-0.762
		F1	-0.136*	0.0264	1.987E-004	-0.216	-0.056
		F2	-0.297*	0.0264	3.897E-011	-0.378	-0.217
		F3	-0.289*	0.0264	7.383E-011	-0.370	-0.209
		F5	0.039	0.0264	6.760E-001	-0.041	0.119
	F5	Influent	-0.882*	0.0264	8.280E-013	-0.962	-0.801
		F1	-0.175*	0.0264	3.284E-006	-0.255	-0.095
		F2	-0.336*	0.0264	2.525E-012	-0.417	-0.256
		F3	-0.329*	0.0264	3.938E-012	-0.409	-0.248
		F4	-0.039	0.0264	6.760E-001	-0.119	0.041
Dunnett T3	Influent	F1	0.706*	0.0206	1.571E-010	0.631	0.782
		F2	0.545*	0.0242	3.700E-008	0.454	0.636
		F3	0.553*	0.0239	2.492E-008	0.463	0.643
		F4	0.842*	0.0191	1.453E-011	0.772	0.913
		F5	0.882*	0.0307	7.387E-008	0.760	1.003
	F1	Influent	-0.706*	0.0206	1.571E-010	-0.782	-0.631
		F2	-0.161*	0.0247	1.174E-003	-0.254	-0.069
		F3	-0.153*	0.0244	1.504E-003	-0.244	-0.062
		F4	0.136*	0.0197	6.222E-004	0.063	0.209
		F5	0.175*	0.0311	6.359E-003	0.053	0.297
	F2	Influent	-0.545*	0.0242	3.700E-008	-0.636	-0.454
		F1	0.161*	0.0247	1.174E-003	0.069	0.254
		F3	0.008	0.0275	1.000E+000	-0.093	0.109
		F4	0.297*	0.0234	9.554E-006	0.208	0.387
		F5	0.336*	0.0336	4.315E-005	0.210	0.463
	F3	Influent	-0.553*	0.0239	2.492E-008	-0.643	-0.463
		F1	0.153*	0.0244	1.504E-003	0.062	0.244
		F2	-0.008	0.0275	1.000E+000	-0.109	0.093
		F4	0.289*	0.0231	9.545E-006	0.202	0.377
		F5	0.329*	0.0334	5.350E-005	0.203	0.454
	F4	Influent	-0.842*	0.0191	1.453E-011	-0.913	-0.772
		F1	-0.136*	0.0197	6.222E-004	-0.209	-0.063
		F2	-0.297*	0.0234	9.554E-006	-0.387	-0.208
		F3	-0.289*	0.0231	9.545E-006	-0.377	-0.202
		F5	0.039	0.0301	9.178E-001	-0.082	0.161
	F5	Influent	-0.882*	0.0307	7.387E-008	-1.003	-0.760
		F1	-0.175*	0.0311	6.359E-003	-0.297	-0.053
		F2	-0.336*	0.0336	4.315E-005	-0.463	-0.210
		F3	-0.329*	0.0334	5.350E-005	-0.454	-0.203
		F4	-0.039	0.0301	9.178E-001	-0.161	0.082

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 26: Collected October 13, 2012

Raw Data

Table B-105: Data Set 26 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.521	3.874	4.082*	4.023	3.715	3.678
		2	4.570	3.908	4.082*	4.080	3.697	3.808
		3	4.630	3.942	4.113*	4.166	3.726	3.785
		Average	4.574	3.908	4.092	4.090	3.713	3.757
	2	1	4.615	3.870	4.029*	4.040	3.720	3.780
		2	4.611	3.935	4.126*	4.011	3.772	3.824
		3	4.574	3.923	4.121*	4.132	3.741	3.849
		Average	4.600	3.909	4.092	4.061	3.744	3.818
	3	1	4.536	3.923	4.055*	4.124	3.841	3.795
		2	4.620	3.983	4.151*	4.145	3.812	3.849
		3	4.626	3.969	4.172*	4.136	3.812	3.866
		Average	4.594	3.958	4.126	4.135	3.822	3.837
	Average		4.589	3.925	4.103	4.075	3.760	3.804
	Standard Deviation		0.0406	0.0381	0.0457	0.0626	0.0515	0.0561
2	1	1	4.503	3.996	4.262*	4.113	3.736	3.751
		2	4.615	4.046	4.318*	4.199	3.766	3.747
		3	4.641	4.052	4.373*	4.121	3.816	3.787
		Average	4.586	4.031	4.318	4.144	3.773	3.762
	2	1	4.549	4.021	4.318*	4.099	3.720	3.755
		2	4.626	4.076	4.360*	4.119	3.784	3.845
		3	4.632	4.078	4.444*	4.189	3.797	3.843
		Average	4.602	4.058	4.374	4.136	3.767	3.814
	3	1	4.538	4.015	4.366*	4.094	3.784	3.739
		2	4.601	4.031	4.402*	4.165	3.893	3.805
		3	4.638	4.055	4.412*	4.126	3.835	3.851
		Average	4.592	4.034	4.393	4.128	3.837	3.798
	Average		4.594	4.041	4.362	4.140	3.792	3.791
	Standard Deviation		0.0507	0.0277	0.0557	0.0426	0.0522	0.0461

* Data excluded from further analysis.

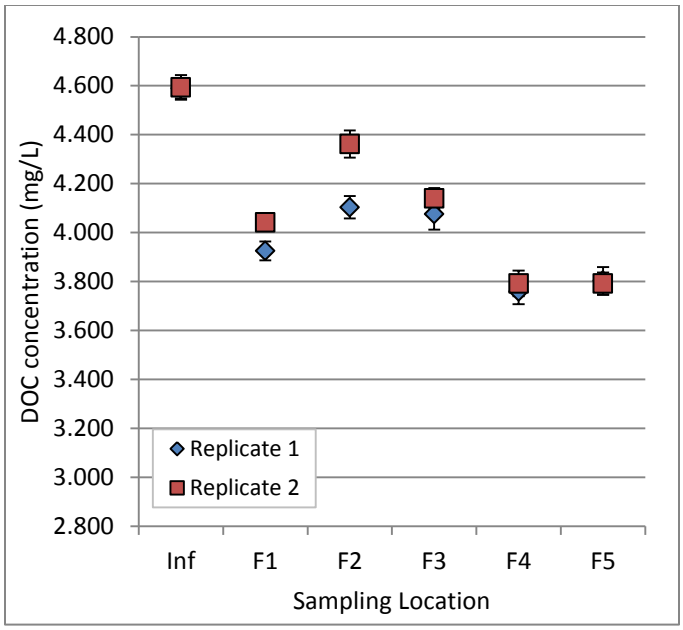

Figure B-104: Data Set 26 plot of average DOC concentrations

List of Excluded Data from Data Set 26, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Data from Filter 2 excluded because readings from bottles containing sample water from the same location were not similar. It was suspected that at least one of the bottles used to collect samples from Filter 2 was contaminated.

ANOVA Results

Table B-106: Data Set 26 ANOVA table for DOC concentration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.644[a]	4	.661	373.042	6.839E-022
Intercept	492.748	1	492.748	278059.930	4.175E-052
filter#	2.644	4	.661	373.042	6.839E-022
Error	.044	25	.002		
Total	495.436	30			
Corrected Total	2.689	29			

a. R Squared = .984 (Adjusted R Squared = .981)

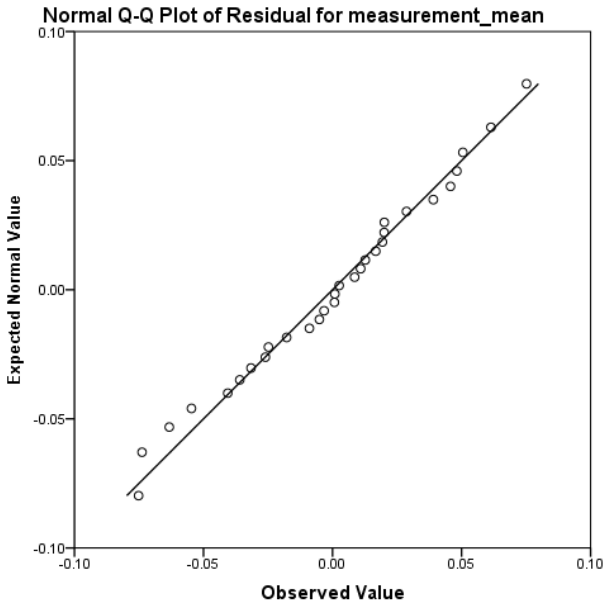

Figure B-105: Data Set 26 normal probability plot of residuals

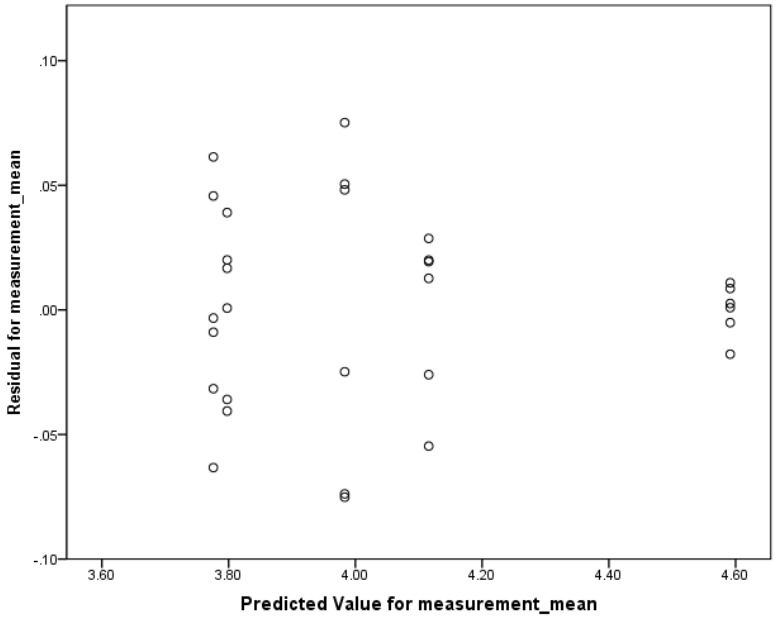

Figure B-106: Data Set 26 plot of residuals versus predicted values

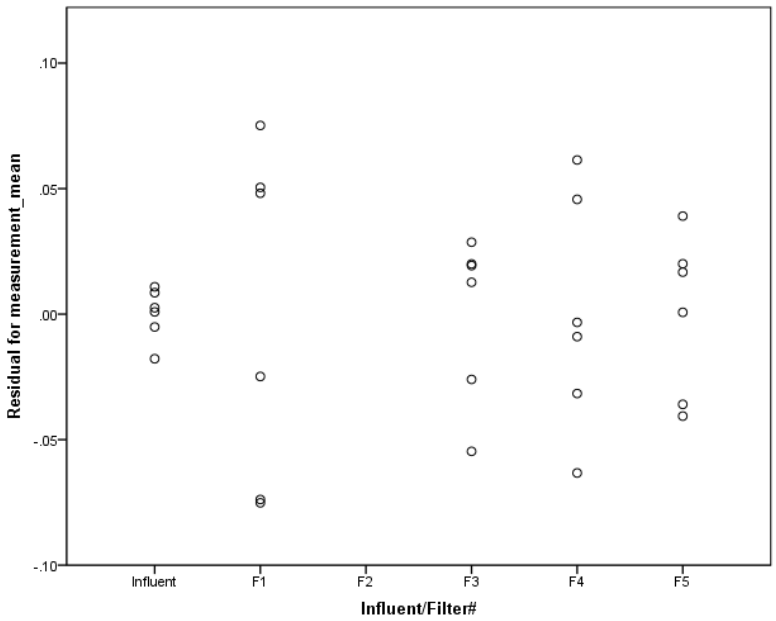

Figure B-107: Data Set 26 plot of residuals versus filter number

Table B-107: Data Set 26 results from Levene's test of equality of variances

F	df1	df2	Sig.
6.354	4	25	1.137E-003

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-108: Data Set 26 multiple comparisons

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	.608*	.0243	9.349E-013	.537	.680
		F3	.476*	.0243	9.355E-013	.404	.547
		F4	.816*	.0243	9.349E-013	.744	.887
		F5	.794*	.0243	9.349E-013	.722	.865
	F1	Influent	-.608*	.0243	9.349E-013	-.680	-.537
		F3	-.132*	.0243	1.055E-004	-.204	-.061
		F4	.207*	.0243	6.890E-008	.136	.279
		F5	.186*	.0243	5.163E-007	.114	.257
	F3	Influent	-.476*	.0243	9.355E-013	-.547	-.404
		F1	.132*	.0243	1.055E-004	.061	.204
		F4	.340*	.0243	3.353E-012	.268	.411
		F5	.318*	.0243	1.150E-011	.247	.389
	F4	Influent	-.816*	.0243	9.349E-013	-.887	-.744
		F1	-.207*	.0243	6.890E-008	-.279	-.136
		F3	-.340*	.0243	3.353E-012	-.411	-.268
		F5	-.022	.0243	8.974E-001	-.093	.050
	F5	Influent	-.794*	.0243	9.349E-013	-.865	-.722
		F1	-.186*	.0243	5.163E-007	-.257	-.114
		F3	-.318*	.0243	1.150E-011	-.389	-.247
		F4	.022	.0243	8.974E-001	-.050	.093
Dunnett T3**	Influent	F1	.608*	.0276	1.664E-005	.492	.725
		F3	.476*	.0141	3.675E-007	.419	.532
		F4	.816*	.0196	3.357E-007	.734	.897
		F5	.794*	.0138	1.313E-008	.739	.849
	F1	Influent	-.608*	.0276	1.664E-005	-.725	-.492
		F3	-.132*	.0304	2.348E-002	-.247	-.018
		F4	.207*	.0333	1.383E-003	.089	.325
		F5	.186*	.0302	3.472E-003	.072	.300
	F3	Influent	-.476*	.0141	3.675E-007	-.532	-.419
		F1	.132*	.0304	2.348E-002	.018	.247
		F4	.340*	.0234	1.396E-006	.257	.423
		F5	.318*	.0188	1.025E-007	.253	.383
	F4	Influent	-.816*	.0196	3.357E-007	-.897	-.734
		F1	-.207*	.0333	1.383E-003	-.325	-.089
		F3	-.340*	.0234	1.396E-006	-.423	-.257
		F5	-.022	.0232	9.736E-001	-.104	.061
	F5	Influent	-.794*	.0138	1.313E-008	-.849	-.739
		F1	-.186*	.0302	3.472E-003	-.300	-.072
		F3	-.318*	.0188	1.025E-007	-.383	-.253
		F4	.022	.0232	9.736E-001	-.061	.104

Based on observed means.
The error term is Mean Square (Error) = .002.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # exhibit some heteroscedasticity in the residuals.
4. Results from Levene's test of equality of variance indicate that the residuals were heteroscedastic.
5. As a result of points 3&4, the residuals and the data were considered to exhibit heteroscedasticity; therefore, results from Dunnett's T3 test were used for multiple comparisons between the filter effluent DOC concentrations.

Data Set 27: Collected June 10, 2013

Raw Data

Table B-109: Data Set 27 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	4.163	3.742	3.901	4.039	3.636	3.765
		2	4.230	3.817	4.009	3.931	3.706	3.811
		3	4.257	3.887	3.907	3.944	3.783	3.799
		Average	4.217	3.815	3.939	3.971	3.708	3.792
	2	1	4.249	3.779	3.964	3.897	3.663	3.722
		2	4.261	3.765	3.940	4.023	3.775	3.791
		3	4.255	3.842	3.933	4.023	3.728	3.736
		Average	4.255	3.795	3.946	3.981	3.722	3.750
	3	1	4.308	3.757	3.952	3.911	3.738	3.838
		2	4.295	3.872	3.923	3.974	3.757	3.846
		3	4.275	3.860	3.992	3.980	3.787	3.858
		Average	4.293	3.830	3.956	3.955	3.761	3.847
	Average		4.255	3.813	3.947	3.969	3.730	3.796
	Standard Deviation		0.0418	0.0544	0.0366	0.0518	0.0534	0.0480
2	1	1	4.180	3.887	4.023	3.817	3.716	3.830
		2	4.222	3.870	4.094	3.876	3.657	3.817
		3	4.239	3.889	4.076	3.852	3.641	3.805
		Average	4.214	3.882	4.064	3.848	3.671	3.817
	2	1	4.180	3.756	3.952	3.858	3.637	3.724
		2	4.338	3.818	4.003	3.877	3.754	3.714
		3	4.261	3.779	4.003	3.844	3.675	3.738
		Average	4.260	3.784	3.986	3.860	3.689	3.725
	3	1	4.365	3.777	3.893	3.785	3.586	3.828
		2	4.501	3.777	3.893	3.818	3.665	3.889
		3	4.503	3.752	3.872	3.864	3.653	3.903
		Average	4.456	3.769	3.886	3.822	3.635	3.873
	Average		4.310	3.812	3.979	3.843	3.665	3.805
	Standard Deviation		0.1258	0.0562	0.0812	0.0309	0.0480	0.0683
3	1	1	4.163	3.718	3.946	3.913	3.818	3.777
		2	4.182	3.836	3.937	3.874	3.840	3.779
		3	4.247	3.846	3.885	3.923	3.815	3.836
		Average	4.197	3.800	3.923	3.903	3.824	3.797
	2	1	4.143	3.726	3.931	3.883	3.628	3.671
		2	4.210	3.777	3.923	3.935	3.667	3.641
		3	4.190	3.789	3.931	3.946	3.728	3.704
		Average	4.181	3.764	3.928	3.921	3.674	3.672
	3	1	4.373	3.820	3.854	4.062	3.63	3.681
		2	4.438	3.807	3.919	4.011	3.657	3.657
		3	4.405	3.795	3.927	4.007	3.693	3.689
		Average	4.405	3.807	3.900	4.027	3.660	3.676
	Average		4.261	3.790	3.917	3.950	3.720	3.715
	Standard Deviation		0.1130	0.0446	0.0291	0.0634	0.0845	0.0664

* Data excluded from further analysis.

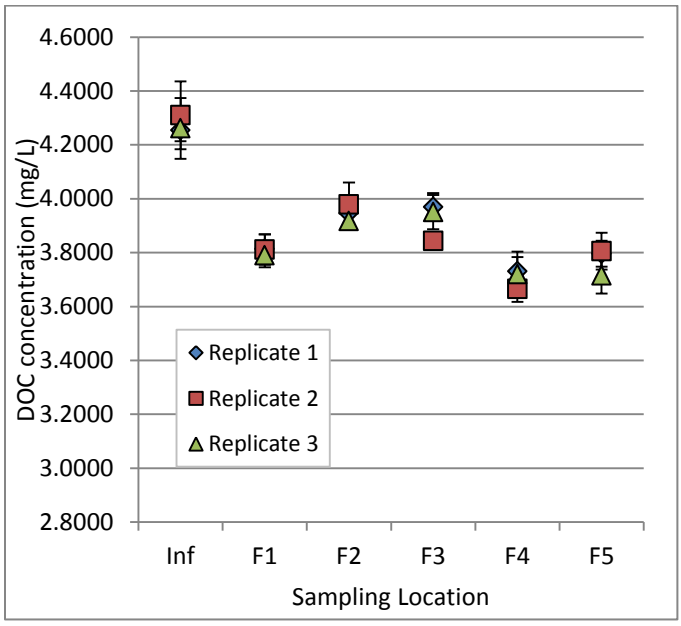

Figure B-108: Data Set 27 plot of average DOC concentrations

List of Excluded Data from Data Set 27, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. Influent, bottle 2, aliquot 3 (top left corner of the probability plot) and Filter 5 effluent, bottle 3, aliquot 2 excluded in the final analysis as potential outliers (see analysis of ANOVA results sections below)

ANOVA Results (All Data Included)

Table B-110: Data Set 27 ANOVA table for DOC concentration (all data included)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.862[a]	5	.372	84.966	1.174E-022
Intercept	823.158	1	823.158	187810.843	6.870E-088
filter#	1.862	5	0.372	84.966	1.174E-022
Error	0.210	48	0.004		
Total	825.231	54			
Corrected Total	2.072	53			

a. R Squared = .898 (Adjusted R Squared = .888)

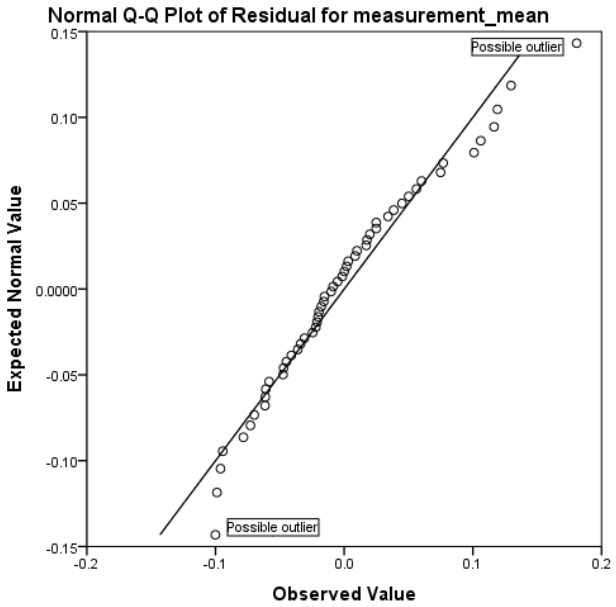

Figure B-109: Data Set 27 normal probability plot of residuals (all data included)

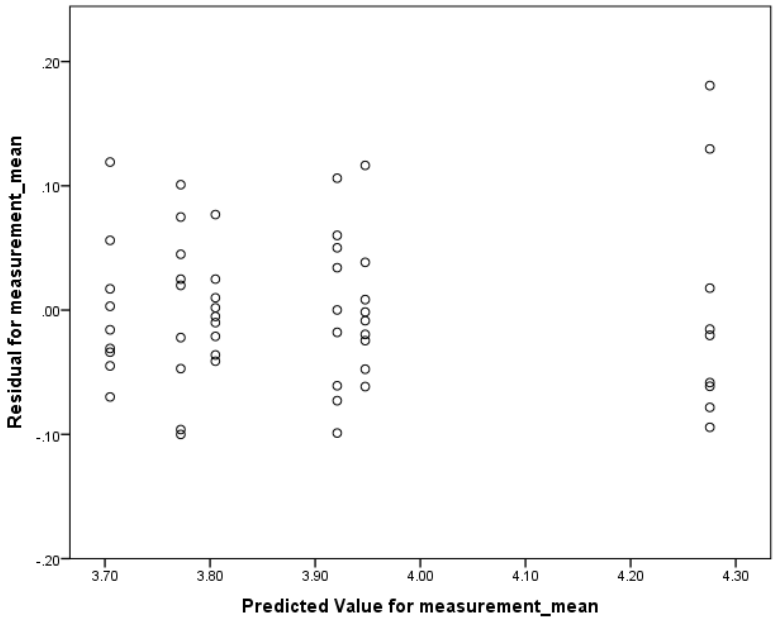

Figure B-110: Data Set 27 plot of residuals versus predicted values (all data included)

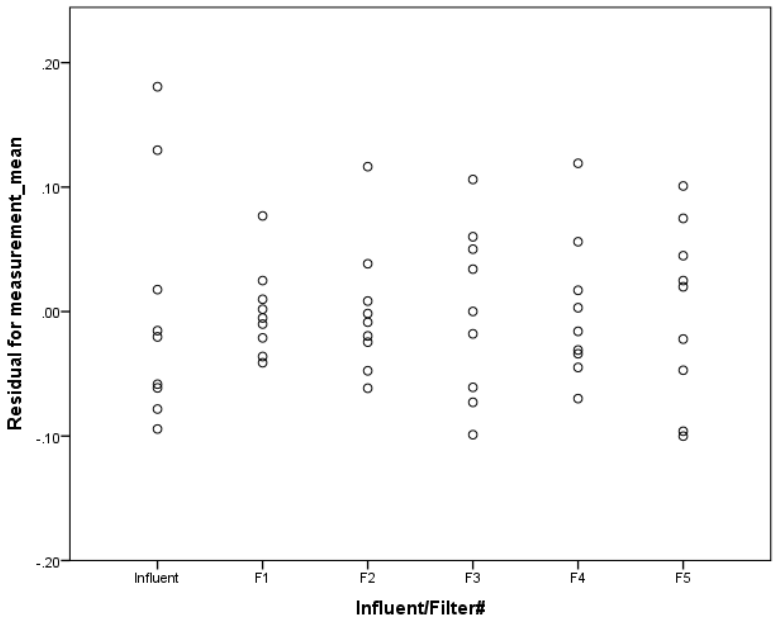

Figure B-111: Data Set 27 plot of residuals versus filter number (all data included)

Table B-111: Data Set 27 results from Levene's test of equality of variances (all data included)

F	df1	df2	Sig.
1.849	5	48	1.212E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-112: Data Set 27 multiple comparisons (all data included)

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.470*	0.0312	6.223E-013	0.378	0.563
		F2	0.328*	0.0312	1.349E-012	0.235	0.420
		F3	0.354*	0.0312	6.687E-013	0.262	0.447
		F4	0.570*	0.0312	6.223E-013	0.478	0.663
		F5	0.503*	0.0312	6.223E-013	0.411	0.596
	F1	Influent	-0.470*	0.0312	6.223E-013	-0.563	-0.378
		F2	-0.142*	0.0312	4.773E-004	-0.235	-0.050
		F3	-0.116*	0.0312	6.735E-003	-0.208	-0.023
		F4	0.100*	0.0312	2.691E-002	0.008	0.193
		F5	0.033	0.0312	8.955E-001	-0.060	0.126
	F2	Influent	-0.328*	0.0312	1.349E-012	-0.420	-0.235
		F1	0.142*	0.0312	4.773E-004	0.050	0.235
		F3	0.027	0.0312	9.553E-001	-0.066	0.119
		F4	0.243*	0.0312	7.125E-009	0.150	0.335
		F5	0.175*	0.0312	1.354E-005	0.083	0.268
	F3	Influent	-0.354*	0.0312	6.687E-013	-0.447	-0.262
		F1	0.116*	0.0312	6.735E-003	0.023	0.208
		F2	-0.027	0.0312	9.553E-001	-0.119	0.066
		F4	0.216*	0.0312	1.427E-007	0.123	0.309
		F5	0.149*	0.0312	2.455E-004	0.056	0.241
	F4	Influent	-0.570*	0.0312	6.223E-013	-0.663	-0.478
		F1	-0.100*	0.0312	2.691E-002	-0.193	-0.008
		F2	-0.243*	0.0312	7.125E-009	-0.335	-0.150
		F3	-0.216*	0.0312	1.427E-007	-0.309	-0.123
		F5	-0.067	0.0312	2.782E-001	-0.160	0.025
	F5	Influent	-0.503*	0.0312	6.223E-013	-0.596	-0.411
		F1	-0.033	0.0312	8.955E-001	-0.126	0.060
		F2	-0.175*	0.0312	1.354E-005	-0.268	-0.083
		F3	-0.149*	0.0312	2.455E-004	-0.241	-0.056
		F4	0.067	0.0312	2.782E-001	-0.025	0.160
Dunnett T3	Influent	F1	0.470*	0.0339	8.249E-007	0.346	0.594
		F2	0.328*	0.0363	1.131E-005	0.200	0.455
		F3	0.354*	0.0391	3.393E-006	0.220	0.488
		F4	0.570*	0.0372	1.221E-008	0.441	0.700
		F5	0.503*	0.0397	3.417E-008	0.368	0.639
	F1	Influent	-0.470*	0.0339	8.249E-007	-0.594	-0.346
		F2	-0.142*	0.0212	1.386E-004	-0.216	-0.069
		F3	-0.116*	0.0258	9.683E-003	-0.207	-0.025
		F4	0.100*	0.0227	8.913E-003	0.021	0.179
		F5	0.033	0.0266	9.494E-001	-0.062	0.128
	F2	Influent	-0.328*	0.0363	1.131E-005	-0.455	-0.200
		F1	0.142*	0.0212	1.386E-004	0.069	0.216
		F3	0.027	0.0288	9.958E-001	-0.072	0.125
		F4	0.243*	0.0261	1.202E-006	0.154	0.331
		F5	0.175*	0.0296	4.266E-004	0.074	0.277
	F3	Influent	-0.354*	0.0391	3.393E-006	-0.488	-0.220
		F1	0.116*	0.0258	9.683E-003	0.025	0.207
		F2	-0.027	0.0288	9.958E-001	-0.125	0.072
		F4	0.216*	0.0299	3.539E-005	0.114	0.318
		F5	0.149*	0.0330	5.048E-003	0.037	0.260
	F4	Influent	-0.570*	0.0372	1.221E-008	-0.700	-0.441
		F1	-0.100*	0.0227	8.913E-003	-0.179	-0.021
		F2	-0.243*	0.0261	1.202E-006	-0.331	-0.154
		F3	-0.216*	0.0299	3.539E-005	-0.318	-0.114
		F5	-0.067	0.0307	4.170E-001	-0.171	0.037
	F5	Influent	-0.503*	0.0397	3.417E-008	-0.639	-0.368
		F1	-0.033	0.0266	9.494E-001	-0.128	0.062
		F2	-0.175*	0.0296	4.266E-004	-0.277	-0.074
		F3	-0.149*	0.0330	5.048E-003	-0.260	-0.037
		F4	0.067	0.0307	4.170E-001	-0.037	0.171

Based on observed means.
*. The mean difference is significant at the .05 level.

Initial Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed. However, there were two points that are potential outliers. These points correspond to Influent, bottle 2, aliquot 3 (top right corner of the probability plot) and Filter 5 effluent, bottle 3, aliquot 2. The analysis was re-done without these data points to see the impact of removing these points on the normality of the residuals and on the final multiple comparison results.

ANOVA Results (Possible Outliers Removed)

Table B-113: Data Set 27 ANOVA table for DOC concentration (possible outlier removed)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.550[a]	5	0.310	87.800	2.305E-022
Intercept	789.553	1	789.553	223663.494	1.858E-086
filter#	1.550	5	0.310	87.800	2.305E-022
Error	.162	46	0.004		
Total	791.891	52			
Corrected Total	1.712	51			

a. R Squared = .905 (Adjusted R Squared = .895)

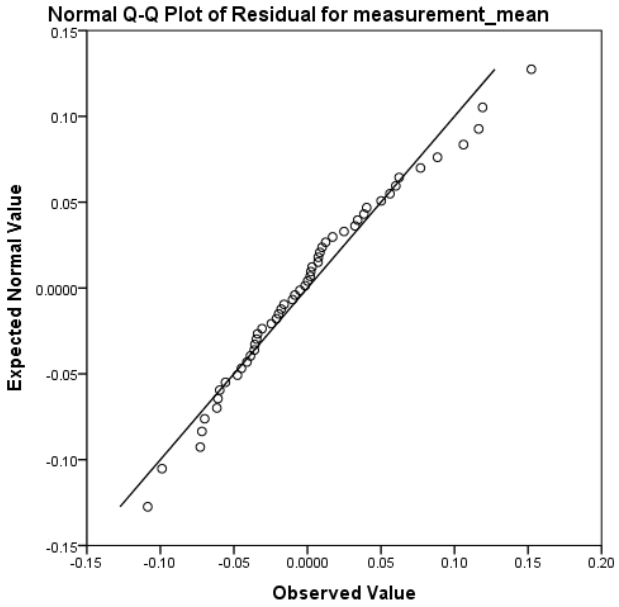

Figure B-112: Data Set 27 normal probability plot of residuals (possible outlier removed)

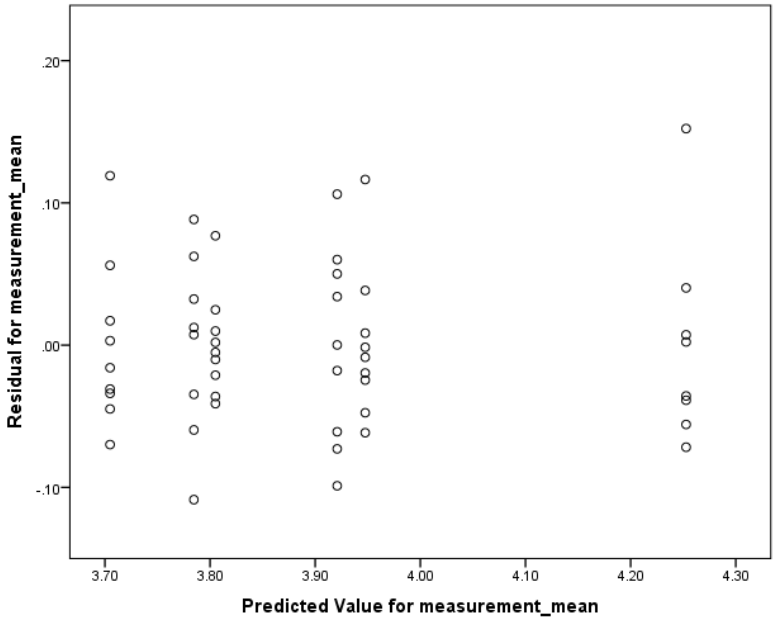

Figure B-113: Data Set 27 plot of residuals versus predicted values (possible outlier removed)

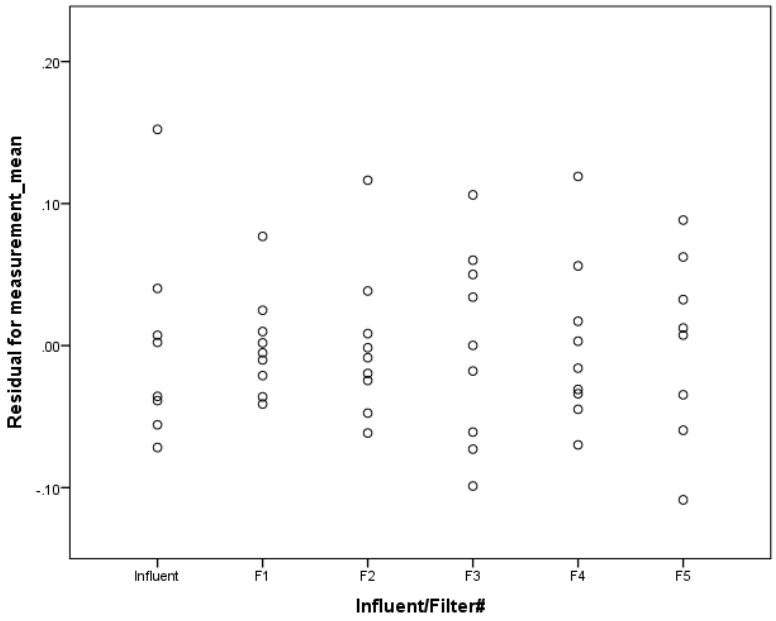

Figure B-114: Data Set 27 plot of residuals versus filter number (possible outlier removed)

Table B-114: Data Set 27 results from Levene's test of equality of variances (possible outlier removed)

F	df1	df2	Sig.
.876	5	46	5.046E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-115: Data Set 27 multiple comparisons (possible outlier removed)

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.448*	0.0289	6.338E-013	0.362	0.533
		F2	0.305*	0.0289	1.637E-012	0.219	0.391
		F3	0.332*	0.0289	6.902E-013	0.246	0.418
		F4	0.548*	0.0289	6.338E-013	0.462	0.634
		F5	0.468*	0.0297	6.338E-013	0.380	0.556
	F1	Influent	-0.448*	0.0289	6.338E-013	-0.533	-0.362
		F2	-0.142*	0.0280	9.240E-005	-0.226	-0.059
		F3	-0.116*	0.0280	1.963E-003	-0.199	-0.033
		F4	0.100*	0.0280	1.011E-002	0.017	0.183
		F5	0.020	0.0289	9.798E-001	-0.065	0.106
	F2	Influent	-0.305*	0.0289	1.637E-012	-0.391	-0.219
		F1	0.142*	0.0280	9.240E-005	0.059	0.226
		F3	0.027	0.0280	9.304E-001	-0.057	0.110
		F4	0.243*	0.0280	4.704E-010	0.159	0.326
		F5	0.163*	0.0289	1.414E-005	0.077	0.249
	F3	Influent	-0.332*	0.0289	6.902E-013	-0.418	-0.246
		F1	0.116*	0.0280	1.963E-003	0.033	0.199
		F2	-0.027	0.0280	9.304E-001	-0.110	0.057
		F4	0.216*	0.0280	1.165E-008	0.133	0.299
		F5	0.136*	0.0289	3.076E-004	0.050	0.222
	F4	Influent	-0.548*	0.0289	6.338E-013	-0.634	-0.462
		F1	-0.100*	0.0280	1.011E-002	-0.183	-0.017
		F2	-0.243*	0.0280	4.704E-010	-0.326	-0.159
		F3	-0.216*	0.0280	1.165E-008	-0.299	-0.133
		F5	-0.080	0.0289	8.237E-002	-0.166	0.006
	F5	Influent	-0.468*	0.0297	6.338E-013	-0.556	-0.380
		F1	-0.020	0.0289	9.798E-001	-0.106	0.065
		F2	-0.163*	0.0289	1.414E-005	-0.249	-0.077
		F3	-0.136*	0.0289	3.076E-004	-0.222	-0.050
		F4	0.080	0.0289	8.237E-002	-0.006	0.166
Dunnett T3	Influent	F1	0.448*	0.0280	2.556E-007	0.345	0.550
		F2	0.305*	0.0308	3.366E-006	0.197	0.413
		F3	0.332*	0.0341	1.345E-006	0.215	0.449
		F4	0.548*	0.0319	2.050E-009	0.437	0.658
		F5	0.468*	0.0342	2.771E-008	0.350	0.586
	F1	Influent	-0.448*	0.0280	2.556E-007	-0.550	-0.345
		F2	-0.142*	0.0212	1.386E-004	-0.216	-0.069
		F3	-0.116*	0.0258	9.683E-003	-0.207	-0.025
		F4	0.100*	0.0227	8.913E-003	0.021	0.179
		F5	0.020	0.0259	9.987E-001	-0.073	0.114
	F2	Influent	-0.305*	0.0308	3.366E-006	-0.413	-0.197
		F1	0.142*	0.0212	1.386E-004	0.069	0.216
		F3	0.027	0.0288	9.958E-001	-0.072	0.125
		F4	0.243*	0.0261	1.202E-006	0.154	0.331
		F5	0.163*	0.0289	9.787E-004	0.063	0.263
	F3	Influent	-0.332*	0.0341	1.345E-006	-0.449	-0.215
		F1	0.116*	0.0258	9.683E-003	0.025	0.207
		F2	-0.027	0.0288	9.958E-001	-0.125	0.072
		F4	0.216*	0.0299	3.539E-005	0.114	0.318
		F5	0.136*	0.0324	1.058E-002	0.026	0.247
	F4	Influent	-0.548*	0.0319	2.050E-009	-0.658	-0.437
		F1	-0.100*	0.0227	8.913E-003	-0.179	-0.021
		F2	-0.243*	0.0261	1.202E-006	-0.331	-0.154
		F3	-0.216*	0.0299	3.539E-005	-0.318	-0.114
		F5	-0.080	0.0300	2.051E-001	-0.183	0.023
	F5	Influent	-0.468*	0.0342	2.771E-008	-0.586	-0.350
		F1	-0.020	0.0259	9.987E-001	-0.114	0.073
		F2	-0.163*	0.0289	9.787E-004	-0.263	-0.063
		F3	-0.136*	0.0324	1.058E-002	-0.247	-0.026
		F4	0.080	0.0300	2.051E-001	-0.023	0.183

Based on observed means.

*. The mean difference is significant at the .05 level.

**Results from this test used for multiple comparisons

Continued Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were relatively normally distributed. Removing the two potential outliers resulted in residuals that appeared more normally distributed than when the two data points were included; therefore, data from the analysis with the two potential outliers removed was used.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.
6. At a significance level of 0.05, conclusions drawn from the multiple comparisons were the same regardless of whether or not the two potential outliers are included or excluded; therefore conclusions taken from this analysis can be considered valid regardless of whether the two potential outliers are included or excluded from the data set.

Data Set 28: Collected June 14, 2013

Raw Data

Table B-116: Data Set 28 DOC measurements

Bottle	Aliquot	Measurement	DOC concentration at location (mg/L)					
			Influent	Filter 1 Effluent	Filter 2 Effluent	Filter 3 Effluent	Filter 4 Effluent	Filter 5 Effluent
1	1	1	3.957	3.535	3.789	3.795	3.470	3.541
		2	4.122	3.585	3.715	3.719	3.520	3.594
		3	4.044	3.520	3.838	3.780	3.585	3.648
		Average	4.040	3.560	3.752	3.757	3.495	3.568
	2	1	4.012	3.522	3.771	3.827	3.552	3.526
		2	4.120	3.607	3.847	3.849	3.600	3.613
		3	4.139	3.522	3.773	3.780	3.641	3.628
		Average	4.059	3.550	3.819	3.819	3.579	3.596
	3	1	4.109	3.476	3.83	3.828	3.609	3.594
		2	4.038	3.580	3.875	3.856	3.626	3.685
		3	4.167	3.609	3.828	3.801	3.615	3.645
		Average	4.095	3.526	3.826	3.821	3.625	3.636
	Average		4.079	3.551	3.807	3.804	3.580	3.608
	Standard Deviation		0.0690	0.0461	0.0492	0.0423	0.0557	0.0511
2	1	1	3.953	3.554	3.799	3.750	3.680	3.585
		2	4.001	3.646	3.862	3.797	3.728	3.659
		3	4.126	3.641	3.838	3.825	3.587	3.665
		Average	3.977	3.600	3.831	3.774	3.704	3.622
	2	1	4.135	3.615	3.858	3.838	3.583	3.568
		2	4.116	3.645	3.944	3.711	3.684	3.619
		3	4.142	3.607	3.962	3.821	3.593	3.611
		Average	4.126	3.634	3.880	3.791	3.618	3.617
	3	1	4.163	3.533	3.899	3.786	3.509	3.574
		2	4.141	3.637	3.908	3.812	3.619	3.609
		3	4.217	3.576	3.921	3.830	3.637	3.685
		Average	4.149	3.592	3.923	3.806	3.574	3.598
	Average		4.110	3.606	3.888	3.797	3.624	3.619
	Standard Deviation		0.0819	0.0423	0.0527	0.0420	0.0661	0.0419
3	1	1	4.116	3.528	3.793	3.695	3.585	3.633
		2	4.131	3.613	3.892	3.812	3.613	3.680
		3	4.196	3.630	3.882	3.834	3.630	3.676
		Average	4.124	3.571	3.843	3.754	3.599	3.657
	2	1	4.332	3.620	3.866	3.827	3.606	3.658
		2	4.185	3.724	3.864	3.855	3.626	3.639
		3	4.241	3.622	3.769	3.888	3.606	3.685
		Average	4.238	3.658	3.871	3.839	3.621	3.658
	3	1	4.399	3.648	3.76	3.89	3.667	3.570
		2	4.423	3.702	3.864	3.879	3.741	3.672
		3	4.328	3.661	3.860	3.895	3.710	3.63
		Average	4.354	3.657	3.798	3.886	3.671	3.642
	Average		4.261	3.639	3.839	3.842	3.643	3.649
	Standard Deviation		0.1135	0.0564	0.0504	0.0628	0.0526	0.0363

* Data excluded from further analysis.

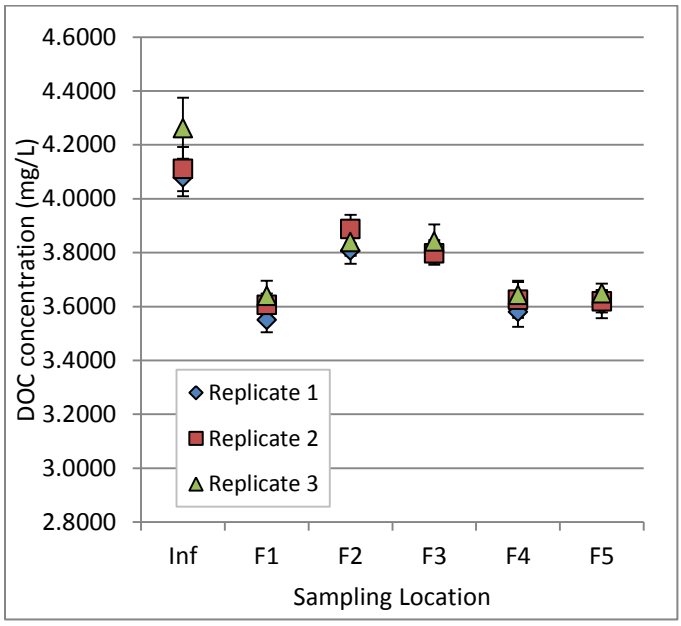

Figure B-115: Data Set 28 plot of average DOC concentrations

List of Excluded Data from Data Set 28, Reasons for Exclusions, and Other Notes Related to the Raw Data:

1. No data excluded

ANOVA Results (All Data Included)

Table B-117: Data Set 28 ANOVA table for DOC concentration (all data included)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.921[a]	5	0.384	98.229	5.133E-024
Intercept	765.989	1	765.989	195851.634	2.512E-088
filter#	1.921	5	0.384	98.229	5.133E-024
Error	0.188	48	0.004		
Total	768.098	54			
Corrected Total	2.109	53			

a. R Squared = .911 (Adjusted R Squared = .902)

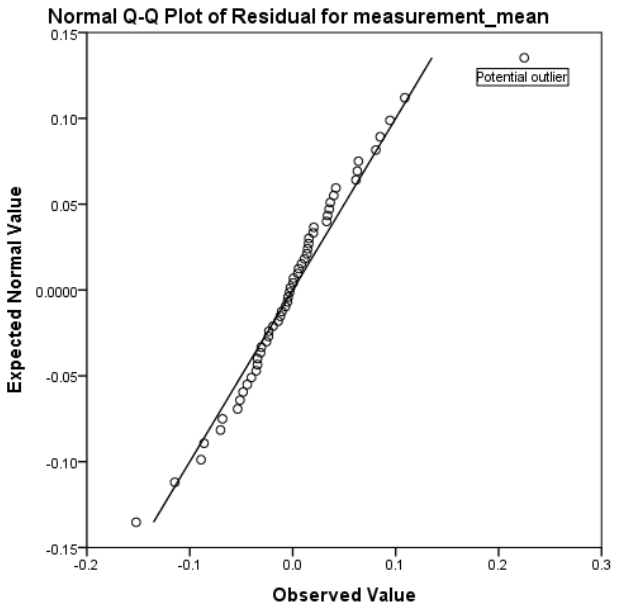

Figure B-116: Data Set 28 normal probability plot of residuals (all data included)

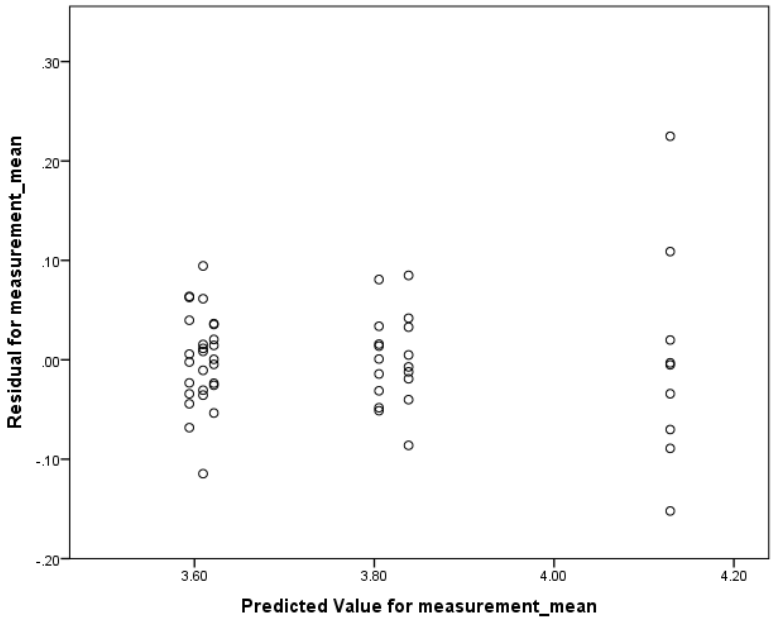

Figure B-117: Data Set 28 plot of residuals versus predicted values (all data included)

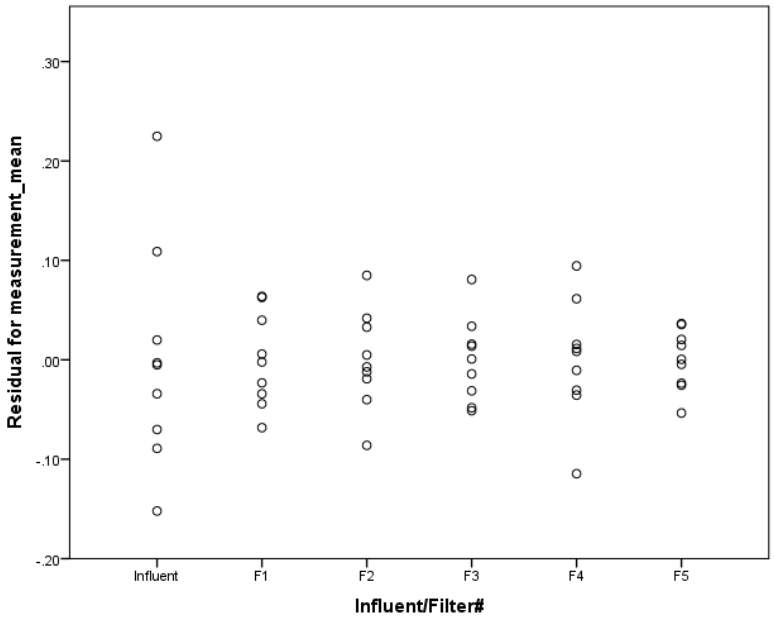

Figure B-118: Data Set 28 plot of residuals versus filter number (all data included)

Table B-118: Data Set 28 results from Levene's test of equality of variances (all data included)

F	df1	df2	Sig.
2.050	5	48	8.829E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-119: Data Set 28 multiple comparisons (all data included)

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Influent	F1	0.535*	0.0295	6.223E-013	0.447	0.622
		F2	0.291*	0.0295	6.359E-012	0.204	0.378
		F3	0.324*	0.0295	7.750E-013	0.236	0.411
		F4	0.520*	0.0295	6.223E-013	0.432	0.607
		F5	0.508*	0.0295	6.223E-013	0.420	0.595
	F1	Influent	-0.535*	0.0295	6.223E-013	-0.622	-0.447
		F2	-0.244*	0.0295	1.269E-009	-0.331	-0.156
		F3	-0.211*	0.0295	6.221E-008	-0.298	-0.124
		F4	-0.015	0.0295	9.951E-001	-0.103	0.072
		F5	-0.027	0.0295	9.375E-001	-0.115	0.060
	F2	Influent	-0.291*	0.0295	6.359E-012	-0.378	-0.204
		F1	0.244*	0.0295	1.269E-009	0.156	0.331
		F3	0.033	0.0295	8.725E-001	-0.055	0.120
		F4	0.229*	0.0295	7.720E-009	0.141	0.316
		F5	0.217*	0.0295	3.209E-008	0.129	0.304
	F3	Influent	-0.324*	0.0295	7.750E-013	-0.411	-0.236
		F1	0.211*	0.0295	6.221E-008	0.124	0.298
		F2	-0.033	0.0295	8.725E-001	-0.120	0.055
		F4	0.196*	0.0295	3.880E-007	0.108	0.283
		F5	0.184*	0.0295	1.623E-006	0.096	0.271
	F4	Influent	-0.520*	0.0295	6.223E-013	-0.607	-0.432
		F1	0.015	0.0295	9.951E-001	-0.072	0.103
		F2	-0.229*	0.0295	7.720E-009	-0.316	-0.141
		F3	-0.196*	0.0295	3.880E-007	-0.283	-0.108
		F5	-0.012	0.0295	9.985E-001	-0.099	0.075
	F5	Influent	-0.508*	0.0295	6.223E-013	-0.595	-0.420
		F1	0.027	0.0295	9.375E-001	-0.060	0.115
		F2	-0.217*	0.0295	3.209E-008	-0.304	-0.129
		F3	-0.184*	0.0295	1.623E-006	-0.271	-0.096
		F4	0.012	0.0295	9.985E-001	-0.075	0.099
Dunnett T3	Influent	F1	0.535*	0.0405	7.454E-007	0.388	0.681
		F2	0.291*	0.0408	2.570E-004	0.144	0.438
		F3	0.324*	0.0398	1.200E-004	0.178	0.470
		F4	0.520*	0.0423	4.347E-007	0.370	0.669
		F5	0.508*	0.0386	3.952E-006	0.363	0.652
	F1	Influent	-0.535*	0.0405	7.454E-007	-0.681	-0.388
		F2	-0.244*	0.0229	1.663E-007	-0.321	-0.167
		F3	-0.211*	0.0211	4.709E-007	-0.283	-0.139
		F4	-0.015	0.0254	1.000E+000	-0.102	0.071
		F5	-0.027	0.0187	8.719E-001	-0.092	0.038
	F2	Influent	-0.291*	0.0408	2.570E-004	-0.438	-0.144
		F1	0.244*	0.0229	1.663E-007	0.167	0.321
		F3	0.033	0.0217	8.469E-001	-0.041	0.106
		F4	0.229*	0.0259	2.876E-006	0.141	0.316
		F5	0.217*	0.0194	5.862E-007	0.149	0.284
	F3	Influent	-0.324*	0.0398	1.200E-004	-0.470	-0.178
		F1	0.211*	0.0211	4.709E-007	0.139	0.283
		F2	-0.033	0.0217	8.469E-001	-0.106	0.041
		F4	0.196*	0.0244	1.596E-005	0.112	0.279
		F5	0.184*	0.0173	4.600E-007	0.124	0.243
	F4	Influent	-0.520*	0.0423	4.347E-007	-0.669	-0.370
		F1	0.015	0.0254	1.000E+000	-0.071	0.102
		F2	-0.229*	0.0259	2.876E-006	-0.316	-0.141
		F3	-0.196*	0.0244	1.596E-005	-0.279	-0.112
		F5	-0.012	0.0223	1.000E+000	-0.091	0.067
	F5	Influent	-0.508*	0.0386	3.952E-006	-0.652	-0.363
		F1	0.027	0.0187	8.719E-001	-0.038	0.092
		F2	-0.217*	0.0194	5.862E-007	-0.284	-0.149
		F3	-0.184*	0.0173	4.600E-007	-0.243	-0.124
		F4	0.012	0.0223	1.000E+000	-0.067	0.091

Based on observed means.
The error term is Mean Square (Error) = .004.
*. The mean difference is significant at the .05 level.

Initial Brief Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicates that the residuals were relatively normally distributed. However, there was one point that was a potential outlier. This point corresponds to Influent, bottle 3, aliquot 3 (top right corner of the probability plot). The analysis was re-done without this data point to see how it impacted the normality of the residuals and the multiple comparison results.

ANOVA Results (Potential Outliers Excluded)

Table B-120: Data Set 28 ANOVA table for DOC concentration (potential outliers excluded)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.626[a]	5	0.325	116.815	2.575E-025
Intercept	748.491	1	748.491	268882.458	5.773E-090
filter#	1.626	5	0.325	116.815	2.575E-025
Error	0.131	47	0.003		
Total	749.141	53			
Corrected Total	1.757	52			

a. R Squared = .926 (Adjusted R Squared = .918)

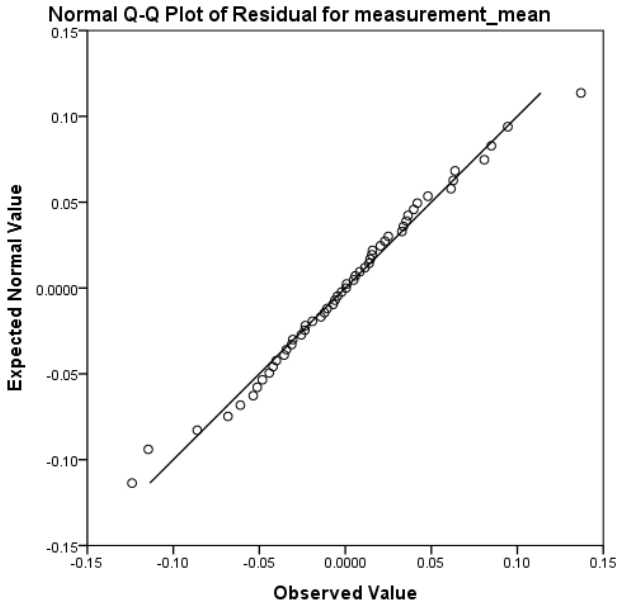

Figure B-119: Data Set 28 normal probability plot of residuals (potential outliers excluded)

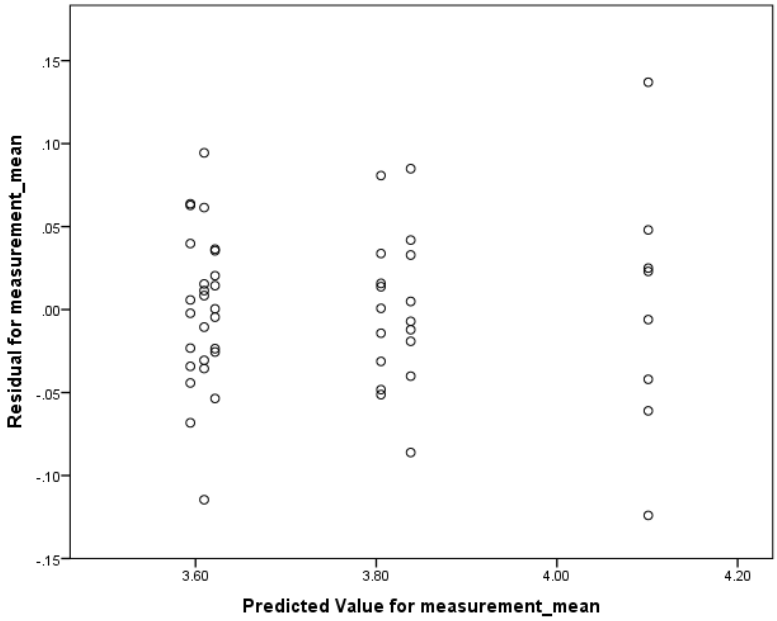

Figure B-120: Data Set 28 plot of residuals versus predicted values (potential outliers excluded)

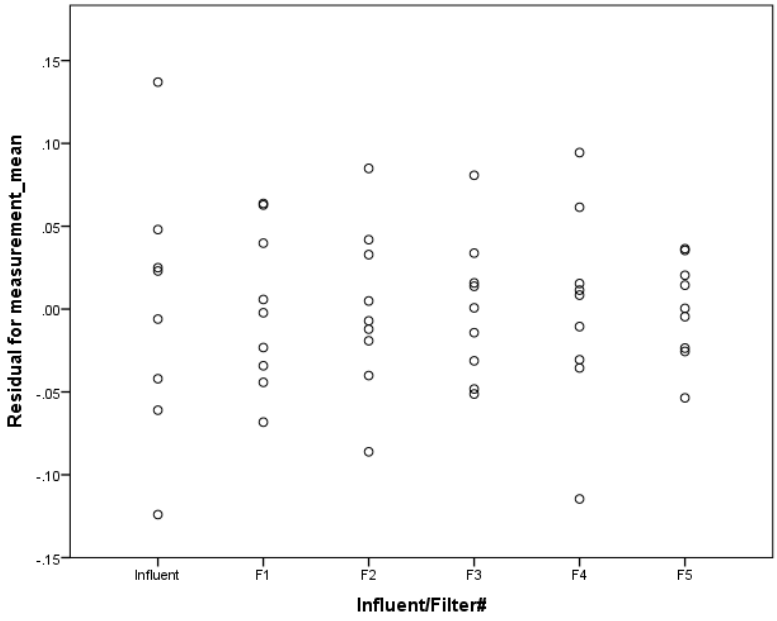

Figure B-121: Data Set 28 plot of residuals versus filter number (potential outliers excluded)

Table B-121: Data Set 28 results from Levene's test of equality of variances (potential outliers excluded)

F	df1	df2	Sig.
1.099	5	47	3.735E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table B-122: Data Set 28 multiple comparisons (potential outliers excluded)

Test	(I) Influent/Filter#	(J) Influent/Filter#	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD**	Influent	F1	0.507*	0.0256	6.521E-013	0.431	0.583
		F2	0.263*	0.0256	2.739E-012	0.187	0.339
		F3	0.296*	0.0256	6.877E-013	0.220	0.372
		F4	0.491*	0.0256	6.521E-013	0.415	0.568
		F5	0.479*	0.0256	6.521E-013	0.403	0.556
	F1	Influent	-0.507*	0.0256	6.521E-013	-0.583	-0.431
		F2	-0.244*	0.0249	9.558E-012	-0.318	-0.170
		F3	-0.211*	0.0249	7.250E-010	-0.285	-0.137
		F4	-0.015	0.0249	9.893E-001	-0.089	0.059
		F5	-0.027	0.0249	8.793E-001	-0.101	0.047
	F2	Influent	-0.263*	0.0256	2.739E-012	-0.339	-0.187
		F1	0.244*	0.0249	9.558E-012	0.170	0.318
		F3	0.033	0.0249	7.713E-001	-0.041	0.107
		F4	0.229*	0.0249	6.837E-011	0.155	0.302
		F5	0.217*	0.0249	3.411E-010	0.143	0.290
	F3	Influent	-0.296*	0.0256	6.877E-013	-0.372	-0.220
		F1	0.211*	0.0249	7.250E-010	0.137	0.285
		F2	-0.033	0.0249	7.713E-001	-0.107	0.041
		F4	0.196*	0.0249	5.956E-009	0.122	0.270
		F5	0.184*	0.0249	3.155E-008	0.110	0.258
	F4	Influent	-0.491*	0.0256	6.521E-013	-0.568	-0.415
		F1	0.015	0.0249	9.893E-001	-0.059	0.089
		F2	-0.229*	0.0249	6.837E-011	-0.302	-0.155
		F3	-0.196*	0.0249	5.956E-009	-0.270	-0.122
		F5	-0.012	0.0249	9.966E-001	-0.086	0.062
	F5	Influent	-0.479*	0.0256	6.521E-013	-0.556	-0.403
		F1	0.027	0.0249	8.793E-001	-0.047	0.101
		F2	-0.217*	0.0249	3.411E-010	-0.290	-0.143
		F3	-0.184*	0.0249	3.155E-008	-0.258	-0.110
		F4	0.012	0.0249	9.966E-001	-0.062	0.086
Dunnett T3	Influent	F1	0.507*	0.0319	6.789E-008	0.392	0.621
		F2	0.263*	0.0323	5.591E-005	0.148	0.378
		F3	0.296*	0.0311	2.483E-005	0.183	0.409
		F4	0.491*	0.0342	3.215E-008	0.372	0.611
		F5	0.479*	0.0295	9.250E-007	0.368	0.591
	F1	Influent	-0.507*	0.0319	6.789E-008	-0.621	-0.392
		F2	-0.244*	0.0229	1.663E-007	-0.321	-0.167
		F3	-0.211*	0.0211	4.709E-007	-0.283	-0.139
		F4	-0.015	0.0254	1.000E+000	-0.102	0.071
		F5	-0.027	0.0187	8.719E-001	-0.092	0.038
	F2	Influent	-0.263*	0.0323	5.591E-005	-0.378	-0.148
		F1	0.244*	0.0229	1.663E-007	0.167	0.321
		F3	0.033	0.0217	8.469E-001	-0.041	0.106
		F4	0.229*	0.0259	2.876E-006	0.141	0.316
		F5	0.217*	0.0194	5.862E-007	0.149	0.284
	F3	Influent	-0.296*	0.0311	2.483E-005	-0.409	-0.183
		F1	0.211*	0.0211	4.709E-007	0.139	0.283
		F2	-0.033	0.0217	8.469E-001	-0.106	0.041
		F4	0.196*	0.0244	1.596E-005	0.112	0.279
		F5	0.184*	0.0173	4.600E-007	0.124	0.243
	F4	Influent	-0.491*	0.0342	3.215E-008	-0.611	-0.372
		F1	0.015	0.0254	1.000E+000	-0.071	0.102
		F2	-0.229*	0.0259	2.876E-006	-0.316	-0.141
		F3	-0.196*	0.0244	1.596E-005	-0.279	-0.112
		F5	-0.012	0.0223	1.000E+000	-0.091	0.067
	F5	Influent	-0.479*	0.0295	9.250E-007	-0.591	-0.368
		F1	0.027	0.0187	8.719E-001	-0.038	0.092
		F2	-0.217*	0.0194	5.862E-007	-0.284	-0.149
		F3	-0.184*	0.0173	4.600E-007	-0.243	-0.124
		F4	0.012	0.0223	1.000E+000	-0.067	0.091

Based on observed means.
*. The mean difference is significant at the .05 level.
**Results from this test used for multiple comparisons

Continued Analysis of ANOVA Results:

1. Filter # (i.e. influent and media type) was a factor that had a statistically significant impact on DOC concentration.
2. The normal probability plot of residuals indicated that the residuals were relatively normally distributed. The potential outlier was not from the same normal distribution as the other data points; therefore, the analysis with the potential outlier removed was used.
3. The plots of residuals versus the predicted values and residuals versus influent/filter # indicate that the residuals were not heteroscedastic.
4. Results from Levene's test of equality of variance do not indicate heteroscedasticity.
5. As a result of points 3&4, the data were considered to not exhibit heteroscedasticity; therefore, results from Tukey's HSD were used for multiple comparisons between the filter effluent DOC concentrations.
6. At a significance level of 0.05, conclusions drawn from the multiple comparisons were the same regardless of whether the potential outlier was included or excluded; therefore conclusions taken from this analysis can be considered valid regardless of whether the potential outlier is included or excluded from the data set.

Sign Test Raw Results

Table B-123: Results from sign tests

		Category	N	Observed Proportion	Test Proportion	Exact Sig. (2-tailed)
1=Coal-based GAC has a lower effluent DOC concentration than anthracite; -1=Anthracite has a lower effluent DOC concentration than coal-based GAC	Group 1	<= 0	0	0.00	0.50	1.221E-004
	Group 2	> 0	14	1.00		
	Total		14	1.00		
1=Coal-based GAC has a lower effluent DOC concentration than REC; -1=REC has a lower effluent DOC concentration than coal-based GAC	Group 1	<= 0	0	0.00	0.50	6.104E-005
	Group 2	> 0	15	1.00		
	Total		15	1.00		
1=Coal-based GAC has a lower effluent DOC concentration than wood-based GAC; -1=Wood-based GAC has a lower effluent DOC concentration than coal-based GAC	Group 1	<= 0	13	1.00	0.50	2.441E-004
	Total		13	1.00		
1=Wood-based GAC has a lower effluent DOC concentration than anthracite; -1=Anthracite has a lower effluent DOC concentration than wood-based GAC	Group 1	<= 0	0	0.00	0.50	3.815E-006
	Group 2	> 0	19	1.00		
	Total		19	1.00		
1=Wood-based GAC has a lower effluent DOC concentration than REC; -1=REC has a lower effluent DOC concentration than wood-based GAC	Group 1	<= 0	0	0.00	0.50	4.768E-007
	Group 2	> 0	22	1.00		
	Total		22	1.00		
1=Coal-based GAC (declining rate) has a lower effluent DOC concentration than coal-based GAC (constant rate); -1=Coal-based GAC (constant rate) has a lower effluent DOC concentration than coal-based GAC (declining rate)	Group 1	<= 0	0	0.00	0.50	7.813E-003
	Group 2	> 0	8	1.00		
	Total		8	1.00		

		Category	N	Observed Proportion	Test Proportion	Exact Sig. (2-tailed)
1=Coal-based GAC (declining rate) has a lower effluent DOC concentration than wood-based GAC (constant rate); -1=Wood-based GAC (constant rate) has a lower effluent DOC concentration than coal-based GAC (declining rate)	Group 1	<= 0	6	0.86	0.50	1.250E-001
	Group 2	> 0	1	0.14		
	Total		7	1.00		
1=Coal-based GAC (declining rate) has a lower effluent DOC concentration than anthracite (constant rate); -1=Anthracite (constant rate) has a lower effluent DOC concentration than coal-based GAC (declining rate)	Group 1	<= 0	0	0.00	0.50	6.104E-005
	Group 2	> 0	15	1.00		
	Total		15	1.00		
1=Coal-based GAC (declining rate) has a lower effluent DOC concentration than REC (constant rate); -1=REC (constant rate) has a lower effluent DOC concentration than coal-based GAC (declining rate)	Group 1	<= 0	0	0.00	0.50	7.629E-006
	Group 2	> 0	18	1.00		
	Total		18	1.00		

Appendix C
AOC Data

Contents

This Appendix contains raw data and summarized data from each sampling event. The appendix also contains results from statistical analysis of the AOC data.

Structure of the Appendix

The appendix is arranged into separate sections for each sampling date. Each section is subdivided into up to three subsections: "Raw and Summarized AOC Results", "Boxplots to Determine Which of the Counts in the Range of 30 to 300 Should Be Used", and "Summary of Results and Calculated Values from Statistical Tests".

The "Raw and Summarized AOC Results" subsection contains plate count data, calculated AOC values, and growth control data for all samples, in tabular format.

The boxplot subsection is provided for only select data sets. In some cases, more than one plate count in the range of 30-300 was observed for a given vial; in these cases, boxplots of the estimated counts (i.e. the final count taking into account the dilution factor and volume plated) were used to determine which plate count to use. Plate counts that were identified as outliers in the boxplots were excluded from consideration. If neither plate count was an outlier, then the higher of the two plate counts was used.

The "Summary of Results and Calculated Values from Statistical Tests" contains the results from Kruskal-Wallis and Mann-Whitney tests on the AOC data. Histograms of the total AOC concentrations in each sample are also provided.

Figure C-1 shows a labelled example AOC data table. Table C-2 provides a summary of plate count codes used in the AOC data tables. Finally, Table C-3 presents select calculations that were used when calculating data presented in the AOC tables.

The reader is referred to the Materials and Methods section of the main thesis for more information on the materials and methods that were used.

P-17 AOC in each vial.

Estimated P-17 count in each vial

Sample date and location

Estimated NOX count in each vial

NOX AOC in each vial

Sum of P-17 and NOX AOC from a given vial

P-17 Plate counts

Summary statistics for select columns

Growth control data

Sum of the average P-17 and NOX AOC (from P-17 and NOX enumeration sections)

March 21, 2012 Filter 1	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
sample dilutions:	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
volume plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 1-1-1	TNTC	89	8	8.90E+05	217.16	TNTC	87	10	8.70E+05	300.15	517.31	
Vial 1-1-2	TNTC	43	3	4.30E+05	104.92	TNTC	107	9	1.07E+06	369.15	474.07	
Vial 1-1-3	TNTC	54	4	5.40E+05	131.76	TNTC	122	13	1.22E+06	420.90	552.66	
Vial 1-1-4	TNTC	65	2	6.50E+05	158.60	TNTC	72	10	7.20E+05	248.40	407.00	
Vial 1-1-5	TNTC	80	9	8.00E+05	195.20	TNTC	97	17	9.70E+05	334.65	529.85	
Vial 1-1-6	TNTC	57	5	5.70E+05	139.08	TNTC	66	8	6.60E+05	227.70	366.78	
Vial 1-1-7	TNTC	104	9	1.04E+06	253.76	TNTC	109	9	1.09E+06	376.05	629.81	
Vial 1-1-8	TNTC	54	7	5.40E+05	131.76	TNTC	87	17	8.70E+05	300.15	431.91	
Vial 1-1-9	TNTC	93	11	9.30E+05	226.92	TNTC	81	4	8.10E+05	279.45	506.37	
Vial 1-1-11	TNTC	73	6	7.30E+05	178.12	TNTC	109	6	1.09E+06	376.05	554.17	
Vial 1-1-12	TNTC	90	9	9.00E+05	219.60	TNTC	105	19	1.05E+06	362.25	581.85	
Vial 1-1-13	TNTC	88	17	8.80E+05	214.72	TNTC	93	16	9.30E+05	320.85	535.57	
Vial 1-1-14	TNTC	81	10	8.10E+05	197.64	TNTC	95	18	9.50E+05	327.75	525.39	
Vial 1-1-15	TNTC	76	4	7.60E+05	185.44	TNTC	102	15	1.02E+06	351.90	537.34	
Vial 1-1-16	TNTC	67	8	6.70E+05	163.48	TNTC	86	10	8.60E+05	296.70	460.18	
Average				7.43E+05	181.21				9.45E+05	326.14	507.35	507.35
Median				7.60E+05	185.44				9.50E+05	327.75	525.39	
St. Dev.				1.73E+05	42.30				1.51E+05	52.11	68.80	
Vial 1-1-10 G control (Plated Mar 29)	TNTC	44	12	4.40E+05	107.36	TNTC	75	7	7.50E+05	258.75	366.11	
Vial 1-1-10 G control (Plated Mar 30)	TNTC	63		6.30E+05	153.72	TNTC	77		7.70E+05	265.65	419.37	
Average				5.4E+05	130.54				7.60E+05	262.20	392.74	392.74
Median				7.43E+05	181.21				9.30E+05	320.85	507.35	
St. Dev.				1.3E+05	32.78				1.41E+04	4.88	37.66	

Figure C-1: Example AOC data table

Table C-1: Plate count codes

Plate count code	Description
0	No colonies on the plate.
TNTC	The number of colonies were too numerous to count (i.e. >>300).
BP	Bad Plate. Plate was seriously contaminated or exhibited serious confluent growth.
PCDA-51	Plate contaminated but data are considered acceptable. The plate had colonies or confluent growth that may have affected the results. Contamination/confluent growth was minimal and the counts were similar to other counts. The plate count for P-17 or NOX (as appropriate) is noted.
PCDS-#	Plate contaminated but data are suspect. Contamination or some confluent growth was seen on the plate. A count was possible; however data were considered suspect. The plate count for P-17 or NOX (as appropriate) is noted.

Table 2: Calculations for values in AOC tables

Value	Calculation
Estimated count (all samples except yields and blanks)	$\frac{(Plate\ count)}{dilution \cdot (volume\ plated)}$ Where (plate count) is the chosen plate count for a given vial[1], dilution is the dilution factor used for the chosen plate, and volume plated was the v
Estimated count (yields, blanks)[2]	$\frac{\sum_{i=1}^{n} \frac{(Plate\ count)_i}{dilution_i \cdot (volume\ plated)_i}}{n}$ Where i is the plate associated with a given vial, n is the total number of plates plated for a given vial, $(\text{plate count})_i$ is the plate count associated with plate_i, dilution_i is the dilution factor used for plate_i, and $(\text{volume plated})_i$ is the volume of sample plated for plate_i
P-17 AOC for a vial[3]	$\frac{(Estimated\ count)}{4.1 \times 10^6\ \frac{CFU\ P17}{\mu g\ acetate\ C}}$
NOX AOC for a vial[3]	$\frac{(Estimated\ count)}{2.9 \times 10^6\ \frac{CFU\ NOX}{\mu g\ oxalate\ C}}$
Total AOC from vials	$P17\ AOC + NOX\ AOC$
Sum of Avgs total AOC	$Average\ P17\ AOC + Average\ NOX\ AOC$ Where average P17 AOC is the average of all P17 AOC values and average NOX AOC is the average of all NOX values calculated for a given sample[4].

1. One plate count was chosen per vial. See the Materials and Methods section of the main thesis for selection criteria.
2. When no counts between 30 and 300 were available for yield or blank vials, the average estimated count was calculated from all plate counts associated with a given vial.
3. Conversion factors between CFU and carbon concentration taken from Eaton et al., 2005.
4. i.e. the average of the P17 (or NOX) AOC values from all vials for a given sample. These values are summarized in the "average" row of the tabulated data.

March 21, 2012 Sampling Event

Raw Data and Summarized AOC Results

Table C-3: AOC results related to Filter 1 from the March 21, 2012 sampling event

March 21, 2012 Filter 1	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions:	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 1-1-1	TNTC	89	8	8.90E+05	217.16	TNTC	87	10	8.70E+05	300.15	517.31	
Vial 1-1-2	TNTC	43	3	4.30E+05	104.92	TNTC	107	9	1.07E+06	369.15	474.07	
Vial 1-1-3	TNTC	54	4	5.40E+05	131.76	TNTC	122	13	1.22E+06	420.90	552.66	
Vial 1-1-4	TNTC	65	2	6.50E+05	158.60	TNTC	72	10	7.20E+05	248.40	407.00	
Vial 1-1-5	TNTC	80	9	8.00E+05	195.20	TNTC	97	17	9.70E+05	334.65	529.85	
Vial 1-1-6	TNTC	57	5	5.70E+05	139.08	TNTC	66	8	6.60E+05	227.70	366.78	
Vial 1-1-7	TNTC	104	9	1.04E+06	253.76	TNTC	109	9	1.09E+06	376.05	629.81	
Vial 1-1-8	TNTC	54	7	5.40E+05	131.76	TNTC	87	17	8.70E+05	300.15	431.91	
Vial 1-1-9	TNTC	93	11	9.30E+05	226.92	TNTC	81	4	8.10E+05	279.45	506.37	
Vial 1-1-11	TNTC	73	6	7.30E+05	178.12	TNTC	109	6	1.09E+06	376.05	554.17	
Vial 1-1-12	TNTC	90	9	9.00E+05	219.60	TNTC	105	19	1.05E+06	362.25	581.85	
Vial 1-1-13	TNTC	88	17	8.80E+05	214.72	TNTC	93	16	9.30E+05	320.85	535.57	
Vial 1-1-14	TNTC	81	10	8.10E+05	197.64	TNTC	95	18	9.50E+05	327.75	525.39	
Vial 1-1-15	TNTC	76	4	7.60E+05	185.44	TNTC	102	15	1.02E+06	351.90	537.34	
Vial 1-1-16	TNTC	67	8	6.70E+05	163.48	TNTC	86	10	8.60E+05	296.70	460.18	
Average				7.43E+05	181.21				9.45E+05	326.14	507.35	507.35
Median				7.60E+05	185.44				9.50E+05	327.75	525.39	
St. Dev.				1.73E+05	42.30				1.51E+05	52.11	68.80	
Vial 1-1-10 G control (Plated Mar 29)	TNTC	44	12	4.40E+05	107.36	TNTC	75	7	7.50E+05	258.75	366.11	
Vial 1-1-10 G control (Plated Mar 30)	TNTC	63		6.30E+05	153.72	TNTC	77		7.70E+05	265.65	419.37	
Average				5.4E+05	130.54				7.60E+05	262.20	392.74	392.74
Median				7.43E+05	181.21				9.30E+05	320.85	507.35	
St. Dev.				1.3E+05	32.78				1.41E+04	4.88	37.66	

Table C-4: AOC results related to Filter 2 from the March 21, 2012 sampling event

March 21, 2012 Filter 2	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 2-1-1	293	25	3	2.93E+05	71.49	TNTC	87	10	8.70E+05	300.15	371.64	
Vial 2-1-2	278	30	2	2.78E+05	67.83	TNTC	90	14	9.00E+05	310.50	378.33	
Vial 2-1-3	272	22	2	2.72E+05	66.37	TNTC	82	7	8.20E+05	282.90	349.27	
Vial 2-1-4	TNTC	42	4	4.20E+05	102.48	TNTC	83	8	8.30E+05	286.35	388.83	
Vial 2-1-5	TNTC	38	6	3.80E+05	92.72	TNTC	83	7	8.30E+05	286.35	379.07	
Vial 2-1-6	TNTC	23	3			TNTC	67	4	6.70E+05	231.15		
Vial 2-1-7	190	19	2	1.90E+05	46.36	TNTC	102	6	1.02E+06	351.90	398.26	
Vial 2-1-8	TNTC	53	7	5.30E+05	129.32	TNTC	77	9	7.70E+05	265.65	394.97	
Vial 2-1-9	TNTC	23	2			TNTC	97	11	9.70E+05	334.65		
Vial 2-1-11	TNTC	63	5	6.30E+05	153.72	TNTC	89	10	8.90E+05	307.05	460.77	
Vial 2-1-12	TNTC	41	5	4.10E+05	100.04	TNTC	71	11	7.10E+05	244.95	344.99	
Vial 2-1-13	TNTC	53	7	5.30E+05	129.32	TNTC	88	12	8.80E+05	303.60	432.92	
Vial 2-1-14	0	51	3	5.10E+05	124.44	TNTC	110	13	1.10E+06	379.50	503.94	
Vial 2-1-15	TNTC	58	5	5.80E+05	141.52	TNTC	106	12	1.06E+06	365.70	507.22	
Vial 2-1-16	331	36	4	3.60E+05	87.84	TNTC	96	14	9.60E+05	331.20	419.04	
Average				4.14E+05	101.03				8.85E+05	305.44	409.94	406.47
Median				4.10E+05	100.04				8.80E+05	303.60	394.97	
St. Dev.				1.35E+05	32.88				1.22E+05	42.13	52.93	
Vial 2-1-10 G control (Plated Mar 29)	TNTC	40	6	4.00E+05	97.60	TNTC	82	10	8.20E+05	282.90	380.50	
Vial 2-1-10 G control (Plated Mar 30)	TNTC	50		5.00E+05	122.00	TNTC	90		9.00E+05	310.50	432.50	
Average				4.50E+05	109.80				8.60E+05	296.70	406.50	406.50
Median				4.50E+05	109.80				8.60E+05	296.70	406.50	
St. Dev.				7.07E+04	17.25				5.66E+04	19.52	36.77	

Table C-5: AOC results related to Filter 3 from the March 21, 2012 sampling event

March 21, 2012 Filter 3	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 3-1-1	236	27	2	2.36E+05	57.58	TNTC	86	3	8.60E+05	296.70	354.28	
Vial 3-1-2	271	21	0	2.71E+05	66.12	TNTC	101	7	1.01E+06	348.45	414.57	
Vial 3-1-3	310	60	4	6.00E+05	146.40	TNTC	85	7	8.50E+05	293.25	439.65	
Vial 3-1-4	TNTC	47	1	4.70E+05	114.68	TNTC	85	6	8.50E+05	293.25	407.93	
Vial 3-1-5	268	26	3	2.68E+05	65.39	TNTC	78	8	7.80E+05	269.10	334.49	
Vial 3-1-6	TNTC	43	8	4.30E+05	104.92	TNTC	93	3	9.30E+05	320.85	425.77	
Vial 3-1-7	220	23	2	2.20E+05	53.68	TNTC	58	7	5.80E+05	200.10	253.78	
Vial 3-1-8	TNTC	31	5	3.10E+05	75.64	TNTC	65	7	6.50E+05	224.25	299.89	
Vial 3-1-9	BP	BP	4			BP	BP	7				
Average				3.51E+05	85.55				8.14E+05	280.74	366.30	366.30
Median				2.91E+05	70.88				8.50E+05	293.25	381.11	
St. Dev.				1.35E+05	32.96				1.41E+05	48.68	66.77	
Vial 3-1-10 G control (Plated Mar 29)	TNTC	55	2	5.50E+05	134.20	TNTC	88	13	8.80E+05	303.60	437.80	
Vial 3-1-10 G control (Plated Mar 30)	TNTC	66		6.60E+05	161.04	TNTC	97		9.70E+05	334.65	495.69	
Average				6.05E+05	147.62				9.25E+05	319.13	466.75	466.75
Median				6.05E+05	147.62				9.25E+05	319.13	466.75	
St. Dev.				7.78E+04	18.98				6.36E+04	21.96	40.93	

Table C-6: AOC results related to Filter 4 from the March 21, 2012 sampling event

March 21, 2012 Filter 4	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 4-1-1	295	33	5	2.95E+05	71.98	TNTC	65	3	6.50E+05	224.25	296.23	
Vial 4-1-2	TNTC	44	3	4.40E+05	107.36	TNTC	75	14	7.50E+05	258.75	366.11	
Vial 4-1-3	343	45	3	4.50E+05	109.80	TNTC	64	9	6.40E+05	220.80	330.60	
Vial 4-1-4	185	18	0	1.85E+05	45.14	TNTC	73	9	7.30E+05	251.85	296.99	
Vial 4-1-5	130	26	BP	1.30E+05	31.72	TNTC	47	4	4.70E+05	162.15	193.87	
Vial 4-1-6	229	31	2	2.29E+05	55.88	TNTC	81	8	8.10E+05	279.45	335.33	
Vial 4-1-7	240	24	3	2.40E+05	58.56	TNTC	70	7	7.00E+05	241.50	300.06	
Vial 4-1-8	TNTC	32	3	3.20E+05	78.08	TNTC	91	8	9.10E+05	313.95	392.03	
Vial 4-1-9	275	28	2	2.75E+05	67.10	TNTC	68	7	6.80E+05	234.60	301.70	
Average				2.85E+05	69.51				7.04E+05	243.03	312.55	312.55
Median				2.75E+05	67.10				7.00E+05	241.50	301.70	
St. Dev.				1.07E+05	26.15				1.22E+05	42.05	55.79	
Vial 4-1-10 G control (Plated Mar 29)	BP	BP	BP			BP	BP	BP				
Vial 4-1-10 G control (Plated Mar 30)	TNTC	91		9.10E+05	222.04	TNTC	88		8.80E+05	303.60	525.64	
Average				9.10E+05	222.04				8.80E+05	303.60	525.64	525.64
Median				2.75E+05	67.10				7.02E+05	242.27	307.12	
St. Dev.												

Table C-7: AOC results related to Filter 5 from the March 21, 2012 sampling event

March 21, 2012 Filter 5	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 5-1-1	BP		2			BP	4	6				
Vial 5-1-2	TNTC	33	2	3.30E+05	80.52	TNTC	75	8	7.50E+05	258.75	339.27	
Vial 5-1-3	274	23	2	2.74E+05	66.86	TNTC	57	9	5.70E+05	196.65	263.51	
Vial 5-1-4	329	37	3	3.70E+05	90.28	TNTC	78	7	7.80E+05	269.10	359.38	
Vial 5-1-5	239	11	2	2.39E+05	58.32	TNTC	45	3	4.50E+05	155.25	213.57	
Vial 5-1-6	124	11	1	1.24E+05	30.26	TNTC	56	4	5.60E+05	193.20	223.46	
Vial 5-1-7	TNTC	30	1	3.00E+05	73.20	TNTC	70	7	7.00E+05	241.50	314.70	
Vial 5-1-8	TNTC	25	7			TNTC	70	10	7.00E+05	241.50		
Vial 5-1-9	119	20	4	1.19E+05	29.04	TNTC	57	6	5.70E+05	196.65	225.69	
Average				2.51E+05	61.21				6.35E+05	219.08	277.08	280.28
Median				2.74E+05	66.86				6.35E+05	219.08	263.51	
St. Dev.				9.75E+04	23.79				1.14E+05	39.34	60.27	
Vial 5-1-10 G control (Plated Mar 29)	TNTC	54	2	5.40E+05	131.76	TNTC	69	8	6.90E+05	238.05	369.81	
Vial 5-1-10 G control (Plated Mar 30)	TNTC	61		6.10E+05	148.84	TNTC	59		5.90E+05	203.55	352.39	
Average				5.75E+05	140.30				6.40E+05	220.80	361.10	361.10
Median				5.75E+05	140.30				6.40E+05	220.80	361.10	
St. Dev.				4.95E+04	12.08				7.07E+04	24.40	12.32	

Table C-8: Summarized AOC results related to Influent replicate 1 from the March 21, 2012 sampling event

March 21, 2012 Influent 1	*P-17* Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	351	31	3	3.10E+05	75.64	TNTC	208	16	2.08E+06	717.60	793.24	
Vial Inf1-1-2	255	32	4	2.55E+05	62.22	TNTC	214	28	2.14E+06	738.30	800.52	
Vial Inf1-1-3	TNTC	89	1	8.90E+05	217.16	TNTC	247	24	2.47E+06	852.15	1069.31	
Vial Inf1-1-4	TNTC	42	4	4.20E+05	102.48	TNTC	221	24	2.21E+06	762.45	864.93	
Vial Inf1-1-5	TNTC	20	3	2.00E+05	48.80	TNTC	186	18	1.86E+06	641.70	690.50	
Vial Inf1-1-6	TNTC	34	7	3.40E+05	82.96	TNTC	223	21	2.23E+06	769.35	852.31	
Vial Inf1-1-7	TNTC	47	6	4.70E+05	114.68	TNTC	185	18	1.85E+06	638.25	752.93	
Vial Inf1-1-8	TNTC	31	4	3.10E+05	75.64							
Vial Inf1-1-9	TNTC	41	2	4.10E+05	100.04	TNTC	226	36	2.26E+06	779.70	879.74	
Average				4.01E+05	97.74				2.14E+06	737.44	837.94	835.17
Median				3.40E+05	82.96				2.18E+06	750.38	826.42	
St. Dev.				2.02E+05	49.28				2.08E+05	71.70	112.49	
INF1-1-10 G control (Plated Mar 29)	TNTC	37	4	3.70E+05	90.28	TNTC	193	27	1.93E+06	665.85	756.13	
INF1-1-10 G control (Plated Mar 30)	TNTC	67		6.70E+05	163.48	TNTC	203		2.03E+06	700.35	863.83	
Average				5.20E+05	126.88				1.98E+06	683.10	809.98	809.98
Median				5.20E+05	126.88				1.98E+06	683.10	809.98	
St. Dev.				2.12E+05	51.76				7.07E+04	24.40	76.16	

Table C-9: AOC results related to Influent replicate 2 from the March 21, 2012 sampling event

March 21, 2012 Influent 2	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf2-1-1	324	42	3	4.20E+05	102.48	TNTC	104	22	1.04E+06	358.80	461.28	
Vial Inf2-1-2	BP	41	4	4.10E+05	100.04	TNTC	277	31	2.77E+06	955.65	1055.69	
Vial Inf2-1-3	328	39	2	3.90E+05	95.16	TNTC	212	24	2.12E+06	731.40	826.56	
Vial Inf2-1-4	340	37	2	3.70E+05	90.28	TNTC	160	21	1.60E+06	552.00	642.28	
Vial Inf2-1-5	TNTC	41	6	4.10E+05	100.04	TNTC	237	25	2.37E+06	817.65	917.69	
Vial Inf2-1-6	TNTC	48	2	4.80E+05	117.12	TNTC	192	20	1.92E+06	662.40	779.52	
Vial Inf2-1-7	TNTC	54	5	5.40E+05	131.76	TNTC	221	24	2.21E+06	762.45	894.21	
Vial Inf2-1-8	TNTC	BP	BP			TNTC	BP	BP				
Vial Inf2-1-9	TNTC	39	5	3.90E+05	95.16	TNTC	228	22	2.28E+06	786.60	881.76	
Average				4.26E+05	104.01				2.04E+06	703.37	807.37	807.37
Median				4.10E+05	100.04				2.17E+06	746.93	854.16	
St. Dev.				5.63E+04	13.74				5.27E+05	181.75	183.26	
INF2-1-10 G control (Plated Mar 29)	TNTC	PCDS-44	8			TNTC	212	8	2.12E+06	731.40		
INF2-1-10 G control (Plated Mar 30)	TNTC	40		4.00E+05	97.60	TNTC	189		1.89E+06	652.05	749.65	
Average				4.00E+05	97.60				2.01E+06	691.73	749.65	789.33
Median				4.00E+05	97.60				2.01E+06	691.73	749.65	
St. Dev.									1.63E+05	56.11		

Table C-10: Pooled Influent AOC data from the March 21, 2012 sampling event

March 21, 2012 Pooled Influent[1]	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	351	31	3	3.10E+05	75.64	TNTC	208	16	2.08E+06	717.60	793.24	
Vial Inf1-1-2	255	32	4	2.55E+05	62.22	TNTC	214	28	2.14E+06	738.30	800.52	
Vial Inf1-1-3	TNTC	89	1	8.90E+05	217.16	TNTC	247	24	2.47E+06	852.15	1069.31	
Vial Inf1-1-4	TNTC	42	4	4.20E+05	102.48	TNTC	221	24	2.21E+06	762.45	864.93	
Vial Inf1-1-5	TNTC	20	3	2.00E+05	48.80	TNTC	186	18	1.86E+06	641.70	690.50	
Vial Inf1-1-6	TNTC	34	7	3.40E+05	82.96	TNTC	223	21	2.23E+06	769.35	852.31	
Vial Inf1-1-7	TNTC	47	6	4.70E+05	114.68	TNTC	185	18	1.85E+06	638.25	752.93	
Vial Inf1-1-8	TNTC	31	4	3.10E+05	75.64							
Vial Inf1-1-9	TNTC	41	2	4.10E+05	100.04	TNTC	226	36	2.26E+06	779.70	879.74	
Vial Inf2-1-1	324	42	3	4.20E+05	102.48	TNTC	104	22	1.04E+06	358.80	461.28	
Vial Inf2-1-2	BP	41	4	4.10E+05	100.04	TNTC	277	31	2.77E+06	955.65	1055.69	
Vial Inf2-1-3	328	39	2	3.90E+05	95.16	TNTC	212	24	2.12E+06	731.40	826.56	
Vial Inf2-1-4	340	37	2	3.70E+05	90.28	TNTC	160	21	1.60E+06	552.00	642.28	
Vial Inf2-1-5	TNTC	41	6	4.10E+05	100.04	TNTC	237	25	2.37E+06	817.65	917.69	
Vial Inf2-1-6	TNTC	48	2	4.80E+05	117.12	TNTC	192	20	1.92E+06	662.40	779.52	
Vial Inf2-1-7	TNTC	54	5	5.40E+05	131.76	TNTC	221	24	2.21E+06	762.45	894.21	
Vial Inf2-1-8	TNTC	BP	BP			TNTC	BP	BP				
Vial Inf2-1-9	TNTC	39	5	3.90E+05	95.16	TNTC	228	22	2.28E+06	786.60	881.76	
Average				4.13E+05	100.69				2.09E+06	720.40	822.65	821.09
Median				4.10E+05	100.04				2.18E+06	750.38	839.44	
St. Dev.				1.48E+05	36.16				3.90E+05	134.62	147.74	

1. Same data as influent replicate 1 and influent replicate 2 but pooled as a single data set

Table C-11: AOC results related to the Process Blank from the March 21, 2012 sampling event

March 21, 2012 Process Blank	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
PB -1	BP	BP	189				9.45E+02	0.23	BP	BP	BP							
PB-2	72	62	70				3.40E+02	0.08	TNTC	TNTC	TNTC							
PB-3	5	12	7				4.00E+01	0.01	176	171	173				8.67E+02	0.30	0.31	
PB-4	8	7	5				3.33E+01	0.01	430	TNTC	TNTC				2.15E+03	0.74	0.75	
PB-5	17	16	11				7.33E+01	0.02	TNTC	TNTC	TNTC							
PB-6	4	3	2				1.50E+01	0.00	TNTC	TNTC	TNTC							
PB-7 A (Mar 31)				0	0	0						2	0	0				
PB-8 A (Mar 31)				0	0	0						0	1	0				
PB-9 A (Mar 31)				0	0	0						83	9	BP	8.30E+04			
PB-7 B (Mar 31)				0	0	0						0	0	0				
PB-8 B (Mar 31)				0	0	0						1	0	0				
PB-9 B (Mar 31)				0	0	0						63	13		6.30E+04			
PB-7 (Apr 3)[1]	7	PCDS-3					3.50E+01	0.01	TNTC	PCDS-264								
PB-8 (Apr 3)[1]	5	PCDS-0					2.50E+01	0.01	198	PCDS-87					9.90E+02	0.34	0.35	
PB-9 (Apr 3)[1]	PCDS-104	112					5.60E+02	0.14	BP	TNTC								
Average							2.30E+02	0.06							3.00E+04	0.46	0.47	0.52
Median							4.00E+01	0.01							2.15E+03	0.34	0.35	
St. Dev.							3.27E+02	0.08							3.99E+04	0.24	0.24	
PB-10 G Control (Plated Mar 29)	0	0	0						0	0	0							
Average																		
Median																		
St. Dev.																		

1. Re-plated on April 3, 2012 since P-17 counts from March 31 were 0

Table C-12: AOC results related to the Blank Controls from the March 21, 2012 sampling event

March 21, 2012 Blank Controls	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Blank Control 1 (plated Mar 29)	0	3	0				5.83E+00	0.00	83	73	101				4.63E+02	0.16	0.16	
Blank Control 1 (plated Mar 30)	2	2	0	0	0	0			99	112	88	0	0	0				
Blank Control-2 (Plated Mar 29)	0	0	1				8.33E-01	0.00	63	81	76				3.76E+02	0.13	0.13	
Blank Control-2 (Plated Mar 30)	0	0	0	0	0	0			70	83	78	0	0	0				
Blank Control-3 (Plated Mar 29	0	0	0				0.00E+00	0.00	14	16	15				1.03E+02	0.04	0.04	
Blank Control-3 (Plated Mar 30)	0	0	0	0	0	0			21	33	25	0	0	0				
Average							2.22E+00	0.00							3.14E+02	0.11	0.11	0.11
Median							8.33E-01	0.00							3.76E+02	0.13	0.13	
St. Dev.							3.15E+00	0.00							1.88E+02	0.06	0.07	

Table C-13: AOC results related to the Yield Controls from the March 21, 2012 sampling event

March 21, 2012 Yield Controls	P-17 Enumeration						NOX Enumeration						TOTAL AOC	
Sample Dilutions	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Yield Control-1 (Mar 29)	TNTC	183	20		1.83E+05	44.65	TNTC	153	8		1.17E+05	40.19	84.84	
Yield Control-1 (Mar 30)		TNTC	21	2				80	13	1				
Yield Control -2 (Mar 29)	TNTC	79	14		7.90E+04	19.28	TNTC	TNTC	59		5.30E+05	182.85	202.13	
Yield Control -2 (Mar 30)		79	11	2				320	47	3				
Yield Control-3 (Mar 29)	TNTC	58	4		6.05E+04	14.76	TNTC	106	21		1.28E+05	44.16	58.92	
Yield Control-3 (Mar 30)		63	4	1				150	14	2				
Yield Control-4 (Mar 29)	TNTC	50	10		5.35E+04	13.05	BP	18	1					
Yield Control-4 (Mar 30)		57	5	0				9	3	2				
Average					9.40E+04	22.94					2.58E+05	89.07	115.30	112.00
Median					6.98E+04	17.02					1.28E+05	44.16	84.84	
St. Dev.					6.03E+04	14.71					2.35E+05	81.24	76.30	

Summary of Results and Calculated Values from Statistical Tests

Table C-14: Calculated mean ranks from Kruskal-Wallis test on the March 21, 2012 AOC data

ID	N	Mean Rank
F1	15	43.33
F2	13	29.54
F3	8	22.63
F4	9	12.56
F5	7	9.00
Pooled Influent	16	59.69
Total	68	

Table C-15: Calculated test values and significance level from Kruskal-Wallis test on the March 21, 2012 data

Calculated Value			Value
	Chi-Square		55.383
	Degrees of freedom		5
	Asymptotic Sig.		1.089E-010
Monte Carlo Sig.	Sig.		0.000E+000[1]
	99% Confidence Interval	Lower Bound	0.000E+000
		Upper Bound	4.605E-006

1. Based on 1000000 sampled tables with starting seed 2000000.

Table C-16: Calculated Values from Mann-Whitney Tests on AOC data from the March 21, 2012 sampling event

Comparison	N1[1]	N2[1]	Sum of Ranks 1[2]	Sum of Ranks 2[3]	Mann-Whitney U	Z	p-value (Asymptotic 2-tailed)	p-value (Exact 2-tailed)
Influent 1 vs Influent 2[4]	8	8	66	70	30.00	-0.210	8.336E-01	8.785E-01
Pooled Influent vs F1 Effluent	16	15	365	131	11.00	-4.309	1.643E-05	1.298E-06
Pooled Influent vs F2 Effluent	16	13	342	93	2.00	-4.473	7.713E-06	1.179E-07
Pooled Influent vs F3 Effluent	16	8	264	36	0.00	-3.919	8.885E-05	2.719E-06
Pooled Influent vs F4 Effluent	16	9	280	45	0.00	-4.076	4.578E-05	9.790E-07
Pooled Influent vs F5 Effluent	16	7	248	28	0.00	-3.742	1.828E-04	8.158E-06
F1Effluent vs F2 Effluent	15	13	289	117	26.00	-3.294	9.889E-04	5.565E-04
F1 Effluent vs F3 Effluent	15	8	231	45	9.00	-3.292	9.946E-04	3.916E-04
F1 Effluent vs F4 Effluent	15	9	254	46	1.00	-4.076	7.331E-05	3.059E-06
F1 Effluent vs F5 Effluent	15	7	225	28	0.00	-3.701	2.150E-04	1.173E-05
F2 Effluent vs F3 Effluent	13	8	158	73	37.00	-1.086	2.773E-01	3.011E-01
F2 Effluent vs F4 Effluent	13	9	200	53	8.00	-3.372	7.455E-04	2.694E-04
F2 Effluent vs F5 Effluent	13	7	180	30	2.00	-3.447	5.667E-04	1.032E-04
F3 Effluent vs F4 Effluent	8	9	89	64	19.00	-1.636	1.019E-01	1.139E-01
F3 Effluent vs F5 Effluent	8	7	82	38	10.00	-2.083	3.724E-02	4.009E-02
F4 Effluent vs F5 Effluent	9	7	85	51	23.00	-0.900	3.683E-01	4.079E-01

1. Number of data points of the first data set in the comparison. For example, in the comparison of the pooled influent data vs Filter 2 effluent, N=16 is the number of total AOC concentrations measured for the pooled influent and N=15 is the number of total AOC concentrations measured for the Filter 2 effluent.
2. Sum of ranks associated with the first sampling location listed in the comparison
3. Sum of ranks associated with the second sampling location listed in the comparison
4. Influent replicate 1 versus influent replicate 2

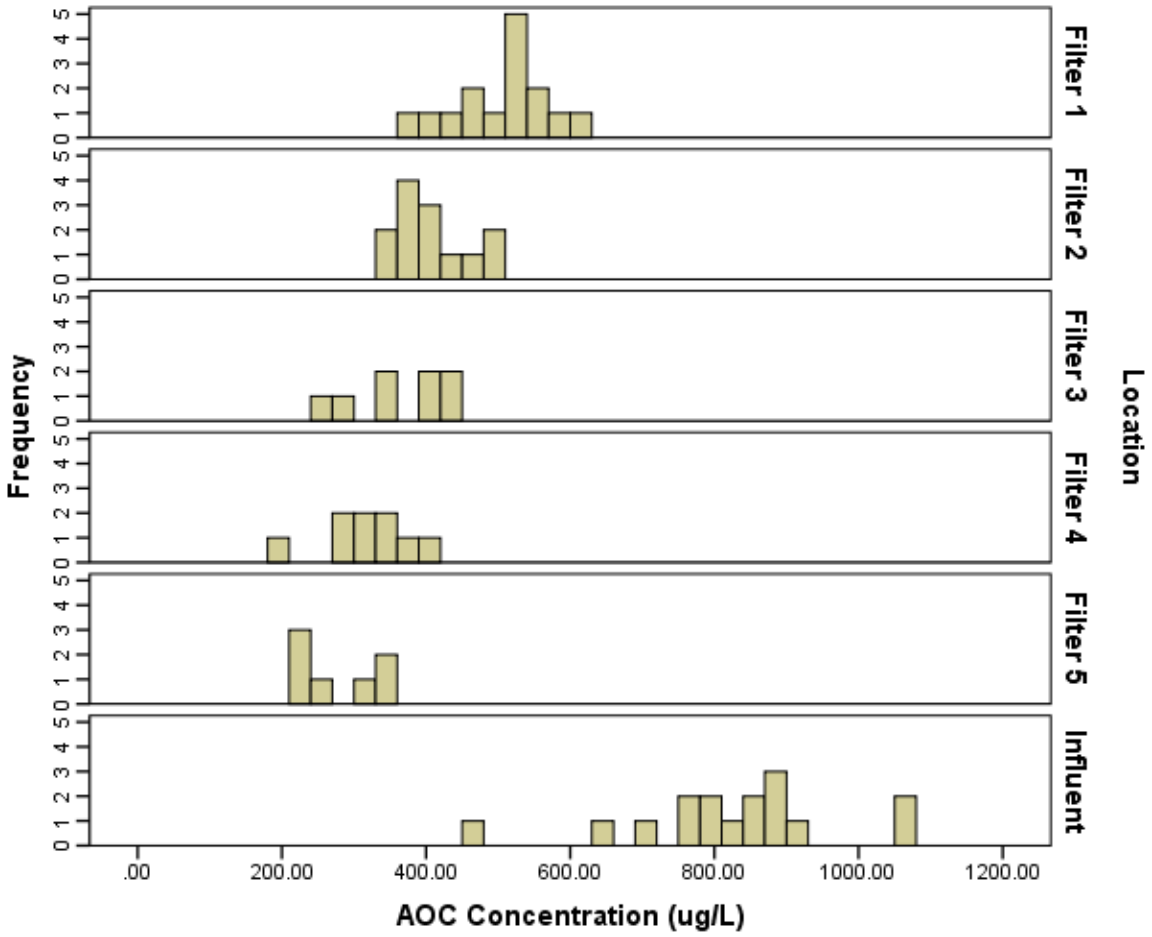

Figure C-2: Histograms of total AOC concentrations from the March 21, 2012 AOC sampling event

April 12, 2012 Sampling Event

Raw Data and Summarized AOC results

Table C-17: AOC results related to Filter 1 from the April 12, 2012 sampling event

April 12, 2012 Filter 1	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 1-1-1	180	18	2	1.80E+05	43.92	310	32	2	3.20E+05	110.40	154.32	
Vial 1-1-2	TNTC	37	5	3.70E+05	90.28	286	25	0	2.86E+05	98.67	188.95	
Vial 1-1-3	230	20	3	2.30E+05	56.12	265	24	2	2.65E+05	91.43	147.55	
Vial 1-1-4	**270**[1]	46	4	2.70E+05	65.88	TNTC	42	2	4.20E+05	144.90	210.78	
Vial 1-1-5	233	14	1	2.33E+05	56.85	TNTC	32	6	3.20E+05	110.40	167.25	
Vial 1-1-6	TNTC	33	4	3.30E+05	80.52	TNTC	35	6	3.50E+05	120.75	201.27	
Vial 1-1-7	343	35	3	3.50E+05	85.40	TNTC	37	1	3.70E+05	127.65	213.05	
Vial 1-1-8	148	18	0	1.48E+05	36.11	TNTC	29	4				
Vial 1-1-9	323	26	3	3.23E+05	78.81	TNTC	35	4	3.50E+05	120.75	199.56	
Average				2.70E+05	65.99				3.35E+05	115.62	185.34	181.61
Median				2.70E+05	65.88				3.35E+05	115.58	194.26	
St. Dev.				7.81E+04	19.05				4.88E+04	16.83	25.64	
Vial 1-1-10 GC-A	319	42	4	4.20E+05	102.48	279	20	2	2.79E+05	96.26	198.74	
Vial 1-1-10 GC-B	TNTC	44	4	4.40E+05	107.36	63	0	0	6.30E+04	21.74	129.10	
Vial 1-1-10 GC-C	332	29	3	3.32E+05	81.01	14	0	0				
Vial 1-1-10 GC-D	TNTC	66	3	6.60E+05	161.04	0	0	0				
Vial 1-1-10 GC-E	251	24	2	2.51E+05	61.24	227	20	2	2.27E+05	78.32	139.56	
Average				4.21E+05	102.63				1.90E+05	65.44	155.80	168.06
Median				4.20E+05	102.48				2.27E+05	78.32	139.56	
St. Dev. GC				1.54E+05	37.46				1.13E+05	38.89	37.55	

1. This value used

Table C-18: AOC results related to Filter 2 from the April 12, 2012 sampling event

April 12, 2012 Filter 2	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 2-1-1	220	22	2	2.20E+05	53.68	262	26	2	2.62E+05	90.39	144.07	
Vial 2-1-2	238	23	5	2.38E+05	58.07	273	26	2	2.73E+05	94.19	152.26	
Vial 2-1-3	225	17	0	2.25E+05	54.90	255	22	3	2.55E+05	87.98	142.88	
Vial 2-1-4	203	26	1	2.03E+05	49.53	343	28	2	3.43E+05	118.34	167.87	
Vial 2-1-5	334	22	4	3.34E+05	81.50	TNTC	31	3	3.10E+05	106.95	188.45	
Vial 2-1-6	TNTC	45	4	4.50E+05	109.80	TNTC	46	5	4.60E+05	158.70	268.50	
Vial 2-1-7	283	29	3	2.83E+05	69.05	TNTC	38	5	3.80E+05	131.10	200.15	
Vial 2-1-8	244	22	2	2.44E+05	59.54	TNTC	40	3	4.00E+05	138.00	197.54	
Vial 2-1-9	232	19	4	2.32E+05	56.61	TNTC	32	2	3.20E+05	110.40	167.01	
Vial 2-1-11												
Vial 2-1-12												
Vial 2-1-13												
Vial 2-1-14												
Vial 2-1-15		11	1			137	26	0	1.37E+05	47.27		
Vial 2-1-16												
Average				2.70E+05	65.85				3.14E+05	108.33	180.97	174.18
Median				2.38E+05	58.07				3.15E+05	108.68	167.87	
St. Dev.				7.81E+04	19.06				9.02E+04	31.10	39.31	
Vial 2-1-10 GC-A	142	11	1	1.42E+05	34.65	TNTC	131	6	1.31E+06	451.95	486.60	
Vial 2-1-10 GC-B	97	7	2	9.70E+04	23.67	TNTC	84	9	8.40E+05	289.80	313.47	
Vial 2-1-10 GC-C	77	15	0	7.70E+04	18.79	TNTC	74	7	7.40E+05	255.30	274.09	
Vial 2-1-10 GC-D	80	4	0	8.00E+04	19.52	TNTC	63	6	6.30E+05	217.35	236.87	
Vial 2-1-10 GC-E						TNTC	44	7	4.40E+05	151.80		
Average				9.90E+04	24.16				7.92E+05	273.24	327.76	297.40
Median				8.85E+04	21.59				7.40E+05	255.30	293.78	
St. Dev. GC				3.00E+04	7.32				3.25E+05	112.25	110.42	

Table C-19: AOC results related to Filter 3 from the April 12, 2012 sampling event

April 12, 2012 Filter 3	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 3-1-1	240	29	3	2.40E+05	58.56	TNTC	54	4	5.4E+05	186.30	244.86	
Vial 3-1-2	TNTC	56	5	5.60E+05	136.64	TNTC	53	9	5.3E+05	182.85	319.49	
Vial 3-1-3	201	24	1	2.01E+05	49.04	TNTC	47	4	4.7E+05	162.15	211.19	
Vial 3-1-4	TNTC	42	5	4.20E+05	102.48	TNTC	57	8	5.7E+05	196.65	299.13	
Vial 3-1-5	256	22	4	2.56E+05	62.46	TNTC	57	5	5.7E+05	196.65	259.11	
Vial 3-1-6	TNTC	40	4	4.00E+05	97.60	TNTC	58	6	5.8E+05	200.10	297.70	
Vial 3-1-7	**255**[1]	34	3	2.55E+05	62.22	TNTC	53	4	5.3E+05	182.85	245.07	
Vial 3-1-8	230	23	4	2.30E+05	56.12	TNTC	67	5	6.7E+05	231.15	287.27	
Vial 3-1-9	157	9	2	1.57E+05	38.31	TNTC	71	4	7.1E+05	244.95	283.26	
Average				3.02E+05	73.72				5.74E+05	198.18	271.90	271.90
Median				2.55E+05	62.22				5.70E+05	196.65	283.26	
St. Dev.				1.30E+05	31.66				7.38E+04	25.48	34.16	
Vial 3-1-10 GC-A	154	19	2	1.54E+05	37.58	TNTC	58	4	5.8E+05	200.10	237.68	
Vial 3-1-10 GC-B	BP	27	2			TNTC	33	3	3.3E+05	113.85		
Vial 3-1-10 GC-C	284	25	1	2.84E+05	69.30	TNTC	32	2	3.2E+05	110.40	179.70	
Vial 3-1-10 GC-D	**274**[1]	34	5	2.74E+05	66.86	TNTC	32	4	3.2E+05	110.40	177.26	
Vial 3-1-10 GC-E	199	23	3	1.99E+05	48.56	TNTC	49	4	4.9E+05	169.05	217.61	
Average				2.28E+05	55.57				4.1E+05	140.76	203.06	196.33
Median				2.37E+05	57.71				3.30E+05	113.85	198.65	
St. Dev. GC				6.21E+04	15.15				1.2E+05	41.50	29.56	

1. This value used

Table C-20: AOC results related to Filter 4 from the April 12, 2012 sampling event

April 12, 2012 Filter 4	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 4-1-1	TNTC	52	1	5.20E+05	126.88	TNTC	33	2	3.30E+05	113.85	240.73	
Vial 4-1-2	TNTC	66	7	6.60E+05	161.04	TNTC	42	2	4.20E+05	144.90	305.94	
Vial 4-1-3	TNTC	74	5	7.40E+05	180.56	TNTC	32	4	3.20E+05	110.40	290.96	
Vial 4-1-4	TNTC	48	4	4.80E+05	117.12	TNTC	32	5	3.20E+05	110.40	227.52	
Vial 4-1-5	TNTC	**237**[1]	38	2.37E+06	578.28	TNTC	133	17	1.33E+06	458.85	1037.13[2]	
Vial 4-1-6	TNTC	57	10	5.70E+05	139.08	TNTC	40	5	4.00E+05	138.00	277.08	
Vial 4-1-7	TNTC	43	1	4.30E+05	104.92	TNTC	30	2	3.00E+05	103.50	208.42	
Vial 4-1-8	TNTC	48	1	4.80E+05	117.12	301	26	0	3.01E+05	103.85	220.97	
Vial 4-1-9	TNTC	51	8	5.10E+05	124.44	TNTC	44	5	4.40E+05	151.80	276.24	
Average				7.51E+05	183.27				4.62E+05	159.51	255.98	342.78
Median				5.20E+05	126.88				3.30E+05	113.85	258.49	
St. Dev.				6.15E+05	150.01				3.30E+05	113.73	36.07	
Vial 4-1-10 GC-A	TNTC	116	10	1.16E+06	283.04	TNTC	49	2	4.90E+05	169.05	452.09	
Vial 4-1-10 GC-B	BP	27	2			TNTC	55	9	5.50E+05	189.75	189.75	
Vial 4-1-10 GC-C	TNTC	78	11	7.80E+05	190.32	TNTC	49	5	4.90E+05	169.05	359.37	
Vial 4-1-10 GC-D	TNTC	102	19	1.02E+06	248.88	TNTC	41	11	4.10E+05	141.45	390.33	
Vial 4-1-10 GC-E	TNTC	120	12	1.20E+06	292.80	TNTC	19	1				
Average				1.04E+06	253.76				4.85E+05	167.33	347.89	421.09
Median				1.09E+06	265.96				4.90E+05	169.05	374.85	
St. Dev. GC				1.90E+05	46.30				5.74E+04	19.82	112.25	

1. This value used
2. Data considered an outlier and excluded from analysis

Table C-21: AOC results related to Filter 5 from the April 12, 2012 sampling event

April 12, 2012 Filter 5	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 5-1-1	TNTC	46	5	4.60E+05	112.24	173	16	2	1.73E+05	59.69	171.93	
Vial 5-1-2	203	21	4	2.03E+05	49.53		20	2				
Vial 5-1-3	TNTC	37	6	3.70E+05	90.28	134	11	0	1.34E+05	46.23	136.51	
Vial 5-1-4	TNTC	35	5	3.50E+05	85.40	184	16	1	1.84E+05	63.48	148.88	
Vial 5-1-5	TNTC	47	8	4.70E+05	114.68	257	21	2	2.57E+05	88.67	203.35	
Vial 5-1-6	TNTC	55	4	5.50E+05	134.20	TNTC	30	4	3.00E+05	103.50	237.70	
Vial 5-1-7	349	28	3	3.49E+05	85.16	145	6	2	1.45E+05	50.03	135.18	
Vial 5-1-8	**299**[1]	39	4	2.99E+05	72.96	163	18	1	1.63E+05	56.24	129.19	
Vial 5-1-9	374	50	10	5.00E+05	122.00	188	20	1	1.88E+05	64.86	186.86	
Average				3.95E+05	96.27				1.93E+05	66.59	168.70	162.86
Median				3.70E+05	90.28				1.79E+05	61.58	160.40	
St. Dev.				1.09E+05	26.69				5.70E+04	19.66	38.57	
Vial 5-1-10 GC-A	147	15	6	1.47E+05	35.87	TNTC	53	PCDS-4	5.30E+05	182.85	218.72	
Vial 5-1-10 GC-B	331	26	3	3.31E+05	80.76	217	11	8	2.17E+05	74.87	155.63	
Vial 5-1-10 GC-C	TNTC	45	2	4.50E+05	109.80	174	18	PCDA-3	1.74E+05	60.03	169.83	
Vial 5-1-10 GC-D	285	27	1	2.85E+05	69.54	187	16	0	1.87E+05	64.52	134.06	
Vial 5-1-10 GC-E	189	22	1	1.89E+05	46.12	TNTC	73	5	7.30E+05	251.85	297.97	
Average				2.80E+05	68.42				3.68E+05	126.82	195.24	195.24
Median				2.85E+05	69.54				2.17E+05	74.87	169.83	
St. Dev.				1.20E+05	29.25				2.50E+05	86.33	65.31	

1. This value used

Table C-22: AOC results related to Influent replicate1 from the April 12, 2012 sampling event

April 12, 2012 Influent 1	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	TNTC	96	7	9.60E+05	234.24	TNTC	55	10	5.50E+05	189.75	423.99	
Vial Inf1-1-2	TNTC	73	9	7.30E+05	178.12	TNTC	77	14	7.70E+05	265.65	443.77	
Vial Inf1-1-3	TNTC	103	13	1.03E+06	251.32	TNTC	81	8	8.10E+05	279.45	530.77	
Vial Inf1-1-4	TNTC	83	8	8.30E+05	202.52	TNTC	106	8	1.06E+06	365.70	568.22	
Vial Inf1-1-5	TNTC	79	8	7.90E+05	192.76	TNTC	65	9	6.50E+05	224.25	417.01	
Vial Inf1-1-6	TNTC	77	7	7.70E+05	187.88	TNTC	72	8	7.20E+05	248.40	436.28	
Vial Inf1-1-7	TNTC	102	15	1.02E+06	248.88	TNTC	110	10	1.10E+06	379.50	628.38	
Vial Inf1-1-8	TNTC	96	14	9.60E+05	234.24	TNTC	118	10	1.18E+06	407.10	641.34	
Vial Inf1-1-9	TNTC	89	6	8.90E+05	217.16	TNTC	71	7	7.10E+05	244.95	462.11	
Average				8.87E+05	216.35				8.39E+05	289.42	505.76	505.76
Median				8.90E+05	217.16				7.70E+05	265.65	462.11	
St. Dev.				1.12E+05	27.25				2.20E+05	76.07	88.80	
Vial Inf1-1-10 GC-A	TNTC	85	8	8.50E+05	207.40	TNTC	90	13	9.00E+05	310.50	517.90	
Vial Inf1-1-10 GC-B	TNTC	90	11	9.00E+05	219.60	TNTC	103	15	1.03E+06	355.35	574.95	
Vial Inf1-1-10 GC-C	TNTC	57	7	5.70E+05	139.08	TNTC	163	18	1.63E+06	562.35	701.43	
Vial Inf1-1-10 GC-D	TNTC	82	6	8.20E+05	200.08	TNTC	76	4	7.60E+05	262.20	462.28	
Vial Inf1-1-10 GC-E	TNTC	62	6	6.20E+05	151.28	TNTC	103	8	1.03E+06	355.35	506.63	
Average				7.52E+05	183.49				1.07E+06	369.15	552.64	552.64
Median				8.20E+05	200.08				1.03E+06	355.35	517.90	
St. Dev.				1.47E+05	35.92				3.32E+05	114.66	92.36	

Table C-23: AOC results related to Influent replicate 2 from the April 12, 2012 sampling event

April 12, 2012 Influent 2	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf2-1-1	TNTC	43	2	4.30E+05	104.92	TNTC	53	6	5.30E+05	182.85	287.77	
Vial Inf2-1-2	TNTC	71	9	7.10E+05	173.24	TNTC	84	11	8.40E+05	289.80	463.04	
Vial Inf2-1-3	TNTC	81	13	8.10E+05	197.64	TNTC	90	12	9.00E+05	310.50	508.14	
Vial Inf2-1-4	TNTC	108	11	1.08E+06	263.52	TNTC	92	8	9.20E+05	317.40	580.92	
Vial Inf2-1-5	TNTC	87	10	8.70E+05	212.28	TNTC	98	10	9.80E+05	338.10	550.38	
Vial Inf2-1-6	TNTC	89	10	8.90E+05	217.16	TNTC	89	5	8.90E+05	307.05	524.21	
Vial Inf2-1-7	TNTC	89	14	8.90E+05	217.16	TNTC	BP	13				
Vial Inf2-1-8	TNTC	73	7	7.30E+05	178.12	TNTC	93	13	9.30E+05	320.85	498.97	
Vial Inf2-1-9	TNTC	64	6	6.40E+05	156.16	TNTC	87	11	8.70E+05	300.15	456.31	
Average				7.83E+05	191.13				8.58E+05	295.84	483.72	486.97
Median				8.10E+05	197.64				8.95E+05	308.78	503.56	
St. Dev.				1.85E+05	45.04				1.39E+05	47.87	89.39	
Vial Inf2-1-10 GC-A	TNTC	70	9	7.00E+05	170.80	TNTC	93	12	9.30E+05	320.85	491.65	
Vial Inf2-1-10 GC-B	TNTC	62	5	6.20E+05	151.28	TNTC	125	14	1.25E+06	431.25	582.53	
Vial Inf2-1-10 GC-C	TNTC	72	6	7.20E+05	175.68	TNTC	165	16	1.65E+06	569.25	744.93	
Vial Inf2-1-10 GC-D	TNTC	61	7	6.10E+05	148.84	TNTC	109	7	1.09E+06	376.05	524.89	
Vial Inf2-1-10 GC-E	TNTC	92	4	9.20E+05	224.48	TNTC	0	0				
Average				7.14E+05	174.22				1.23E+06	424.35	586.00	598.57
Median				7.00E+05	170.80				1.17E+06	403.65	553.71	
St. Dev. GC				1.25E+05	30.46				3.09E+05	106.60	112.41	

Table C-24: Pooled influent AOC data from the April 12, 2012 sampling event

April 12, 2012 Pooled Influent[1]	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	TNTC	96	7	9.60E+05	234.24	TNTC	55	10	5.50E+05	189.75	423.99	
Vial Inf1-1-2	TNTC	73	9	7.30E+05	178.12	TNTC	77	14	7.70E+05	265.65	443.77	
Vial Inf1-1-3	TNTC	103	13	1.03E+06	251.32	TNTC	81	8	8.10E+05	279.45	530.77	
Vial Inf1-1-4	TNTC	83	8	8.30E+05	202.52	TNTC	106	8	1.06E+06	365.70	568.22	
Vial Inf1-1-5	TNTC	79	8	7.90E+05	192.76	TNTC	65	9	6.50E+05	224.25	417.01	
Vial Inf1-1-6	TNTC	77	7	7.70E+05	187.88	TNTC	72	8	7.20E+05	248.40	436.28	
Vial Inf1-1-7	TNTC	102	15	1.02E+06	248.88	TNTC	110	10	1.10E+06	379.50	628.38	
Vial Inf1-1-8	TNTC	96	14	9.60E+05	234.24	TNTC	118	10	1.18E+06	407.10	641.34	
Vial Inf1-1-9	TNTC	89	6	8.90E+05	217.16	TNTC	71	7	7.10E+05	244.95	462.11	
Vial Inf2-1-1	TNTC	43	2	4.30E+05	104.92	TNTC	53	6	5.30E+05	182.85	287.77	
Vial Inf2-1-2	TNTC	71	9	7.10E+05	173.24	TNTC	84	11	8.40E+05	289.80	463.04	
Vial Inf2-1-3	TNTC	81	13	8.10E+05	197.64	TNTC	90	12	9.00E+05	310.50	508.14	
Vial Inf2-1-4	TNTC	108	11	1.08E+06	263.52	TNTC	92	8	9.20E+05	317.40	580.92	
Vial Inf2-1-5	TNTC	87	10	8.70E+05	212.28	TNTC	98	10	9.80E+05	338.10	550.38	
Vial Inf2-1-6	TNTC	89	10	8.90E+05	217.16	TNTC	89	5	8.90E+05	307.05	524.21	
Vial Inf2-1-7	TNTC	89	14	8.90E+05	217.16	TNTC	BP	13				
Vial Inf2-1-8	TNTC	73	7	7.30E+05	178.12	TNTC	93	13	9.30E+05	320.85	498.97	
Vial Inf2-1-9	TNTC	64	6	6.40E+05	156.16	TNTC	87	11	8.70E+05	300.15	456.31	
Average				8.35E+05	203.74				8.48E+05	292.44	495.39	496.18
Median				8.50E+05	207.40				8.70E+05	300.15	498.97	
St. Dev.				1.57E+05	38.37				1.81E+05	62.50	86.99	

1. Same data as influent replicate 1 and influent replicate 2 but pooled as a single data set

Table C-25: AOC results related to the Blank Controls from the April 12, 2012 sampling event

April 12, 2012 Blank Controls	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.5	0.5	0.5	0.2	0.2	0.2	(cfu/mL)	(ug/L)	0.5	0.5	0.5	0.2	0.2	0.2	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Blank Control 1	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	-	-	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	-	-	-	-
Blank Control-2	27	22	39				5.87E+01	0.01	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	-	-	-	-
Blank Control-3	0	0	0	0	0	0	0.00E+00	0				21	21	32	1.23E+02	0.04	0.04	-
Blank Control-4				TNTC	TNTC	TNTC	-	-				TNTC	TNTC	TNTC	-	-	-	-
Blank Control-5				TNTC	TNTC	TNTC	-	-				TNTC	TNTC	TNTC	-	-	-	-
Average							2.93E+01	0.01							1.23E+02	0.04	0.04	0.05
Median							2.93E+01	0.01							1.23E+02	0.04	0.04	
St. Dev.							4.15E+01	0.01										

Table C-26: AOC results related to the Yield Controls from the April 12, 2012 sampling event

April 12, 2012 Yield Controls	P-17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	1.0E-02	1.0E-03	1.0E-04	Est. Count	P-17 AOC	1.0E-02	1.0E-03	1.0E-04	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Yield Control -1	1	1	0	-	-	7	1	0	-	-	-	-
Yield Control -2	6	1	0	-	-	0	0	0	-	-	-	-
Yield Control-3	8	1	0	-	-	88	8	1	8.80E+04	30.36	-	-
Yield Control-4	0	0	0	-	-	0	0	0	-	-	-	-
Yield Control-5	0	0	0	-	-	0	0	0	-	-	-	-
Average												
Median												
St. Dev. GC												

Boxplots to Determine Which of the Counts in the Range of 30 to 300 Should Be Used

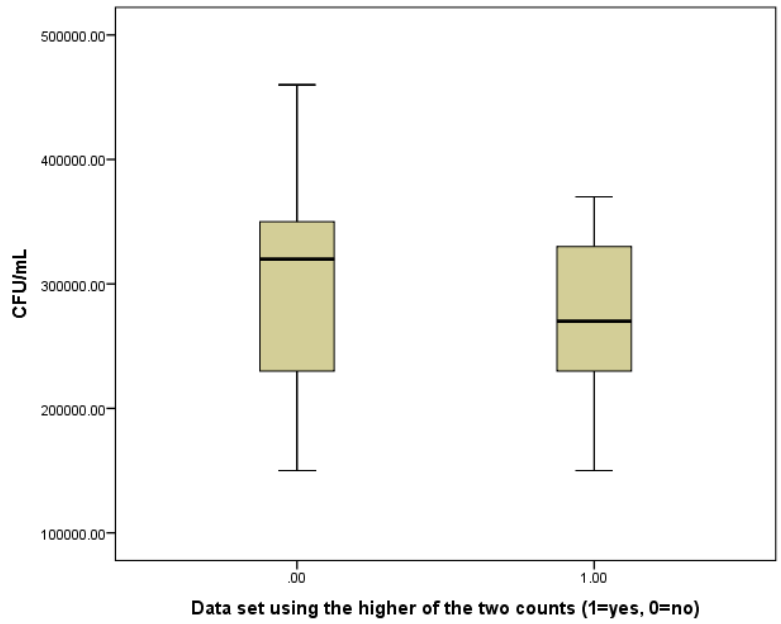

Figure C-3: Boxplots of Filter 1 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

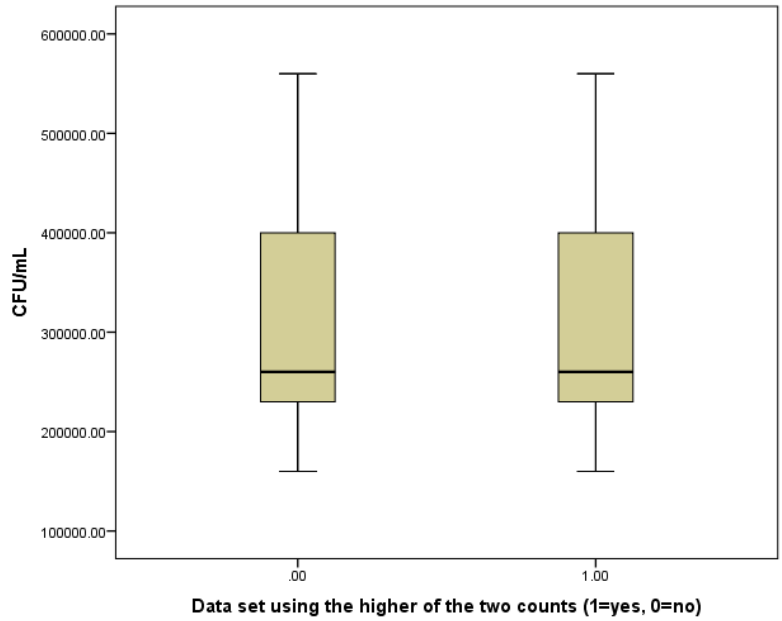

Figure C-4: Boxplots of Filter 3 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

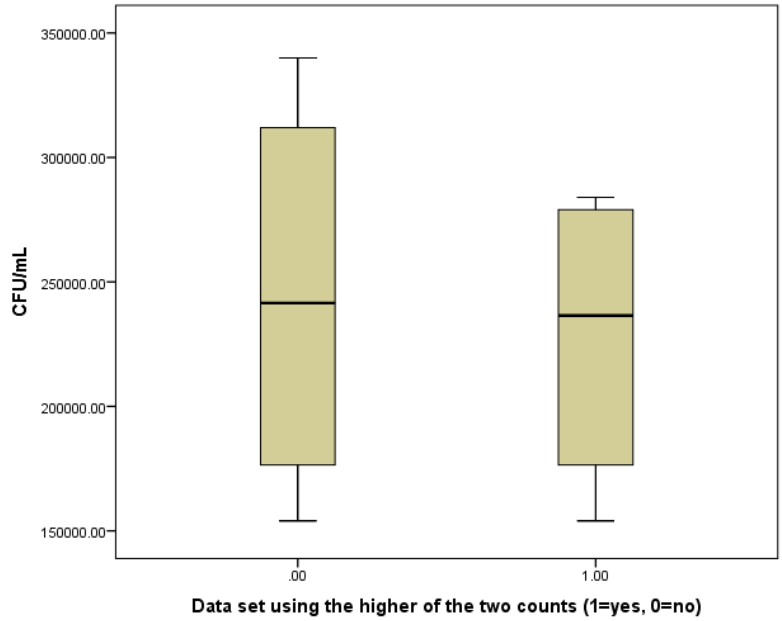

Figure C-5: Boxplots of Filter 3 Growth Control P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

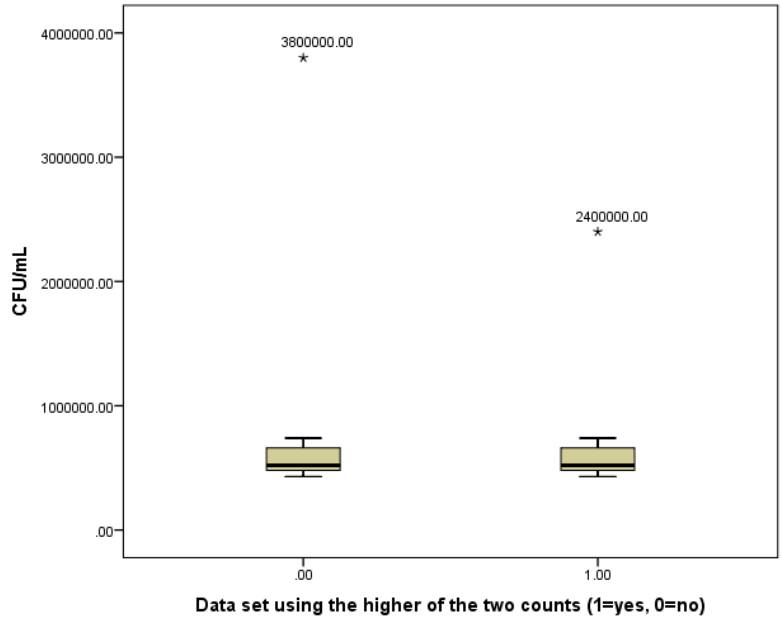

Figure C-6: Boxplots of Filter 4 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

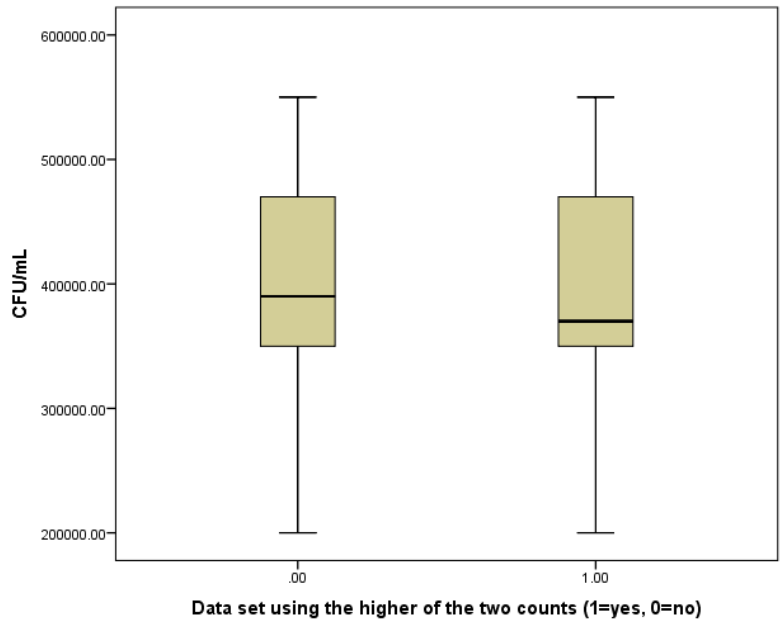

Figure C-7: Boxplots of Filter 5 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

Summary of Results and Calculated values from Statistical Tests

Table C-27: Calculated mean ranks from Kruskal-Wallis test on the April 12, 2012 AOC concentrations

ID	N	Mean Rank
F1	8	16.00
F2	9	13.67
F3	9	34.89
F4	9	31.75
F5	8	11.13
Pooled Influent	17	50.71
Total	60	

Table C-28: Calculated test values and significance level from Kruskal-Wallis test on the April 12, 2012 AOC concentrations

Calculated Value			Value
	Chi-Square		48.635
	Df		5
	Asymp. Sig.		2.64E-09
Monte Carlo Sig.	Sig.		0.00E+00[1]
	99% Confidence Interval	Lower Bound	0.00E+00
		Upper Bound	4.61E-06

1. Based on 1000000 sampled tables with starting seed 2000000.

Table C-29: Calculated Values from Mann-Whitney Tests on AOC data from the April 12, 2012 sampling event

Comparison	N1[1]	N2[1]	Sum of Ranks 1[2]	Sum of Ranks 2[3]	Mann-Whitney U	Z	p-value (Asymptotic 2-tailed)	p-value (Exact 2-tailed)
Influent 1 vs Influent 2[4]	9	8	80	73	35.00	-.096	9.233E-01	9.626E-01
Pooled Influent vs F1 Effluent	17	8	289	36	0.00	-3.96	7.453E-05	1.849E-06
Pooled Influent vs F2 Effluent	17	9	306	45	0.00	-4.12	3.738E-05	6.401E-07
Pooled Influent vs F3 Effluent	17	9	303	48	3.00	-3.96	7.451E-05	4.481E-06
Pooled Influent vs F4 Effluent	17	8	287	38	2.00	-3.84	1.206E-04	7.397E-06
Pooled Influent vs F5 Effluent	17	8	289	36	0.00	-3.96	7.453E-05	1.849E-06
F1Effluent vs F2 Effluent	8	9	82	71	26.00	-0.96	3.359E-01	3.704E-01
F1 Effluent vs F3 Effluent	8	9	37	116	1.00	-3.37	7.575E-04	1.645E-04
F1 Effluent vs F4 Effluent	8	8	38	98	2.00	-3.15	1.629E-03	6.216E-04
F1 Effluent vs F5 Effluent	8	8	79	57	21.00	-1.16	2.480E-01	2.786E-01
F2 Effluent vs F3 Effluent	9	9	49	122	4.00	-3.22	1.268E-03	4.936E-04
F2 Effluent vs F4 Effluent	9	8	49	104	4.00	-3.08	2.076E-03	9.872E-04
F2 Effluent vs F5 Effluent	9	8	89	64	28.00	-0.77	4.414E-01	4.807E-01
F3 Effluent vs F4 Effluent	9	8	92	61	25.00	-1.06	2.898E-01	3.213E-01
F3 Effluent vs F5 Effluent	9	8	116	37	1.00	-3.37	7.575E-04	1.645E-04
F4 Effluent vs F5 Effluent	8	8	97	39	3.00	-3.05	2.322E-03	1.088E-03

1. Number of data points of the first data set in the comparison. For example, in the comparison of the pooled influent data vs Filter 2 effluent, N=17 is the number of total AOC concentrations measured for the pooled influent and N=8 is the number of total AOC concentrations measured for the filter 2 effluent.
2. Sum of ranks associated with the first sampling location listed in the comparison
3. Sum of ranks associated with the second sampling location listed in the comparison
4. Influent replicate 1 versus influent replicate 2

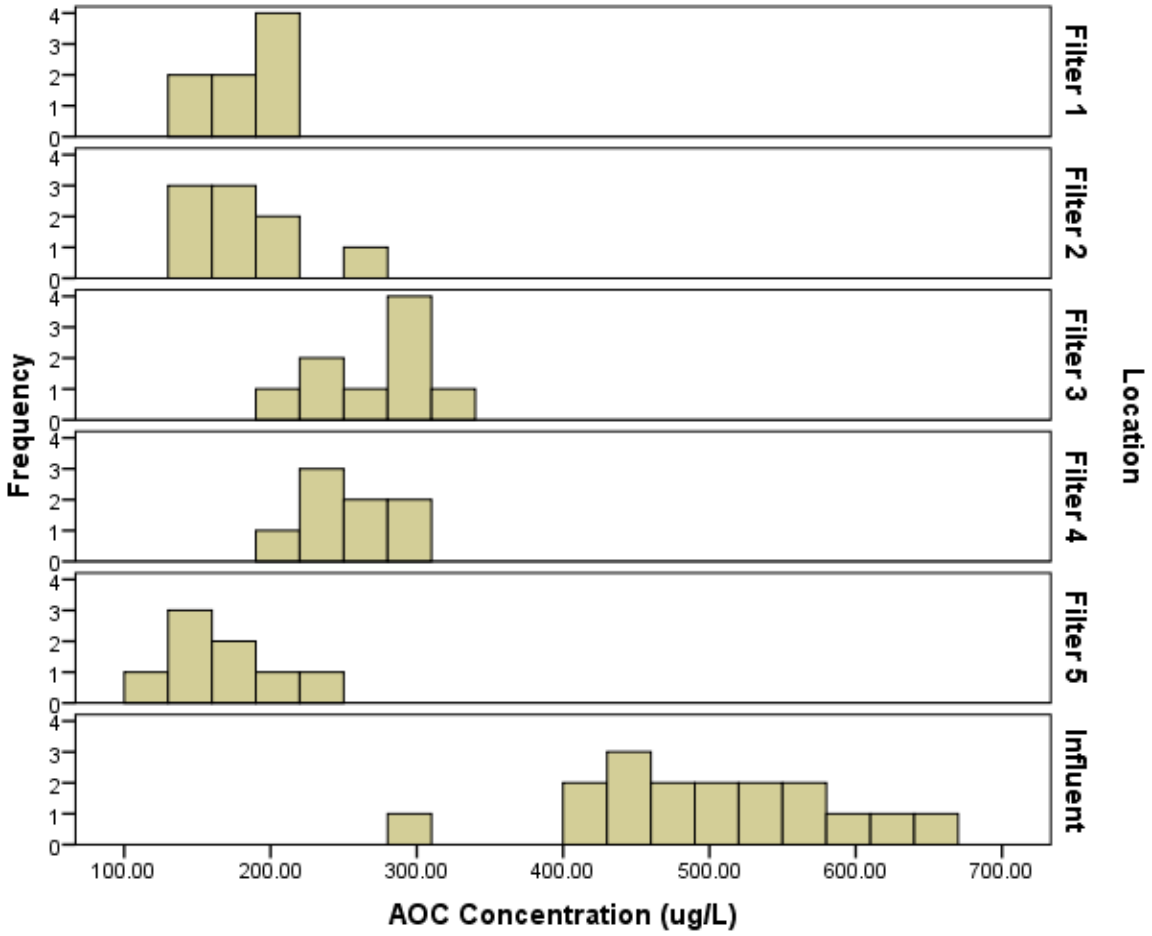

Figure C-8: Histograms of AOC concentrations from April 12, 2012 AOC sampling event

June 27, 2012 Sampling Event

Raw Data and Summarized AOC results

Table C-30: AOC results related to Filter 1 from the June 27, 2012 sampling event

June 27, 2012 Filter 1	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 1-1-1	155	23	1	1.55E+05	37.82	TNTC	87		8.70E+05	300.15	337.97	
Vial 1-1-2	207	18	5	2.07E+05	50.51	TNTC	66					
Vial 1-1-3	198	23	3	1.98E+05	48.31	TNTC	71		7.10E+05	244.95	293.26	
Vial 1-1-4	BP	BP	BP			BP	BP	BP				
Vial 1-1-5	BP	BP	PCDS-1			BP	BP	PCDS-6				
Vial 1-1-6	BP	BP	3			BP	BP	11				
Vial 1-1-7	172	18	3	1.72E+05	41.97	TNTC	59	7	5.90E+05	203.55	245.52	
Vial 1-1-7	209	16	4	2.09E+05	51.00	TNTC	71	9	7.10E+05	244.95	295.95	
Vial 1-1-8	267	27	2	2.67E+05	65.15	TNTC	54	3	5.40E+05	186.30	251.45	
Vial 1-1-9	TNTC	34	1	3.40E+05	82.96	TNTC	50	6	5.00E+05	172.50		
Vial 1-1-11	155	18	0	1.55E+05	37.82	TNTC	49	4	4.90E+05	169.05	206.87	
Vial 1-1-12	157	14	1	1.57E+05	38.31	TNTC	66	4	6.60E+05	227.70	266.01	
Vial 1-1-13	229	29	PCDS-1	2.29E+05	55.88	TNTC	60	PCDS-9	6.00E+05	207.00	262.88	
Vial 1-1-14	250	22	PCDS-6	2.50E+05	61.00	TNTC	54	PCDS-10	5.40E+05	186.30	247.30	
Vial 1-1-15	179	19	0	1.79E+05	43.68	TNTC	62	13	6.20E+05	213.90	257.58	
Vial 1-1-16	**286**[1]	35	5	2.86E+05	69.78	TNTC	55	8	5.50E+05	189.75	259.53	
Average				2.16E+05	52.63				6.15E+05	212.18	265.85	264.80
Median				2.07E+05	50.51				5.95E+05	205.28	259.53	
St. Dev.				5.69E+04	13.89				1.09E+05	37.55	33.79	
Vial 1-1-10 GC-A	PCDS-194	16	2			BP	56	5	5.60E+05	193.20		
Vial 1-1-10 GC-B	PCDS-134	PCDS-13	BP			BP	BP	BP				
Vial 1-1-10 GC-C		32	3	3.20E+05	78.08	TNTC	60	5	6.00E+05	207.00	285.08	
Vial 1-1-10 GC-D	**286**[1]	36	1	2.86E+05	69.78	TNTC	121	16	1.21E+06	417.45	487.23	
Vial 1-1-10 GC-E	**278**[1]	38	4	2.78E+05	67.83	TNTC	110	7	1.10E+06	379.50	447.33	
Average				2.95E+05	71.90				8.68E+05	299.29	406.55	371.19
Median				2.86E+05	69.78				8.50E+05	293.25	447.33	
St. Dev.				2.23E+04	5.44				3.35E+05	100.21	107.07	

1. This value used

Table C-31: AOC results related to Filter 2 from the June 27, 2012 sampling event

June 27, 2012 Filter 2	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 2-1-1	188	18	3	1.88E+05	45.87	TNTC	78	8	7.80E+05	269.10	314.97	
Vial 2-1-2	178	15	1	1.78E+05	43.43	TNTC	64	13	6.40E+05	220.80	264.23	
Vial 2-1-3	240	24	3	2.40E+05	58.56	TNTC	73	8	7.30E+05	251.85	310.41	
Vial 2-1-4	119	13	2	1.19E+05	29.04	TNTC	82	11	8.20E+05	282.90	311.94	
Vial 2-1-5	219	26	8	2.19E+05	53.44	TNTC	51	5	5.10E+05	175.95	229.39	
Vial 2-1-6	253	26	3	2.53E+05	61.73	TNTC	52	6	5.20E+05	179.40	241.13	
Vial 2-1-7	169	23	2	1.69E+05	41.24	TNTC	75	11	7.50E+05	258.75	299.99	
Vial 2-1-8	251	25	4	2.51E+05	61.24	TNTC	55	5	5.50E+05	189.75	250.99	
Vial 2-1-9	180	15	2	1.80E+05	43.92	TNTC	81	6	8.10E+05	279.45	323.37	
Vial 2-1-11	193	26	1	1.93E+05	47.09	TNTC	73	8	7.30E+05	251.85	298.94	
Vial 2-1-12	120	8	2	1.20E+05	29.28	TNTC	68	8	6.80E+05	234.60	263.88	
Vial 2-1-13	208	19	4	2.08E+05	50.75	TNTC	84	7	8.40E+05	289.80	340.55	
Vial 2-1-14	206	16	5	2.06E+05	50.26	TNTC	69	5	6.90E+05	238.05	288.31	
Vial 2-1-15	201	22	3	2.01E+05	49.04	TNTC	82	4	8.20E+05	282.90	331.94	
Vial 2-1-16	PCDS-240	PCDS-35	3			BP	PCDS-68	12				
Average				1.95E+05	47.49				7.05E+05	243.23	290.72	290.72
Median				1.97E+05	48.07				7.30E+05	251.85	299.46	
St. Dev.				4.12E+04	10.05				1.13E+05	38.98	35.14	
Vial 2-1-10 GC-A	PCDS-54	BP	BP			BP	BP	BP				
Vial 2-1-10 GC-B	227	22	3	2.27E+05	55.39	TNTC	79	8	7.90E+05	272.55	327.94	
Vial 2-1-10 GC-C	**239**[1]	37	4	2.39E+05	58.32	TNTC	73	10	7.30E+05	251.85	310.17	
Vial 2-1-10 GC-D		39	2	3.90E+05	95.16	TNTC	66	4	6.60E+05	227.70	322.86	
Vial 2-1-10 GC-E	54	9	1	5.40E+04	13.18	TNTC	81	3	8.10E+05	279.45	292.63	
Average				2.28E+05	55.51				7.48E+05	257.89	313.40	313.40
Median				2.33E+05	56.85				7.60E+05	262.20	316.51	
St. Dev.				1.37E+05	33.53				6.75E+04	23.29	15.74	

1. This value used

Table C-32: AOC results related to Filter 3 from the June 27, 2012 sampling event

June 27,2012 Filter 3	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 3-1-1	153	21	1	1.53E+05	37.33	TNTC	94	11	9.40E+05	324.30	361.63	
Vial 3-1-2	168	22	1	1.68E+05	40.99	TNTC	80	10	8.00E+05	276.00	316.99	
Vial 3-1-3	192	18	3	1.92E+05	46.85	TNTC	72	11	7.20E+05	248.40	295.25	
Vial 3-1-4												
Vial 3-1-5												
Vial 3-1-6												
Vial 3-1-7	156	26	2	1.56E+05	38.06	TNTC	85	15	8.50E+05	293.25	331.31	
Vial 3-1-8	207	21	1	2.07E+05	50.51	TNTC	62	4	6.20E+05	213.90	264.41	
Vial 3-1-9[1]	211	18	2	1.84E+05	44.98	TNTC	86	6	6.57E+05	226.55	271.53	
Vial 3-1-9[1]	175	24	3			TNTC	41	6				
Vial 3-1-9[1]	167	22	3			TNTC	70	4				
Vial 3-1-11	191	23		1.91E+05	46.60	TNTC	81	5	8.10E+05	279.45	326.05	
Vial 3-1-12	183	17		1.83E+05	44.65	TNTC	83	5	8.30E+05	286.35	331.00	
Vial 3-1-13	184	22	4	1.84E+05	44.90	TNTC	69	8	6.90E+05	238.05	282.95	
Vial 3-1-14	184	13	1	1.84E+05	44.90	TNTC	72	6	7.20E+05	248.40	293.30	
Vial 3-1-15	183	17	1	1.83E+05	44.65	TNTC	87	4	8.70E+05	300.15	344.80	
Vial 3-1-16	120	17	2	1.20E+05	29.28	TNTC	69	9	6.90E+05	238.05	267.33	
Average				1.75E+05	42.81				7.66E+05	264.40	307.21	307.21
Median				1.84E+05	44.77				7.60E+05	262.20	306.12	
St. Dev.				2.31E+04	5.63				9.74E+04	33.61	32.47	
Vial 3-1-10 GC-A												
Vial 3-1-10 GC-B												
Vial 3-1-10 GC-C												
Vial 3-1-10 GC-D	51	9	1	5.10E+04	12.44	TNTC	93	12	9.30E+05	320.85	333.29	
Vial 3-1-10 GC-E	146	10	2	1.46E+05	35.62	TNTC	121	8	1.21E+06	417.45	453.07	
Average GC				9.85E+04	24.03				1.07E+06	369.15	393.18	393.18
Median				9.85E+04	24.03				1.07E+06	369.15	393.18	
St. Dev. GC				6.72E+04	16.39				1.98E+05	68.31	84.70	

1. Vial 3-1-9 plated in triplicate. Final counts are the average of measurements with counts between 30 and 300.

Table C-33: AOC results related to Filter 4 from the June 27, 2012 sampling event

June 27, 2012 Filter 4	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 4-1-1	**260**[1]	33	2	2.60E+05	63.44	TNTC	61	8	6.10E+05	210.45	273.89	
Vial 4-1-2	221	8	1	2.21E+05	53.92	TNTC	53	10	5.30E+05	182.85	236.77	
Vial 4-1-3	186	18	PCDS-2	1.86E+05	45.38	TNTC	70	PCDS-9	7.00E+05	241.50	286.88	
Vial 4-1-4												
Vial 4-1-5												
Vial 4-1-6												
Vial 4-1-7	244	28	PCDS-4	2.44E+05	59.54	TNTC	52	PCDS-6	5.20E+05	179.40	238.94	
Vial 4-1-8	256	25	3	2.56E+05	62.46	TNTC	52	8	5.20E+05	179.40	241.86	
Vial 4-1-9	**251**[1]	31	3	2.51E+05	61.24	TNTC	71	8	7.10E+05	244.95	306.19	
Vial 4-1-11	**260**[1]	32	1	2.60E+05	63.44	TNTC	45	12	4.50E+05	155.25	218.69	
Vial 4-1-12	245	27	3	2.45E+05	59.78	TNTC	65	4	6.50E+05	224.25	284.03	
Vial 4-1-13	**275**[1]	34	2	2.75E+05	67.10	TNTC	48	5	4.80E+05	165.60	232.70	
Vial 4-1-14	**225**[1]	30	2	2.25E+05	54.90	TNTC	65	10	6.50E+05	224.25	279.15	
Vial 4-1-15	176	19	1	1.76E+05	42.94	TNTC	56	6	5.60E+05	193.20	236.14	
Vial 4-1-16	181	14	2	1.81E+05	44.16	TNTC	58	8	5.80E+05	200.10	244.26	
Average				2.32E+05	56.53				5.80E+05	200.10	256.63	256.63
Median				2.45E+05	59.66				5.70E+05	196.65	243.06	
St. Dev.				3.40E+04	8.29				8.47E+04	29.24	27.70	
Vial 4-1-10 GC-A												
Vial 4-1-10 GC-B												
Vial 4-1-10 GC-C												
Vial 4-1-10 GC-D	286	24	2	2.86E+05	69.78	TNTC	55	11	5.50E+05	189.75	259.53	
Vial 4-1-10 GC-E	TNTC	33	4	3.30E+05	80.52	TNTC	72	9	7.20E+05	248.40	328.92	
Average				3.08E+05	75.15				6.35E+05	219.08	294.23	294.23
Median				3.08E+05	75.15				6.35E+05	219.08	294.23	
St. Dev.				3.11E+04	7.59				1.20E+05	41.47	49.06	

1. This value used

Table C-34: AOC results related to Filter 5 from the June 27, 2012 sampling event

June 27, 2012 Filter 5	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 5-1-1	TNTC	32	1	3.20E+05	78.08	TNTC	51	1	5.10E+05	175.95	254.03	
Vial 5-1-2	PCDS-156	17	1			BP	44	3	4.40E+05	151.80		
Vial 5-1-3	163	PCDS-32	5	1.63E+05	39.77	TNTC	PCDS-52	8				
Vial 5-1-4	TNTC	29	2			TNTC	40	6	4.00E+05	138.00		
Vial 5-1-5	TNTC	19	3			TNTC	45	6	4.50E+05	155.25		
Vial 5-1-6	199	PCDS-35	2	1.99E+05	48.56	TNTC	PCDS-73	5				
Vial 5-1-7	250	24	2	2.50E+05	61.00	TNTC	58	7	5.80E+05	200.10	261.10	
Vial 5-1-8	**251**[1]	32	3	2.51E+05	61.24	TNTC	85	10	8.50E+05	293.25	354.49	
Vial 5-1-9	209	22	0	2.09E+05	51.00	TNTC	40	5	4.00E+05	138.00	189.00	
Vial 5-1-11	220	19	1	2.20E+05	53.68	TNTC	40	3	4.00E+05	138.00	191.68	
Vial 5-1-12	231	29	3	2.31E+05	56.36	TNTC	59	7	5.90E+05	203.55	259.91	
Vial 5-1-13	162	18	2	1.62E+05	39.53	TNTC	67	4	6.70E+05	231.15	270.68	
Vial 5-1-14	152	PCDS-16	2	1.52E+05	37.09	TNTC	PCDS-47	5				
Vial 5-1-15	200	20	1	2.00E+05	48.80	TNTC	60	3	6.00E+05	207.00	255.80	
Vial 5-1-16	198	21	0	1.98E+05	48.31	TNTC	54	10	5.40E+05	186.30	234.61	
Average				2.13E+05	51.95				5.36E+05	184.86	252.37	236.81
Median				2.05E+05	49.90				5.25E+05	181.13	255.80	
St. Dev.				4.68E+04	11.41				1.34E+05	46.32	48.64	
Vial 5-1-10 GC-A	241	19	5	2.41E+05	58.80	TNTC	48	4	4.80E+05	165.60	224.40	
Vial 5-1-10 GC-B	135	13	2	1.35E+05	32.94	TNTC	49	7	4.90E+05	169.05	201.99	
Vial 5-1-10 GC-C	143	12	0	1.43E+05	34.89	TNTC	55	PCDS-6	5.50E+05	189.75	224.64	
Vial 5-1-10 GC-D	167	19	0	1.67E+05	40.75	TNTC	58	5	5.80E+05	200.10	240.85	
Vial 5-1-10 GC-E	157	21	1	1.57E+05	38.31	TNTC	58	5	5.80E+05	200.10	238.41	
Average				1.69E+05	41.14				5.36E+05	184.92	226.06	226.06
Median				1.57E+05	38.31				5.50E+05	189.75	224.64	
St. Dev.				4.23E+04	10.33				4.83E+04	16.65	15.45	

1. This value used

Table C-35: AOC results related to Influent 1 from the June 27, 2012 sampling event

June 27, 2012 Influent 1	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	PCDS-55	6	0			BP	189	26	1.89E+06	652.05		
Vial Inf1-1-2	108	10	0	1.08E+05	26.35	TNTC	179	13	1.79E+06	617.55	643.90	
Vial Inf1-1-3	93	10	0	9.30E+04	22.69	TNTC	214	PCDS-27	2.14E+06	738.30	760.99	
Vial Inf1-1-4												
Vial Inf1-1-5												
Vial Inf1-1-6												
Vial Inf1-1-7	80	6	2	8.00E+04	19.52	TNTC	138	8	1.38E+06	476.10	495.62	
Vial Inf1-1-8	78	11	0	7.80E+04	19.03	TNTC	193	22	1.93E+06	665.85	684.88	
Vial Inf1-1-9	137	14	3	1.37E+05	33.43	TNTC	167	26	1.67E+06	576.15	609.58	
Vial Inf1-1-11	**264**[1]	33	2	2.64E+05	64.42	TNTC	163	18	1.63E+06	562.35	626.77	
Vial Inf1-1-12	74	12	1	7.40E+04	18.06	TNTC	191	27	1.91E+06	658.95	677.01	
Vial Inf1-1-13	90	8	1	9.00E+04	21.96	TNTC	149	20	1.49E+06	514.05	536.01	
Vial Inf1-1-14	98	7	0	9.80E+04	23.91	TNTC	121	9	1.21E+06	417.45	441.36	
Vial Inf1-1-15	107	15	1	1.07E+05	26.11	TNTC	165	18	1.65E+06	569.25	595.36	
Vial Inf1-1-16	108	12	1	1.08E+05	26.35	TNTC	250	27	2.50E+06	862.50	888.85	
Average				1.12E+05	27.44				1.77E+06	609.21	632.76	636.65
Median				9.80E+04	23.91				1.73E+06	596.85	626.77	
St. Dev.				5.33E+04	13.01				3.46E+05	119.41	123.93	
Vial Inf1-1-10 GC-A												
Vial Inf1-1-10 GC-B												
Vial Inf1-1-10 GC-C												
Vial Inf1-1-10 GC-D	105	17	1	1.05E+05	25.62	TNTC	257	24	2.57E+06	886.65	912.27	
Vial Inf1-1-10 GC-E	117	9	0	1.17E+05	28.55	TNTC	282	18	2.82E+06	972.90	1001.45	
Average				1.11E+05	27.08				2.70E+06	929.78	956.86	956.86
Median				1.11E+05	27.08				2.70E+06	929.78	956.86	
St. Dev.				8.49E+03	2.07				1.77E+05	60.99	63.06	

1. This value used

Table C-36: AOC results related to Influent 2 from the June 27, 2012 sampling event

June 27, 2012 Influent 2	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf2-1-1	232	21	0	2.32E+05	56.61	TNTC	139	16	1.39E+06	479.55	536.16	
Vial Inf2-1-2	140	26	3	1.40E+05	34.16	TNTC	100	4	1.00E+06	345.00	379.16	
Vial Inf2-1-3	93	13	3	9.30E+04	22.69	TNTC	234	12	2.34E+06	807.30	829.99	
Vial Inf2-1-4												
Vial Inf2-1-5												
Vial Inf2-1-6												
Vial Inf2-1-7	110	6	2	1.10E+05	26.84	TNTC	128	17	1.28E+06	441.60	468.44	
Vial Inf2-1-8	123	13	2	1.23E+05	30.01	TNTC	**227**[1]	33	2.27E+06	783.15	813.16	
Vial Inf2-1-9	121	8	1	1.21E+05	29.52	TNTC	135	8	1.35E+06	465.75	495.27	
Vial Inf2-1-11	110	13	1	1.10E+05	26.84	TNTC	199	20	1.99E+06	686.55	713.39	
Vial Inf2-1-12	121	11	PCDS-1	1.21E+05	29.52	TNTC	122	PCDS-10	1.22E+06	420.90	450.42	
Vial Inf2-1-13	101	10	1	1.01E+05	24.64	TNTC	180	24	1.80E+06	621.00	645.64	
Vial Inf2-1-14	121	9	1	1.21E+05	29.52	TNTC	177	29	1.77E+06	610.65	640.17	
Vial Inf2-1-15	185	14	0	1.85E+05	45.14	TNTC	141	19	1.41E+06	486.45	531.59	
Vial Inf2-1-16	73	4	1	7.30E+04	17.81	TNTC	151	21	1.51E+06	520.95	538.76	
Average				1.28E+05	31.11				1.61E+06	555.74	586.85	586.85
Median				1.21E+05	29.52				1.46E+06	503.70	537.46	
St. Dev.				4.26E+04	10.41				4.24E+05	146.14	142.94	
Vial Inf2-1-10 GC-A												
Vial Inf2-1-10 GC-B												
Vial Inf2-1-10 GC-C												
Vial Inf2-1-10 GC-D	97	11	0	9.70E+04	23.67	TNTC	144	13	1.44E+06	496.80	520.47	
Vial Inf2-1-10 GC-E	108	12	2	1.08E+05	26.35	TNTC	157	19	1.57E+06	541.65	568.00	
Average				1.03E+05	25.01				1.51E+06	519.23	544.24	544.24
Median				1.03E+05	25.01				1.51E+06	519.23	544.24	
St. Dev.				7.78E+03	1.90				9.19E+04	31.71	33.61	

1. This value used

Table C-37: Pooled influent AOC data from the June 27, 2012 sampling event

June 27, 2012 Influent 1	P17 Enumeration					NOX Enumeration					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	PCDS-55	6	0			BP	189	26	1.89E+06	652.05		
Vial Inf1-1-2	108	10	0	1.08E+05	26.35	TNTC	179	13	1.79E+06	617.55	643.90	
Vial Inf1-1-3	93	10	0	9.30E+04	22.69	TNTC	214	PCDS-27	2.14E+06	738.30	760.99	
Vial Inf1-1-4												
Vial Inf1-1-5												
Vial Inf1-1-6												
Vial Inf1-1-7	80	6	2	8.00E+04	19.52	TNTC	138	8	1.38E+06	476.10	495.62	
Vial Inf1-1-8	78	11	0	7.80E+04	19.03	TNTC	193	22	1.93E+06	665.85	684.88	
Vial Inf1-1-9	137	14	3	1.37E+05	33.43	TNTC	167	26	1.67E+06	576.15	609.58	
Vial Inf1-1-11	**264**	33	2	2.64E+05	64.42	TNTC	163	18	1.63E+06	562.35	626.77	
Vial Inf1-1-12	74	12	1	7.40E+04	18.06	TNTC	191	27	1.91E+06	658.95	677.01	
Vial Inf1-1-13	90	8	1	9.00E+04	21.96	TNTC	149	20	1.49E+06	514.05	536.01	
Vial Inf1-1-14	98	7	0	9.80E+04	23.91	TNTC	121	9	1.21E+06	417.45	441.36	
Vial Inf1-1-15	107	15	1	1.07E+05	26.11	TNTC	165	18	1.65E+06	569.25	595.36	
Vial Inf1-1-16	108	12	1	1.08E+05	26.35	TNTC	250	27	2.50E+06	862.50	888.85	
Vial Inf2-1-1	232	21	0	2.32E+05	56.61	TNTC	139	16	1.39E+06	479.55	536.16	
Vial Inf2-1-2	140	26	3	1.40E+05	34.16	TNTC	100	4	1.00E+06	345.00	379.16	
Vial Inf2-1-3	93	13	3	9.30E+04	22.69	TNTC	234	12	2.34E+06	807.30	829.99	
Vial Inf2-1-4												
Vial Inf2-1-5												
Vial Inf2-1-6												
Vial Inf2-1-7	110	6	2	1.10E+05	26.84	TNTC	128	17	1.28E+06	441.60	468.44	
Vial Inf2-1-8	123	13	2	1.23E+05	30.01	TNTC	**227**	33	2.27E+06	783.15	813.16	
Vial Inf2-1-9	121	8	1	1.21E+05	29.52	TNTC	135	8	1.35E+06	465.75	495.27	
Vial Inf2-1-11	110	13	1	1.10E+05	26.84	TNTC	199	20	1.99E+06	686.55	713.39	
Vial Inf2-1-12	121	11	PCDS-1	1.21E+05	29.52	TNTC	122	PCDS-10	1.22E+06	420.90	450.42	
Vial Inf2-1-13	101	10	1	1.01E+05	24.64	TNTC	180	24	1.80E+06	621.00	645.64	
Vial Inf2-1-14	121	9	1	1.21E+05	29.52	TNTC	177	29	1.77E+06	610.65	640.17	
Vial Inf2-1-15	185	14	0	1.85E+05	45.14	TNTC	141	19	1.41E+06	486.45	531.59	
Vial Inf2-1-16	73	4	1	7.30E+04	17.81	TNTC	151	21	1.51E+06	520.95	538.76	
Average				1.20E+05	29.35				1.69E+06	582.48	608.80	611.83
Median				1.08E+05	26.35				1.66E+06	572.70	609.58	
St. Dev.				4.76E+04	11.60				3.86E+05	133.34	133.22	

Table C-38: AOC results related to the Process Blank from the June 27, 2012 sampling event

June 27, 2012 Process Blank	P-17 ENUMERATION						NOX ENUMERATION						TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial PB-1	TNTC	TNTC	128	7	1.3E+05	31.23	TNTC	28	6	0				
Vial PB-2	TNTC	TNTC	36	3	3.6E+04	8.78	TNTC	TNTC	58	9	5.8E+04	20.01	28.79	
Vial PB-3	TNTC	TNTC	121	12	1.2E+05	29.52	TNTC	40	12	1	4.0E+03	1.38	30.90	
Vial PB-4	TNTC	BP	BP	BP			TNTC	BP	BP	BP				
Vial PB-5	TNTC	BP	BP	BP			TNTC	BP	BP	BP				
Vial PB-6	TNTC	BP	BP	BP			TNTC	BP	BP	BP				
Vial PB-7	TNTC	TNTC	100	12	1.0E+05	24.40	TNTC	TNTC	9	0				
Vial PB-8	TNTC	TNTC	41	8	4.1E+04	10.00	TNTC	TNTC	26	0				
Vial PB-9	TNTC	TNTC	74	8	7.4E+04	18.06	TNTC	TNTC	40	2	4.0E+04	13.80	31.86	
Vial PB-11	TNTC	TNTC	39	5	3.9E+04	9.52	TNTC	TNTC	31	4	3.1E+04	10.70	20.21	
Vial PB-12	TNTC	TNTC	64		6.4E+04	15.62	TNTC	89	13	1	8.9E+03	3.07	18.69	
Vial PB-13	TNTC	TNTC	65	11	6.5E+04	15.86	TNTC	TNTC	28	0				
Vial PB-14	TNTC	TNTC	50	4	5.0E+04	12.20	TNTC	90	13	2	9.0E+03	3.11	15.31	
Vial PB-15	TNTC	TNTC	62	5	6.2E+04	15.13	TNTC	TNTC	56	5	5.6E+04	19.32	34.45	
Vial PB-16	TNTC	TNTC	57	5	5.7E+04	13.91	TNTC	TNTC	63	9	6.3E+04	21.74	35.64	
Average					6.98E+04	17.02					3.37E+04	11.64	26.98	28.66
Median					6.30E+04	15.37								
St. Dev.					3.09E+04	7.55					2.42E+04	8.35	7.78	
Vial PB-10 GC-A														
Vial PB-10 GC-B														
Vial PB-10 GC-C														
Vial PB-10 GC-D		**59**	11	1	5.9E+03	1.44	TNTC	TNTC	TNTC	118	1.2E+06	407.10	408.54	
Vial PB-10 GC-E				44[1]			TNTC	TNTC	TNTC					
Average					5.9E+03	1.44					1.2E+06	407.10	408.54	408.54
Median														
St. Dev.														

1. AOC concentration is high compared to the other data. This data point is considered an outlier and is not used.

Table C-39: AOC results related to the Blank Controls from the June 27, 2012 sampling event

June 27, 2012 Blank Controls	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Blank Control 1																		
Blank Control-2																		
Blank Control-3																		
Blank Control-4	66	67	83	0	0	0	3.6E+02	0.09	54	54	68	3	0	0	2.9E+02	0.10	0.19	
Blank Control-5	78	87	99	0	0	0	4.4E+02	0.11	132	117	119	0	0	0	6.1E+02	0.21	0.32	
Average							4.0E+02	0.10							4.5E+02	0.16	0.25	0.25
Median							4.0E+02	0.10							4.5E+02	0.16	0.25	
St. Dev.							5.7E+01	0.01							2.3E+02	0.08	0.09	

Table C-40: AOC results related to the Yield Controls from the June 27, 2012 sampling event

June 27, 2012 Yield Controls	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Yield Control -1																		
Yield Control -2																		
Yield Control-3																		
Yield Control-4	TNTC	TNTC	TNTC	4	0	0	4.0E+03	0.98	TNTC	TNTC	TNTC	104	7	2	1.0E+05	35.88	36.86	
Yield Control-5	0	0	0	0	0	0			TNTC	TNTC	TNTC	TNTC	55	9	5.5E+05	189.75		
Average							4.0E+03	0.98							3.3E+05	112.82	36.86	113.79
Median							4.0E+03	0.98							3.3E+05	112.82	36.86	
St. Dev.															3.2E+05	108.80		

Boxplots to Determine Which of the Counts in the Range of 30 to 300 Should Be Used

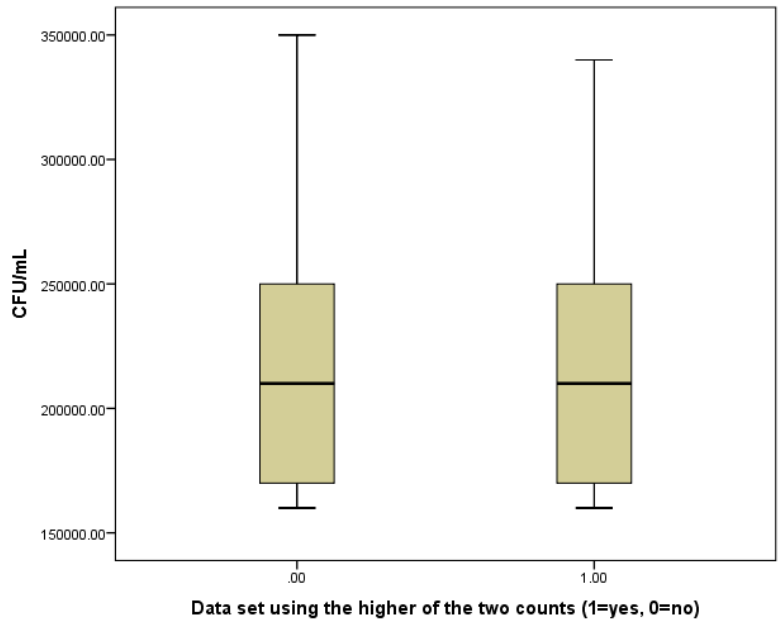

Figure C-9: Boxplots of Filter 1 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

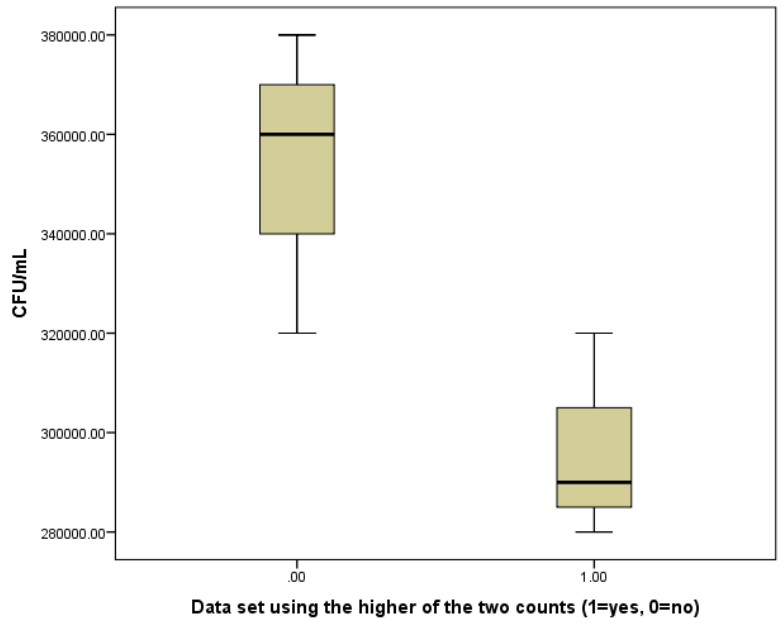

Figure C-10: Boxplots of Filter 1 Growth Control P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

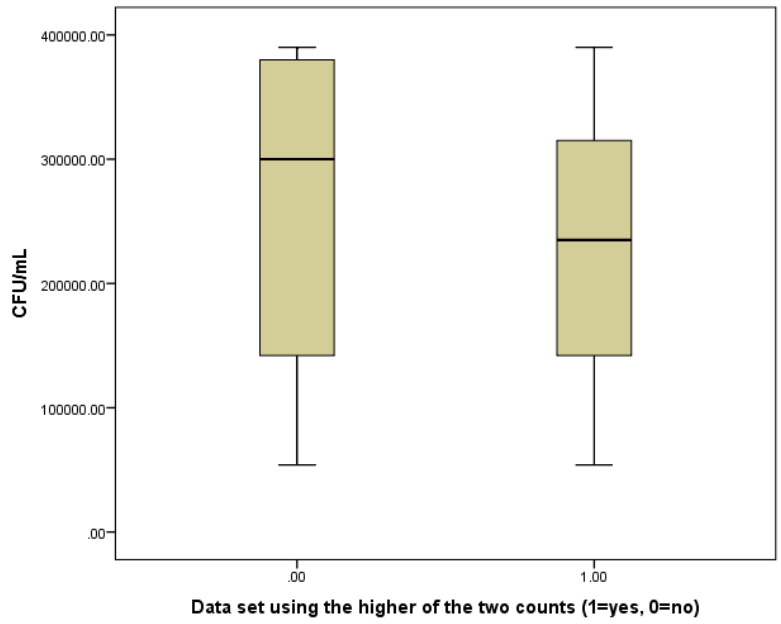

Figure C-11: Boxplots of Filter 2 Growth Control P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

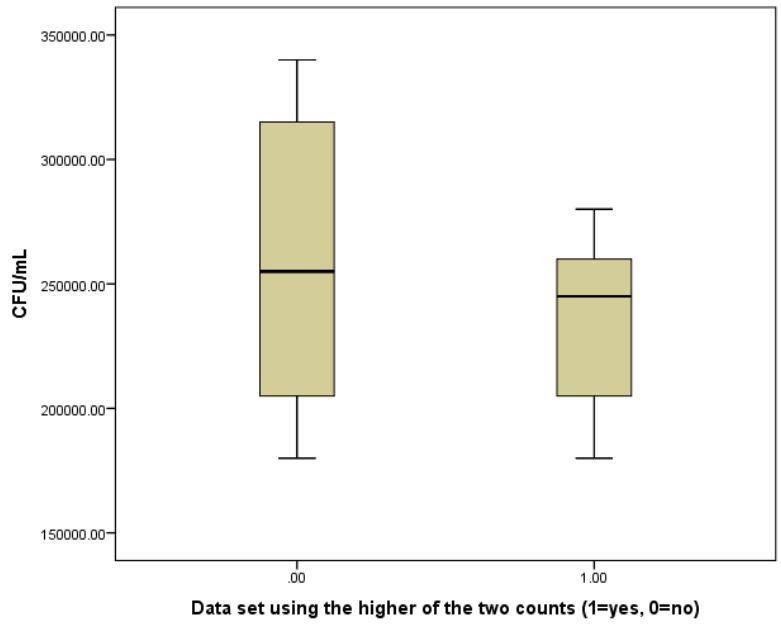

Figure C-12: Boxplots of Filter 4 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

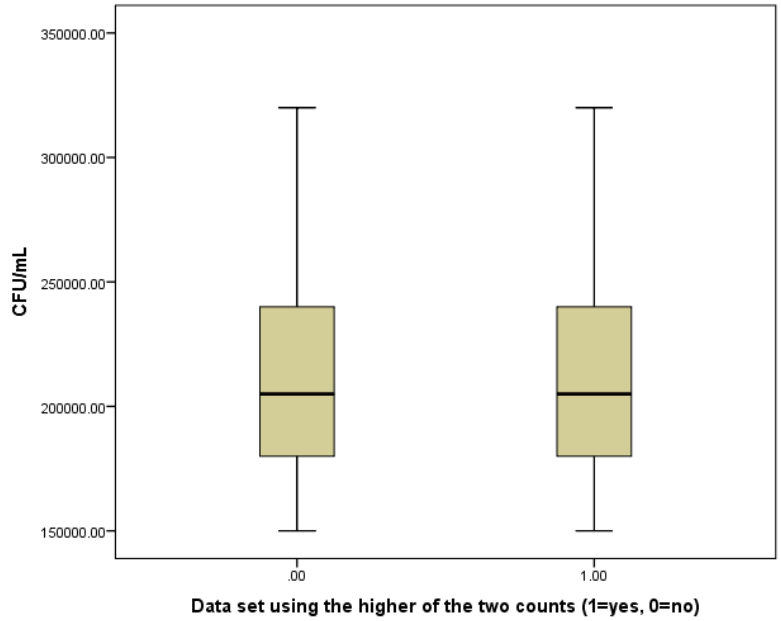

Figure C-13: Boxplots of Filter 5 P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

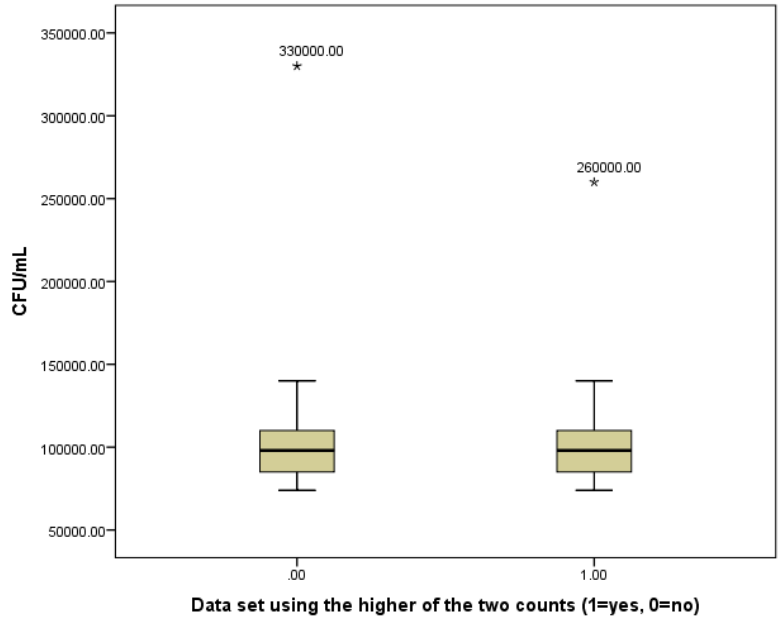

Figure C-14: Boxplots of Influent replicate 1P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

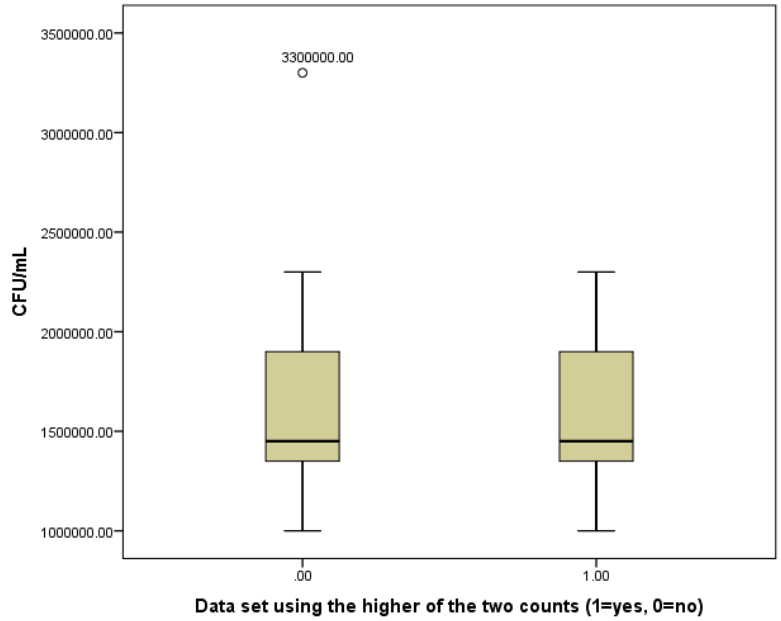

Figure C-15: Boxplots of Influent replicate 2 NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

Summary of Results and Calculated Values from Statistical Tests

Table C-41: Calculated mean ranks from Kruskal-Wallis test on the June 27, 2012 AOC concentrations

ID	N	Mean Rank
F1	11	25.00
F2	14	35.71
F3	12	42.92
F4	12	20.17
F5	9	19.89
Pooled Influent	23	70.00
Total	81	

Table C-42: Calculated test values and significance level from Kruskal-Wallis test on the June 27, 2012 AOC concentrations

Calculated Value			Value
Chi-Square			57.477
Degrees of freedom			5
Asymptotic Sig.			4.032E-11
Monte Carlo Sig.	Sig.		0.000E+00[1]
	99% Confidence Interval	Lower Bound	0.000E+00
		Upper Bound	4.605E-06

1. Based on 1000000 sampled tables with starting seed 2000000.

Table C-43: Summary of Calculated Values from Mann-Whitney Tests on AOC data from the June 27, 2012S sampling event

Comparison	N1[1]	N2[1]	Sum of Ranks 1[2]	Sum of Ranks 2[3]	Mann-Whitney U	Z	p-value (Asymptotic 2-tailed)	p-value (Exact 2-tailed)
Influent 1 vs Influent 2[4]	11	12	145	131	53.00	-0.800	4.237E-01	4.491E-01
Pooled Influent vs F1 Effluent	23	11	529	66	0.00	-4.657	3.212E-06	6.991E-09
Pooled Influent vs F2 Effluent	23	14	598	105	0.00	-5.042	4.609E-07	3.275E-10
Pooled Influent vs F3 Effluent	23	12	552	78	0.00	-4.796	1.620E-06	2.397E-09
Pooled Influent vs F4 Effluent	23	12	552	78	0.00	-4.796	1.620E-06	2.397E-09
Pooled Influent vs F5 Effluent	23	9	483	45	0.00	-4.338	1.438E-05	7.130E-08
F1Effluent vs F2 Effluent	11	14	112	213	46.00	-1.697	8.968E-02	9.543E-02
F1 Effluent vs F3 Effluent	11	12	87	189	21.00	-2.770	5.613E-03	4.489E-03
F1 Effluent vs F4 Effluent	11	12	149	127	49.00	-1.046	2.954E-01	3.164E-01
F1 Effluent vs F5 Effluent	11	9	125	85	40.00	-0.722	4.704E-01	5.027E-01
F2 Effluent vs F3 Effluent	14	12	166	185	61.00	-1.183	2.368E-01	2.520E-01
F2 Effluent vs F4 Effluent	14	12	237	114	36.00	-2.469	1.355E-02	1.267E-02
F2 Effluent vs F5 Effluent	14	9	199	77	32.00	-1.953	5.084E-02	5.338E-02
F3 Effluent vs F4 Effluent	12	12	202	98	20.00	-3.002	2.680E-03	1.830E-03
F3 Effluent vs F5 Effluent	12	9	173	58	13.00	-2.914	3.571E-03	2.436E-03
F4 Effluent vs F5 Effluent	12	9	137	94	49.00	-0.355	7.223E-01	7.544E-01

1. Number of data points of the first data set in the comparison. For example, in the comparison of the pooled influent data vs Filter 2 effluent, N=23 is the number of total AOC concentrations measured for the pooled influent and N=14 is the number of total AOC concentrations measured for the Filter 2 effluent.
2. Sum of ranks associated with the first sampling location listed in the comparison
3. Sum of ranks associated with the second sampling location listed in the comparison
4. Influent replicate 1 versus influent replicate 2

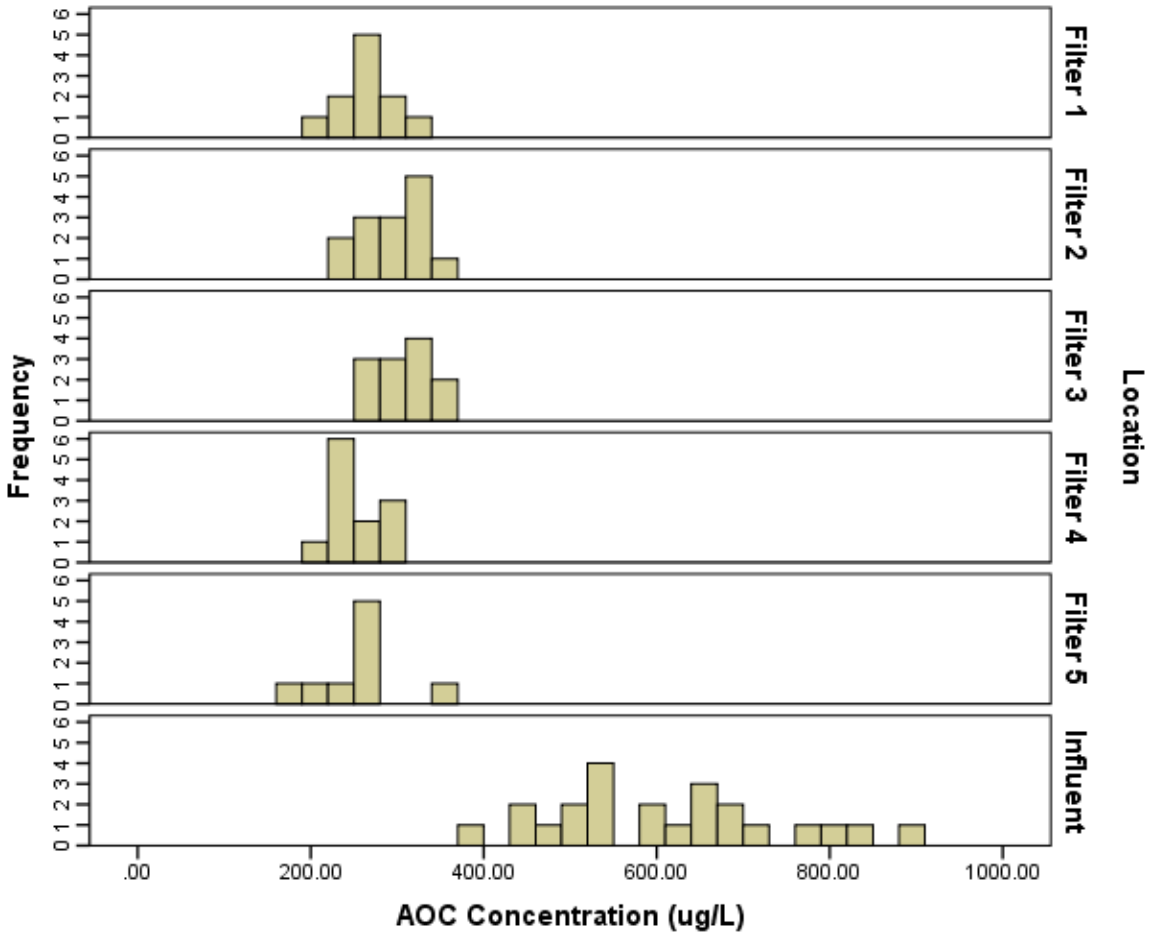

Figure C-16: Histograms of AOC concentrations from the June 27, 2012 AOC sampling event

August 8, 2012 Sampling Event

Raw Data and Summarized AOC Results

Table C-44: AOC results related to Filter 1 from the August 8, 2012 sampling event

August 8, 2102 Filter 1	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 1-1-1	206	29	0	2.06E+05	50.26	TNTC	68	8	6.80E+05	234.60	284.86	
Vial 1-1-2	188	17	4	1.88E+05	45.87	TNTC	77	13	7.70E+05	265.65	311.52	
Vial 1-1-3	173	24	1	1.73E+05	42.21	TNTC	69	8	6.90E+05	238.05	280.26	
Vial 1-1-4	132	14	3	1.32E+05	32.21	TNTC	60	7	6.00E+05	207.00	239.21	
Vial 1-1-5*												
Vial 1-1-6	183	25	1	1.83E+05	44.65	TNTC	63	8	6.30E+05	217.35	262.00	
Vial 1-1-7	120	11		1.20E+05	29.28	109	**58**[1]		5.80E+05	200.10	229.38	
Vial 1-1-8	82	11	3	8.20E+04	20.01	78	**44**[1]	2	4.40E+05	151.80	171.81	
Vial 1-1-9			2			TNTC		1				
Vial 1-1-11	104	22	3	1.04E+05	25.38	TNTC	51	8	5.10E+05	175.95	201.33	
Vial 1-1-12	174	18	1	1.74E+05	42.46	TNTC	65	10	6.50E+05	224.25	266.71	
Vial 1-1-13	150	18	1	1.50E+05	36.60	TNTC	49	6	4.90E+05	169.05	205.65	
Vial 1-1-14	PCDA-183	PCDA-13	BP	1.83E+05	44.65	TNTC	BP	BP				
Vial 1-1-15	PCDA-93	BP	0	9.30E+04	22.69	TNTC	BP	PCDS-15				
Vial 1-1-16	BP	PCDS-31	BP			BP	PCDS-95	BP				
Average				1.49E+05	36.36				6.04E+05	208.38	245.27	244.74
Median				1.62E+05	39.41				6.15E+05	212.18	250.61	
St. Dev.				4.16E+04	10.16				1.02E+05	35.04	43.60	
Vial 1-1-10 GC-A	31	3	1	3.10E+04	7.56	TNTC	104	8	1.04E+06	358.80	366.36	
Vial 1-1-10 GC-B	61	8	0	6.10E+04	14.88	TNTC	85	5	8.50E+05	293.25	308.13	
Vial 1-1-10 GC-C	130	9	1	1.30E+05	31.72	TNTC	89	7	8.90E+05	307.05	338.77	
Vial 1-1-10 GC-D	62	10	4	6.20E+04	15.13	TNTC	71	5	7.10E+05	244.95	260.08	
Vial 1-1-10 GC-E	74	5	1	7.40E+04	18.06	TNTC	106	9	1.06E+06	365.70	383.76	
Average				7.16E+04	17.47				9.10E+05	313.95	331.42	331.42
Median				6.20E+04	15.13				8.90E+05	307.05	338.77	
St. Dev.				3.63E+04	8.86				1.44E+05	49.82	49.11	

1. This value used

Table C-45: AOC results related to Filter 2 from the August 8, 2012 sampling event

August 8, 2012 Filter 3	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 3-1-1	93	9	1	9.30E+04	22.69	TNTC	68	7	6.80E+05	234.60	257.29	
Vial 3-1-2	73	12	0	7.30E+04	17.81	TNTC	84	7	8.40E+05	289.80	307.61	
Vial 3-1-3	76	11	0	7.60E+04	18.54	TNTC	73	7	7.30E+05	251.85	270.39	
Vial 3-1-4	102	12	2	1.02E+05	24.89	TNTC	80	8	8.00E+05	276.00	300.89	
Vial 3-1-5	123	12	2	1.23E+05	30.01	TNTC	103	18	1.03E+06	355.35	385.36	
Vial 3-1-6	57	11	2	5.70E+04	13.91	TNTC	80	7	8.00E+05	276.00	289.91	
Vial 3-1-7	68	9	14	6.80E+04	16.59	204	**62**[1]		6.20E+05	213.90	230.49	
Vial 3-1-8	77	12	1	7.70E+04	18.79	251	**54**[1]	4	5.40E+05	186.30	205.09	
Vial 3-1-9	58	6	0	5.80E+04	14.15		53	0	5.30E+05	182.85	197.00	
Vial 3-1-11	64	10	1	6.40E+04	15.62		70	13	7.00E+05	241.50	257.12	
Vial 3-1-12	82	4	2	8.20E+04	20.01		63	6	6.30E+05	217.35	237.36	
Vial 3-1-13	110	15	11	1.10E+05	26.84		58		5.80E+05	200.10	226.94	
Vial 3-1-14	PCDA-67	BP	BP	6.70E+04	16.35	TNTC	BP	BP				
Vial 3-1-15	PCDA-81	BP	1	8.10E+04	19.76	TNTC	BP	5				
Vial 3-1-16	91	PCDA-8	1	9.10E+04	22.20		PCDA-86	4	8.60E+05	296.70	318.90	
Average				8.15E+04	19.88				7.18E+05	247.87	268.03	267.75
Median				7.70E+04	18.79				7.00E+05	241.50	257.29	
St. Dev.				1.92E+04	4.68				1.45E+05	49.91	52.25	
Vial 3-1-10 GC-A	67	10	0	6.70E+04	16.35		117	15	1.17E+06	403.65	420.00	
Vial 3-1-10 GC-B	67	11	0	6.70E+04	16.35		114	13	1.14E+06	393.30	409.65	
Vial 3-1-10 GC-C	58	6	0	5.80E+04	14.15		112	11	1.12E+06	386.40	400.55	
Vial 3-1-10 GC-D	78	8	0	7.80E+04	19.03		107	8	1.07E+06	369.15	388.18	
Vial 3-1-10 GC-E	83	9	0	8.30E+04	20.25		63	6	6.30E+05	217.35	237.60	
Average				7.06E+04	17.23				1.03E+06	353.97	371.20	371.20
Median				6.70E+04	16.35				1.12E+06	386.40	400.55	
St. Dev.				9.91E+03	2.42				2.24E+05	77.40	75.59	

1. This value used

Table C-46: AOC results related to Filter 3 from the August 8, 2012 sampling event

August 8, 2012 Filter 3	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 3-1-1	93	9	1	9.30E+04	22.69	TNTC	68	7	6.80E+05	234.60	257.29	
Vial 3-1-2	73	12	0	7.30E+04	17.81	TNTC	84	7	8.40E+05	289.80	307.61	
Vial 3-1-3	76	11	0	7.60E+04	18.54	TNTC	73	7	7.30E+05	251.85	270.39	
Vial 3-1-4	102	12	2	1.02E+05	24.89	TNTC	80	8	8.00E+05	276.00	300.89	
Vial 3-1-5	123	12	2	1.23E+05	30.01	TNTC	103	18	1.03E+06	355.35	385.36	
Vial 3-1-6	57	11	2	5.70E+04	13.91	TNTC	80	7	8.00E+05	276.00	289.91	
Vial 3-1-7	68	9	14	6.80E+04	16.59	204	**62**[1]		6.20E+05	213.90	230.49	
Vial 3-1-8	77	12	1	7.70E+04	18.79	**251**[1]	54	4	2.51E+05	86.60	105.38	
Vial 3-1-9	58	6	0	5.80E+04	14.15		53	0	5.30E+05	182.85	197.00	
Vial 3-1-11	64	10	1	6.40E+04	15.62		70	13	7.00E+05	241.50	257.12	
Vial 3-1-12	82	4	2	8.20E+04	20.01		63	6	6.30E+05	217.35	237.36	
Vial 3-1-13	110	15	11	1.10E+05	26.84		58		5.80E+05	200.10	226.94	
Vial 3-1-14	PCDA-67	BP	BP	6.70E+04	16.35	TNTC	BP	BP				
Vial 3-1-15	PCDA-81	BP	1	8.10E+04	19.76	TNTC	BP	5				
Vial 3-1-16	91	PCDA-8	1	9.10E+04	22.20		PCDA-86	4	8.60E+05	296.70	318.90	
Average				8.15E+04	19.88				7.18E+05	247.87	260.36	260.08
Median				7.70E+04	18.79				7.00E+05	241.50	257.29	
St. Dev.				1.92E+04	4.68				1.45E+05	49.91	67.39	
Vial 3-1-10 GC-A	67	10	0	6.70E+04	16.35		117	15	1.17E+06	403.65	420.00	
Vial 3-1-10 GC-B	67	11	0	6.70E+04	16.35		114	13	1.14E+06	393.30	409.65	
Vial 3-1-10 GC-C	58	6	0	5.80E+04	14.15		112	11	1.12E+06	386.40	400.55	
Vial 3-1-10 GC-D	78	8	0	7.80E+04	19.03		107	8	1.07E+06	369.15	388.18	
Vial 3-1-10 GC-E	83	9	0	8.30E+04	20.25		63	6	6.30E+05	217.35	237.60	
Average				7.06E+04	17.23				1.03E+06	353.97	371.20	371.20
Median				6.70E+04	16.35				1.12E+06	386.40	400.55	
St. Dev.				9.91E+03	2.42				2.24E+05	77.40	75.59	

1. This value used.

Table C-47: AOC results related to Filter 4 from the August 8, 2012 sampling event

August 8, 2012 Filter 4	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 4-1-1	147	16	2	1.47E+05	35.87	TNTC	96	18	9.60E+05	331.20	367.07	
Vial 4-1-2	155	23	0	1.55E+05	37.82	TNTC	98	13	9.80E+05	338.10	375.92	
Vial 4-1-3	93	21	3	9.30E+04	22.69	TNTC	93	13	9.30E+05	320.85	343.54	
Vial 4-1-4	53	7	1	5.30E+04	12.93	TNTC	90	7	9.00E+05	310.50	323.43	
Vial 4-1-5	96	16	3	9.60E+04	23.42	TNTC	73	4	7.30E+05	251.85	275.27	
Vial 4-1-6	79	8	0	7.90E+04	19.28	TNTC	97	17	9.70E+05	334.65	353.93	
Vial 4-1-7	68	4	1	6.80E+04	16.59		72	4	7.20E+05	248.40	264.99	
Vial 4-1-8	120	15	0	1.20E+05	29.28	108	**62**[1]	0	6.20E+05	213.90	243.18	
Vial 4-1-9	95	12	3	9.50E+04	23.18	193	**79**[1]	10	7.90E+05	272.55	295.73	
Vial 4-1-11	135	15	2	1.35E+05	32.94		64	12	6.40E+05	220.80	253.74	
Vial 4-1-12	125	21	2	1.25E+05	30.50		68	8	6.80E+05	234.60	265.10	
Vial 4-1-13	89	9	1	8.90E+04	21.72		81	11	8.10E+05	279.45	301.17	
Vial 4-1-14	212	23	2	2.12E+05	51.73	TNTC	107	10	1.07E+06	369.15	420.88	
Vial 4-1-15	124	BP	0	1.24E+05	30.26	TNTC	BP	6				
Vial 4-1-16	119	BP	BP	1.19E+05	29.04	TNTC	BP	BP				
Average				1.14E+05	27.82				8.31E+05	286.62	314.15	314.43
Median				1.19E+05	29.04				8.10E+05	279.45	301.17	
St. Dev.				3.96E+04	9.65				1.47E+05	50.62	54.82	
Vial 4-1-10 GC-A	**232**[1]	32	2	2.32E+05	56.61	TNTC	219	18	2.19E+06	755.55	812.16	
Vial 4-1-10 GC-B	135	21	1	1.35E+05	32.94	TNTC	165	16	1.65E+06	569.25	602.19	
Vial 4-1-10 GC-C	125	13	3	1.25E+05	30.50	TNTC	168	16	1.68E+06	579.60	610.10	
Vial 4-1-10 GC-D	115	12	1	1.15E+05	28.06	TNTC	173	1	1.73E+06	596.85	624.91	
Vial 4-1-10 GC-E	129	8	0	1.29E+05	31.48	TNTC	158	0	1.58E+06	545.10	576.58	
Average				1.47E+05	35.92				1.77E+06	609.27	645.19	645.19
Median				1.29E+05	31.48				1.68E+06	579.60	610.10	
St. Dev.				4.80E+04	11.70				2.43E+05	83.89	94.97	

1. This value used

Table C-48: AOC results related to Filter 5 from the August 8, 2012 sampling event

August 8, 2012 Filter 5	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 5-1-1	52	7	0	5.20E+04	12.69	TNTC	60	3	6.00E+05	207.00	219.69	
Vial 5-1-2	59	3	1	5.90E+04	14.40	TNTC	61	2	6.10E+05	210.45	224.85	
Vial 5-1-3	46	4	1	4.60E+04	11.22	TNTC	56	4	5.60E+05	193.20	204.42	
Vial 5-1-4	31	3	2	3.10E+04	7.56	TNTC	64	3	6.40E+05	220.80	228.36	
Vial 5-1-5	54	5	0	5.40E+04	13.18	TNTC	68	3	6.80E+05	234.60	247.78	
Vial 5-1-6	45	4	2	4.50E+04	10.98	TNTC	65	5	6.50E+05	224.25	235.23	
Vial 5-1-7	63	7	1	6.30E+04	15.37	TNTC	57	10	5.70E+05	196.65	212.02	
Vial 5-1-8	32	1	0	3.20E+04	7.81	TNTC	32	0	3.20E+05	110.40	118.21	
Vial 5-1-9	47	5	0	4.70E+04	11.47	TNTC	42	0	4.20E+05	144.90	156.37	
Vial 5-1-11	38	5	1	3.80E+04	9.27	TNTC	51	7	5.10E+05	175.95	185.22	
Vial 5-1-12	64	7	0	6.40E+04	15.62	TNTC	64	9	6.40E+05	220.80	236.42	
Vial 5-1-13	44	7	0	4.40E+04	10.74	TNTC	51	5	5.10E+05	175.95	186.69	
Vial 5-1-14	57	6	0	5.70E+04	13.91	TNTC	66	PCDS-10	6.60E+05	227.70	241.61	
Vial 5-1-15	BP	BP	PCDS-1			BP	BP	PCDS-8				
Vial 5-1-16	29	BP	BP	2.90E+04	7.08	PCDS-415	BP	BP				
Average				4.72E+04	11.52				5.67E+05	195.59	207.45	207.11
Median				4.65E+04	11.35				6.00E+05	207.00	219.69	
St. Dev.				1.16E+04	2.84				1.05E+05	36.06	37.44	
Vial 5-1-10 GC-A	141	16	2	1.41E+05	34.40	TNTC	229	17	2.29E+06	790.05	824.45	
Vial 5-1-10 GC-B	159	23	1	1.59E+05	38.80	TNTC	195	25	1.95E+06	672.75	711.55	
Vial 5-1-10 GC-C	134	17	3	1.34E+05	32.70	TNTC	210	25	2.10E+06	724.50	757.20	
Vial 5-1-10 GC-D	114	16	1	1.14E+05	27.82	TNTC	156	7	1.56E+06	538.20	566.02	
Vial 5-1-10 GC-E	135	11	0	1.35E+05	32.94	TNTC	177	0	1.77E+06	610.65	643.59	
Average				1.37E+05	33.33				1.93E+06	667.23	700.56	700.56
Median				1.35E+05	32.94				1.95E+06	672.75	711.55	
St. Dev.				1.61E+04	3.94				2.83E+05	97.78	100.03	

Table C-49: AOC results related to Influent 1 from the August 8, 2012 sampling event

August 8, 2012 Influent 1	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	96	8	0	9.60E+04	23.42	TNTC	148	8	1.48E+06	510.60	534.02	
Vial Inf1-1-2	104	11	2	1.04E+05	25.38	TNTC	144	19	1.44E+06	496.80	522.18	
Vial Inf1-1-3	61	11	0	6.10E+04	14.88	TNTC	104	12	1.04E+06	358.80	373.68	
Vial Inf1-1-4	61	5	1	6.10E+04	14.88	TNTC	118	13	1.18E+06	407.10	421.98	
Vial Inf1-1-5	114	14	0	1.14E+05	27.82	TNTC	157	17	1.57E+06	541.65	569.47	
Vial Inf1-1-6	54	5	2	5.40E+04	13.18	TNTC	102	12	1.02E+06	351.90	365.08	
Vial Inf1-1-7	105		0	1.05E+05	25.62	TNTC		0				
Vial Inf1-1-8	BP	6	0			TNTC	100	0	1.00E+06	345.00		
Vial Inf1-1-9	20	0	0			TNTC	0	0				
Vial Inf1-1-11	84	5	PCDS-3	8.40E+04	20.50	TNTC	197	11	1.97E+06	679.65	700.15	
Vial Inf1-1-12	300	PCDS-25	3	3.00E+05	73.20	TNTC	PCDA-118	PCDA-23	1.18E+06	407.10	480.30	
Vial Inf1-1-13	113	7	PCDS-3	1.13E+05	27.57	TNTC	149	17	1.49E+06	514.05	541.62	
Vial Inf1-1-14	82	BP	2	8.20E+04	20.01	TNTC	BP	PCDS-9				
Vial Inf1-1-15	108	BP	BP	1.08E+05	26.35	TNTC	BP	BP				
Vial Inf1-1-16	97	14	0	9.70E+04	23.67	TNTC	125	14	1.25E+06	431.25	454.92	
Average				1.06E+05	25.88				1.33E+06	458.54	496.34	484.42
Median				9.70E+04	23.67				1.25E+06	431.25	501.24	
St. Dev.				6.17E+04	15.07				2.95E+05	101.64	100.44	
Vial Inf1-1-10 GC-A	160	22	4	1.60E+05	39.04	TNTC	TNTC	54	5.40E+06	1863.00	1902.04	
Vial Inf1-1-10 GC-B	170	21	2	1.70E+05	41.48	TNTC	TNTC	37	3.70E+06	1276.50	1317.98	
Vial Inf1-1-10 GC-C	176	22	3	1.76E+05	42.94	TNTC	TNTC	54	5.40E+06	1863.00	1905.94	
Vial Inf1-1-10 GC-D	174	26	1	1.74E+05	42.46	TNTC	TNTC	48	4.80E+06	1656.00	1698.46	
Vial Inf1-1-10 GC-E	139	12	1	1.39E+05	33.92	TNTC	TNTC	BP				
Average				1.64E+05	39.97				4.83E+06	1664.63	1706.11	1704.59
Median				1.70E+05	41.48				5.10E+06	1759.50	1800.25	
St. Dev.				1.52E+04	3.70				8.02E+05	276.54	276.30	

Table C-50: AOC results related to Influent 2 from the August 8, 2012 sampling event

August 8, 2012 Influent 2	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf2-1-1	44	4	0	4.40E+04	10.74	TNTC	76	19	7.60E+05	262.20	272.94	
Vial Inf2-1-2	145	13	4	1.45E+05	35.38	TNTC	144	15	1.44E+06	496.80	532.18	
Vial Inf2-1-3	79	3	2	7.90E+04	19.28	TNTC	136	11	1.36E+06	469.20	488.48	
Vial Inf2-1-4	81	7	0	8.10E+04	19.76	TNTC	129	11	1.29E+06	445.05	464.81	
Vial Inf2-1-5	112	14	1	1.12E+05	27.33	TNTC	148	9	1.48E+06	510.60	537.93	
Vial Inf2-1-6	48	6	1	4.80E+04	11.71	TNTC	98	11	9.80E+05	338.10	349.81	
Vial Inf2-1-7	110	12	0	1.10E+05	26.84	TNTC	230	0	2.30E+06	793.50	820.34	
Vial Inf2-1-8	57	0	0	5.70E+04	13.91	TNTC	0	0				
Vial Inf2-1-9	27	BP	0			TNTC	BP	0				
Vial Inf2-1-11	49	PCDS-6	0	4.90E+04	11.96	TNTC	PCDA-102	PCDA-13	1.02E+06	351.90	363.86	
Vial Inf2-1-12	70	7	PCDS-1	7.00E+04	17.08	TNTC	108	PCDA-9	1.08E+06	372.60	389.68	
Vial Inf2-1-13	PCDS-57	PCDS-9	0			TNTC	PCDS-173	PCDS-8				
Vial Inf2-1-14	76	BP	0	7.60E+04	18.54	TNTC	BP	23				
Vial Inf2-1-15	BP	PCDS-5	1			BP	154	8	1.54E+06	531.30		
Vial Inf2-1-16	121	8	1	1.21E+05	29.52	TNTC	122	25	1.22E+06	420.90	450.42	
Average				8.27E+04	20.17				1.32E+06	453.83	467.04	474.00
Median				7.75E+04	18.91				1.29E+06	445.05	457.62	
St. Dev.				3.26E+04	7.95				4.05E+05	139.62	150.14	
Vial Inf2-1-10 GC-A	145	11	1	1.45E+05	35.38	TNTC	TNTC	48	4.80E+06	1656.00	1691.38	
Vial Inf2-1-10 GC-B	147	12	1	1.47E+05	35.87	TNTC	TNTC	49	4.90E+06	1690.50	1726.37	
Vial Inf2-1-10 GC-C	135	18	2	1.35E+05	32.94	TNTC	TNTC	48	4.80E+06	1656.00	1688.94	
Vial Inf2-1-10 GC-D	70	1	0	7.00E+04	17.08	TNTC	PCDS-36	0				
Vial Inf2-1-10 GC-E	108	1	0	1.08E+05	26.35	TNTC	PCDS-55	26				
Average				1.21E+05	29.52				4.83E+06	1667.50	1702.23	1697.02
Median				1.35E+05	32.94				4.80E+06	1656.00	1691.38	
St. Dev.				3.25E+04	7.92				5.77E+04	19.92	20.94	

Table C-51: Pooled influent AOC data from the August 8, 2012 sampling event

Pooled Influent	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	96	8	0	9.60E+04	23.42	TNTC	148	8	1.48E+06	510.60	534.02	
Vial Inf1-1-2	104	11	2	1.04E+05	25.38	TNTC	144	19	1.44E+06	496.80	522.18	
Vial Inf1-1-3	61	11	0	6.10E+04	14.88	TNTC	104	12	1.04E+06	358.80	373.68	
Vial Inf1-1-4	61	5	1	6.10E+04	14.88	TNTC	118	13	1.18E+06	407.10	421.98	
Vial Inf1-1-5	114	14	0	1.14E+05	27.82	TNTC	157	17	1.57E+06	541.65	569.47	
Vial Inf1-1-6	54	5	2	5.40E+04	13.18	TNTC	102	12	1.02E+06	351.90	365.08	
Vial Inf1-1-7	105		0	1.05E+05	25.62	TNTC		0				
Vial Inf1-1-8	BP	6	0			TNTC	100	0	1.00E+06	345.00		
Vial Inf1-1-9	20	0	0			TNTC	0	0				
Vial Inf1-1-11	84	5	PCDS-3	8.40E+04	20.50	TNTC	197	11	1.97E+06	679.65	700.15	
Vial Inf1-1-12	**300**[1]	PCDS-25	3	3.00E+05	73.20	TNTC	PCDA-118	PCDA-23	1.18E+06	407.10	480.30	
Vial Inf1-1-13	113	7	PCDS-3	1.13E+05	27.57	TNTC	149	17	1.49E+06	514.05	541.62	
Vial Inf1-1-14	82	BP	2	8.20E+04	20.01	TNTC	BP	PCDS-9				
Vial Inf1-1-15	108	BP	BP	1.08E+05	26.35	TNTC	BP	BP				
Vial Inf1-1-16	97	14	0	9.70E+04	23.67	TNTC	125	14	1.25E+06	431.25	454.92	
Vial Inf2-1-1	44	4	0	4.40E+04	10.74	TNTC	76	19	7.60E+05	262.20	272.94	
Vial Inf2-1-2	145	13	4	1.45E+05	35.38	TNTC	144	15	1.44E+06	496.80	532.18	
Vial Inf2-1-3	79	3	2	7.90E+04	19.28	TNTC	136	11	1.36E+06	469.20	488.48	
Vial Inf2-1-4	81	7	0	8.10E+04	19.76	TNTC	129	11	1.29E+06	445.05	464.81	
Vial Inf2-1-5	112	14	1	1.12E+05	27.33	TNTC	148	9	1.48E+06	510.60	537.93	
Vial Inf2-1-6	48	6	1	4.80E+04	11.71	TNTC	98	11	9.80E+05	338.10	349.81	
Vial Inf2-1-7	110	12	0	1.10E+05	26.84	TNTC	230	0	2.30E+06	793.50	820.34	
Vial Inf2-1-8	57	0	0	5.70E+04	13.91	TNTC	0	0				
Vial Inf2-1-9	27	BP	0			TNTC	BP	0				
Vial Inf2-1-11	49	PCDS-6	0	4.90E+04	11.96	TNTC	PCDA-102	PCDA-13	1.02E+06	351.90	363.86	
Vial Inf2-1-12	70	7	PCDS-1	7.00E+04	17.08	TNTC	108	PCDA-9	1.08E+06	372.60	389.68	
Vial Inf2-1-13	PCDS-57	PCDS-9	0			TNTC	PCDS-173	PCDS-8				
Vial Inf2-1-14	76	BP	0	7.60E+04	18.54	TNTC	BP	23				
Vial Inf2-1-15	BP	PCDS-5	1			BP	154	8	1.54E+06	531.30		
Vial Inf2-1-16	121	8	1	1.21E+05	29.52	TNTC	122	25	1.22E+06	420.90	450.42	
Average				9.48E+04	23.14				1.32E+06	456.18	481.69	479.33
Median				8.40E+04	20.50				1.27E+06	438.15	472.56	
St. Dev.				5.04E+04	12.29				3.46E+05	119.20	125.23	

1. This value used

Table C-52: AOC results related to the Process Blank from August 8, 2012 sampling event

August 8, 2012 Process Blank	P-17 ENUMERATION								NOX ENUMERATION								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.1	0.1	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Process Blank																		
Vial PB-1	TNTC	TNTC	TNTC	TNTC	78	3	7.80E+04	19.03	TNTC	TNTC	TNTC	TNTC	13	1	1.30E+04	4.49	23.52	
Vial PB-2	TNTC	TNTC	TNTC	TNTC	68	15	6.80E+04	16.59	TNTC	TNTC	TNTC	TNTC	9	3				
Vial PB-3	TNTC	TNTC	TNTC	TNTC	54	6	5.40E+04	13.18	TNTC	TNTC	TNTC	TNTC	12	2	1.20E+04	4.14	17.32	
Vial PB-4	TNTC	TNTC	TNTC	TNTC	68	3	6.80E+04	16.59	TNTC	TNTC	TNTC	TNTC	21	4	2.10E+04	7.25	23.84	
Vial PB-5	TNTC	TNTC	TNTC	TNTC	53	4	5.30E+04	12.93	TNTC	TNTC	TNTC	TNTC	14	1	1.40E+04	4.83	17.76	
Vial PB-6	TNTC	TNTC	TNTC	TNTC	51	3	5.10E+04	12.44	TNTC	TNTC	TNTC	TNTC	10	1	1.00E+04	3.45	15.89	
Vial PB-7	TNTC	TNTC	TNTC	TNTC	27	3			TNTC	TNTC	TNTC	TNTC	15	1	1.50E+04	5.18		
Vial PB-8	TNTC	TNTC	TNTC	TNTC	42	9	4.20E+04	10.25	TNTC	TNTC	TNTC	TNTC	161	0	1.61E+05	55.55	65.79	
Vial PB-9	TNTC	TNTC	TNTC	TNTC	42	3	4.20E+04	10.25	TNTC	TNTC	TNTC	TNTC	21	1	2.10E+04	7.25	17.49	
Vial PB-11	TNTC	TNTC	TNTC	TNTC	PCDA-51	PCDA-3	5.10E+04	12.44	TNTC	TNTC	TNTC	TNTC	PCDA-47	PCDA-3	4.70E+04	16.22	28.66	
Vial PB-12	TNTC	TNTC	TNTC	386	28	BP	3.86E+04	9.42	TNTC	TNTC	TNTC	118	PCDS-16	BP	1.18E+04	4.07	13.49	
Vial PB-13	TNTC	TNTC	TNTC	77	PCDS-11	0	7.70E+03	1.88	TNTC	TNTC	TNTC	PCDS-190	BP	PCDS-2				
Vial PB-14	TNTC	TNTC	TNTC	TNTC	44	5	4.40E+04	10.74	TNTC	TNTC	TNTC	95	0	1	9.50E+03	3.28	14.01	
Vial PB-15	TNTC	TNTC	TNTC	45	BP	0	4.50E+03	1.10	TNTC	TNTC	TNTC	83	BP	0	8.30E+03	2.86	3.96	
Vial PB-16	TNTC	TNTC	TNTC	PCDS-39	BP	0			TNTC	TNTC	TNTC	PCDS-41	BP	5				
Average							4.63E+04	11.30							2.86E+04	9.88	21.98	21.17
Median							5.10E+04	12.44							1.35E+04	4.66	17.49	
St. Dev.							2.13E+04	5.19							4.30E+04	14.82	15.90	
Vial PB-1-10 GC-A	TNTC	TNTC	TNTC	305	17	1	3.05E+04	7.44	TNTC	TNTC	TNTC	TNTC	TNTC	190	1.90E+06	655.50	662.94	
Vial PB-1-10 GC-B	TNTC	TNTC	TNTC	120	18	2	1.20E+04	2.93	TNTC	TNTC	TNTC	TNTC	TNTC	258	2.58E+06	890.10	893.03	
Vial PB-1-10 GC-C	TNTC	TNTC	TNTC	54	5	3	5.40E+03	1.32	TNTC	TNTC	TNTC	TNTC	TNTC	244	2.44E+06	841.80	843.12	
Vial PB-1-10 GC-D	TNTC	TNTC	TNTC	TNTC	60	3	6.00E+04	14.64	TNTC	TNTC	TNTC	TNTC	TNTC	71	7.10E+05	244.95	259.59	
Vial PB-1-10 GC-E	TNTC	TNTC	TNTC	**283**[1]	31	2	2.83E+04	6.91	TNTC	TNTC	TNTC	TNTC	TNTC	146	1.46E+06	503.70	510.61	
Average							2.72E+04	6.65							1.82E+06	627.21	633.86	633.86
Median							2.83E+04	6.91							1.90E+06	655.50	662.94	
St. Dev.							2.12E+04	5.17							7.63E+05	263.31	258.40	

1. This value used

Table C-53: AOC results related to the Blank Controls from the August 8, 2012 sampling event

April 8, 2012 Blank Controls	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Blank Control-1	0	0	0	0	0	0	0.00	0	20	25	28	2	0	0	1.22E+02	0.04	0.04	
Blank Control-2	0	0	0	0	0	0	0.00	0	41	36	40	0	0	0	1.95E+02	0.07	0.07	
Blank Control-3	0	0	0	0	0	0	0.00	0	32	31	41	2	0	0	1.73E+02	0.06	0.06	
Blank Control-4	0	0	0	0	0	0	0.00	0	55	37	25	0	0	0	1.95E+02	0.07	0.07	
Blank Control-5	0	0	0	0	0	0	0.00	0	23	24	0	0	0	0	7.83E+01	0.03	0.03	
Average GC							0.00	0.00							1.53E+02	0.05	0.05	0.05
Median							0.00	0.00							1.73E+02	0.06	0.06	
St. Dev. GC							0.00	0.00							5.12E+01	0.02	0.02	

Table C-54: AOC results related to the Yield Controls from the August 8, 2012 sampling event

August 8, 2012 Yield Controls	P-17 Enumeration								NOX Enumeration									TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Yield Control -1	1	2	1	0	0	0	6.67E+00	0.00	TNTC	TNTC	TNTC	18	3	BP	0				
Yield Control -2	2	0	0	0	0	0	3.33E+00	0.00	TNTC	TNTC	TNTC	134	20	2	2	1.34E+04	4.62	4.62	
Yield Control-3	0	0	0	0	0	0			TNTC	TNTC	TNTC	40	3	0	0	4.00E+03	1.38		
Yield Control-4	0	0	0	0	0	0			TNTC	TNTC	TNTC	64	7	1	0	6.40E+03	2.21		
Yield Control-5	3	0	1	0	0	0	6.67E+00	0.00	TNTC	TNTC	TNTC	423	0	1	1	4.23E+04	14.59	14.60	
Average							5.56E+00	0.00								1.65E+04	5.70	9.61	5.70
Median							6.67E+00	0.00								9.90E+03	3.42	9.61	
St. Dev.							1.92E+00	0.00								1.76E+04	6.09	7.05	

Boxplots to Determine Which of the Counts in the Range of 30 to 300 Should Be Used

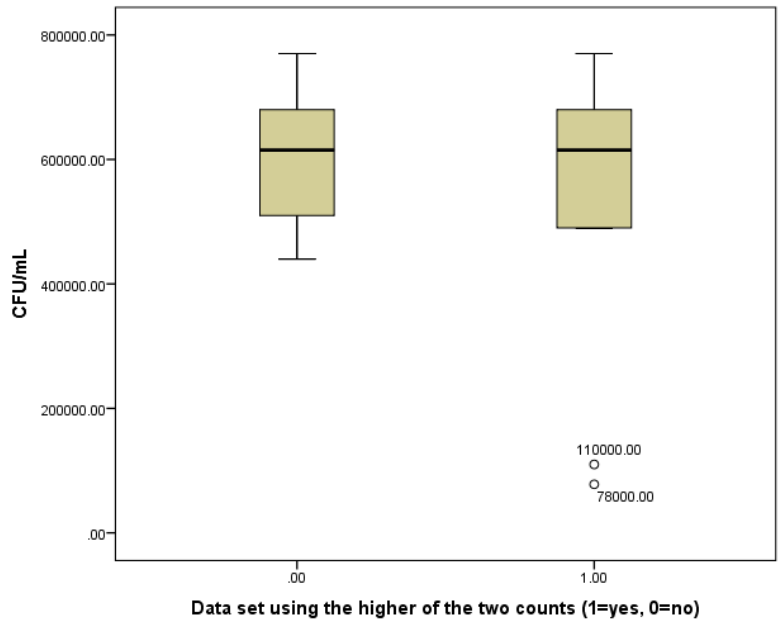

Figure C-17: Boxplots of Filter 1 NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

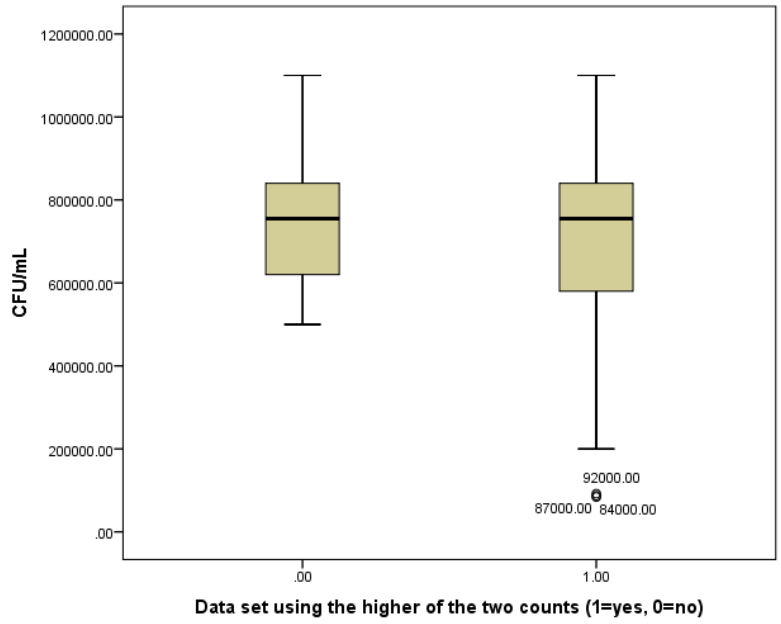

Figure C-18: Boxplots of Filter 2 NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

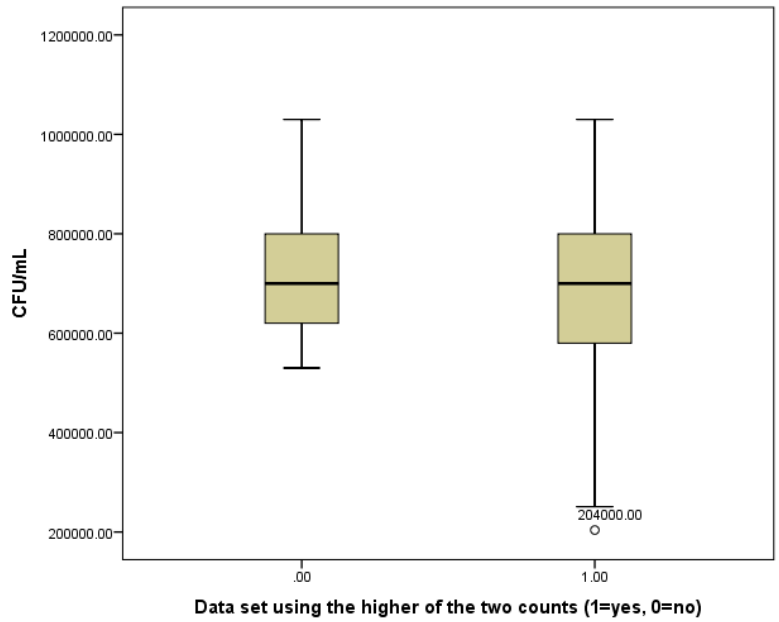

Figure C-19: Boxplots of Filter 3 NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

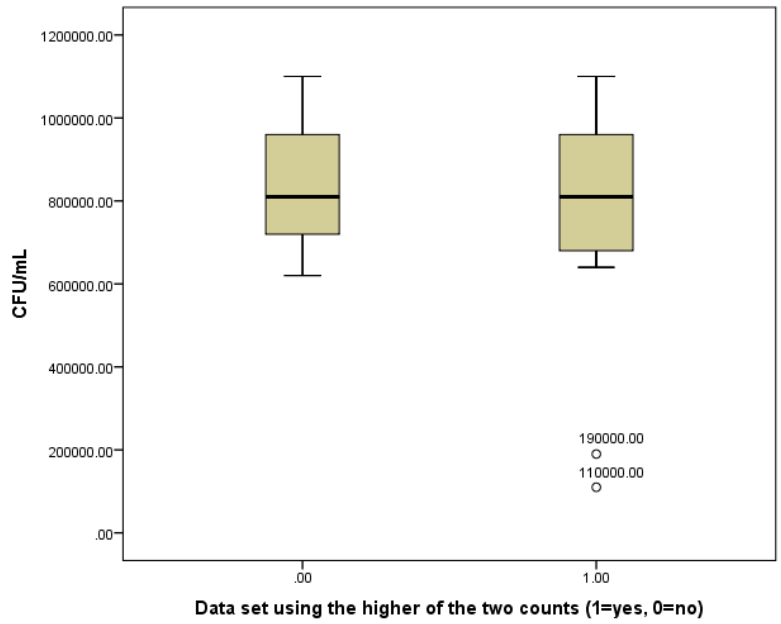

Figure C-20: Boxplots of Filter 4 NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

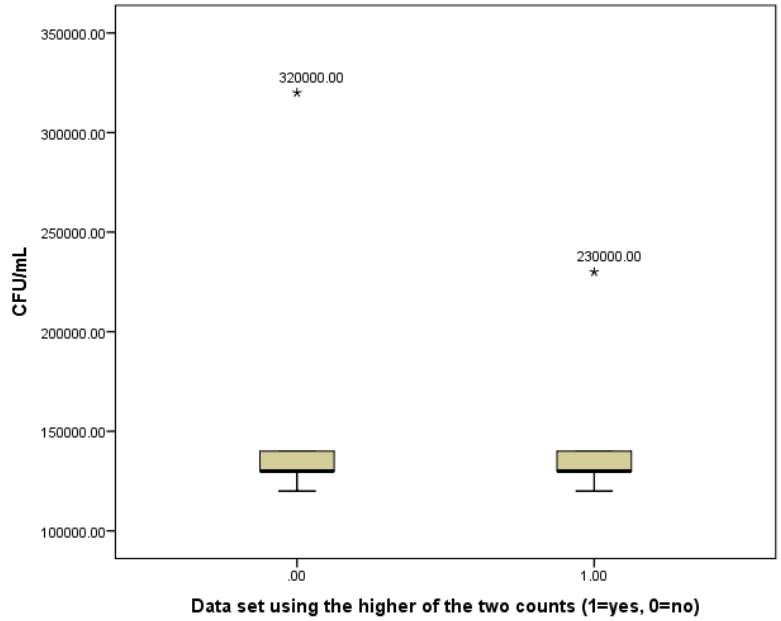

Figure C-21: Boxplots of Filter 4 Growth Control P17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

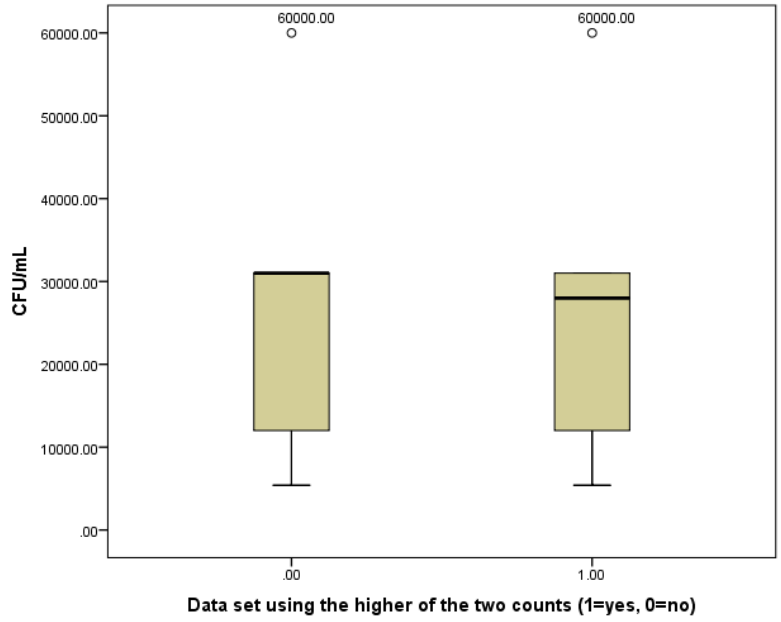

Figure C-22: Boxplots of Process Blank Growth Control P17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

Summary of Results and Calculated values from Statistical Tests

Table C-55: Calculated mean ranks from Kruskal-Wallis test on the August 8, 2012 AOC concentrations

ID	N	Mean Rank
F1	10	25.30
F2	13	44.77
F3	13	31.54
F4	13	46.00
F5	13	12.92
Pooled Influent	20	69.60
Total	82	

Table C-56: Calculated test values and significance level from the Kruskal-Wallis test on August 8, 2012 AOC concentrations

Calculated Value			Value
Chi-Square			54.173
Degrees of freedom			5
Asymptotic Sig.			1.931E-10
Monte Carlo Sig.		Sig.	0.000E+000[1]
	99% Confidence Interval	Lower Bound	0.000E+00
		Upper Bound	4.605E-06

1. Based on 1000000 sampled tables with starting seed 2000000.

Table C-57: Calculated Values from Mann-Whitney Tests on AOC data from the August 8, 2012 sampling event

Comparison	N1[1]	N2[1]	Sum of Ranks 1[2]	Sum of Ranks 2[3]	Mann-Whitney U	Z	p-value (Asymptotic 2-tailed)	p-value (Exact 2-tailed)
Influent 1 vs Influent 2[4]	10	10	118	92	37.00	-.983	3.258E-01	3.527E-01
Pooled Influent vs F1 Effluent	20	10	407	58	3.00	-4.267	1.977E-05	4.660E-07
Pooled Influent vs F2 Effluent	20	13	446	115	24.00	-3.905	9.405E-05	2.408E-05
Pooled Influent vs F3 Effluent	20	13	461	100	9.00	-4.458	8.269E-06	3.385E-07
Pooled Influent vs F4 Effluent	20	13	448	113	22.00	-3.979	6.917E-05	1.507E-05
Pooled Influent vs F5 Effluent	20	13	470	91	0.00	-4.790	1.670E-06	3.489E-09
F1Effluent vs F2 Effluent	10	13	79	197	24.00	-2.543	1.100E-02	9.888E-03
F1 Effluent vs F3 Effluent	10	13	107	169	52.00	-0.806	4.201E-01	4.458E-01
F1 Effluent vs F4 Effluent	10	13	78	198	23.00	-2.605	9.195E-03	8.024E-03
F1 Effluent vs F5 Effluent	10	13	151	125	34.00	-1.923	5.454E-02	5.746E-02
F2 Effluent vs F3 Effluent	13	13	214	137	46.00	-1.974	4.834E-02	5.014E-02
F2 Effluent vs F4 Effluent	13	13	174	177	83.00	-0.077	9.387E-01	9.598E-01
F2 Effluent vs F5 Effluent	13	13	246	105	14.00	-3.615	2.999E-04	9.730E-05
F3 Effluent vs F4 Effluent	13	13	136	215	45.00	-2.026	4.280E-02	4.412E-02
F3 Effluent vs F5 Effluent	13	13	232	119	28.00	-2.897	3.762E-03	2.869E-03
F4 Effluent vs F5 Effluent	13	13	259	92	1.00	-4.282	1.852E-05	3.846E-07

1. Number of data points of the first data set in the comparison. For example, in the comparison of the pooled influent data vs filter 2 effluent, N=16 is the number of total AOC concentrations measured for the pooled influent and N=15 is the number of total AOC concentrations measured for the filter 2 effluent.
2. Sum of ranks associated with the first sampling location listed in the comparison
3. Sum of ranks associated with the second sampling location listed in the comparison
4. Influent replicate 1 versus influent replicate 2

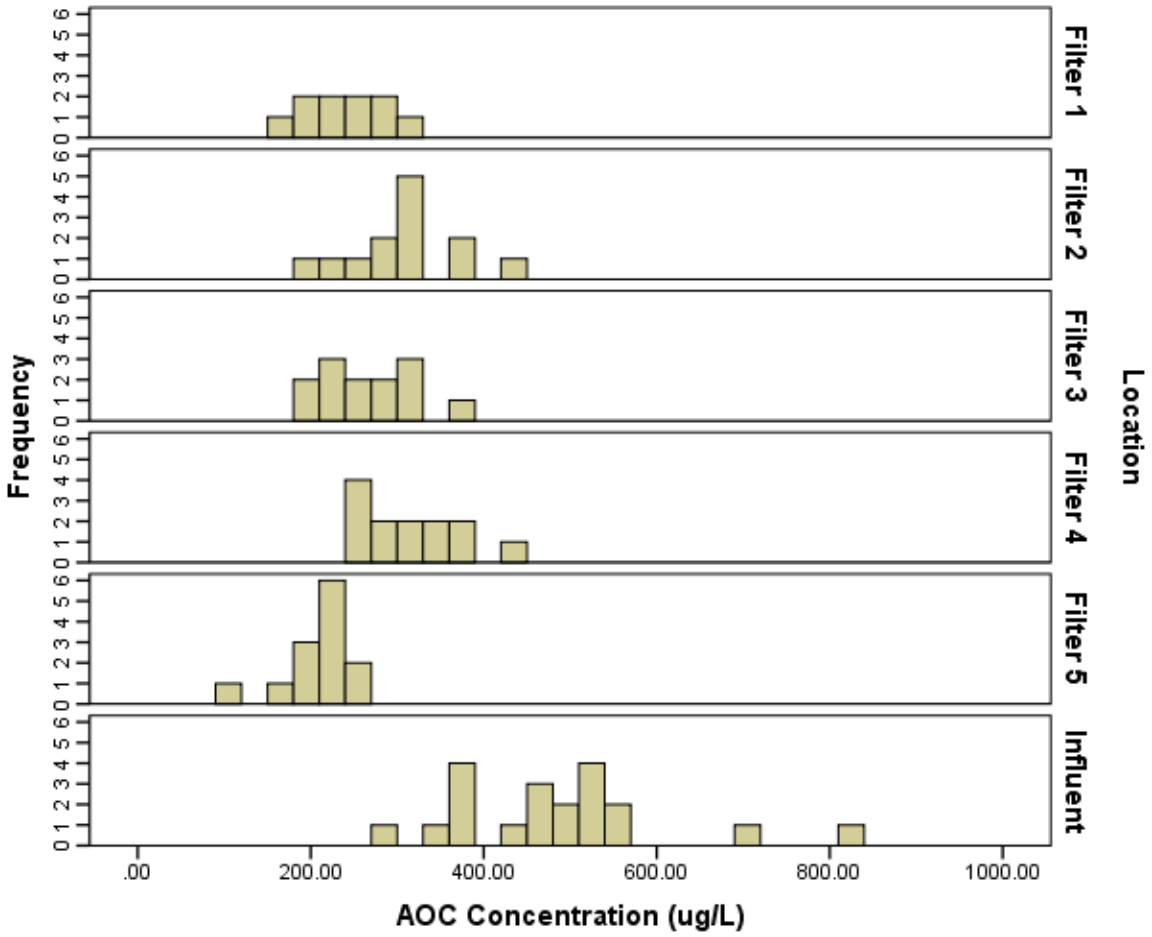

Figure C-23: Histograms of AOC concentrations from August 8, 2012 AOC sampling event

August 14, 2012 Sampling Event

Raw Data and Summarized AOC Results

Table C-58: AOC results related to Filter 1 from the August 14, 2012 sampling event

August 14, 2012 Filter 1	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 1-1-1	47	5	1	4.70E+04	11.47	TNTC	41	6	4.10E+05	141.45	152.92	
Vial 1-1-2	61	8	BP	6.10E+04	14.88	TNTC	37	BP	3.70E+05	127.65	142.53	
Vial 1-1-3	43	4	1	4.30E+04	10.49	TNTC	49	1	4.90E+05	169.05	179.54	
Vial 1-1-4	65	7	0	6.50E+04	15.86	TNTC	53	1	5.30E+05	182.85	198.71	
Vial 1-1-5	52	10	0	5.20E+04	12.69	TNTC	56	8	5.60E+05	193.20	205.89	
Vial 1-1-6	37	6	3	3.70E+04	9.03	TNTC	64	8	6.40E+05	220.80	229.83	
Vial 1-1-7	60	7	0	6.00E+04	14.64	TNTC	45	6	4.50E+05	155.25	169.89	
Vial 1-1-8	49	9	1	4.90E+04	11.96	TNTC	37	0	3.70E+05	127.65	139.61	
Vial 1-1-9	9	0	0			410	25	0				
Vial 1-1-11	66	3	0	6.60E+04	16.10	TNTC	51	6	5.10E+05	175.95	192.05	
Vial 1-1-12	53	8	0	5.30E+04	12.93	TNTC	34	4	3.40E+05	117.30	130.23	
Vial 1-1-13	50	5	1	5.00E+04	12.20	TNTC	41	9	4.10E+05	141.45	153.65	
Vial 1-1-14	37	1	2	3.70E+04	9.03	TNTC	42	4	4.20E+05	144.90	153.93	
Vial 1-1-15	50	7	PCDA-2	5.00E+04	12.20	TNTC	47	PCDA-5	4.70E+05	162.15	174.35	
Vial 1-1-16	46	5	0	4.60E+04	11.22	TNTC	55	3	5.50E+05	189.75	200.97	
Average				5.11E+04	12.48				4.66E+05	160.67	173.15	173.15
Median				5.00E+04	12.20				4.60E+05	158.70	172.12	
St. Dev.				9.24E+03	2.25				8.58E+04	29.61	29.33	
Vial 1-1-10 GC-A	180	23	3	1.80E+05	43.92	TNTC	72	8	7.20E+05	248.40	292.32	
Vial 1-1-10 GC-B	215	17	1	2.15E+05	52.46	TNTC	113	16	1.13E+06	389.85	442.31	
Vial 1-1-10 GC-C	113	11	1	1.13E+05	27.57	TNTC	67	4	6.70E+05	231.15	258.72	
Vial 1-1-10 GC-D	137	PCDA-4	0	1.37E+05	33.43	655	PCDA-61	7	6.10E+05	210.45	243.88	
Vial 1-1-10 GC-E	97	4	0	9.70E+04	23.67	464	31	0	6.10E+05	210.45	234.12	
Average				1.48E+05	36.21				7.48E+05	258.06	294.27	294.27
Median				1.37E+05	33.43				6.70E+05	231.15	258.72	
St. Dev.				4.86E+04	11.87				2.18E+05	75.36	85.65	

Table C-59: AOC results related to Filter 2 from the August 14, 2012 sampling event

August 14, 2012 Filter 2	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 2-1-1	40	5	0	4.00E+04	9.76	TNTC	49	PCDA-7	4.90E+05	169.05	178.81	
Vial 2-1-2	40	3	0	4.00E+04	9.76	TNTC	63	13	6.30E+05	217.35	227.11	
Vial 2-1-3	51	5	0	5.10E+04	12.44	TNTC	61	7	6.10E+05	210.45	222.89	
Vial 2-1-4	25	5	0	2.50E+04	6.10	TNTC	78	10	7.80E+05	269.10	275.20	
Vial 2-1-5	39	5	0	3.90E+04	9.52	TNTC	72	13	7.20E+05	248.40	257.92	
Vial 2-1-6	39	2	0	3.90E+04	9.52	TNTC	64	11	6.40E+05	220.80	230.32	
Vial 2-1-7	34	4	1	3.40E+04	8.30	TNTC	63	3	6.30E+05	217.35	225.65	
Vial 2-1-8	58	3	0	5.80E+04	14.15	TNTC	68	5	6.80E+05	234.60	248.75	
Vial 2-1-9	12	0	1			TNTC	46	1	4.60E+05	158.70		
Vial 2-1-11	43	PCDA-4	0	4.30E+04	10.49	TNTC	PCDA-63	PCDA-3	6.30E+05	217.35	227.84	
Vial 2-1-12	60	4	0	6.00E+04	14.64	TNTC	61	4	6.10E+05	210.45	225.09	
Vial 2-1-13	50	8	0	5.00E+04	12.20	TNTC	50	9	5.00E+05	172.50	184.70	
Vial 2-1-14	49	PCDA-5	1	4.90E+04	11.96	TNTC	PCDA-77	10	7.70E+05	265.65	277.61	
Vial 2-1-15	50	9	0	5.00E+04	12.20	TNTC	54	3	5.40E+05	186.30	198.50	
Vial 2-1-16	33	3	1	3.30E+04	8.05	TNTC	71	15	7.10E+05	244.95	253.00	
Average				4.36E+04	10.65				6.27E+05	216.20	230.96	226.85
Median				4.15E+04	10.13				6.30E+05	217.35	227.48	
St. Dev.				9.85E+03	2.40				9.76E+04	33.67	30.04	
Vial 2-1-10 GC-A	106	11	2	1.06E+05	25.86	TNTC	94	14	9.40E+05	324.30	350.16	
Vial 2-1-10 GC-B	35	9	2	3.50E+04	8.54	TNTC	67	11	6.70E+05	231.15	239.69	
Vial 2-1-10 GC-C	62	7	0	6.20E+04	15.13	TNTC	76	4	7.60E+05	262.20	277.33	
Vial 2-1-10 GC-D	BP	15	0			BP	98	10	9.80E+05	338.10		
Vial 2-1-10 GC-E	41	2	0	4.10E+04	10.00	635	70	11	7.00E+05	241.50	251.50	
Average				6.10E+04	14.88				8.10E+05	279.45	279.67	294.33
Median				5.15E+04	12.57				7.60E+05	262.20	264.42	
St. Dev.				3.22E+04	7.85				1.26E+05	48.79	49.55	

Table C-60: AOC results related to Filter 3 from the August 14, 2012 sampling event

August 14, 2012 Filter 3	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 3-1-1	78	1	0	7.80E+04	19.03	TNTC	66	4	6.60E+05	227.70	246.73	
Vial 3-1-2	67	8	1	6.70E+04	16.35	TNTC	75	5	7.50E+05	258.75	275.10	
Vial 3-1-3	72	4	2	7.20E+04	17.57	TNTC	70	3	7.00E+05	241.50	259.07	
Vial 3-1-4	75	11	0	7.50E+04	18.30	TNTC	84	4	8.40E+05	289.80	308.10	
Vial 3-1-5	77	10	2	7.70E+04	18.79	TNTC	71	6	7.10E+05	244.95	263.74	
Vial 3-1-6	41	9	0	4.10E+04	10.00	TNTC	75	8	7.50E+05	258.75	268.75	
Vial 3-1-7	78	7	1	7.80E+04	19.03	TNTC	36	5	3.60E+05	124.20	143.23	
Vial 3-1-8	63	10	1	6.30E+04	15.37	TNTC	48	4	4.80E+05	165.60	180.97	
Vial 3-1-9	38	1	0	3.80E+04	9.27	107	**75**[1]	0	7.50E+05	258.75	268.02	
Vial 3-1-11	87	9	0	8.70E+04	21.23	TNTC	49	3	4.90E+05	169.05	190.28	
Vial 3-1-12	78	7	PCDA-2	7.80E+04	19.03	TNTC	66	PCDA-9	6.60E+05	227.70	246.73	
Vial 3-1-13	95	4	2	9.50E+04	23.18	TNTC	69	7	6.90E+05	238.05	261.23	
Vial 3-1-14	73	10	1	7.30E+04	17.81	TNTC	60	9	6.00E+05	207.00	224.81	
Vial 3-1-15	78	11	BP	7.80E+04	19.03	TNTC	49	BP	4.90E+05	169.05	188.08	
Vial 3-1-16	43	9	0	4.30E+04	10.49	TNTC	61	13	6.10E+05	210.45	220.94	
Average				6.95E+04	16.97				6.36E+05	219.42	236.39	236.39
Median				7.50E+04	18.30				6.60E+05	227.70	246.73	
St. Dev.				1.67E+04	4.08				1.31E+05	45.11	44.21	
Vial 3-1-10 GC-A	59	6	2	5.90E+04	14.40	TNTC	117	10	1.17E+06	403.65	418.05	
Vial 3-1-10 GC-B	48	6	1	4.80E+04	11.71	TNTC	80	5	8.00E+05	276.00	287.71	
Vial 3-1-10 GC-C	80	6	2	8.00E+04	19.52	TNTC	49	1	4.90E+05	169.05	188.57	
Vial 3-1-10 GC-D	64	0	1	6.40E+04	15.62	684	43	8	4.30E+05	148.35	163.97	
Vial 3-1-10 GC-E	37	2	0	3.70E+04	9.03	TNTC	36	2	3.60E+05	124.20	133.23	
Average				5.76E+04	14.05				6.50E+05	224.25	238.30	238.30
Median				5.90E+04	14.40				4.90E+05	169.05	188.57	
St. Dev.				1.63E+04	3.97				3.36E+05	115.85	115.96	

1. This value used

Table C-61: AOC results related to Filter 4 from the August 14, 2012 sampling event

August 14, 2012 Filter 4	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 4-1-1	34	9	0	3.40E+04	8.30	TNTC	74	5	7.40E+05	255.30	263.60	
Vial 4-1-2	50	7	1	5.00E+04	12.20	TNTC	66	5	6.60E+05	227.70	239.90	
Vial 4-1-3	35	5	0	3.50E+04	8.54	TNTC	56	7	5.60E+05	193.20	201.74	
Vial 4-1-4	34	5	0	3.40E+04	8.30	TNTC	48	10	4.80E+05	165.60	173.90	
Vial 4-1-5	57	6	0	5.70E+04	13.91	TNTC	69	6	6.90E+05	238.05	251.96	
Vial 4-1-6	59	11	1	5.90E+04	14.40	TNTC	71	4	7.10E+05	244.95	259.35	
Vial 4-1-7	25	0	0			422	60	6	6.00E+05	207.00		
Vial 4-1-8	25	4	0			TNTC	33	0	3.30E+05	113.85		
Vial 4-1-9	38	0	1	3.80E+04	9.27	**210**[1]	57	3	2.10E+05	72.45	81.72	
Vial 4-1-11	57	6	0	5.70E+04	13.91	TNTC	55	PCDA-7	5.50E+05	189.75	203.66	
Vial 4-1-12	47	8	PCDA-1	4.70E+04	11.47	TNTC	41	PCDA-1	4.10E+05	141.45	152.92	
Vial 4-1-13	60	4	0	6.00E+04	14.64	TNTC	57	4	5.70E+05	196.65	211.29	
Vial 4-1-14	69	9	0	6.90E+04	16.84	TNTC	39	6	3.90E+05	134.55	151.39	
Vial 4-1-15	35	9	2	3.50E+04	8.54	TNTC	58	7	5.80E+05	200.10	208.64	
Vial 4-1-16	39	11	0	3.90E+04	9.52	TNTC	67	9	6.70E+05	231.15	240.67	
Average				4.72E+04	11.52				5.43E+05	187.45	203.13	198.97
Median				4.70E+04	11.47				5.70E+05	196.65	208.64	
St. Dev.				1.22E+04	2.97				1.52E+05	52.58	52.32	
Vial 4-1-10 GC-A	185	9	3	1.85E+05	45.14	TNTC	71	10	7.10E+05	244.95	290.09	
Vial 4-1-10 GC-B	153	18	1	1.53E+05	37.33	TNTC	84	12	8.40E+05	289.80	327.13	
Vial 4-1-10 GC-C	85	19	3	8.50E+04	20.74	TNTC	62	8	6.20E+05	213.90	234.64	
Vial 4-1-10 GC-D	103	BP	0	1.03E+05	25.13	TNTC	BP	PCDA-4				
Vial 4-1-10 GC-E	91	0	1	9.10E+04	22.20	618	21	9				
Average				1.23E+05	30.11				7.23E+05	249.55	283.95	279.66
Median				1.03E+05	25.13				7.10E+05	244.95	290.09	
St. Dev.				4.36E+04	10.64				1.11E+05	38.16	46.55	

1. This value used

Table C-62: AOC results related to Filter 5 from the August 14, 2012 sampling event

August 14, 2012 Filter 5	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial 5-1-1	35	3	0	3.50E+04	8.54	TNTC	61	5	6.10E+05	210.45	218.99	
Vial 5-1-2	41	3	0	4.10E+04	10.00	TNTC	56	5	5.60E+05	193.20	203.20	
Vial 5-1-3	17	4	1			TNTC	51	2	5.10E+05	175.95		
Vial 5-1-4	36	5	1	3.60E+04	8.78	TNTC	60	6	6.00E+05	207.00	215.78	
Vial 5-1-5	34	4	2	3.40E+04	8.30	TNTC	71	11	7.10E+05	244.95	253.25	
Vial 5-1-6	31	1	0	3.10E+04	7.56	TNTC	82	6	8.20E+05	282.90	290.46	
Vial 5-1-7	17	0	0			TNTC	45	4	4.50E+05	155.25		
Vial 5-1-8	9	2	0			TNTC	49	5	4.90E+05	169.05		
Vial 5-1-9	9	2	0			TNTC	60	2	6.00E+05	207.00		
Vial 5-1-11	74	PCDA-6	0	7.40E+04	18.06	TNTC	PCDA-54	6	5.40E+05	186.30	204.36	
Vial 5-1-12	29	1	0			TNTC	60	6	6.00E+05	207.00		
Vial 5-1-13	57	13	1	5.70E+04	13.91	TNTC	41	7	4.10E+05	141.45	155.36	
Vial 5-1-14	31	2	1	3.10E+04	7.56	TNTC	43	6	4.30E+05	148.35	155.91	
Vial 5-1-15	33	4	1	3.30E+04	8.05	TNTC	42	3	4.20E+05	144.90	152.95	
Vial 5-1-16	37	PCDA-1	1	3.70E+04	9.03	TNTC	PCDA-43	6	4.30E+05	148.35	157.38	
Average				4.09E+04	9.98				5.45E+05	188.14	200.76	198.12
Median				3.55E+04	8.66				5.40E+05	186.30	203.78	
St. Dev.				1.39E+04	3.39				1.16E+05	40.19	46.69	
Vial 5-1-10 GC-A	111	16	1	1.11E+05	27.08	TNTC	83	5	8.30E+05	286.35	313.43	
Vial 5-1-10 GC-B	130	18	2	1.30E+05	31.72	TNTC	83	9	8.30E+05	286.35	318.07	
Vial 5-1-10 GC-C	107	8	0	1.07E+05	26.11	TNTC	72	12	7.20E+05	248.40	274.51	
Vial 5-1-10 GC-D	102	1	5	1.02E+05	24.89	542	16	9			24.89	
Vial 5-1-10 GC-E	PCDS-32	5	1			TNTC	61	5	6.10E+05	210.45		
Average				1.13E+05	27.45				7.48E+05	257.89	232.73	285.34
Median				1.09E+05	26.60				7.75E+05	267.38	293.97	
St. Dev.				1.22E+04	2.99				1.05E+05	36.33	139.93	

Table C-63: AOC results related to Influent 1 from the August 14, 2012 sampling event

August 14, 2012 Influent 1	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	PCDA-47	PCDA-6	0	4.70E+04	11.47	TNTC	PCDA-133	9	1.33E+06	458.85	470.32	
Vial Inf1-1-2	47	5	0	4.70E+04	11.47	TNTC	129	12	1.29E+06	445.05	456.52	
Vial Inf1-1-3	57	12	0	5.70E+04	13.91	TNTC	169	10	1.69E+06	583.05	596.96	
Vial Inf1-1-4	61	4	0	6.10E+04	14.88	TNTC	163	17	1.63E+06	562.35	577.23	
Vial Inf1-1-5	76	5	1	7.60E+04	18.54	TNTC	156	21	1.56E+06	538.20	556.74	
Vial Inf1-1-6	99	4	2	9.90E+04	24.16	TNTC	197	17	1.97E+06	679.65	703.81	
Vial Inf1-1-7	51	2	0	5.10E+04	12.44	TNTC	87	12	8.70E+05	300.15	312.59	
Vial Inf1-1-8	11	0	1			TNTC	PCDA-115	13	1.15E+06	396.75		
Vial Inf1-1-9	32	0	0	3.20E+04	7.81	**976**	BP	6				
Vial Inf1-1-11	PCDA-43	PCDA-8	0	4.30E+04	10.49	TNTC	PCDA-119	17	1.19E+06	410.55	421.04	
Vial Inf1-1-12	67	8	PCDA-2	6.70E+04	16.35	TNTC	142	17	1.42E+06	489.90	506.25	
Vial Inf1-1-13	78	9		7.80E+04	19.03	TNTC	188	13	1.88E+06	648.60	667.63	
Vial Inf1-1-14	7	0	0			TNTC	162	12	1.62E+06	558.90		
Vial Inf1-1-15	17	0	0			TNTC	PCDA-112	PCDA-12	1.12E+06	386.40		
Vial Inf1-1-16	56	8	0	5.60E+04	13.66	1029	40	34				
Average				5.95E+04	14.52				1.44E+06	496.80	526.91	511.32
Median				5.65E+04	13.79				1.42E+06	489.90	531.50	
St. Dev.				1.83E+04	4.45				3.20E+05	110.40	117.92	
Vial Inf1-1-10 GC-A	40	0	BP	4.00E+04	9.76	TNTC	165	BP	1.65E+06	569.25	579.01	
Vial Inf1-1-10 GC-B	52	3	2	5.20E+04	12.69	TNTC	202	24	2.02E+06	696.90	709.59	
Vial Inf1-1-10 GC-C	PCDA-46	6	1	4.60E+04	11.22	TNTC	234	16	2.34E+06	807.30	818.52	
Vial Inf1-1-10 GC-D	67	PCDA-6	PCDA-1	6.70E+04	16.35	TNTC	PCDA-201	PCDA-27	2.01E+06	693.45	709.80	
Vial Inf1-1-10 GC-E	51	5	1	5.10E+04	12.44	TNTC	179	14	1.79E+06	617.55	629.99	
Average				5.12E+04	12.49				1.96E+06	676.89	689.38	689.38
Median				5.10E+04	12.44				2.01E+06	693.45	709.59	
St. Dev.				1.00E+04	2.45				2.62E+05	90.54	91.12	

Table C-64: AOC results related to Influent 2 from the August 14, 2012 sampling event

August 14, 2012 Influent 2	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf2-1-1	PCDA-55	PCDA-6	1	5.50E+04	13.42	TNTC	PCDS-191	13				
Vial Inf2-1-2	40	2	0	4.00E+04	9.76	TNTC	176	11	1.76E+06	607.20	616.96	
Vial Inf2-1-3	24	1	1			TNTC	99	15	9.90E+05	341.55		
Vial Inf2-1-4	35	3	0	3.50E+04	8.54	TNTC	159	34	1.59E+06	548.55	557.09	
Vial Inf2-1-5	35	PCDA-4	0	3.50E+04	8.54	TNTC	PCDA-123	18	1.23E+06	424.35	432.89	
Vial Inf2-1-6	31	5	1	3.10E+04	7.56	TNTC	147	17	1.47E+06	507.15	514.71	
Vial Inf2-1-7	1	0	0			TNTC	135	7	1.35E+06	465.75	465.75	
Vial Inf2-1-8	72	0	0	7.20E+04	17.57	TNTC	119	6	1.19E+06	410.55	428.12	
Vial Inf2-1-9	0	0	0			TNTC	131	9	1.31E+06	451.95	451.95	
Vial Inf2-1-11	67	3	0	6.70E+04	16.35	TNTC	141	20	1.41E+06	486.45	502.80	
Vial Inf2-1-12	43	3	0	4.30E+04	10.49	TNTC	143	17	1.43E+06	493.35	503.84	
Vial Inf2-1-13	43	5	0	4.30E+04	10.49	TNTC	107	14	1.07E+06	369.15	379.64	
Vial Inf2-1-14	80	PCDS-4	2	8.00E+04	19.52	TNTC	PCDS-194	3				
Vial Inf2-1-15	34	2	0	3.40E+04	8.30	TNTC	150	17	1.50E+06	517.50	525.80	
Vial Inf2-1-16	PCDA-52	5	0	5.20E+04	12.69	TNTC	108	14	1.08E+06	372.60	385.29	
Average				4.89E+04	11.94			1	1.34E+06	461.24	480.40	473.17
Median				4.30E+04	10.49				1.35E+06	465.75	484.27	
St. Dev.				1.64E+04	4.00				2.22E+05	76.69	70.09	
Vial Inf2-1-10 GC-A	36	PCDA-2	1	3.60E+04	8.78	TNTC	PCDA-187	19	1.87E+06	645.15	653.93	
Vial Inf2-1-10 GC-B	BP	BP	BP			BP	BP	BP				
Vial Inf2-1-10 GC-C			0			TNTC	153	24	1.53E+06	527.85	527.85	
Vial Inf2-1-10 GC-D	81	9	0	8.10E+04	19.76	TNTC	**215**[1]	30	2.15E+06	741.75	761.51	
Vial Inf2-1-10 GC-E	37	5	0	3.70E+04	9.03	TNTC	119	PCDA-13	1.19E+06	410.55	419.58	
Average				5.13E+04	12.53				1.69E+06	581.33	590.72	593.85
Median				3.70E+04	9.03				1.70E+06	586.50	590.89	
St. Dev.				2.57E+04	6.27				4.16E+05	143.57	148.78	

1. This value used

Table C-65: Pooled influent AOC data from the August 14, 2012 sampling event

August 14, 2012 Pooled Influent	P-17 ENUMERATION					NOX ENUMERATION					TOTAL AOC	
Sample Dilutions	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	P-17 AOC	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial Inf1-1-1	PCDA-47	PCDA-6	0	4.70E+04	11.47	TNTC	PCDA-133	9	1.33E+06	458.85	470.32	
Vial Inf1-1-2	47	5	0	4.70E+04	11.47	TNTC	129	12	1.29E+06	445.05	456.52	
Vial Inf1-1-3	57	12	0	5.70E+04	13.91	TNTC	169	10	1.69E+06	583.05	596.96	
Vial Inf1-1-4	61	4	0	6.10E+04	14.88	TNTC	163	17	1.63E+06	562.35	577.23	
Vial Inf1-1-5	76	5	1	7.60E+04	18.54	TNTC	156	21	1.56E+06	538.20	556.74	
Vial Inf1-1-6	99	4	2	9.90E+04	24.16	TNTC	197	17	1.97E+06	679.65	703.81	
Vial Inf1-1-7	51	2	0	5.10E+04	12.44	TNTC	87	12	8.70E+05	300.15	312.59	
Vial Inf1-1-8	11	0	1			TNTC	PCDA-115	13	1.15E+06	396.75		
Vial Inf1-1-9	32	0	0	3.20E+04	7.81	**976**	BP	6				
Vial Inf1-1-11	PCDA-43	PCDA-8	0	4.30E+04	10.49	TNTC	PCDA-119	17	1.19E+06	410.55	421.04	
Vial Inf1-1-12	67	8	PCDA-2	6.70E+04	16.35	TNTC	142	17	1.42E+06	489.90	506.25	
Vial Inf1-1-13	78	9		7.80E+04	19.03	TNTC	188	13	1.88E+06	648.60	667.63	
Vial Inf1-1-14	7	0	0			TNTC	162	12	1.62E+06	558.90		
Vial Inf1-1-15	17	0	0			TNTC	PCDA-112	PCDA-12	1.12E+06	386.40		
Vial Inf1-1-16	56	8	0	5.60E+04	13.66	1029	40	34				
Vial Inf2-1-1	PCDA-55	PCDA-6	1	5.50E+04	13.42	TNTC	PCDS-191	13				
Vial Inf2-1-2	40	2	0	4.00E+04	9.76	TNTC	176	11	1.76E+06	607.20	616.96	
Vial Inf2-1-3	24	1	1			TNTC	99	15	9.90E+05	341.55		
Vial Inf2-1-4	35	3	0	3.50E+04	8.54	TNTC	159	34	1.59E+06	548.55	557.09	
Vial Inf2-1-5	35	PCDA-4	0	3.50E+04	8.54	TNTC	PCDA-123	18	1.23E+06	424.35	432.89	
Vial Inf2-1-6	31	5	1	3.10E+04	7.56	TNTC	147	17	1.47E+06	507.15	514.71	
Vial Inf2-1-7	1	0	0			TNTC	135	7	1.35E+06	465.75	465.75	
Vial Inf2-1-8	72	0	0	7.20E+04	17.57	TNTC	119	6	1.19E+06	410.55	428.12	
Vial Inf2-1-9	0	0	0			TNTC	131	9	1.31E+06	451.95	451.95	
Vial Inf2-1-11	67	3	0	6.70E+04	16.35	TNTC	141	20	1.41E+06	486.45	502.80	
Vial Inf2-1-12	43	3	0	4.30E+04	10.49	TNTC	143	17	1.43E+06	493.35	503.84	
Vial Inf2-1-13	43	5	0	4.30E+04	10.49	TNTC	107	14	1.07E+06	369.15	379.64	
Vial Inf2-1-14	80	PCDS-4	2	8.00E+04	19.52	TNTC	PCDS-194	3				
Vial Inf2-1-15	34	2	0	3.40E+04	8.30	TNTC	150	17	1.50E+06	517.50	525.80	
Vial Inf2-1-16	PCDA-52	5	0	5.20E+04	12.69	TNTC	108	14	1.08E+06	372.60	385.29	
Average				5.42E+04	13.23				1.39E+06	479.02	501.54	492.25
Median				5.15E+04	12.57				1.38E+06	476.10	503.32	
St. Dev.				1.78E+04	4.34				2.75E+05	94.88	95.36	

Table C-66: AOC results related to the Process Blank from the August 14, 2012 sampling event

August 14, 2012 Process Blank	P-17 ENUMERATION								NOX ENUMERATION								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.1	0.1	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Vial PB-1				134	20	1	1.34E+04	3.27				TNTC	45	7	4.50E+04	15.53	18.79	
Vial PB-2				29	4	0						**288**	28	8	2.88E+04	9.94		
Vial PB-3				14	3	0						TNTC	37	3	3.70E+04	12.77		
Vial PB-4				52	4	1	5.20E+03	1.27				TNTC	63	7	6.30E+04	21.74	23.00	
Vial PB-5				32	0	0	3.20E+03	0.78				TNTC	34	4	3.40E+04	11.73	12.51	
Vial PB-6				216	15	3	2.16E+04	5.27				TNTC	45	1	4.50E+04	15.53	20.80	
Vial PB-7		TNTC	TNTC	0	9	0				TNTC	TNTC	153	PCDA-29	4	1.53E+04	5.28		
Vial PB-8		TNTC	TNTC	0	0	0				TNTC	TNTC	43	4	0	4.30E+03	1.48		
Vial PB-9		BP	268	24	0	0				BP	TNTC	TNTC	41	0	4.10E+04	14.15		
Vial PB-11	TNTC	TNTC	TNTC	PCDA-196	21	2	1.96E+04	4.78	TNTC	TNTC	TNTC	TNTC	28	1				
Vial PB-12	TNTC	TNTC	TNTC	182	23	1	1.82E+04	4.44	TNTC	TNTC	TNTC	TNTC	33	3	3.30E+04	11.39	15.83	
Vial PB-13	TNTC	TNTC	TNTC	115	11	PCDA-1	1.15E+04	2.81	TNTC	TNTC	TNTC	TNTC	74	PCDA-9	7.40E+04	25.53	28.34	
Vial PB-14	TNTC	14	8	1	BP	0			TNTC	TNTC	BP	118	BP	PCDA-1	1.18E+04	4.07		
Vial PB-15	TNTC	TNTC	TNTC	123	BP	BP			TNTC	TNTC	TNTC	TNTC	BP	BP				
Vial PB-16	BP	175	174	**163**[1]	3	0	1.63E+04	3.98	BP	TNTC	TNTC	416	32	2	3.20E+04	11.04	15.02	
Average							1.36E+04	3.32							3.57E+04	12.32	19.18	15.64
Median							1.49E+04	3.62							3.40E+04	11.73	18.79	
St. Dev.							6.67E+03	1.63							1.93E+04	6.65	5.39	
Vial PB-1-10 GC-A				24	8	2							TNTC	178	1.78E+06	614.10		
Vial PB-1-10 GC-B				42	4	0	4.20E+03	1.02					TNTC	153	1.53E+06	527.85	528.87	
Vial PB-1-10 GC-C				32	1	1	3.20E+03	0.78					TNTC	119	1.19E+06	410.55	411.33	
Vial PB-1-10 GC-D	TNTC	TNTC	TNTC	35	5	1	3.50E+03	0.85	TNTC	TNTC	TNTC	TNTC	TNTC	118	1.18E+06	407.10	407.95	
Vial PB-1-10 GC-E		308	14	17	3	0						50	98	0				
Average							3.63E+03	0.89							1.42E+06	489.90	449.39	490.79
Median							3.50E+03	0.85							1.36E+06	469.20	411.33	
St. Dev.							5.13E+02	0.13							2.90E+05	100.03	68.86	

1. This value used

Table C 67: AOC results related to the Blank Controls from the August 14, 2012 sampling event

August 14, 2012 Blank Controls	P-17 Enumeration								NOX Enumeration								TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Blank Control 1	10	6	6	0	0	0	3.67E+01	0.01	42	30	25	2	0		2.43E+02	0.08	0.09	
Blank Control-2	9	17	9	0	0	0	5.83E+01	0.01	57	74	62	3	0		3.22E+02	0.11	0.13	
Blank Control-3	5	7	BP	2	BP	0	3.00E+01	0.01	31	30	BP	4	BP		1.53E+02	0.05	0.06	
Blank Control-4	14			0	0	0	7.00E+01	0.02	50				0		2.50E+02	0.09	0.10	
Blank Control-5	12	5			0	0	4.25E+01	0.01	85	35					3.00E+02	0.10	0.11	
Average							4.75E+01	0.01							2.53E+02	0.09	0.10	0.10
Median							4.25E+01	0.01							2.50E+02	0.09	0.10	
St. Dev.							1.64E+01	0.00							6.55E+01	0.02	0.02	

Table C-68: AOC results related to the Yield Controls from the August 14, 2012 sampling event

August 14, 2012 Blank Controls	P-17 Enumeration								NOX Enumeration									TOTAL AOC	
Sample Dilutions	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	Est. Count	P-17 AOC	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{00}$	$1.0x10^{-01}$	$1.0x10^{-02}$	$1.0x10^{-03}$	$1.0x10^{-04}$	Est. Count	NOX AOC	From Vials	Sum of Avgs
Volume Plated (mL)	0.2	0.2	0.2	0.1	0.1	0.1	(cfu/mL)	(ug/L)	0.2	0.2	0.2	0.1	0.1	0.1	0.1	(cfu/mL)	(ug/L)	(ug/L)	(ug/L)
Yield Control -1		30	18	0	0	0	1.20E+02	0.03		TNTC	TNTC	PCDA-107	6	0	0	1.07E+04	3.69	3.72	
Yield Control -2		12	3	1	0	0	3.75E+01	0.01		BP	410	9	3	0	0	2.05E+03	0.71	0.72	
Yield Control-3		2	5	0	0	0	1.75E+01	0.00		338	256	12	2	0	0	1.49E+03	0.51	0.52	
Yield Control-4	30	48			BP	0	1.95E+02	0.05	TNTC	TNTC			BP	PCDA-56	3	5.60E+05	193.20	193.25	
Yield Control-5	TNTC	TNTC		3[1]	3[1]	4[1]			TNTC	TNTC			57	6	0	5.70E+04	19.67		
Average							9.25E+01	0.02								1.26E+05	43.56	49.55	43.58
Median							7.88E+01	0.02								1.07E+04	3.69	2.22	
St. Dev.							8.15E+01	0.02								2.44E+05	84.03	95.81	

1. Data considered suspect and not used

Boxplots to Determine Which of the Counts in the Range of 30 to 300 Should Be Used

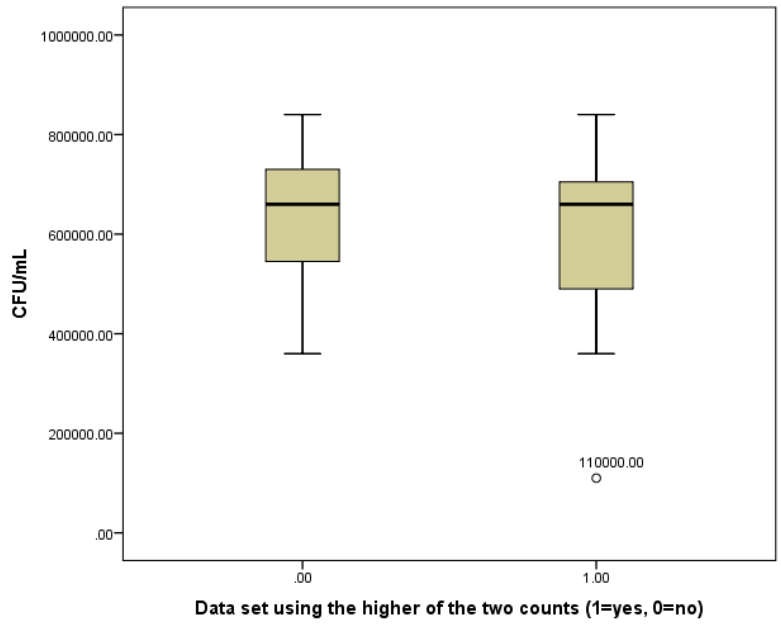

Figure C-24: Boxplots of Filter 3NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

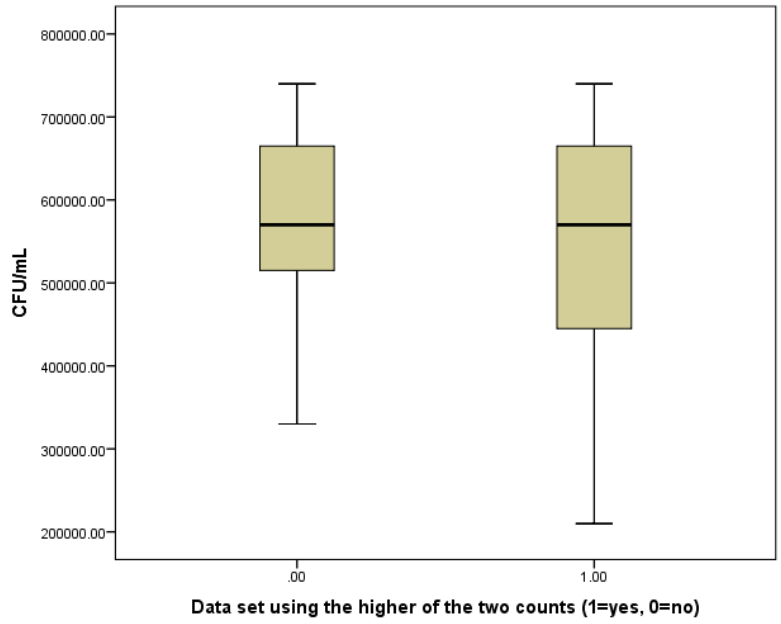

Figure C-25: Boxplots of Filter 4 NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

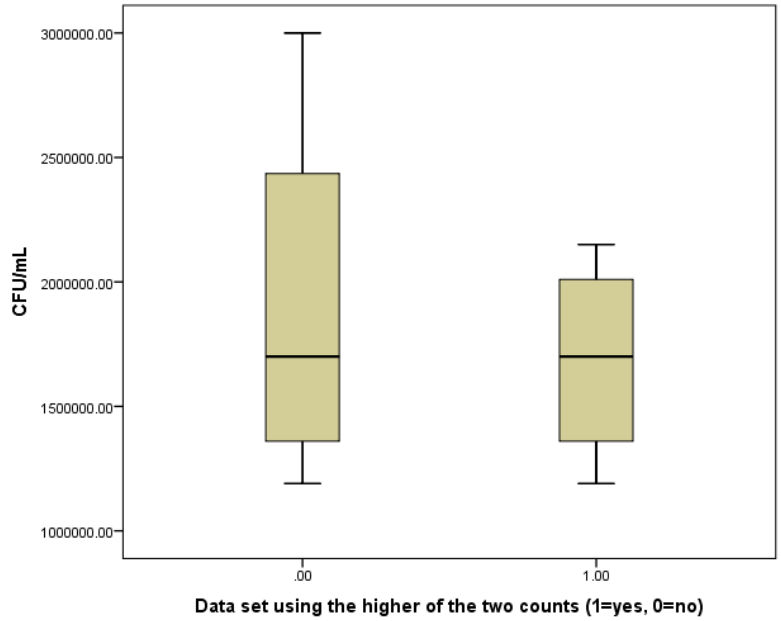

Figure C-26: Boxplots of Influent replicate 2 Growth Control NOX concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

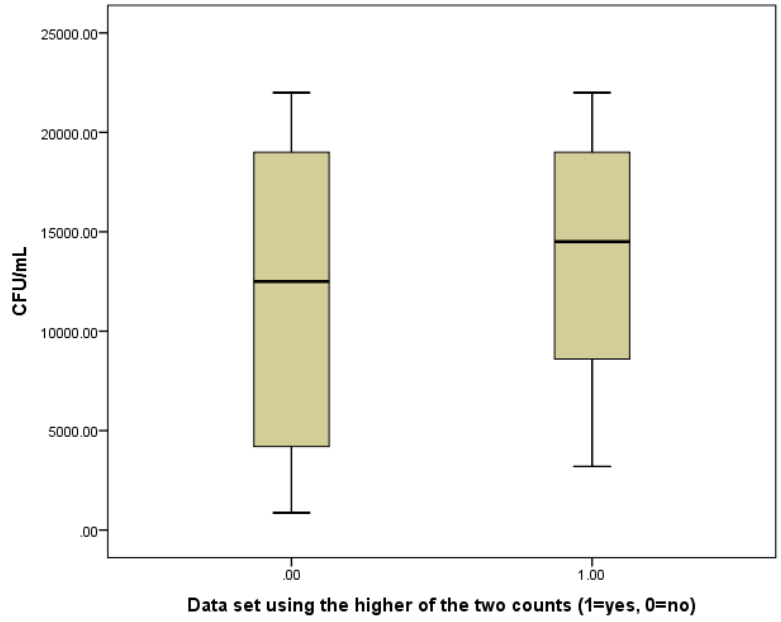

Figure C-27: Boxplots of Process Blank P-17 concentrations using the highest counts and the lowest counts (boxplots 1 and 2, respectively)

Summary of Results and Calculated values from Statistical Tests

Table C-69: Calculated mean ranks from Kruskal-Wallis test on the August 14, 2012 AOC concentrations

ID	N	Mean Rank
F1	14	17.25
F2	14	42.57
F3	15	44.20
F4	13	31.81
F5	10	29.70
Pooled Influent	22	77.50
Total	88	

Table C-70: Calculated test values and significance level from Kruskal-Wallis test on the August 14, 2012 AOC concentrations

Calculated Value			Value
	Chi-Square		59.284
	Degrees of freedom		5
	Asymptotic Sig.		1.709E-11
Monte Carlo Sig.	Sig.		0.000E+000[1]
	99% Confidence Interval	Lower Bound	0.000E+00
		Upper Bound	4.605E-06

1. Based on 1000000 sampled tables with starting seed 2000000.

Table C-71: Summary of Calculated Values from Mann-Whitney Tests on AOC data from the August 14, 2012 sampling event

Comparison	N1[1]	N2[1]	Sum of Ranks 1[2]	Sum of Ranks 2[3]	Mann-Whitney U	Z	p-value (Asymptotic 2-tailed)	p-value (Exact 2-tailed)
Influent 1 vs Influent 2[4]	10	12	132	121	43.00	-1.121	2.623E-01	2.829E-01
Pooled Influent vs F1 Effluent	22	14	561	105	0.00	-4.997	5.814E-07	5.268E-10
Pooled Influent vs F2 Effluent	22	14	561	105	0.00	-4.997	5.814E-07	5.268E-10
Pooled Influent vs F3 Effluent	22	15	583	120	0.00	-5.104	3.317E-07	2.136E-10
Pooled Influent vs F4 Effluent	22	13	539	91	0.00	-4.882	1.050E-06	1.355E-09
Pooled Influent vs F5 Effluent	22	10	473	55	0.00	-4.472	7.744E-06	3.100E-08
F1Effluent vs F2 Effluent	14	14	125	281	20.00	-3.584	3.385E-04	1.308E-04
F1 Effluent vs F3 Effluent	14	15	133	302	28.00	-3.361	7.767E-04	4.048E-04
F1 Effluent vs F4 Effluent	14	13	153.5	224.5	48.50	-2.063	3.914E-02	3.874E-02
F1 Effluent vs F5 Effluent	14	10	145	155	40.00	-1.757	7.898E-02	8.413E-02
F2 Effluent vs F3 Effluent	14	15	199	236	94.00	-0.480	6.311E-01	6.436E-01
F2 Effluent vs F4 Effluent	14	13	223	155	64.00	-1.310	1.901E-01	2.020E-01
F2 Effluent vs F5 Effluent	14	10	208	92	37.00	-1.932	5.332E-02	5.591E-02
F3 Effluent vs F4 Effluent	15	13	257	149	58.00	-1.820	6.878E-02	7.008E-02
F3 Effluent vs F5 Effluent	15	10	228	97	42.00	-1.831	6.712E-02	6.868E-02
F4 Effluent vs F5 Effluent	13	10	158	118	63.00	-0.124	9.013E-01	9.274E-01

1. Number of data points of the first data set in the comparison. For example, in the comparison of the pooled influent data vs Filter 2 effluent, N=22 is the number of total AOC concentrations measured for the pooled influent and N=14 is the number of total AOC concentrations measured for the filter 2 effluent.
2. Sum of ranks associated with the first sampling location listed in the comparison
3. Sum of ranks associated with the second sampling location listed in the comparison
4. Influent replicate 1 versus influent replicate 2

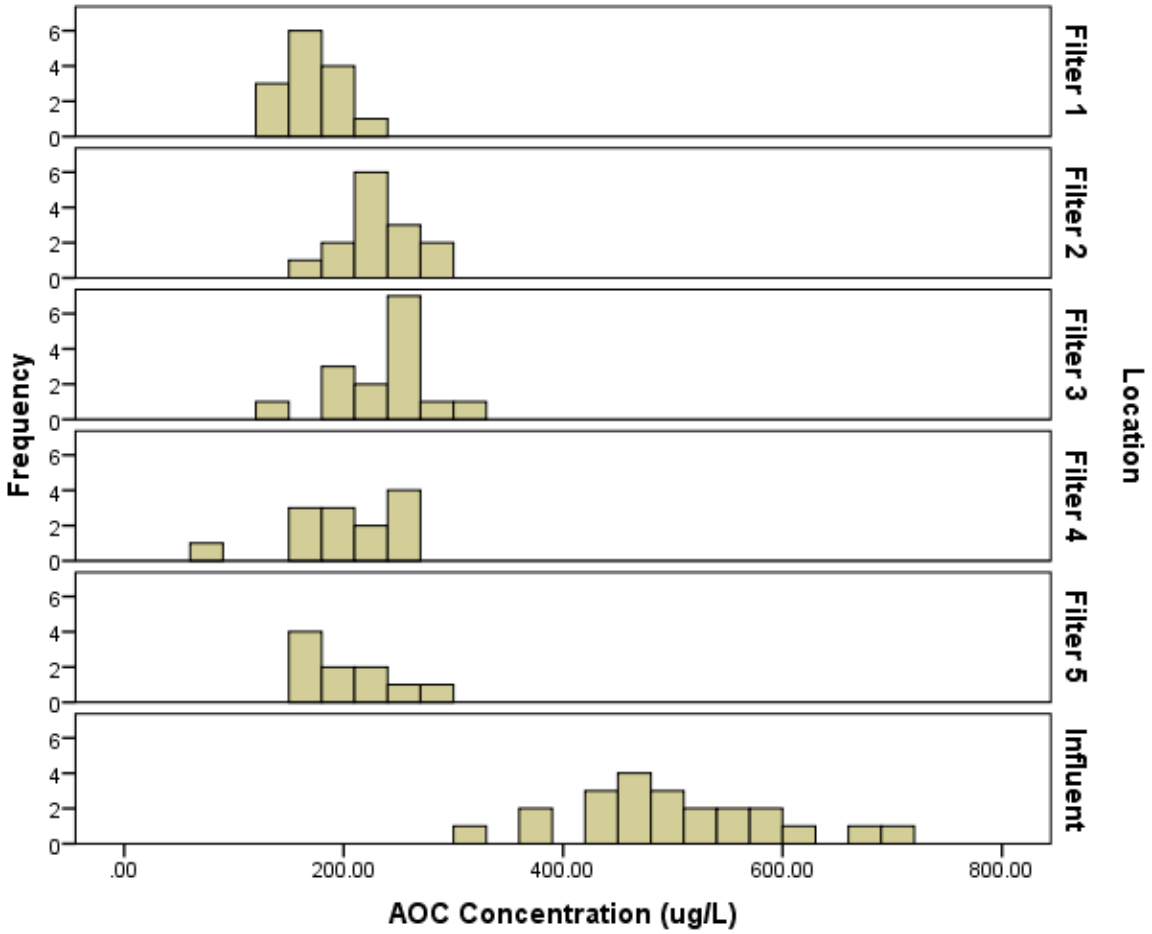

Figure C-28: Histograms of AOC concentrations from August 14, 2012 AOC sampling event

Appendix D

THMFP Data

Contents

This appendix contains total trihalomethane formation potential data, chloroform formation potential data, bromoform formation potential data, bromodichloromethane formation potential data, and dibromochloromethane formation potential data from June 6, 2013 and June 10, 2013 sampling events. The appendix also contains boxplots of the raw data, results from ANOVA diagnostics (Levene's test, Normal probability plots, and residual plots), and detailed results from multiple comparisons (conducted when ANOVAs were significant).

Structure of the appendix

The appendix is subdivided into separate sections for each type of formation potential. In each section, there is a separate subsection for each sampling event and for each additional set of analyses conducted with outliers excluded. Each subsection is further subdivided into sections for raw data, boxplots, multiple comparisons, and diagnostic plots. After the formation potential data, sections containing tables summarizing the amount of chlorine added to the samples at the beginning of the THMFP tests (i.e. chlorine dose) and the final free chlorine remaining in the samples at the end of the tests are also provided.

Location Key

The various sampling locations are identified by abbreviations. Table D-1outlines the abbreviations used for the sampling locations and, where appropriate, the media type associated with a given filter.

Table D-1: List of sampling locations and media types

Sampling Location Abbreviation	Sampling Location	Media Type[1]
F1	Filter 1 effluent	Coal-based GAC
F2	Filter 2 effluent	Anthracite
F3	Filter 3 effluent	Rough engineered ceramic
F4	Filter 4 effluent	Wood-based GAC
F5	Filter 5 effluent	Coal-based GAC (operated in declining rate mode)
Inf	Common filter influent	N/A

1. All filters operated in constant-head-constant-rate mode unless otherwise noted.

Total trihalomethane formation potential results

June 6, 2013 sampling event

Raw Data

Table D-2: Raw trihalomethane formation potential data from June 6, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-06	105	µg/L	2
F1	2	2013-06-06	124	µg/L	2
F1	3	2013-06-06	115	µg/L	2
F2	1	2013-06-06	123	µg/L	2
F2	2	2013-06-06	126	µg/L	2
F2	3	2013-06-06	126	µg/L	2
F3	1	2013-06-06	128	µg/L	2
F3	2	2013-06-06	142	µg/L	2
F3	3	2013-06-06	101	µg/L	2
F4	1	2013-06-06	114	µg/L	2
F4	2	2013-06-06	91	µg/L	2
F4	3	2013-06-06	101	µg/L	2
F5	1	2013-06-06	113	µg/L	2
F5	2	2013-06-06	117	µg/L	2
F5	3	2013-06-06	104	µg/L	2
Inf	1	2013-06-06	141	µg/L	2
Inf	2	2013-06-06	110	µg/L	2
Inf	3	2013-06-06	140	µg/L	2

Boxplots

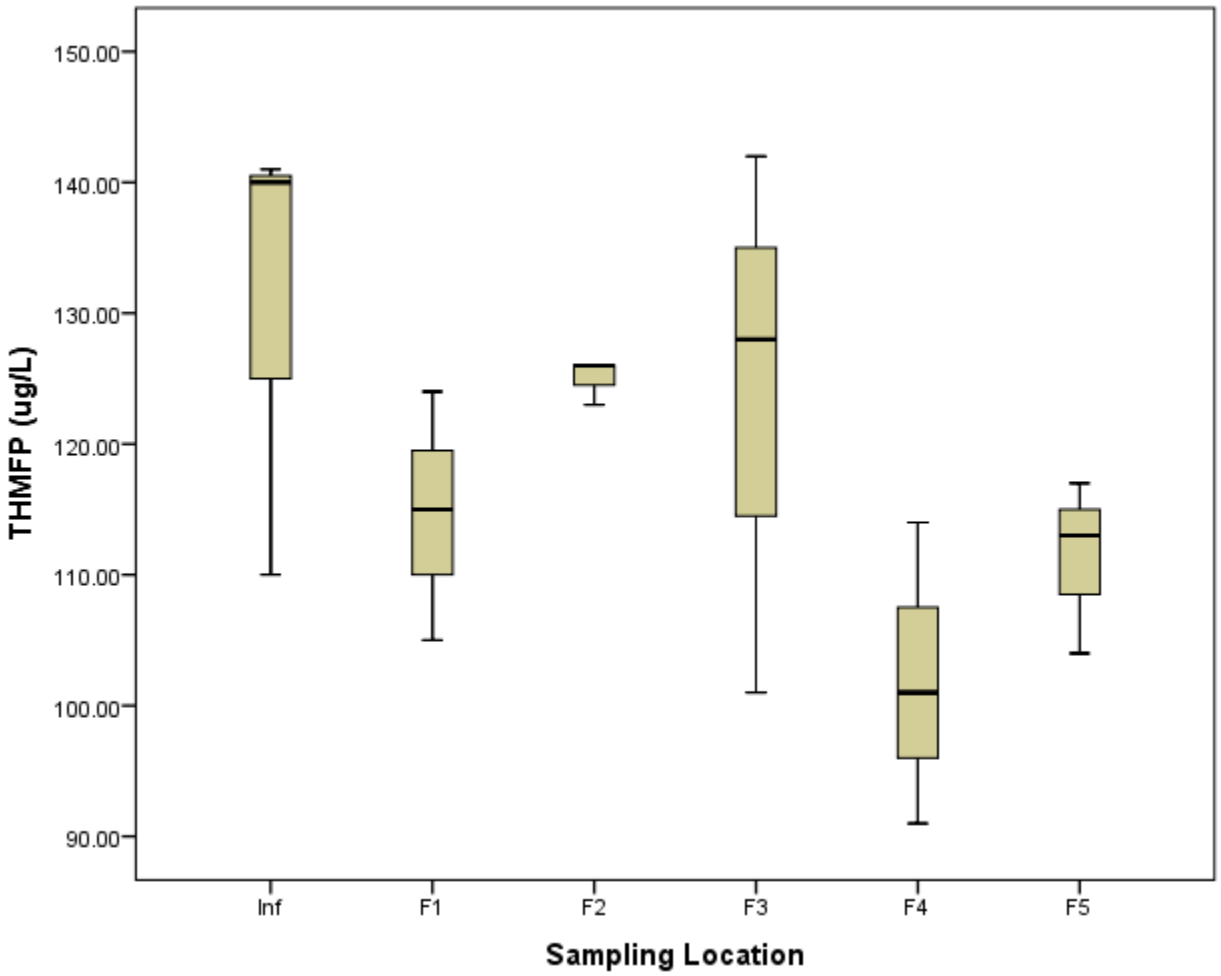

Figure D-1: Boxplot of trihalomethane formation potential data from June 6, 2013 sampling event

ANOVA diagnostics

Table D-3: Results from Levene's test for ANOVA on trihalomethane formation potential data from June 6, 2013 sampling event

F	df1	df2	Sig.
2.474	5	12	9.224E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

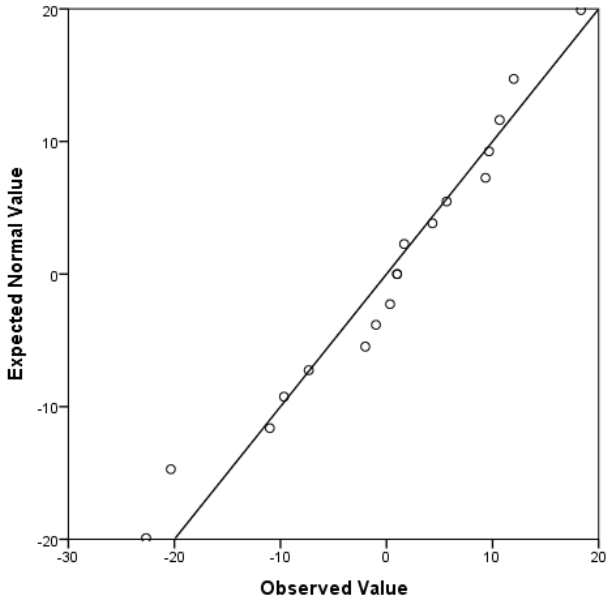

Figure D-2: Normal probability plot of residuals from ANOVA on trihalomethane formation potential data from June 6, 2013 sampling event

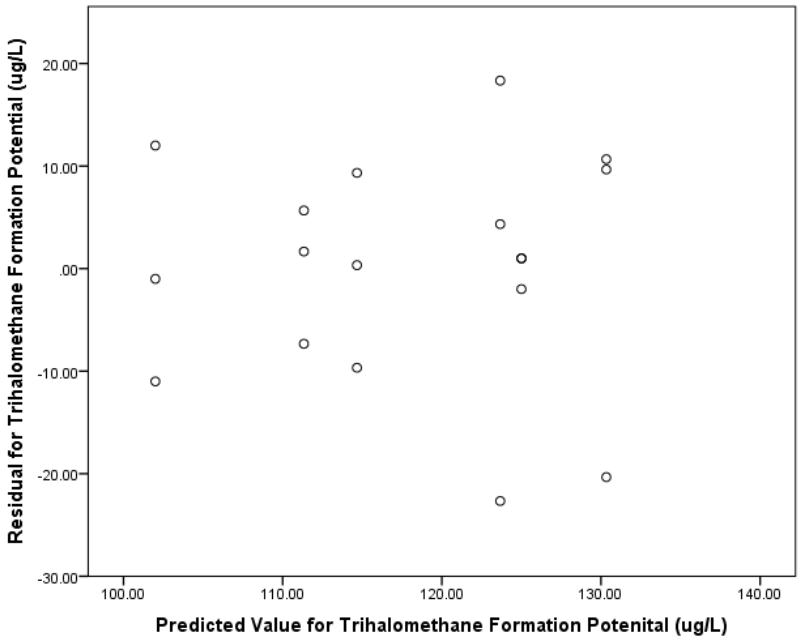

Figure D-3: Plot of residuals from ANOVA on trihalomethane formation potential data from June 6, 2013 sampling event versus the predicted values

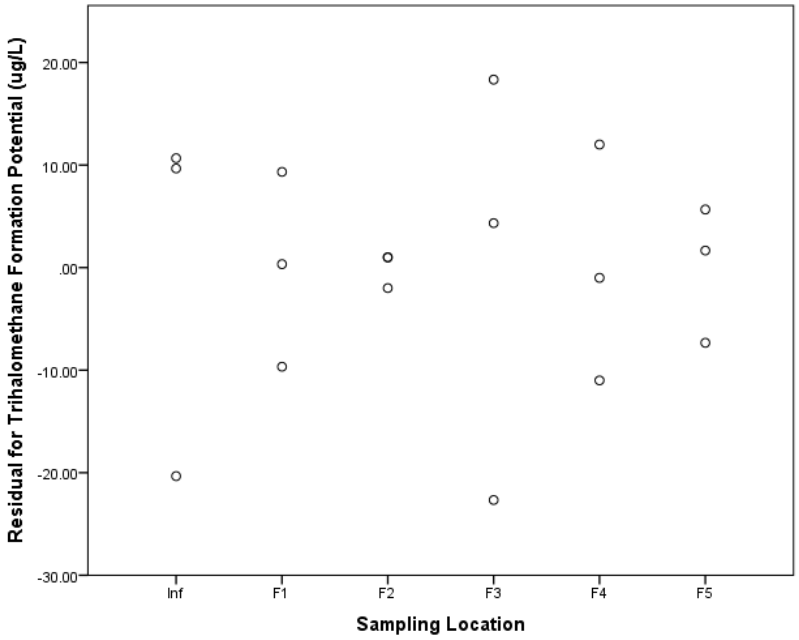

Figure D-4: Plot of residuals from ANOVA on trihalomethane formation potential data from June 6, 2013 sampling event versus the sampling location

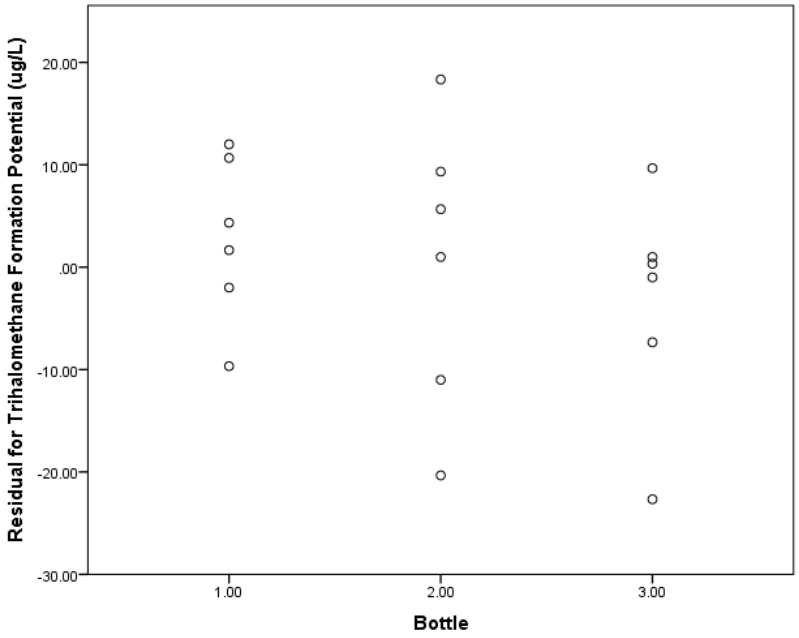

Figure D-5: Plot of residuals from ANOVA on trihalomethane formation potential data from June 6, 2013 sampling event versus the bottle number

June 10, 2013 sampling event (outliers included)

Raw Data

Table D-4: Raw trihalomethane formation potential data from June 10, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-10	124	µg/L	2
F1	2	2013-06-10	119	µg/L	2
F1	3	2013-06-10	126	µg/L	2
F1	4	2013-06-10	115	µg/L	2
F1	5	2013-06-10	118	µg/L	2
F1	6	2013-06-10	98	µg/L	2
F2	1	2013-06-10	119	µg/L	2
F2	2	2013-06-10	130	µg/L	2
F2	3	2013-06-10	113	µg/L	2
F2	4	2013-06-10	126	µg/L	2
F2	5	2013-06-10	125	µg/L	2
F2	6	2013-06-10	131	µg/L	2
F3	1	2013-06-10	123	µg/L	2
F3	2	2013-06-10	131	µg/L	2
F3	3	2013-06-10	126	µg/L	2
F3	4	2013-06-10	121	µg/L	2
F3	5	2013-06-10	127	µg/L	2
F3	6	2013-06-10	130	µg/L	2
F4	1	2013-06-10	111	µg/L	2
F4	2	2013-06-10	114	µg/L	2
F4	3	2013-06-10	109	µg/L	2
F4	4	2013-06-10	114	µg/L	2
F4	5	2013-06-10	123	µg/L	2
F4	6	2013-06-10	119	µg/L	2
F5	1	2013-06-10	119	µg/L	2
F5	2	2013-06-10	115	µg/L	2
F5	3	2013-06-10	95	µg/L	2
F5	4	2013-06-10	119	µg/L	2
F5	5	2013-06-10	112	µg/L	2
F5	6	2013-06-10	113	µg/L	2
Inf	1	2013-06-10	164	µg/L	2
Inf	2	2013-06-10	164	µg/L	2
Inf	3	2013-06-10	143	µg/L	2
Inf	4	2013-06-10	147	µg/L	2
Inf	5	2013-06-10	151	µg/L	2
Inf	6	2013-06-10	144	µg/L	2

Boxplots

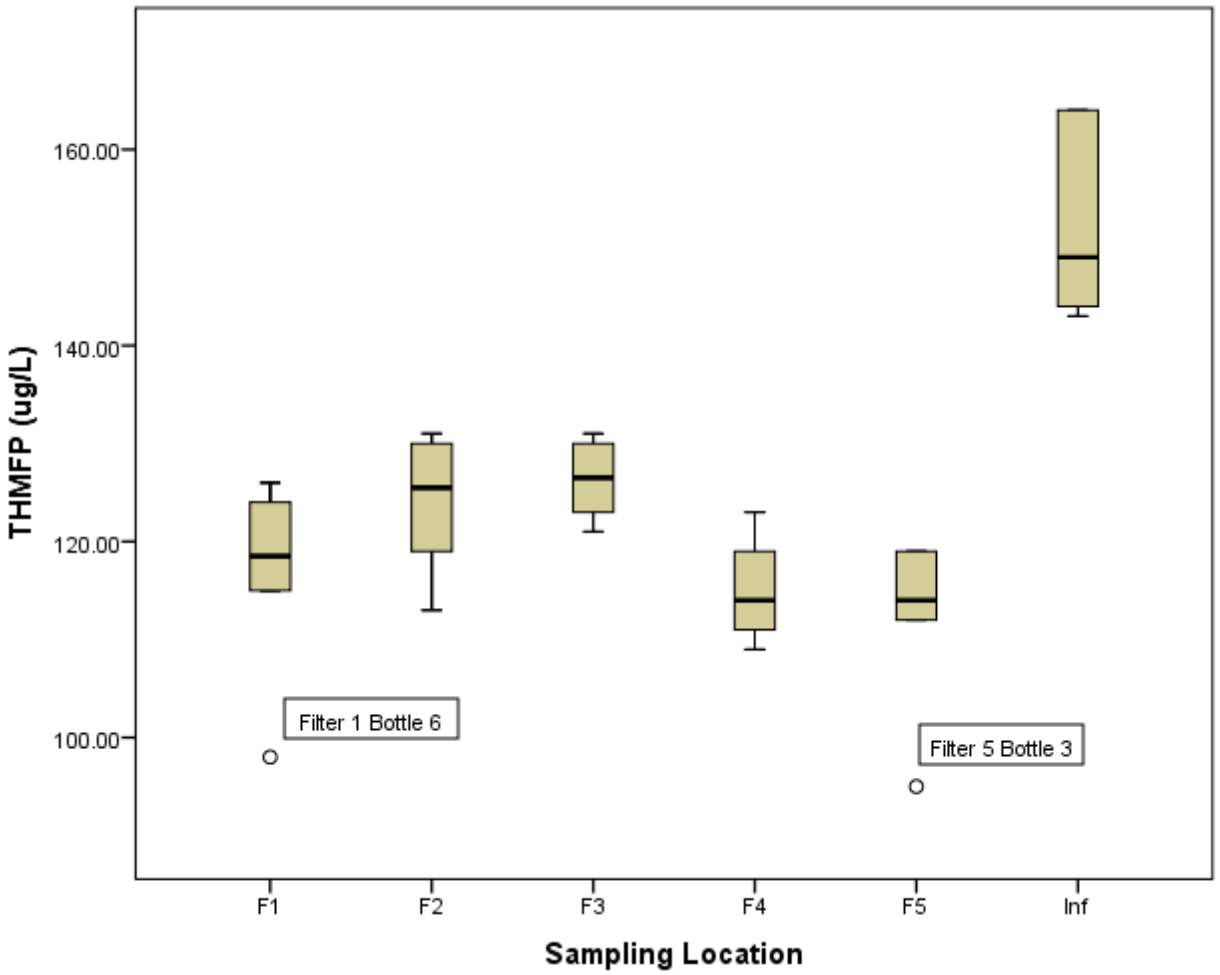

Figure D-6: Boxplot of trihalomethane formation potential data from June 10, 2013 sampling event

ANOVA diagnostics

Table D-5: Results from Levene's test for ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event (outliers included)

F	df1	df2	Sig.
0.910	5	30	4.876E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

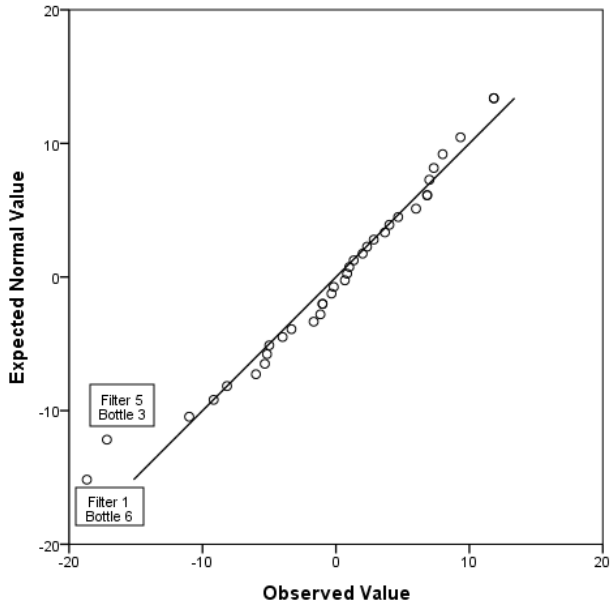

Figure D-7: Normal probability plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event (outliers included)

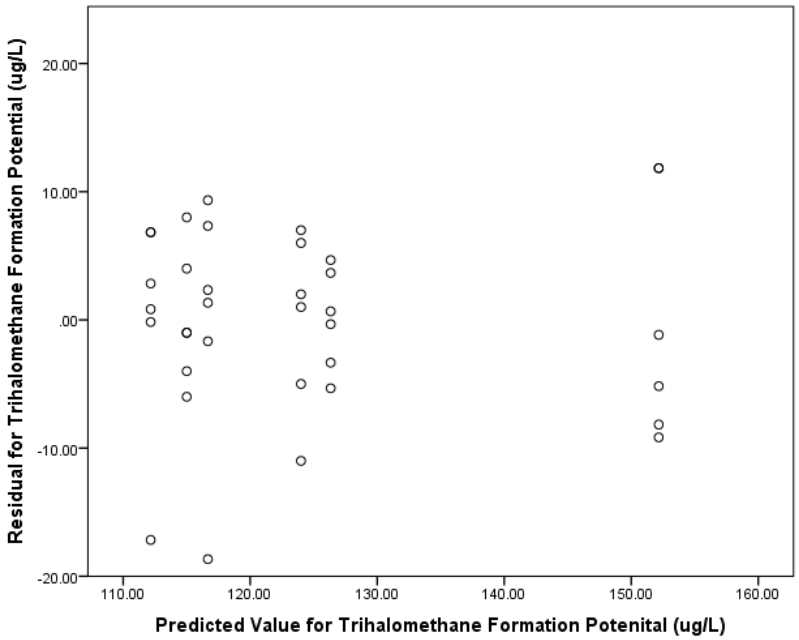

Figure D-8: Plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event versus the predicted values (outliers included)

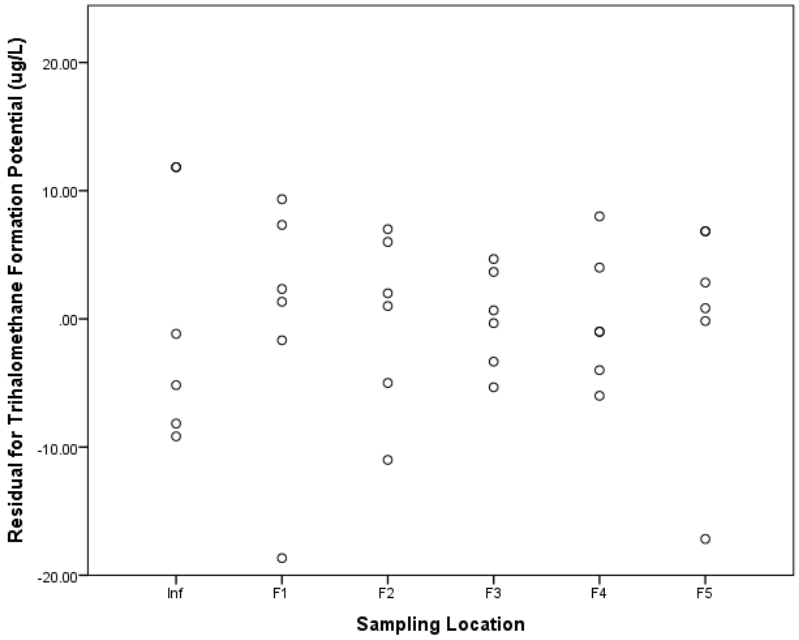

Figure D-9: Plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event versus the sampling location (outliers included)

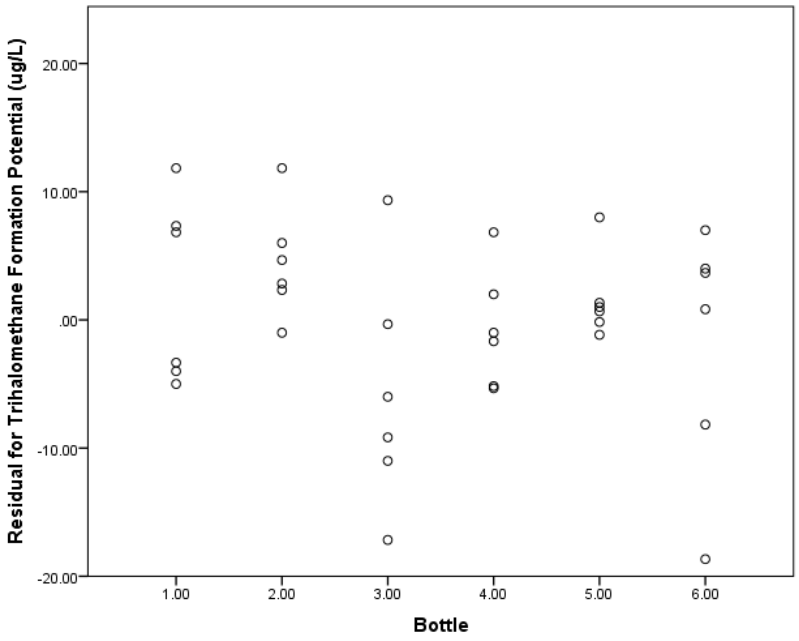

Figure D-10: Plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event versus the bottle number (outliers included)

June 10, 2013 sampling event (outliers excluded)

Boxplots

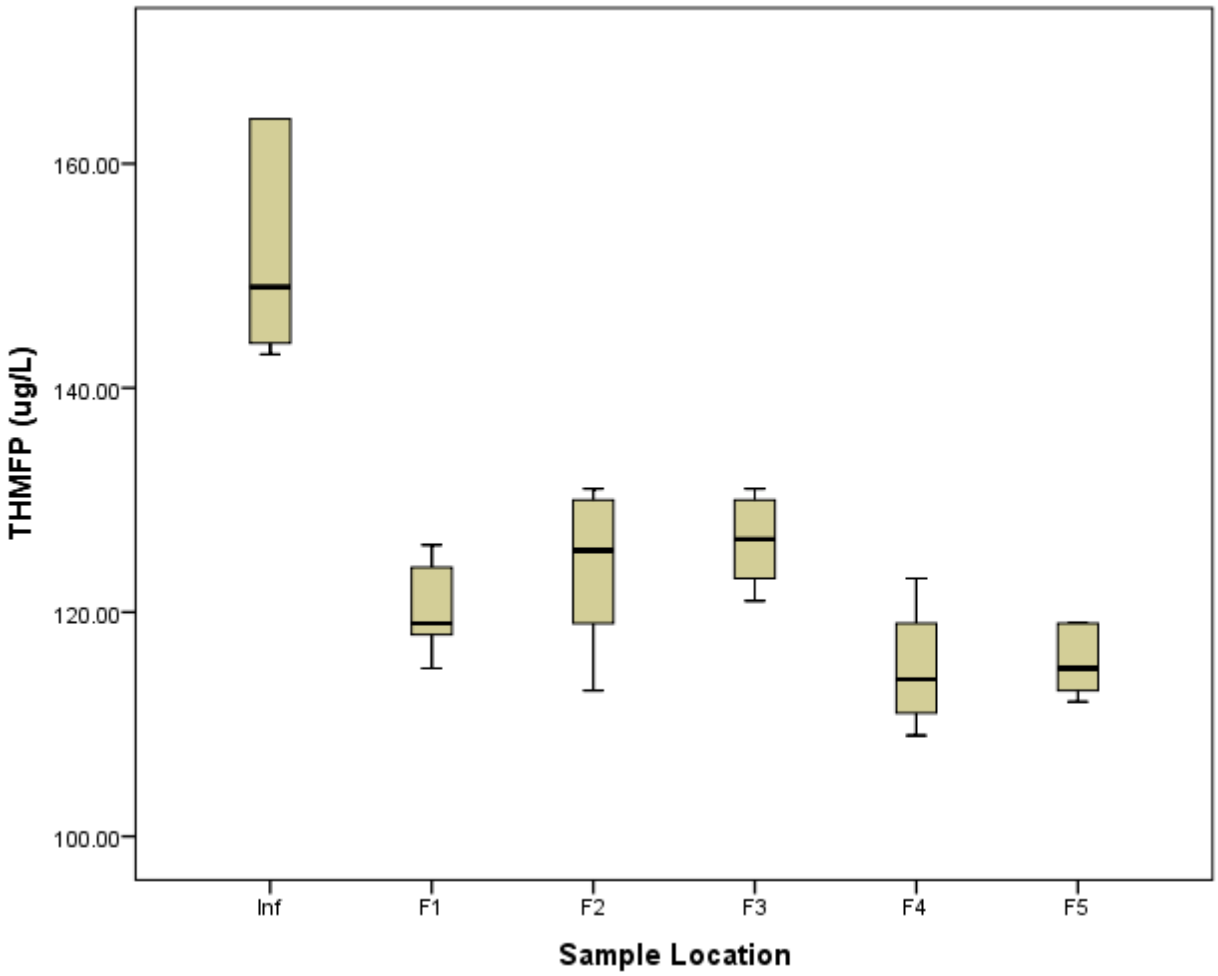

Figure D-11: Boxplot of trihalomethane formation potential data from June 10, 2013 sampling event

ANOVA diagnostics

Table D-6: Results from Levene's test for ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event (outliers excluded)

F	df1	df2	Sig.
2.614	5	28	4.624E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

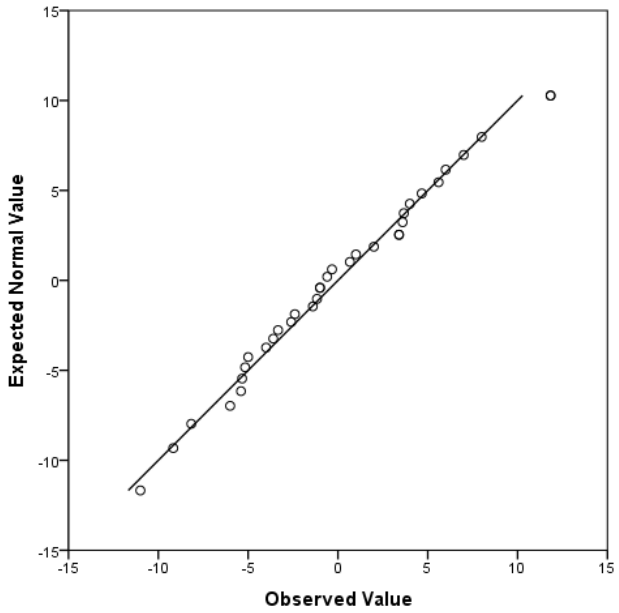

Figure D-12: Normal probability plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event (outliers excluded)

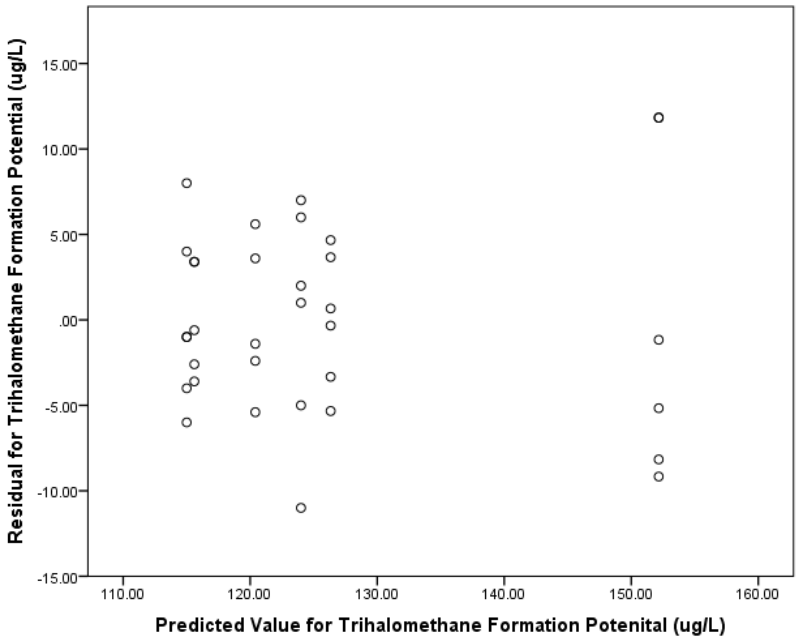

Figure D-13: Plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event versus the predicted values (outliers excluded)

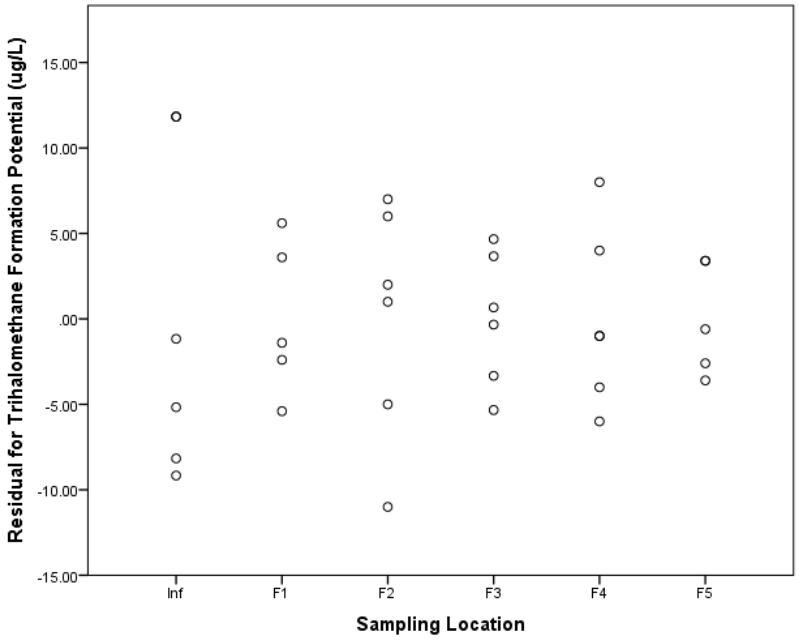

Figure D-14: Plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event versus the sampling location (outliers excluded)

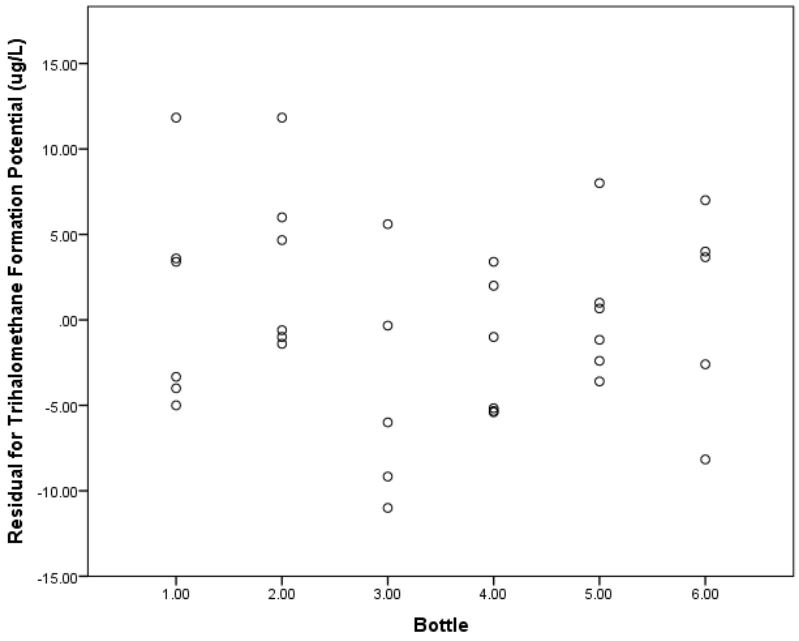

Figure D-15: Plot of residuals from ANOVA on trihalomethane formation potential data from June 10, 2013 sampling event versus the bottle number (outliers excluded)

Multiple comparison results

Table D-7: Detailed multiple comparison results from analysis of trihalomethane formation potential data from June 10, 2013 sampling event (Dunnett's T3 Test)

Test	(I) Filter	(J) Filter	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Dunnett T3	F1	F2	-3.600	3.4535	9.822E-001	-16.765	9.565
		F3	-5.933	2.5634	3.950E-001	-15.899	4.032
		F4	5.400	2.9200	6.447E-001	-5.621	16.421
		F5	4.800	2.4940	6.045E-001	-5.163	14.763
		Inf	-31.767*	4.3994	1.610E-003	-49.310	-14.223
	F2	F1	3.600	3.4535	9.822E-001	-9.565	16.765
		F3	-2.333	3.2215	9.992E-001	-14.913	10.247
		F4	9.000	3.5119	2.767E-001	-4.136	22.136
		F5	8.400	3.1665	2.683E-001	-4.193	20.993
		Inf	-28.167*	4.8126	2.973E-003	-46.278	-10.055
	F3	F1	5.933	2.5634	3.950E-001	-4.032	15.899
		F2	2.333	3.2215	9.992E-001	-10.247	14.913
		F4	11.333*	2.6415	2.253E-002	1.447	21.220
		F5	10.733*	2.1613	9.487E-003	2.582	18.885
		Inf	-25.833*	4.2197	6.569E-003	-43.266	-8.400
	F4	F1	-5.400	2.9200	6.447E-001	-16.421	5.621
		F2	-9.000	3.5119	2.767E-001	-22.136	4.136
		F3	-11.333*	2.6415	2.253E-002	-21.220	-1.447
		F5	-0.600	2.5742	1.000E+000	-10.446	9.246
		Inf	-37.167*	4.4453	4.870E-004	-54.660	-19.674
	F5	F1	-4.800	2.4940	6.045E-001	-14.763	5.163
		F2	-8.400	3.1665	2.683E-001	-20.993	4.193
		F3	-10.733*	2.1613	9.487E-003	-18.885	-2.582
		F4	0.600	2.5742	1.000E+000	-9.246	10.446
		Inf	-36.567*	4.1779	9.855E-004	-54.057	-19.077
	Inf	F1	31.767*	4.3994	1.610E-003	14.223	49.310
		F2	28.167*	4.8126	2.973E-003	10.055	46.278
		F3	25.833*	4.2197	6.569E-003	8.400	43.266
		F4	37.167*	4.4453	4.870E-004	19.674	54.660
		F5	36.567*	4.1779	9.855E-004	19.077	54.057

Based on observed means.
*The mean difference is significant at the .05 level.

Chloroform formation potential

June 6, 2013 sampling event

Raw Data

Table D-8: Raw chloroform potential data from June 6, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-06	86	ug/L	0.29
F1	2	2013-06-06	105	ug/L	0.29
F1	3	2013-06-06	97	ug/L	0.29
F2	1	2013-06-06	105	ug/L	0.29
F2	2	2013-06-06	108	ug/L	0.29
F2	3	2013-06-06	107	ug/L	0.29
F3	1	2013-06-06	110	ug/L	0.29
F3	2	2013-06-06	123	ug/L	0.29
F3	3	2013-06-06	82	ug/L	0.29
F4	1	2013-06-06	94	ug/L	0.29
F4	2	2013-06-06	72	ug/L	0.29
F4	3	2013-06-06	82	ug/L	0.29
F5	1	2013-06-06	94	ug/L	0.29
F5	2	2013-06-06	97	ug/L	0.29
F5	3	2013-06-06	84	ug/L	0.29
Inf	1	2013-06-06	123	ug/L	0.29
Inf	2	2013-06-06	92	ug/L	0.29
Inf	3	2013-06-06	123	ug/L	0.29

Boxplots

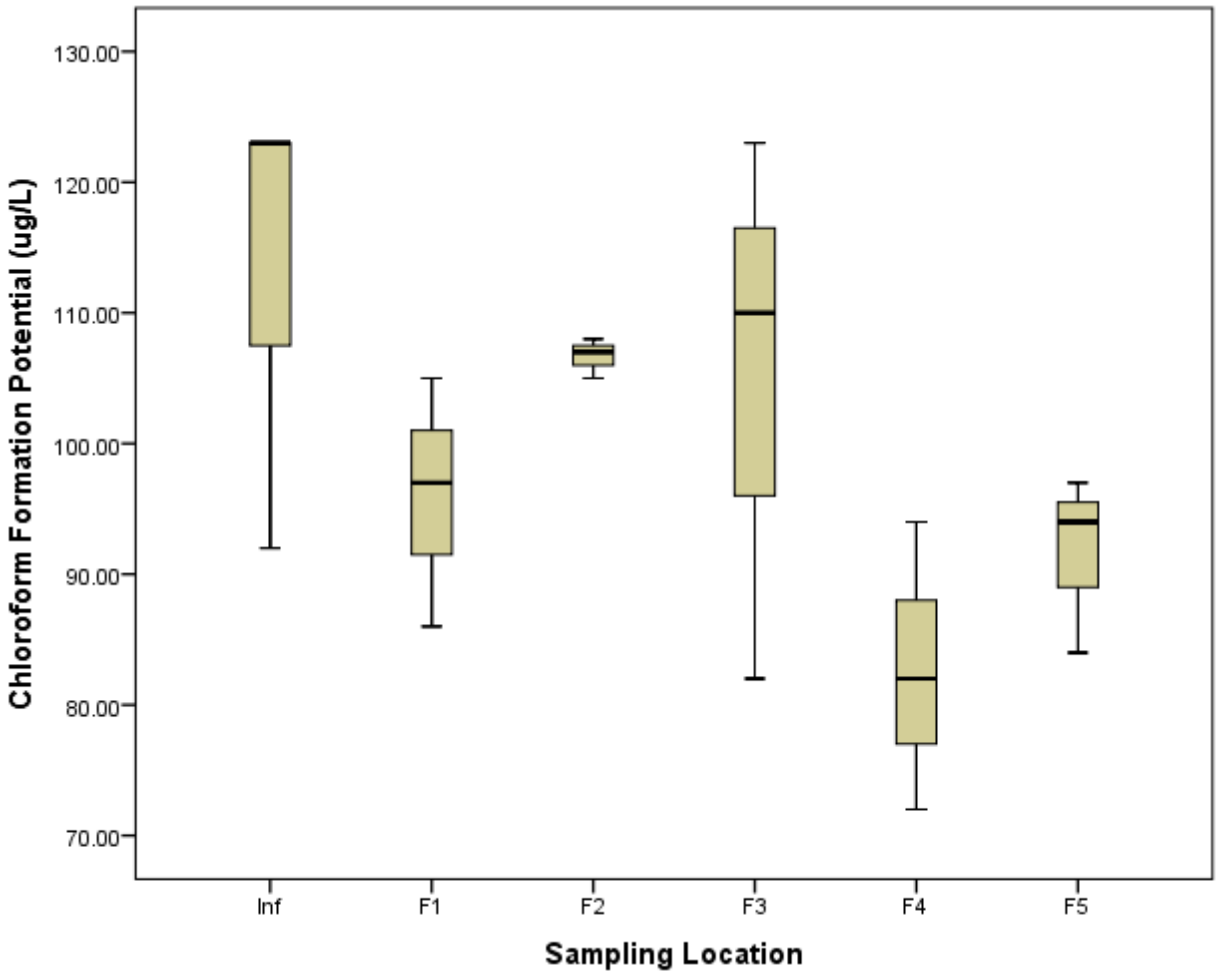

Figure D-16: Boxplot of chloroform formation potential data from June 6, 2013 sampling event

ANOVA diagnostics

Table D-9: Results from Levene's test for ANOVA on chloroform formation potential data from June 6, 2013 sampling event

F	df1	df2	Sig.
2.744	5	12	7.052E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

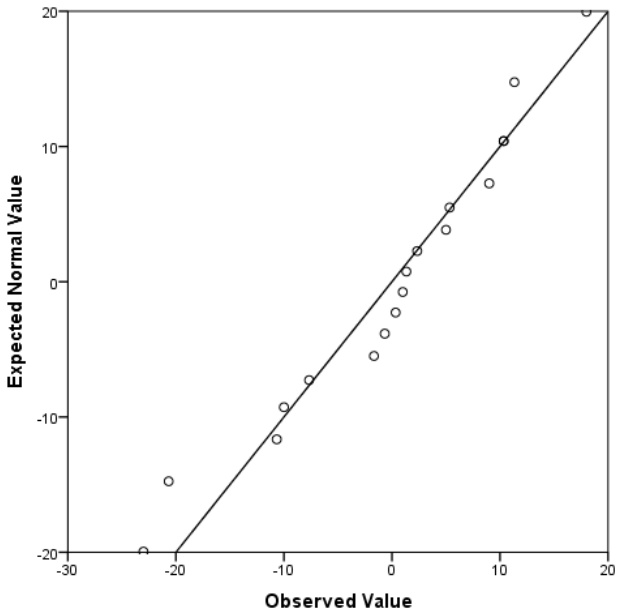

Figure D-17: Normal probability plot of residuals from ANOVA on chloroform formation potential data from June 6, 2013 sampling event

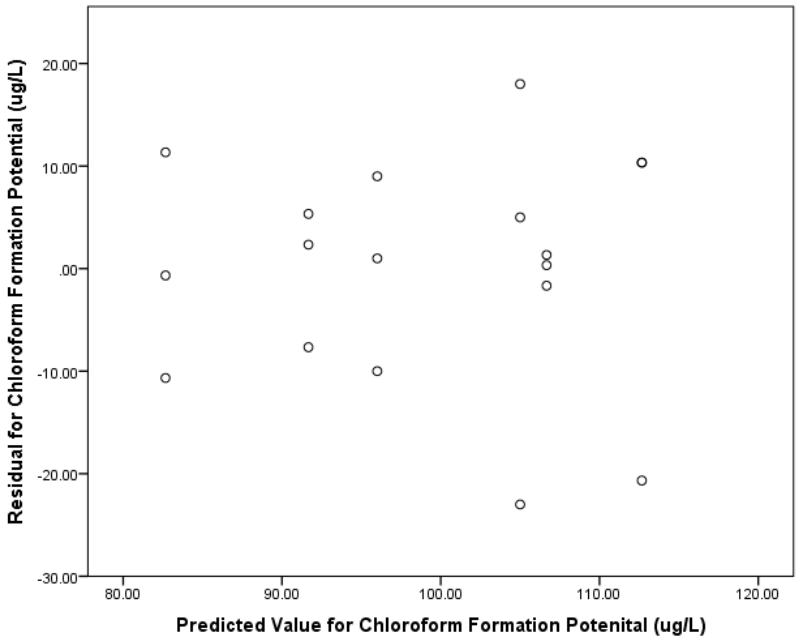

Figure D-18: Plot of residuals from ANOVA on chloroform formation potential data from June 6, 2013 sampling event versus the predicted values

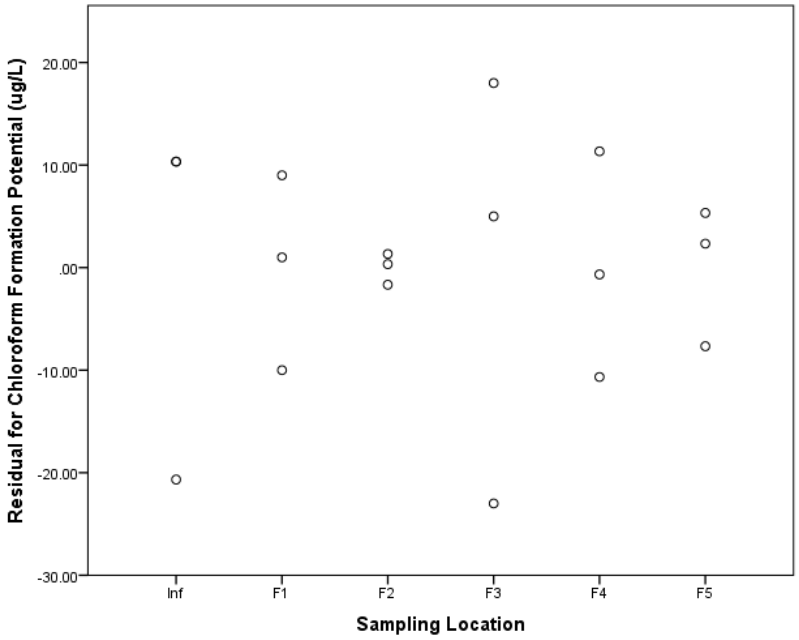

Figure D-19: Plot of residuals from ANOVA on chloroform formation potential data from June 6, 2013 sampling event versus the sampling location

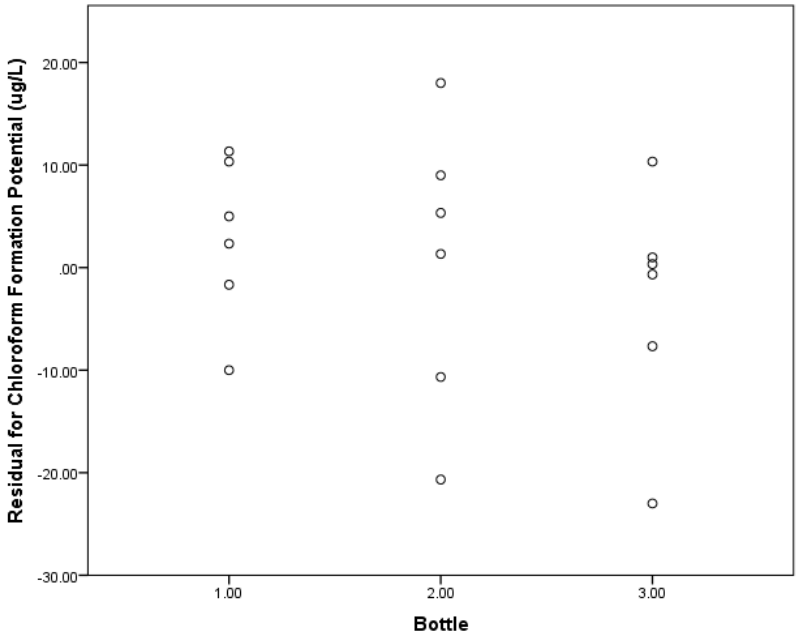

Figure D-20: Plot of residuals from ANOVA on chloroform formation potential data from June 6, 2013 sampling event versus the bottle number

June 10, 2013 sampling event (outliers included)

Raw Data

Table D-10: Raw chloroform formation potential data from June 10, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-10	101	ug/L	0.29
F1	2	2013-06-10	96	ug/L	0.29
F1	3	2013-06-10	103	ug/L	0.29
F1	4	2013-06-10	93	ug/L	0.29
F1	5	2013-06-10	96	ug/L	0.29
F1	6	2013-06-10	75	ug/L	0.29
F2	1	2013-06-10	97	ug/L	0.29
F2	2	2013-06-10	107	ug/L	0.29
F2	3	2013-06-10	92	ug/L	0.29
F2	4	2013-06-10	104	ug/L	0.29
F2	5	2013-06-10	103	ug/L	0.29
F2	6	2013-06-10	108	ug/L	0.29
F3	1	2013-06-10	101	ug/L	0.29
F3	2	2013-06-10	107	ug/L	0.29
F3	3	2013-06-10	104	ug/L	0.29
F3	4	2013-06-10	98	ug/L	0.29
F3	5	2013-06-10	105	ug/L	0.29
F3	6	2013-06-10	108	ug/L	0.29
F4	1	2013-06-10	89	ug/L	0.29
F4	2	2013-06-10	91	ug/L	0.29
F4	3	2013-06-10	87	ug/L	0.29
F4	4	2013-06-10	92	ug/L	0.29
F4	5	2013-06-10	100	ug/L	0.29
F4	6	2013-06-10	96	ug/L	0.29
F5	1	2013-06-10	97	ug/L	0.29
F5	2	2013-06-10	92	ug/L	0.29
F5	3	2013-06-10	73	ug/L	0.29
F5	4	2013-06-10	95	ug/L	0.29
F5	5	2013-06-10	89	ug/L	0.29
F5	6	2013-06-10	91	ug/L	0.29
Inf	1	2013-06-10	141	ug/L	0.29
Inf	2	2013-06-10	140	ug/L	0.29
Inf	3	2013-06-10	120	ug/L	0.29
Inf	4	2013-06-10	123	ug/L	0.29
Inf	5	2013-06-10	128	ug/L	0.29
Inf	6	2013-06-10	122	ug/L	0.29

Boxplots

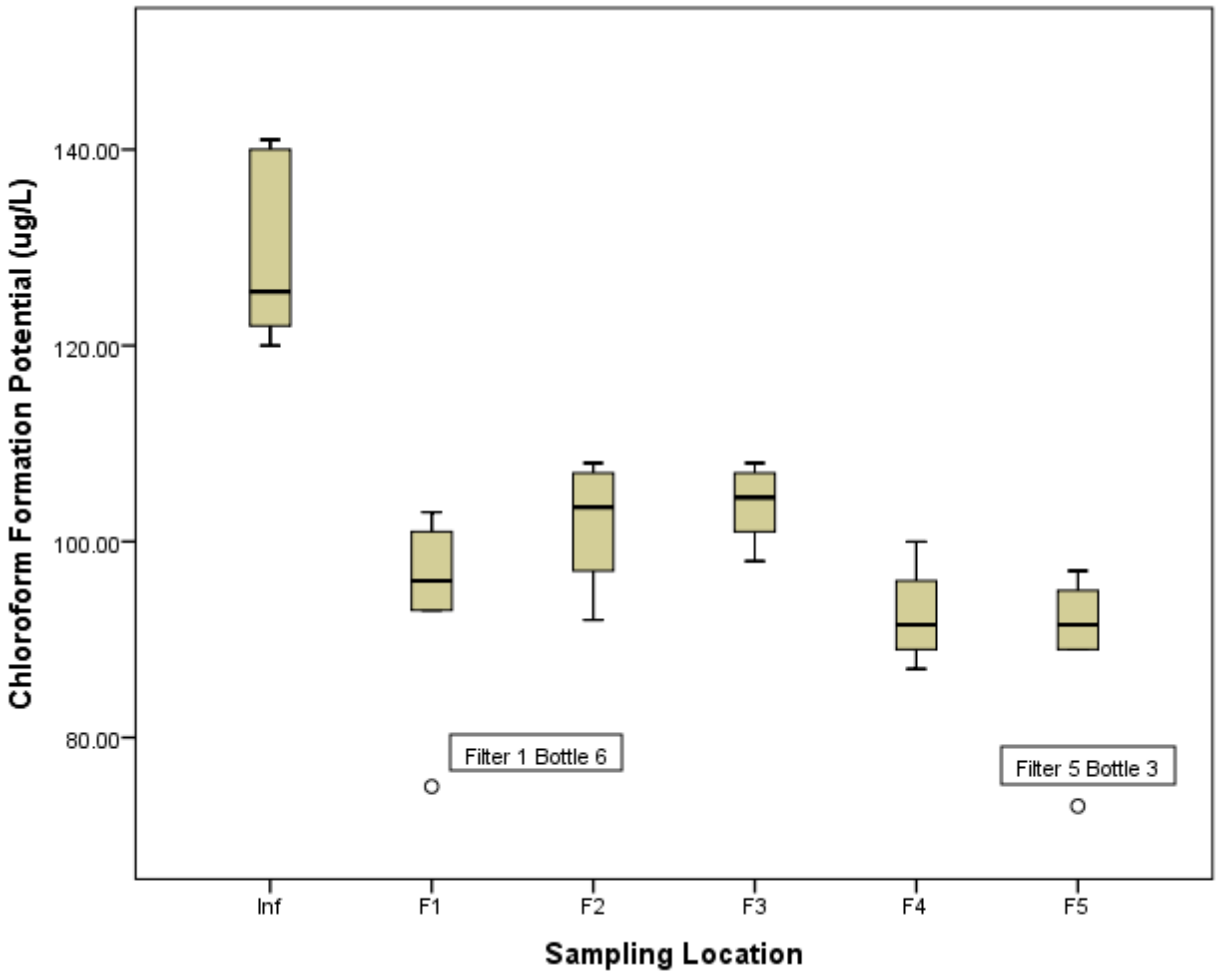

Figure D-21: Boxplot of chloroform formation potential data from June 10, 2013 sampling event (outliers included)

ANOVA diagnostics

Table D-11: Results from Levene's test for ANOVA on chloroform formation potential data from June 10, 2013 sampling event (outliers included)

F	df1	df2	Sig.
0.993	5	30	4.386E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

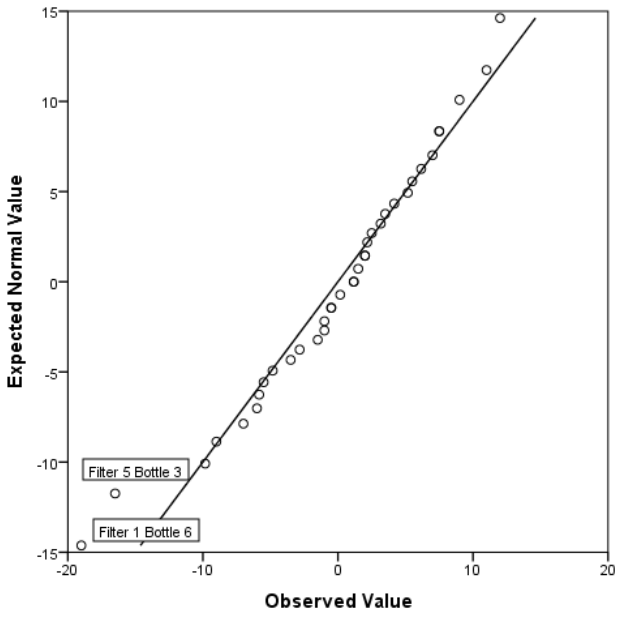

Figure D-22: Normal probability plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event (outliers included)

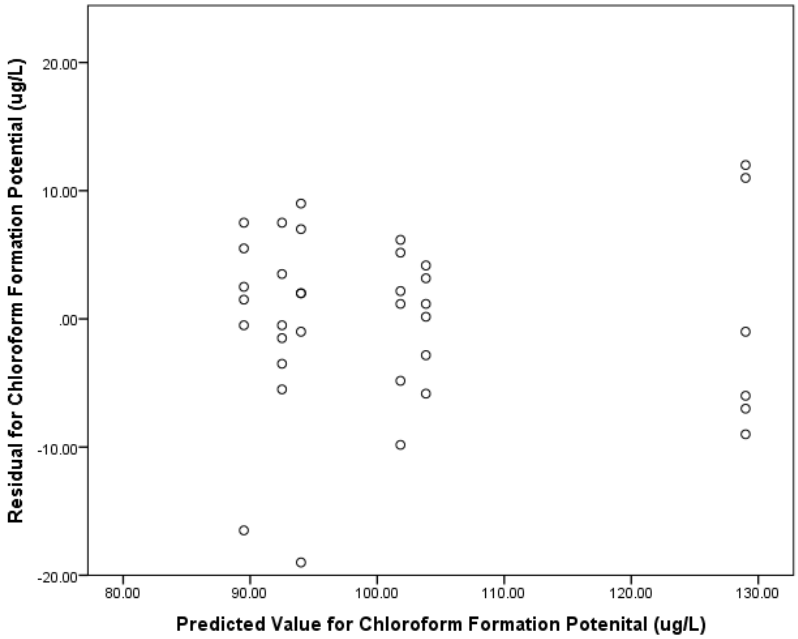

Figure D-23: Plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event versus the predicted values (outliers included)

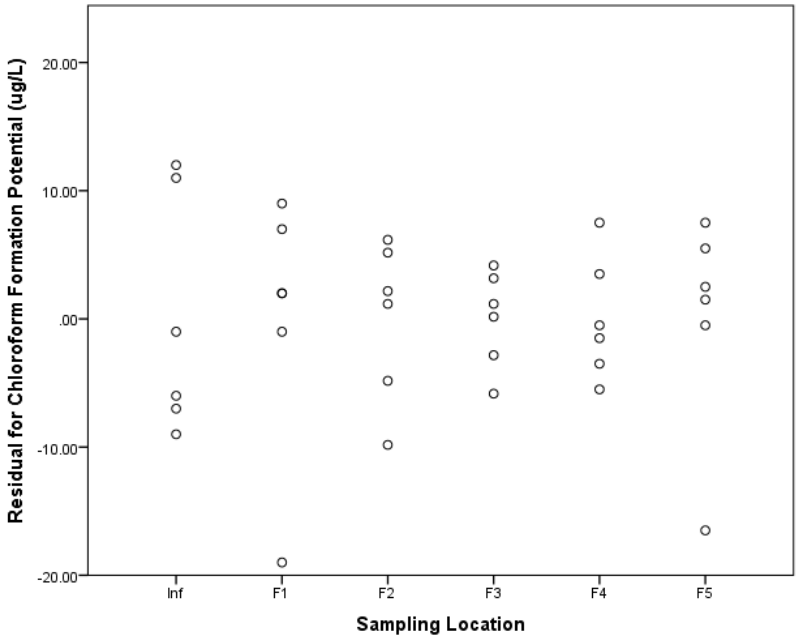

Figure D-24: Plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event versus the sampling location (outliers included)

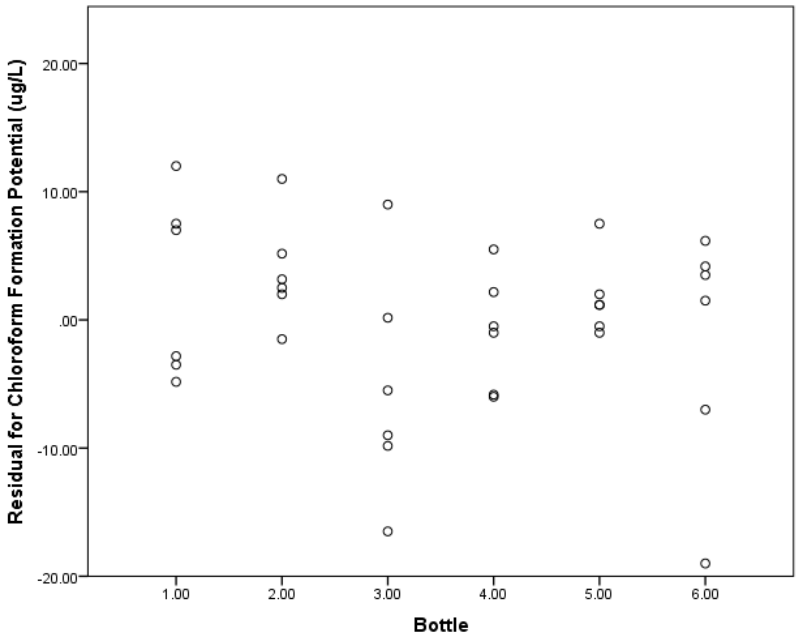

Figure D-25: Plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event versus the bottle number (outliers included)

June 10, 2013 sampling event (outliers excluded)

Boxplots

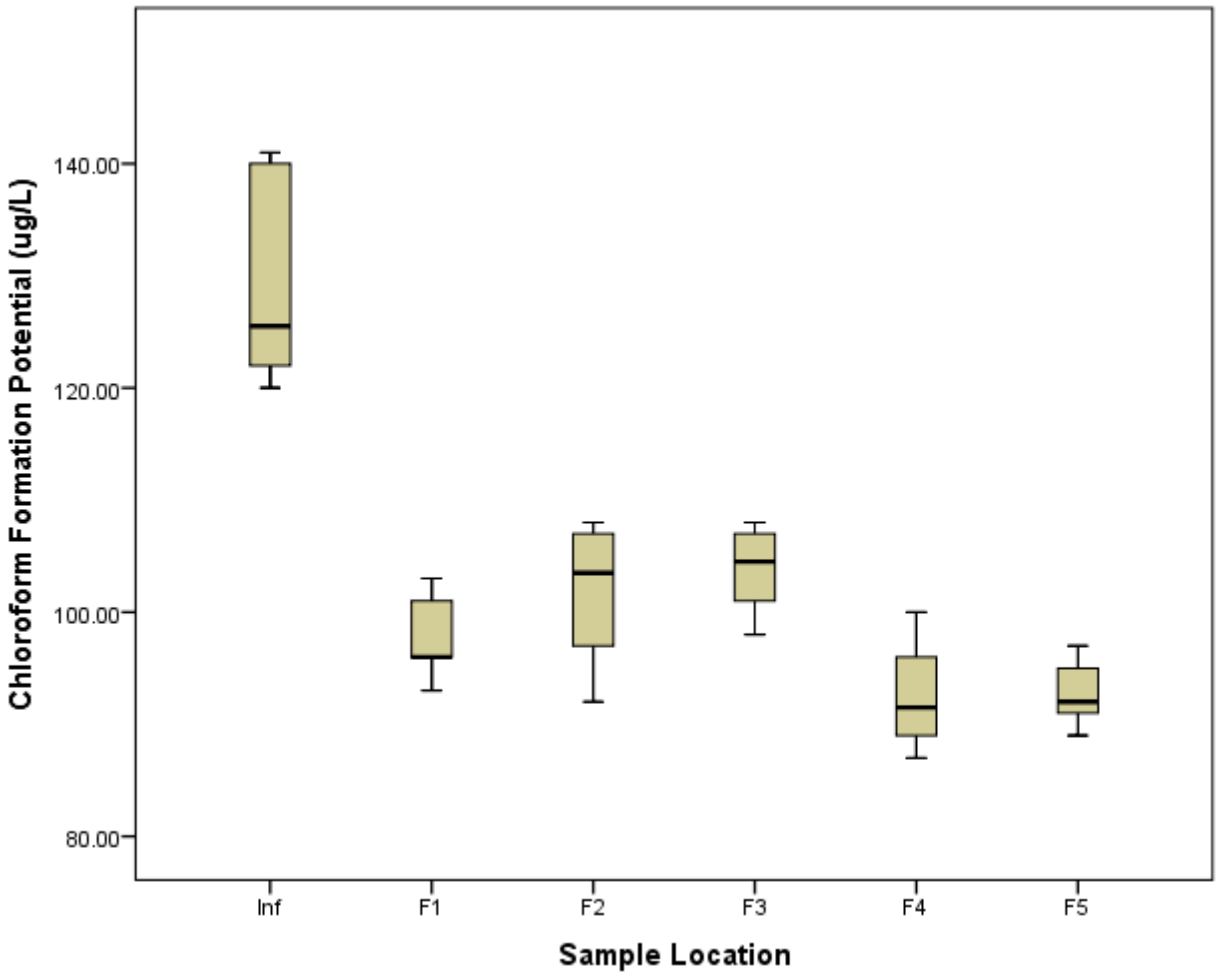

Figure D-26: Boxplot of chloroform formation potential data from June 10, 2013 sampling event (outliers excluded)

ANOVA diagnostics

Table D-12: Results from Levene's test for ANOVA on chloroform formation potential data from June 10, 2013 sampling event (outliers excluded)

F	df1	df2	Sig.
2.927	5	28	3.005E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

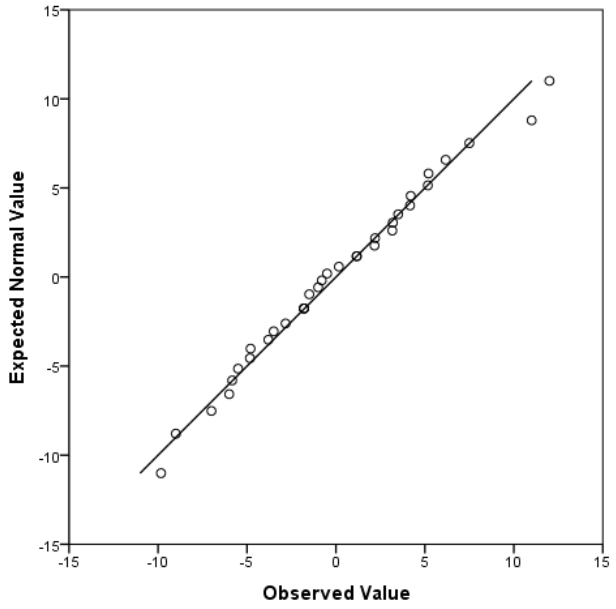

Figure D-27: Normal probability plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event (outliers excluded)

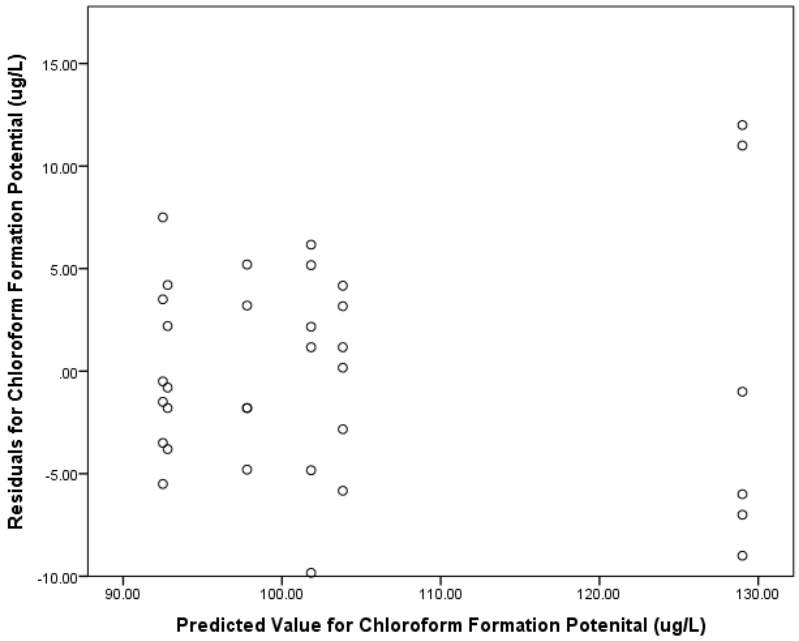

Figure D-28: Plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event versus the predicted values (outliers excluded)

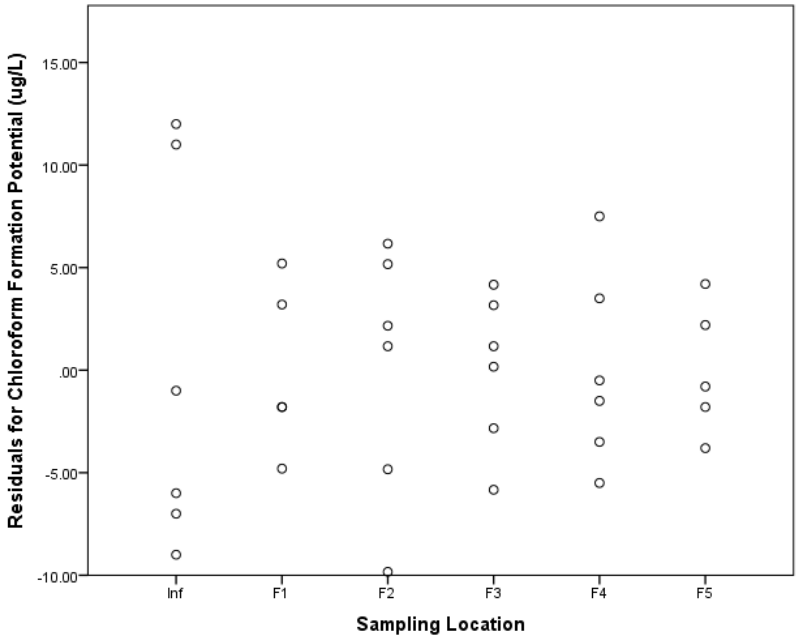

Figure D-29: Plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event versus the sampling location (outliers excluded)

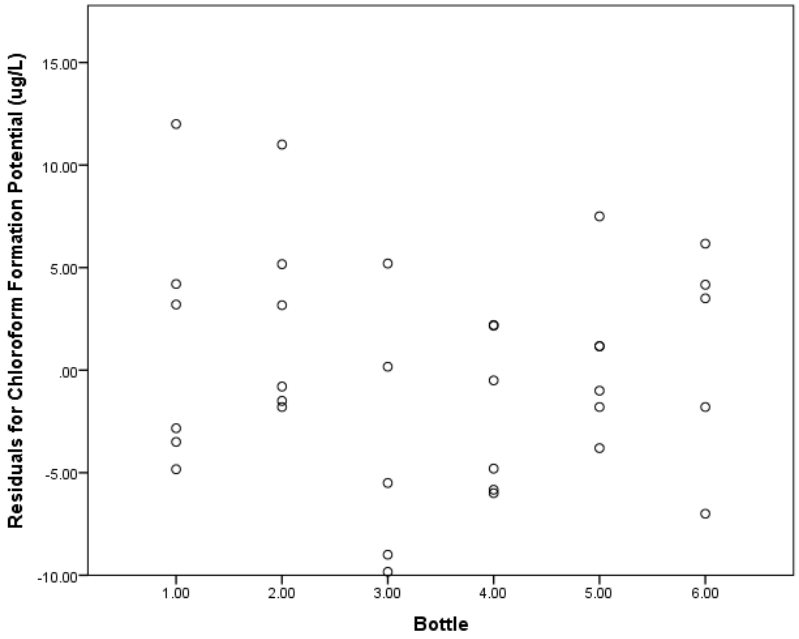

Figure D-30: Plot of residuals from ANOVA on chloroform formation potential data from June 10, 2013 sampling event versus the bottle number (outliers excluded)

Multiple comparison results

Table D-13: Detailed multiple comparison results from analysis of chloroform formation potential data, with outliers excluded, from June 10, 2013 sampling event (Dunnett's T3 Test)

Test	(I) Filter	(J) Filter	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Dunnett T3	F1	F2	-4.033	3.1147	9.256E-001	-15.897	7.831
		F3	-6.033	2.3877	3.012E-001	-15.221	3.154
		F4	5.300	2.6690	5.633E-001	-4.769	15.369
		F5	5.000	2.3195	4.775E-001	-4.175	14.175
		Inf	-31.200*	4.2119	1.591E-003	-48.177	-14.223
	F2	F1	4.033	3.1147	9.256E-001	-7.831	15.897
		F3	-2.000	2.9533	9.996E-001	-13.388	9.388
		F4	9.333	3.1850	1.638E-001	-2.550	21.216
		F5	9.033	2.8985	1.449E-001	-2.357	20.423
		Inf	-27.167*	4.5564	3.019E-003	-44.498	-9.836
	F3	F1	6.033	2.3877	3.012E-001	-3.154	15.221
		F2	2.000	2.9533	9.996E-001	-9.388	13.388
		F4	11.333*	2.4788	1.435E-002	2.108	20.558
		F5	11.033*	2.0979	6.465E-003	3.121	18.946
		Inf	-25.167*	4.0940	6.427E-003	-42.082	-8.251
	F4	F1	-5.300	2.6690	5.633E-001	-15.369	4.769
		F2	-9.333	3.1850	1.638E-001	-21.216	2.550
		F3	-11.333*	2.4788	1.435E-002	-20.558	-2.108
		F5	-0.300	2.4132	1.000E+000	-9.481	8.881
		Inf	-36.500*	4.2642	4.896E-004	-53.435	-19.565
	F5	F1	-5.000	2.3195	4.775E-001	-14.175	4.175
		F2	-9.033	2.8985	1.449E-001	-20.423	2.357
		F3	-11.033*	2.0979	6.465E-003	-18.946	-3.121
		F4	0.300	2.4132	1.000E+000	-8.881	9.481
		Inf	-36.200*	4.0546	8.743E-004	-53.170	-19.230
	Inf	F1	31.200*	4.2119	1.591E-003	14.223	48.177
		F2	27.167*	4.5564	3.019E-003	9.836	44.498
		F3	25.167*	4.0940	6.427E-003	8.251	42.082
		F4	36.500*	4.2642	4.896E-004	19.565	53.435
		F5	36.200*	4.0546	8.743E-004	19.230	53.170

Based on observed means.
*The mean difference is significant at the .05 level.

Bromoform formation potential

June 6, 2013 sampling event

Raw Data

Table D-14: Raw bromoform formation potential data from June 6, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-06	<0.34	ug/L	0.34
F1	2	2013-06-06	<0.34	ug/L	0.34
F1	3	2013-06-06	<0.34	ug/L	0.34
F2	1	2013-06-06	<0.34	ug/L	0.34
F2	2	2013-06-06	<0.34	ug/L	0.34
F2	3	2013-06-06	<0.34	ug/L	0.34
F3	1	2013-06-06	<0.34	ug/L	0.34
F3	2	2013-06-06	<0.34	ug/L	0.34
F3	3	2013-06-06	<0.34	ug/L	0.34
F4	1	2013-06-06	<0.34	ug/L	0.34
F4	2	2013-06-06	<0.34	ug/L	0.34
F4	3	2013-06-06	<0.34	ug/L	0.34
F5	1	2013-06-06	<0.34	ug/L	0.34
F5	2	2013-06-06	<0.34	ug/L	0.34
F5	3	2013-06-06	<0.34	ug/L	0.34
Inf	1	2013-06-06	<0.34	ug/L	0.34
Inf	2	2013-06-06	<0.34	ug/L	0.34
Inf	3	2013-06-06	<0.34	ug/L	0.34

June 10, 2013 sampling event

Raw Data

Table D-15: Raw bromoform formation potential data from June 10, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-10	<0.34	ug/L	0.34
F1	2	2013-06-10	<0.34	ug/L	0.34
F1	3	2013-06-10	<0.34	ug/L	0.34
F1	4	2013-06-10	<0.34	ug/L	0.34
F1	5	2013-06-10	<0.34	ug/L	0.34
F1	6	2013-06-10	<0.34	ug/L	0.34
F2	1	2013-06-10	<0.34	ug/L	0.34
F2	2	2013-06-10	<0.34	ug/L	0.34
F2	3	2013-06-10	<0.34	ug/L	0.34
F2	4	2013-06-10	<0.34	ug/L	0.34
F2	5	2013-06-10	<0.34	ug/L	0.34
F2	6	2013-06-10	<0.34	ug/L	0.34
F3	1	2013-06-10	<0.34	ug/L	0.34
F3	2	2013-06-10	<0.34	ug/L	0.34
F3	3	2013-06-10	<0.34	ug/L	0.34
F3	4	2013-06-10	<0.34	ug/L	0.34
F3	5	2013-06-10	<0.34	ug/L	0.34
F3	6	2013-06-10	<0.34	ug/L	0.34
F4	1	2013-06-10	<0.34	ug/L	0.34
F4	2	2013-06-10	<0.34	ug/L	0.34
F4	3	2013-06-10	<0.34	ug/L	0.34
F4	4	2013-06-10	<0.34	ug/L	0.34
F4	5	2013-06-10	<0.34	ug/L	0.34
F4	6	2013-06-10	<0.34	ug/L	0.34
F5	1	2013-06-10	<0.34	ug/L	0.34
F5	2	2013-06-10	<0.34	ug/L	0.34
F5	3	2013-06-10	<0.34	ug/L	0.34
F5	4	2013-06-10	<0.34	ug/L	0.34
F5	5	2013-06-10	<0.34	ug/L	0.34
F5	6	2013-06-10	<0.34	ug/L	0.34
Inf	1	2013-06-10	<0.34	ug/L	0.34
Inf	2	2013-06-10	<0.34	ug/L	0.34
Inf	3	2013-06-10	<0.34	ug/L	0.34
Inf	4	2013-06-10	<0.34	ug/L	0.34
Inf	5	2013-06-10	<0.34	ug/L	0.34
Inf	6	2013-06-10	<0.34	ug/L	0.34

Bromodichloromethane formation potential

June 6, 2013 sampling event

Raw Data

Table D-16: Raw bromodichloromethane formation potential data from June 10, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-06	15	ug/L	0.26
F1	2	2013-06-06	15	ug/L	0.26
F1	3	2013-06-06	14	ug/L	0.26
F2	1	2013-06-06	15	ug/L	0.26
F2	2	2013-06-06	15	ug/L	0.26
F2	3	2013-06-06	15	ug/L	0.26
F3	1	2013-06-06	15	ug/L	0.26
F3	2	2013-06-06	16	ug/L	0.26
F3	3	2013-06-06	15	ug/L	0.26
F4	1	2013-06-06	16	ug/L	0.26
F4	2	2013-06-06	14	ug/L	0.26
F4	3	2013-06-06	15	ug/L	0.26
F5	1	2013-06-06	15	ug/L	0.26
F5	2	2013-06-06	15	ug/L	0.26
F5	3	2013-06-06	15	ug/L	0.26
Inf	1	2013-06-06	15	ug/L	0.26
Inf	2	2013-06-06	14	ug/L	0.26
Inf	3	2013-06-06	14	ug/L	0.26

Boxplots

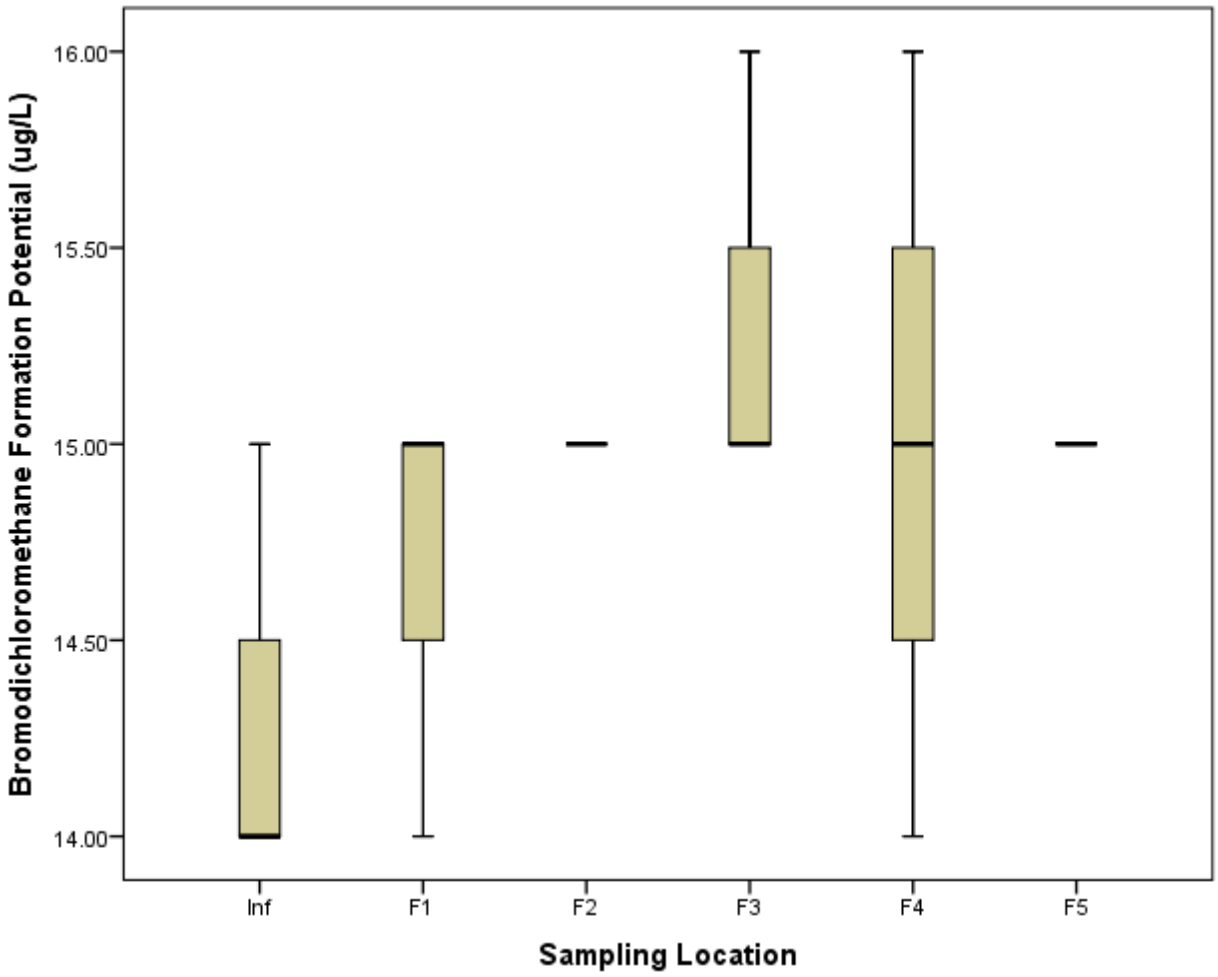

Figure D-31: Boxplot of bromodichloromethane formation potential data from June 6, 2013 sampling event

ANOVA diagnostics

Table D-17: Results from Levene's test for ANOVA on bromodichloromethane formation potential data from June 6, 2013 sampling event

F	df1	df2	Sig.
3.000	5	12	5.520E-002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

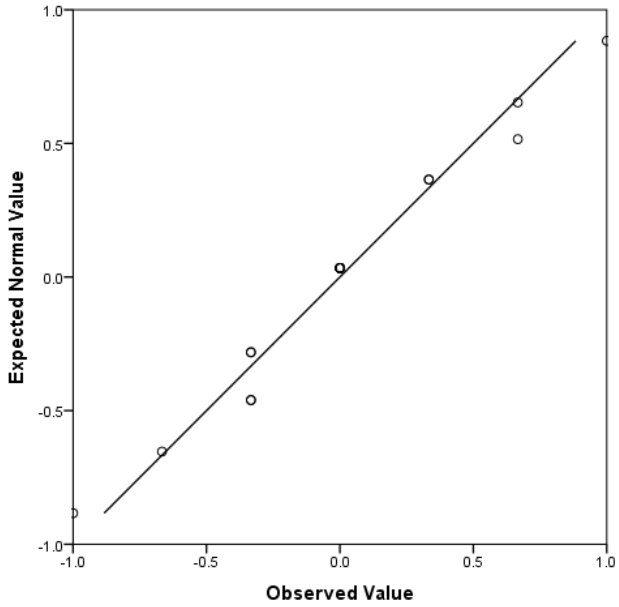

Figure D-32: Normal probability plot of residuals from ANOVA on bromodichloromethane formation potential data from June 6, 2013 sampling event

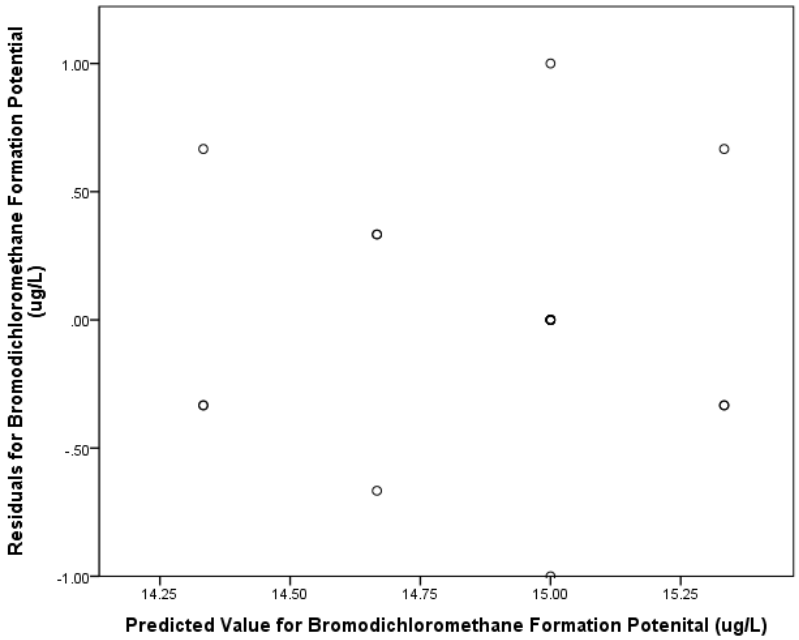

Figure D-33: Plot of residuals from ANOVA on bromodichloromethane formation potential data from June 6, 2013 sampling event versus the predicted values

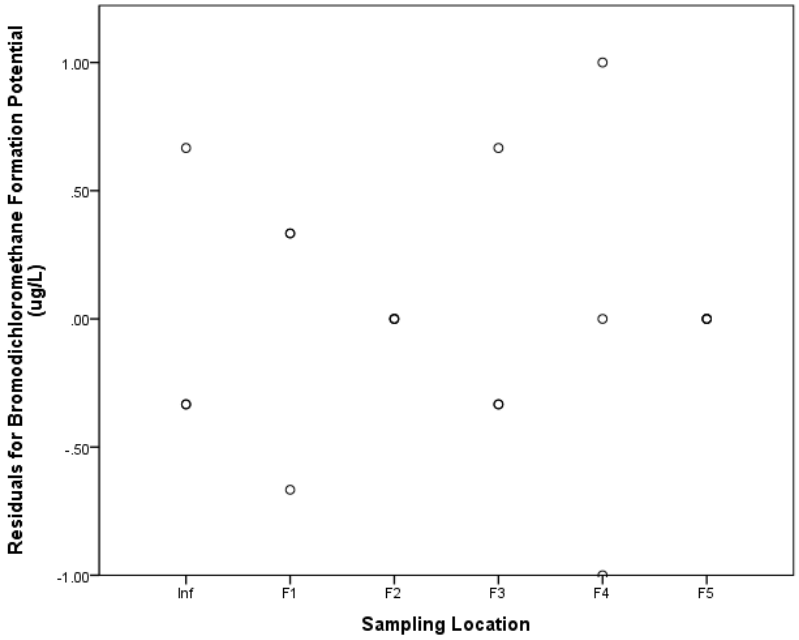

Figure D-34: Plot of residuals from ANOVA on bromodichloromethane formation potential data from June 6, 2013 sampling event versus the sampling location

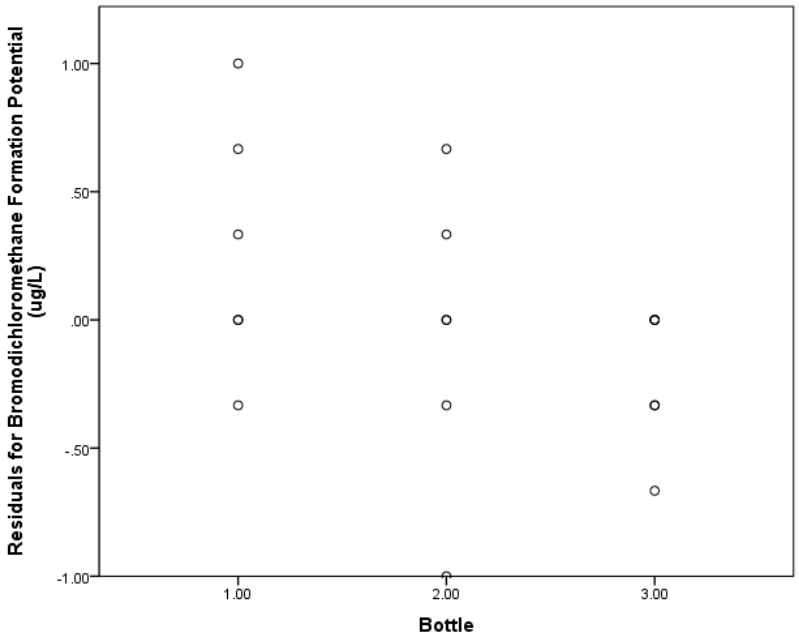

Figure D-35: Plot of residuals from ANOVA on bromodichloromethane formation potential data from June 6, 2013 sampling event versus the bottle number

Multiple comparison results

Table D-18: Detailed multiple comparison results from analysis of bromodichloromethane formation potential data from June 6, 2013 sampling event (Dunnett's T3 Test)

Test	(I) Filter	(J) Filter	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Dunnett T3	F1	F2	-0.333	0.3333	9.579E-001	-3.427	2.760
		F3	-0.667	0.4714	8.562E-001	-3.102	1.769
		F4	-0.333	0.6667	9.999E-001	-4.309	3.643
		F5	-0.333	0.3333	9.579E-001	-3.427	2.760
		Inf	0.333	0.4714	9.982E-001	-2.102	2.769
	F2	F1	0.333	0.3333	9.579E-001	-2.760	3.427
		F3	-0.333	0.3333	9.579E-001	-3.427	2.760
		F4	0.000	0.5774	1.000E+000	-5.358	5.358
		F5	0.000	0.0000	.	0.000	0.000
		Inf	0.667	0.3333	6.291E-001	-2.427	3.760
	F3	F1	0.667	0.4714	8.562E-001	-1.769	3.102
		F2	0.333	0.3333	9.579E-001	-2.760	3.427
		F4	0.333	0.6667	9.999E-001	-3.643	4.309
		F5	0.333	0.3333	9.579E-001	-2.760	3.427
		Inf	1.000	0.4714	5.360E-001	-1.435	3.435
	F4	F1	0.333	0.6667	9.999E-001	-3.643	4.309
		F2	0.000	0.5774	1.000E+000	-5.358	5.358
		F3	-0.333	0.6667	9.999E-001	-4.309	3.643
		F5	0.000	0.5774	1.000E+000	-5.358	5.358
		Inf	0.667	0.6667	9.704E-001	-3.309	4.643
	F5	F1	0.333	0.3333	9.579E-001	-2.760	3.427
		F2	0.000	0.0000	.	0.000	0.000
		F3	-0.333	0.3333	9.579E-001	-3.427	2.760
		F4	0.000	0.5774	1.000E+000	-5.358	5.358
		Inf	0.667	0.3333	6.291E-001	-2.427	3.760
	Inf	F1	-0.333	0.4714	9.982E-001	-2.769	2.102
		F2	-0.667	0.3333	6.291E-001	-3.760	2.427
		F3	-1.000	0.4714	5.360E-001	-3.435	1.435
		F4	-0.667	0.6667	9.704E-001	-4.643	3.309
		F5	-0.667	0.3333	6.291E-001	-3.760	2.427

Based on observed means.
*The mean difference is significant at the .05 level.

June 10, 2013 sampling event

Raw Data

Table D-19: Raw bromodichloromethane formation potential data from June 10, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-10	19	ug/L	0.26
F1	2	2013-06-10	20	ug/L	0.26
F1	3	2013-06-10	20	ug/L	0.26
F1	4	2013-06-10	19	ug/L	0.26
F1	5	2013-06-10	20	ug/L	0.26
F1	6	2013-06-10	19	ug/L	0.26
F2	1	2013-06-10	19	ug/L	0.26
F2	2	2013-06-10	20	ug/L	0.26
F2	3	2013-06-10	18	ug/L	0.26
F2	4	2013-06-10	20	ug/L	0.26
F2	5	2013-06-10	19	ug/L	0.26
F2	6	2013-06-10	20	ug/L	0.26
F3	1	2013-06-10	19	ug/L	0.26
F3	2	2013-06-10	20	ug/L	0.26
F3	3	2013-06-10	20	ug/L	0.26
F3	4	2013-06-10	20	ug/L	0.26
F3	5	2013-06-10	19	ug/L	0.26
F3	6	2013-06-10	19	ug/L	0.26
F4	1	2013-06-10	19	ug/L	0.26
F4	2	2013-06-10	19	ug/L	0.26
F4	3	2013-06-10	19	ug/L	0.26
F4	4	2013-06-10	19	ug/L	0.26
F4	5	2013-06-10	20	ug/L	0.26
F4	6	2013-06-10	19	ug/L	0.26
F5	1	2013-06-10	19	ug/L	0.26
F5	2	2013-06-10	20	ug/L	0.26
F5	3	2013-06-10	18	ug/L	0.26
F5	4	2013-06-10	20	ug/L	0.26
F5	5	2013-06-10	19	ug/L	0.26
F5	6	2013-06-10	19	ug/L	0.26
Inf	1	2013-06-10	21	ug/L	0.26
Inf	2	2013-06-10	21	ug/L	0.26
Inf	3	2013-06-10	20	ug/L	0.26
Inf	4	2013-06-10	21	ug/L	0.26
Inf	5	2013-06-10	21	ug/L	0.26
Inf	6	2013-06-10	20	ug/L	0.26

Boxplots

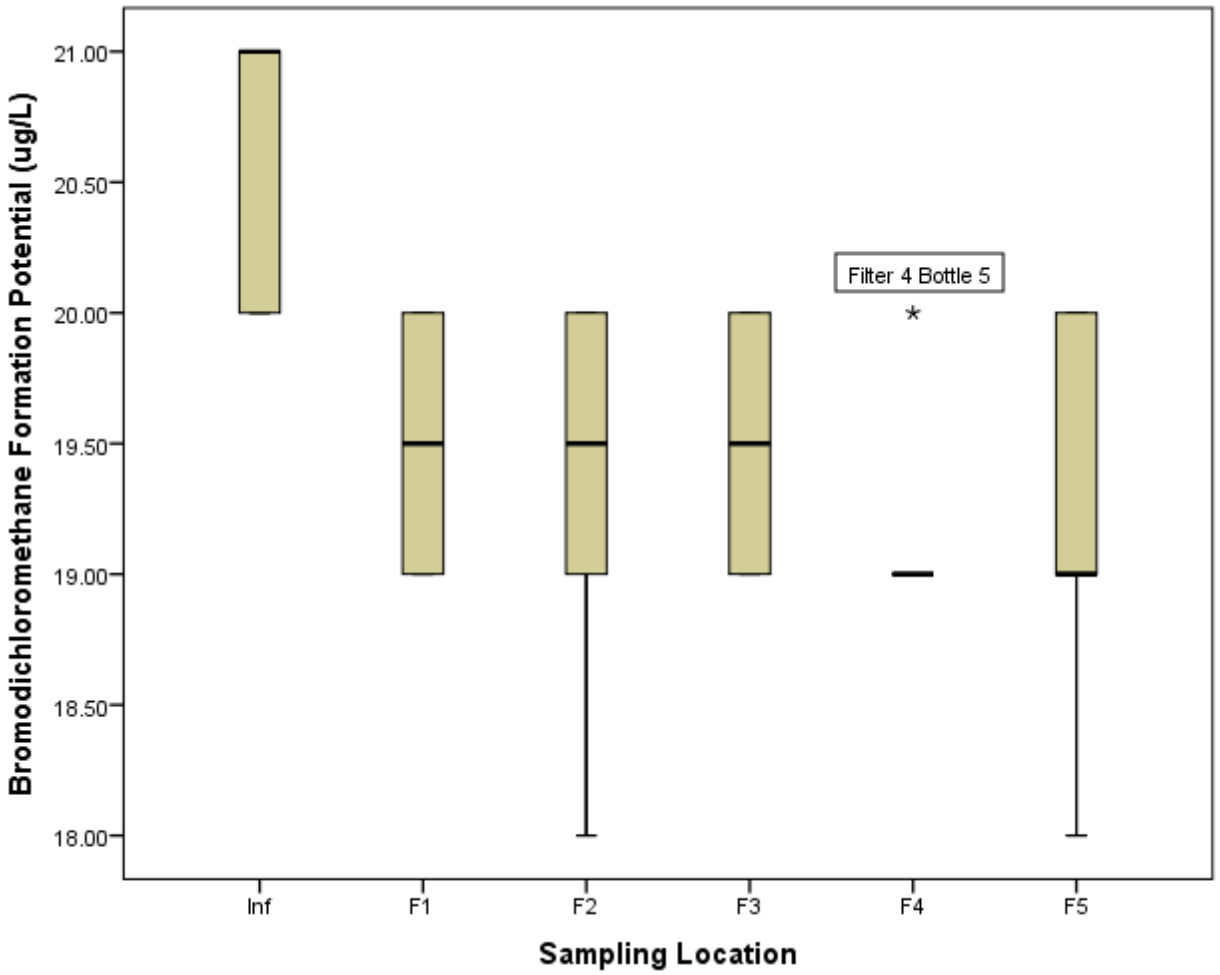

Figure D-36: Boxplot of bromodichloromethane formation potential data from June 10, 2013 sampling event

ANOVA diagnostics

Table D-20: Results from Levene's test for ANOVA on bromodichloromethane formation potential data from June 10, 2013 sampling event

F	df1	df2	Sig.
1.376	5	30	2.611E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

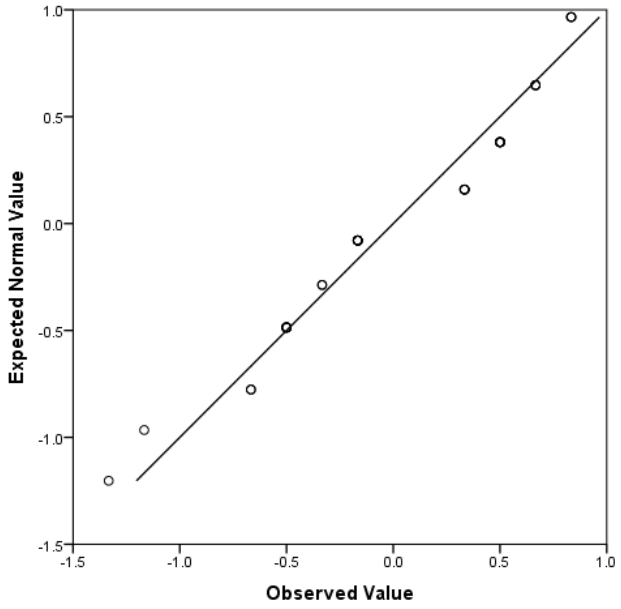

Figure D-37: Normal probability plot of residuals from ANOVA on bromodichloromethane formation potential data from June 10, 2013 sampling event

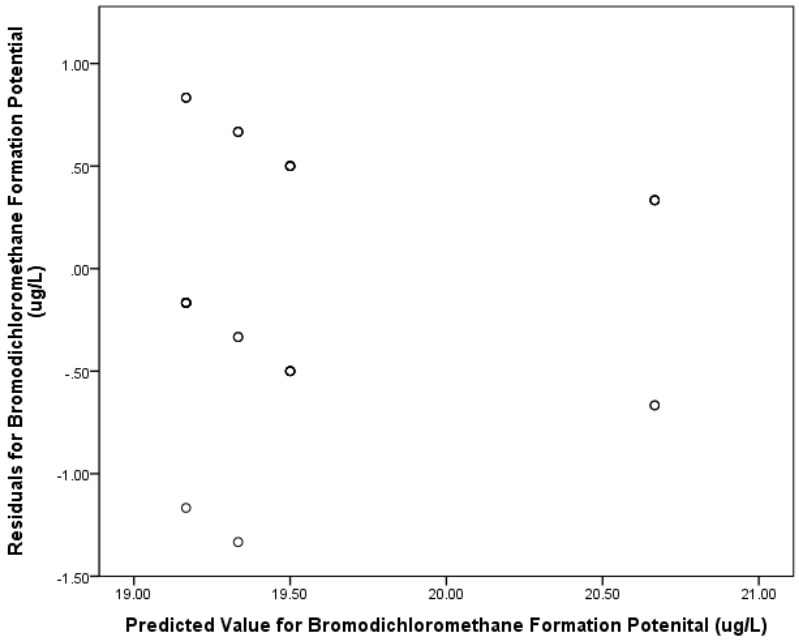

Figure D-38: Plot of residuals from ANOVA on bromodichloromethane formation potential data from June 10, 2013 sampling event versus the predicted values

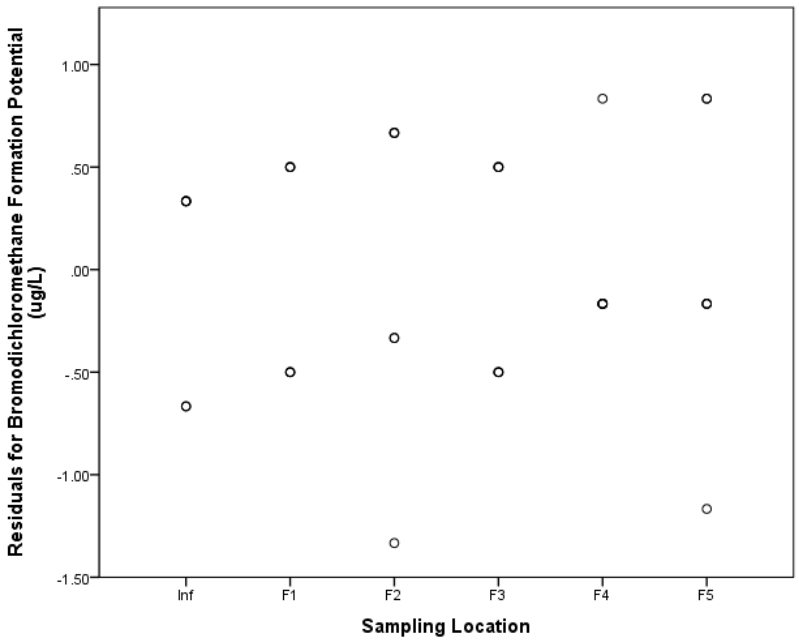

Figure D-39: Plot of residuals from ANOVA on bromodichloromethane formation potential data from June 10, 2013 sampling event versus the sampling location

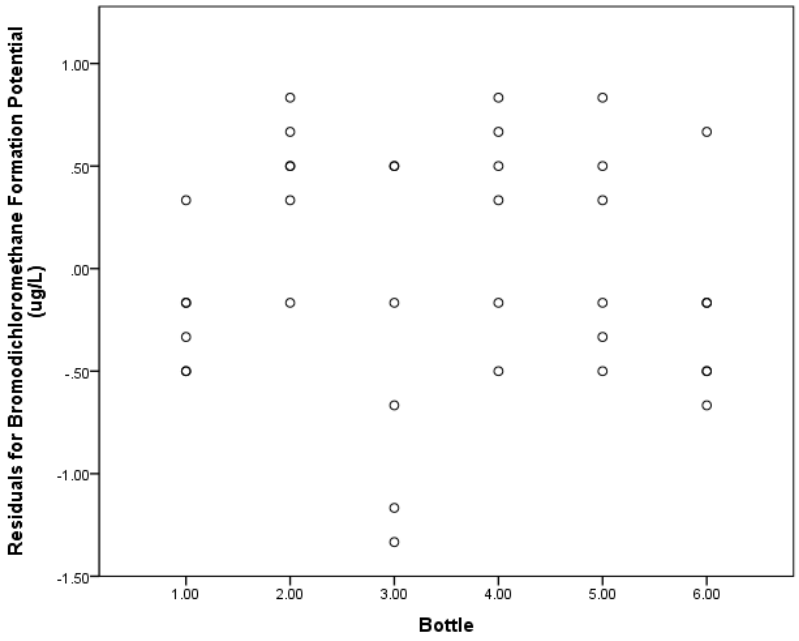

Figure D-40: Plot of residuals from ANOVA on bromodichloromethane formation potential data from June 10, 2013 sampling event versus the bottle number

Multiple comparison results

Table D-21: Detailed multiple comparison results from analysis of bromodichloromethane formation potential data from June 10, 2013 sampling event (Tukey's Test)

Test	(I) Filter	(J) Filter	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey's HSD	F1	F2	0.167	0.3549	9.969E-001	-0.913	1.246
		F3	0.000	0.3549	1.000E+000	-1.079	1.079
		F4	0.333	0.3549	9.329E-001	-0.746	1.413
		F5	0.333	0.3549	9.329E-001	-0.746	1.413
		Inf	-1.167*	0.3549	2.818E-002	-2.246	-0.087
	F2	F1	-0.167	0.3549	9.969E-001	-1.246	0.913
		F3	-0.167	0.3549	9.969E-001	-1.246	0.913
		F4	0.167	0.3549	9.969E-001	-0.913	1.246
		F5	0.167	0.3549	9.969E-001	-0.913	1.246
		Inf	-1.333*	0.3549	8.782E-003	-2.413	-0.254
	F3	F1	0.000	0.3549	1.000E+000	-1.079	1.079
		F2	0.167	0.3549	9.969E-001	-0.913	1.246
		F4	0.333	0.3549	9.329E-001	-0.746	1.413
		F5	0.333	0.3549	9.329E-001	-0.746	1.413
		Inf	-1.167*	0.3549	2.818E-002	-2.246	-0.087
	F4	F1	-0.333	0.3549	9.329E-001	-1.413	0.746
		F2	-0.167	0.3549	9.969E-001	-1.246	0.913
		F3	-0.333	0.3549	9.329E-001	-1.413	0.746
		F5	0.000	0.3549	1.000E+000	-1.079	1.079
		Inf	-1.500*	0.3549	2.560E-003	-2.579	-0.421
	F5	F1	-0.333	0.3549	9.329E-001	-1.413	0.746
		F2	-0.167	0.3549	9.969E-001	-1.246	0.913
		F3	-0.333	0.3549	9.329E-001	-1.413	0.746
		F4	0.000	0.3549	1.000E+000	-1.079	1.079
		Inf	-1.500*	0.3549	2.560E-003	-2.579	-0.421
	Inf	F1	1.167*	0.3549	2.818E-002	0.087	2.246
		F2	1.333*	0.3549	8.782E-003	0.254	2.413
		F3	1.167*	0.3549	2.818E-002	0.087	2.246
		F4	1.500*	0.3549	2.560E-003	0.421	2.579
		F5	1.500*	0.3549	2.560E-003	0.421	2.579

Based on observed means.
*The mean difference is significant at the .05 level.

Dibromochloromethane formation potential

June 6, 2013 sampling event

Raw Data

Table D-22: Raw dibromochloromethane formation potential data from June 6, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-06	4	ug/L	0.37
F1	2	2013-06-06	3.3	ug/L	0.37
F1	3	2013-06-06	3.6	ug/L	0.37
F2	1	2013-06-06	3.1	ug/L	0.37
F2	2	2013-06-06	3.3	ug/L	0.37
F2	3	2013-06-06	3.3	ug/L	0.37
F3	1	2013-06-06	3.2	ug/L	0.37
F3	2	2013-06-06	3.3	ug/L	0.37
F3	3	2013-06-06	3.9	ug/L	0.37
F4	1	2013-06-06	4.1	ug/L	0.37
F4	2	2013-06-06	4.7	ug/L	0.37
F4	3	2013-06-06	4.4	ug/L	0.37
F5	1	2013-06-06	3.9	ug/L	0.37
F5	2	2013-06-06	4.1	ug/L	0.37
F5	3	2013-06-06	4.7	ug/L	0.37
Inf	1	2013-06-06	3.3	ug/L	0.37
Inf	2	2013-06-06	3.6	ug/L	0.37
Inf	3	2013-06-06	2.9	ug/L	0.37

Boxplots

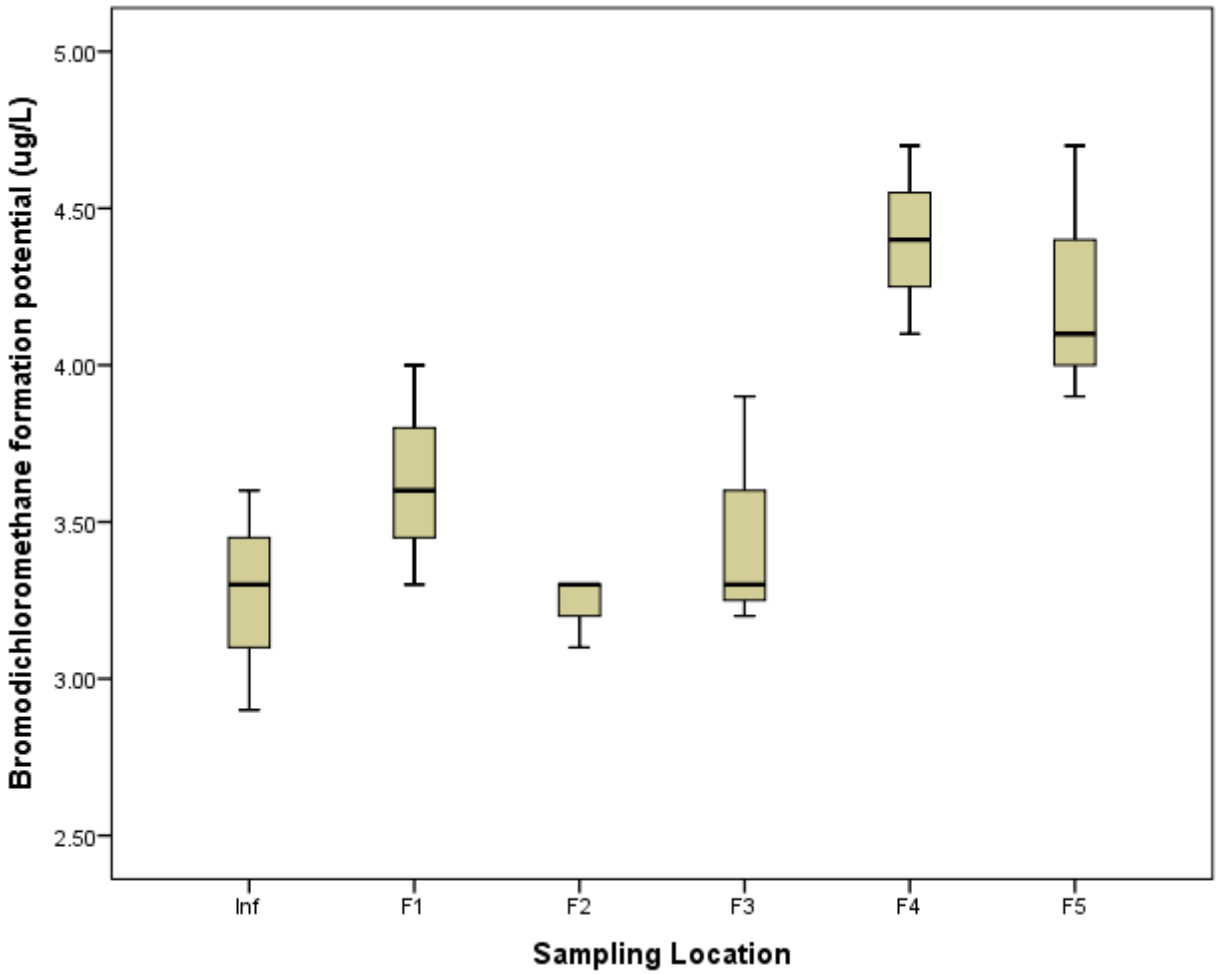

Figure D-41: Boxplot of dibromochloromethane formation potential data from June 6, 2013 sampling event

ANOVA diagnostics

Table D-23: Results from Levene's test for ANOVA on dibromochloromethane formation potential data from June 6, 2013 sampling event

F	df1	df2	Sig.
0.776	5	12	5.856E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

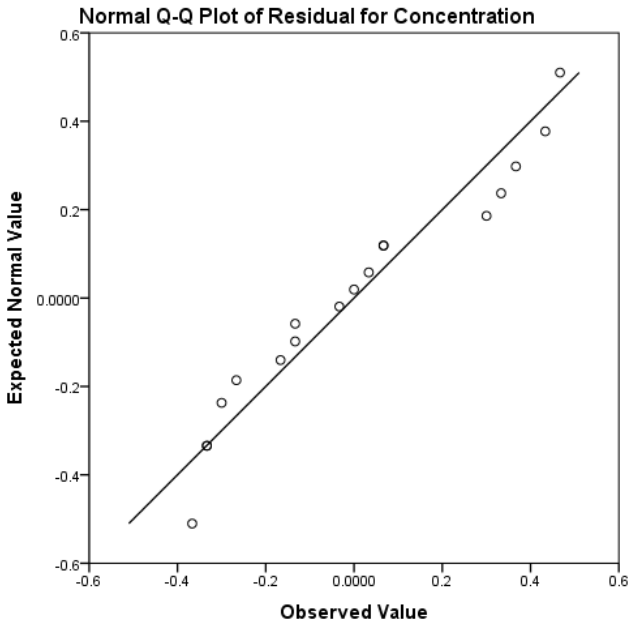

Figure D-42: Normal probability plot of residuals from ANOVA on dibromochloromethane formation potential data from June 6, 2013 sampling event

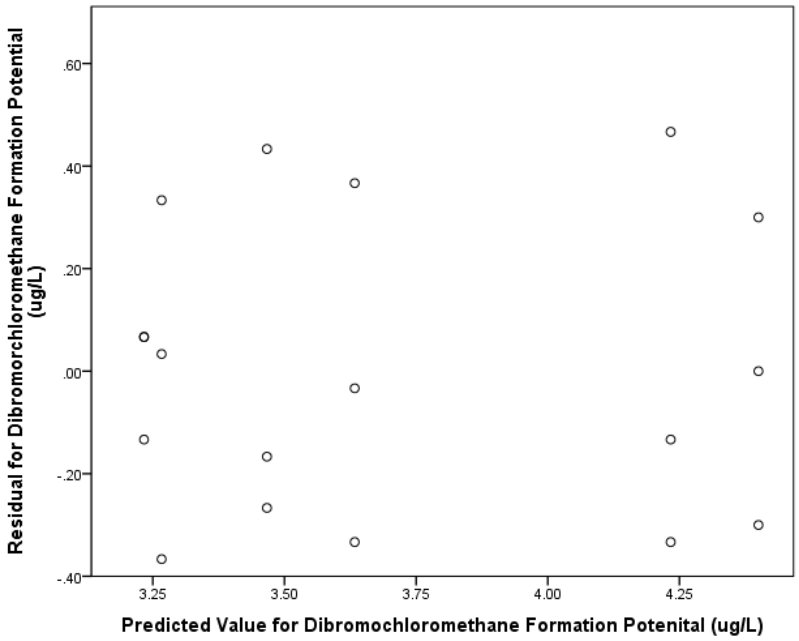

Figure D-43: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 6, 2013 sampling event versus the predicted values

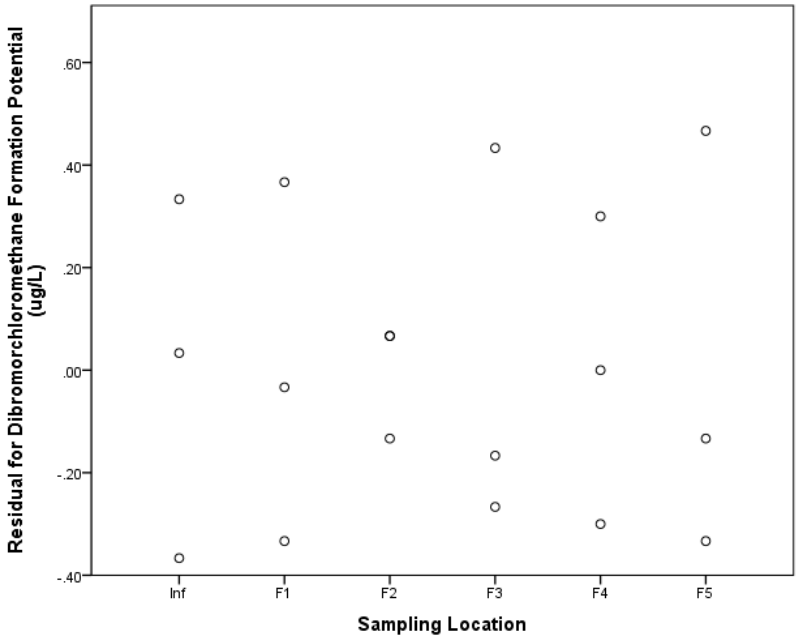

Figure D-44: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 6, 2013 sampling event versus the sampling location

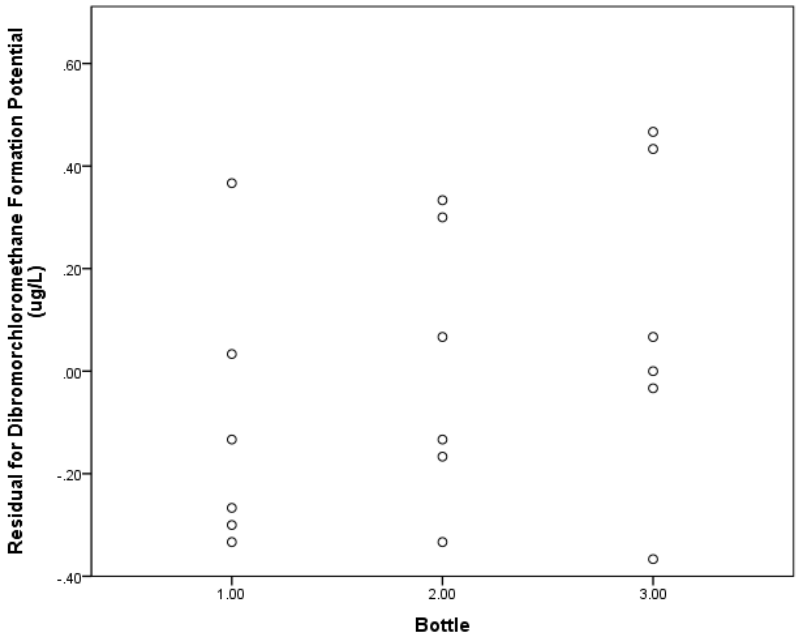

Figure D-45: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 6, 2013 sampling event versus the bottle number

Multiple comparison results

Table D-24: Detailed multiple comparison results from analysis of dibromochloromethane formation potential data from June 6, 2013 sampling event (Tukey's Test)

Test	(I) Filter	(J) Filter	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey's HSD	F1	F2	0.4000	0.27217	0.688	-0.5142	1.3142
		F3	0.1667	0.27217	0.988	-0.7475	1.0808
		F4	-0.7667	0.27217	0.122	-1.6808	0.1475
		F5	-0.6000	0.27217	0.303	-1.5142	0.3142
		Inf	0.3667	0.27217	0.755	-0.5475	1.2808
	F2	F1	-0.4000	0.27217	0.688	-1.3142	0.5142
		F3	-0.2333	0.27217	0.950	-1.1475	0.6808
		F4	-1.1667*	0.27217	0.010	-2.0808	-0.2525
		F5	-1.0000*	0.27217	0.029	-1.9142	-0.0858
		Inf	-0.0333	0.27217	1.000	-0.9475	0.8808
	F3	F1	-0.1667	0.27217	0.988	-1.0808	0.7475
		F2	0.2333	0.27217	0.950	-0.6808	1.1475
		F4	-0.9333*	0.27217	0.044	-1.8475	-0.0192
		F5	-0.7667	0.27217	0.122	-1.6808	0.1475
		Inf	0.2000	0.27217	0.973	-0.7142	1.1142
	F4	F1	0.7667	0.27217	0.122	-0.1475	1.6808
		F2	1.1667*	0.27217	0.010	0.2525	2.0808
		F3	0.9333*	0.27217	0.044	0.0192	1.8475
		F5	0.1667	0.27217	0.988	-0.7475	1.0808
		Inf	1.1333*	0.27217	0.013	0.2192	2.0475
	F5	F1	0.6000	0.27217	0.303	-0.3142	1.5142
		F2	1.0000*	0.27217	0.029	0.0858	1.9142
		F3	0.7667	0.27217	0.122	-0.1475	1.6808
		F4	-0.1667	0.27217	0.988	-1.0808	0.7475
		Inf	0.9667*	0.27217	0.036	0.0525	1.8808
	Inf	F1	-0.3667	0.27217	0.755	-1.2808	0.5475
		F2	0.0333	0.27217	1.000	-0.8808	0.9475
		F3	-0.2000	0.27217	0.973	-1.1142	0.7142
		F4	-1.1333*	0.27217	0.013	-2.0475	-0.2192
		F5	-0.9667*	0.27217	0.036	-1.8808	-0.0525

Based on observed means.
*The mean difference is significant at the .05 level.

June 10, 2013 sampling event (outliers included)

Raw Data

Table D-25: Raw dibromochloromethane formation potential data from June 10, 2013 sampling event

Location	Bottle	Sample Date	Result	Unit	MDL
F1	1	2013-06-10	3.3	ug/L	0.37
F1	2	2013-06-10	3.1	ug/L	0.37
F1	3	2013-06-10	3.4	ug/L	0.37
F1	4	2013-06-10	3.2	ug/L	0.37
F1	5	2013-06-10	3.2	ug/L	0.37
F1	6	2013-06-10	4.6	ug/L	0.37
F2	1	2013-06-10	3	ug/L	0.37
F2	2	2013-06-10	2.9	ug/L	0.37
F2	3	2013-06-10	3.1	ug/L	0.37
F2	4	2013-06-10	2.8	ug/L	0.37
F2	5	2013-06-10	2.8	ug/L	0.37
F2	6	2013-06-10	2.8	ug/L	0.37
F3	1	2013-06-10	2.7	ug/L	0.37
F3	2	2013-06-10	2.9	ug/L	0.37
F3	3	2013-06-10	2.7	ug/L	0.37
F3	4	2013-06-10	3.2	ug/L	0.37
F3	5	2013-06-10	2.7	ug/L	0.37
F3	6	2013-06-10	2.8	ug/L	0.37
F4	1	2013-06-10	3.3	ug/L	0.37
F4	2	2013-06-10	3	ug/L	0.37
F4	3	2013-06-10	3.2	ug/L	0.37
F4	4	2013-06-10	3.4	ug/L	0.37
F4	5	2013-06-10	3.5	ug/L	0.37
F4	6	2013-06-10	3.4	ug/L	0.37
F5	1	2013-06-10	3.1	ug/L	0.37
F5	2	2013-06-10	3.5	ug/L	0.37
F5	3	2013-06-10	4.3	ug/L	0.37
F5	4	2013-06-10	3.5	ug/L	0.37
F5	5	2013-06-10	3.7	ug/L	0.37
F5	6	2013-06-10	3.5	ug/L	0.37
Inf	1	2013-06-10	2.6	ug/L	0.37
Inf	2	2013-06-10	2.7	ug/L	0.37
Inf	3	2013-06-10	2.8	ug/L	0.37
Inf	4	2013-06-10	2.7	ug/L	0.37
Inf	5	2013-06-10	2.5	ug/L	0.37
Inf	6	2013-06-10	2.6	ug/L	0.37

Boxplots

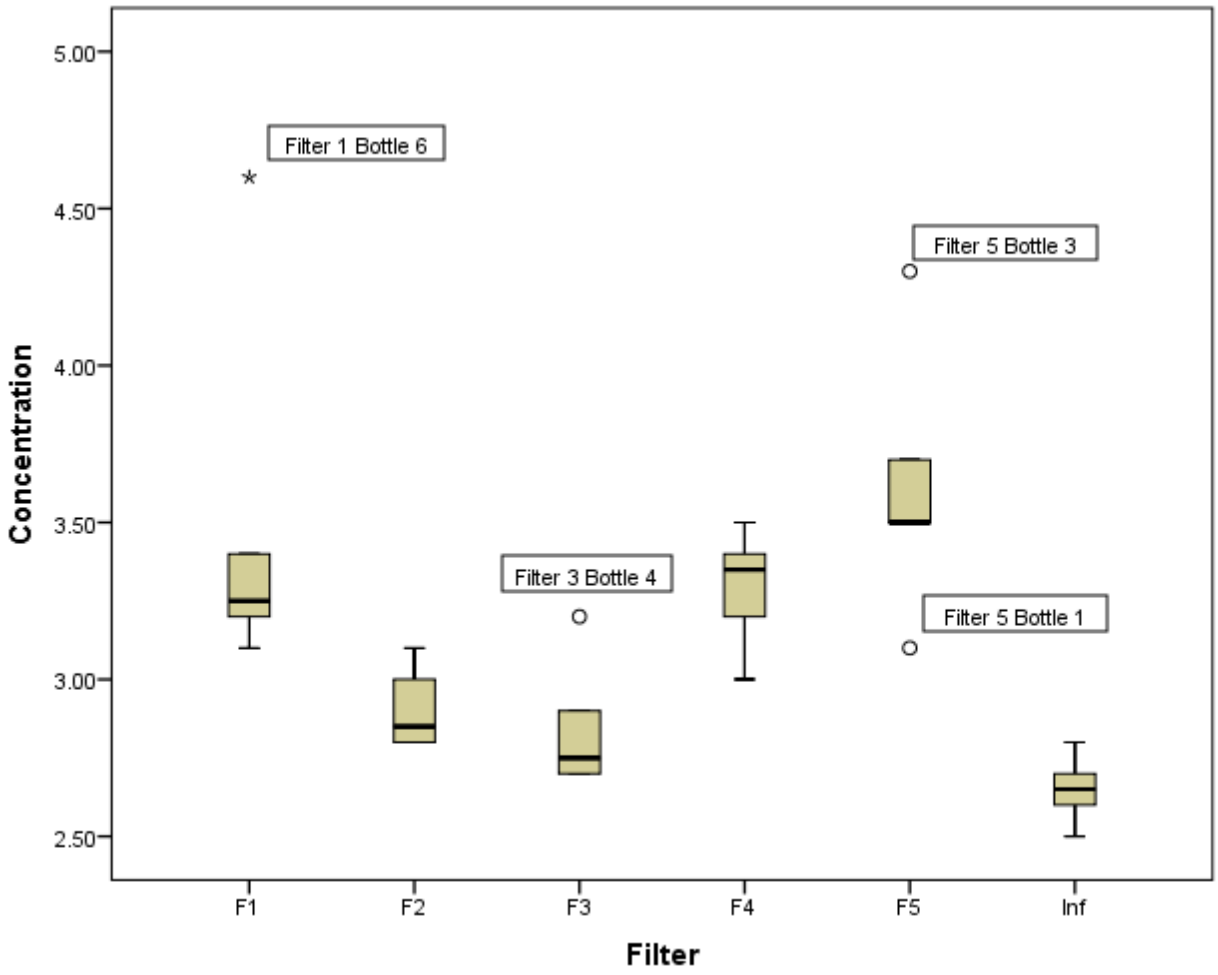

Figure D-46: Boxplots of dibromochloromethane formation potential data from June 10, 2013 sampling event (outliers included)

June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6 and Filter 5 Bottle 3 excluded)

Boxplots

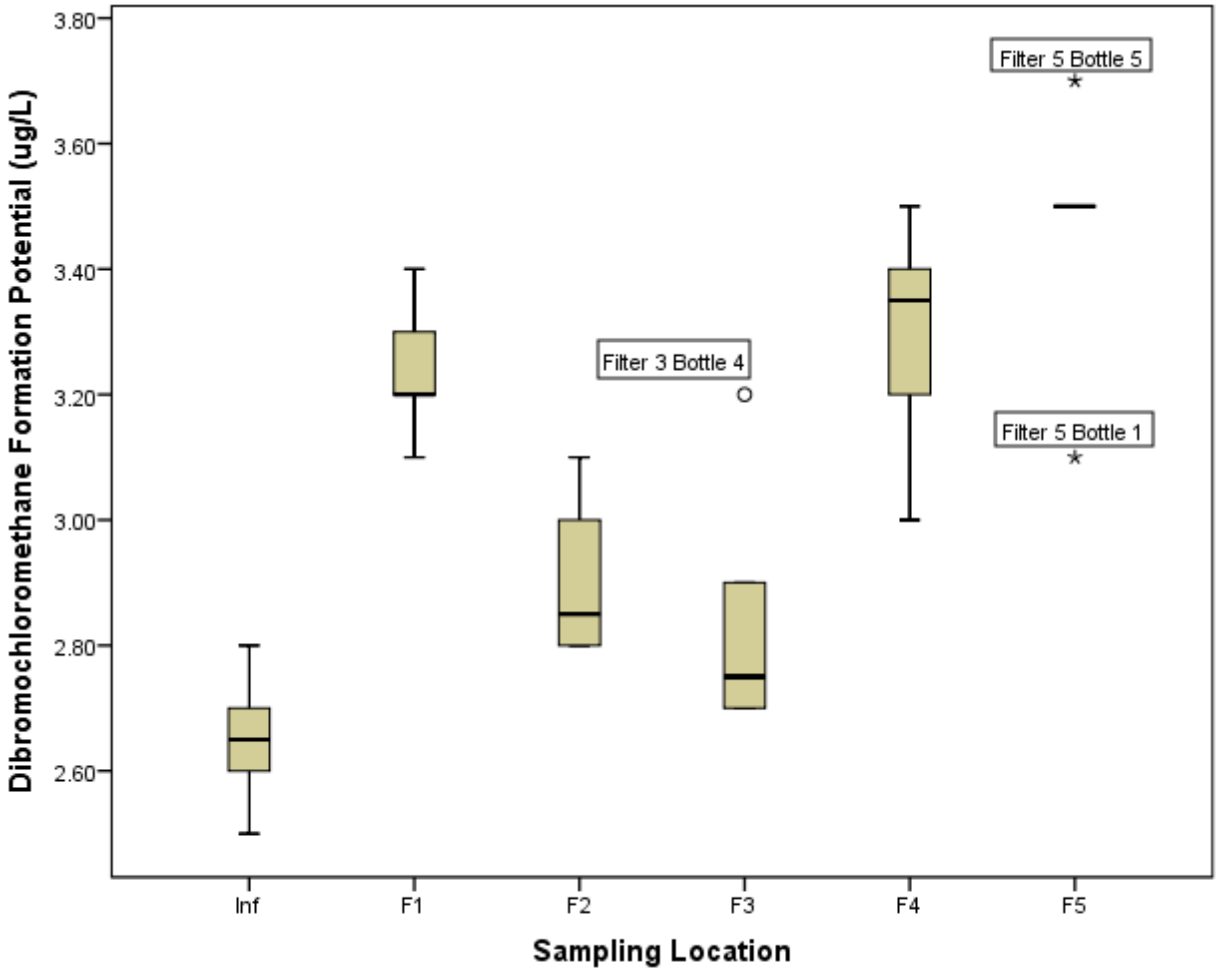

Figure D-47: Boxplot of dibromochloromethane formation potential data from June 10, 2013 sampling event

ANOVA diagnostics

Table D-26: Results from Levene's test for ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6 and Filter 5 Bottle 3 excluded)

F	df1	df2	Sig.
0.490	5	28	7.810E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

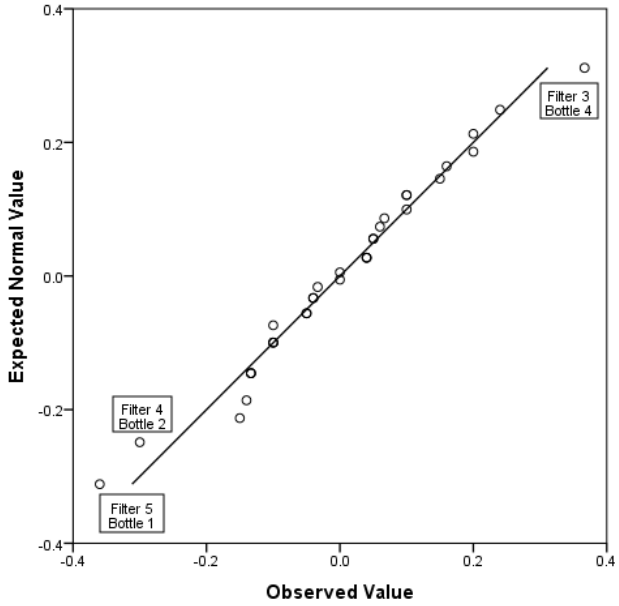

Figure D-48: Normal probability plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6 and Filter 5 Bottle 3 excluded)

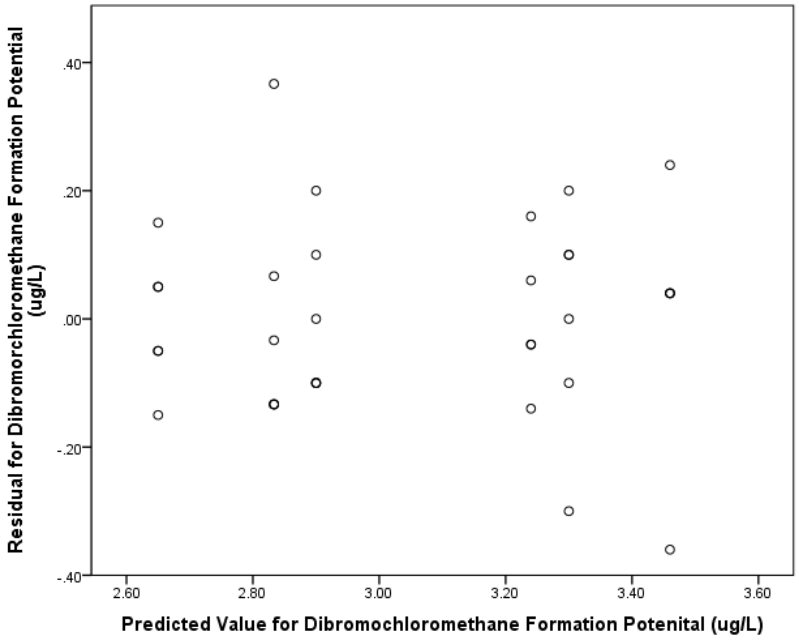

Figure D-49: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event versus the predicted values (Data associated with Filter 1 Bottle 6 and Filter 5 Bottle 3 excluded)

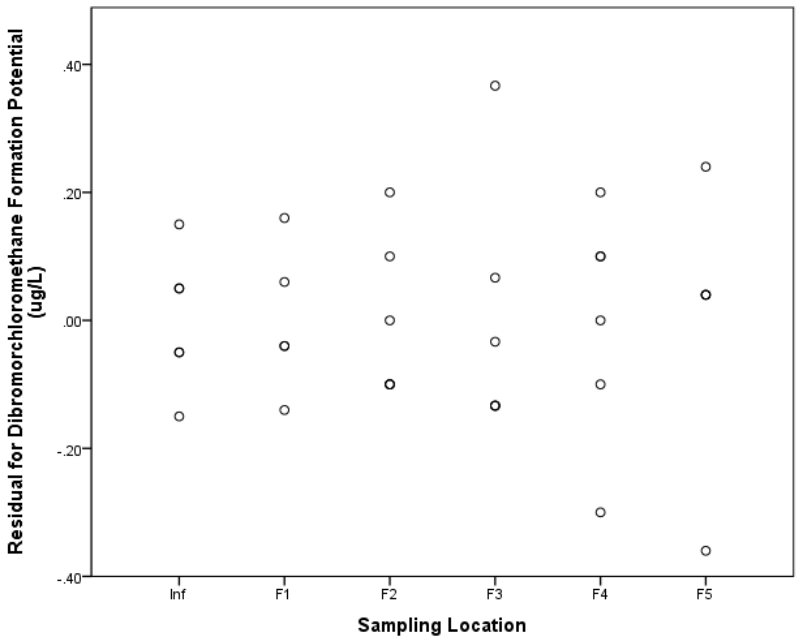

Figure D-50: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event versus the sampling location (Data associated with Filter 1 Bottle 6 and Filter 5 Bottle 3 excluded)

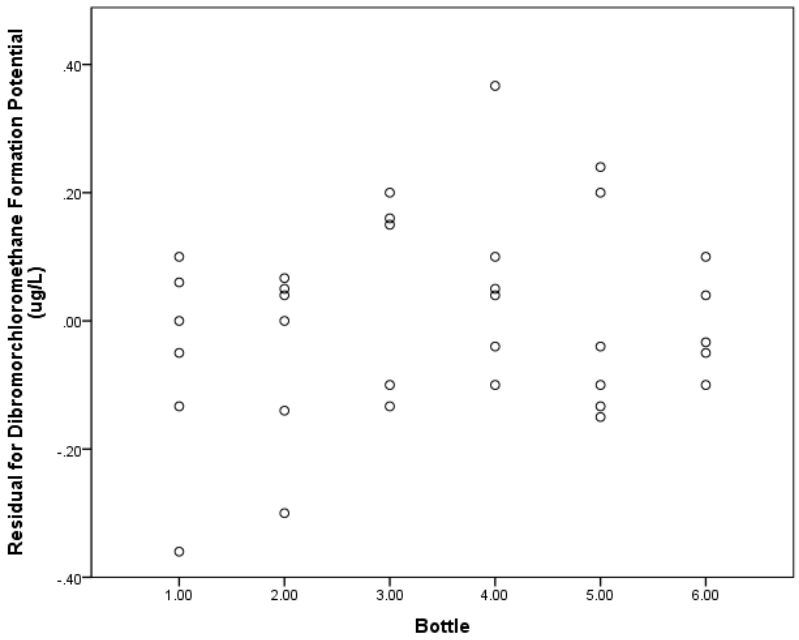

Figure D-51: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event versus the bottle number (Data associated with Filter 1 Bottle 6 and Filter 5 Bottle 3 excluded)

June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

Boxplots

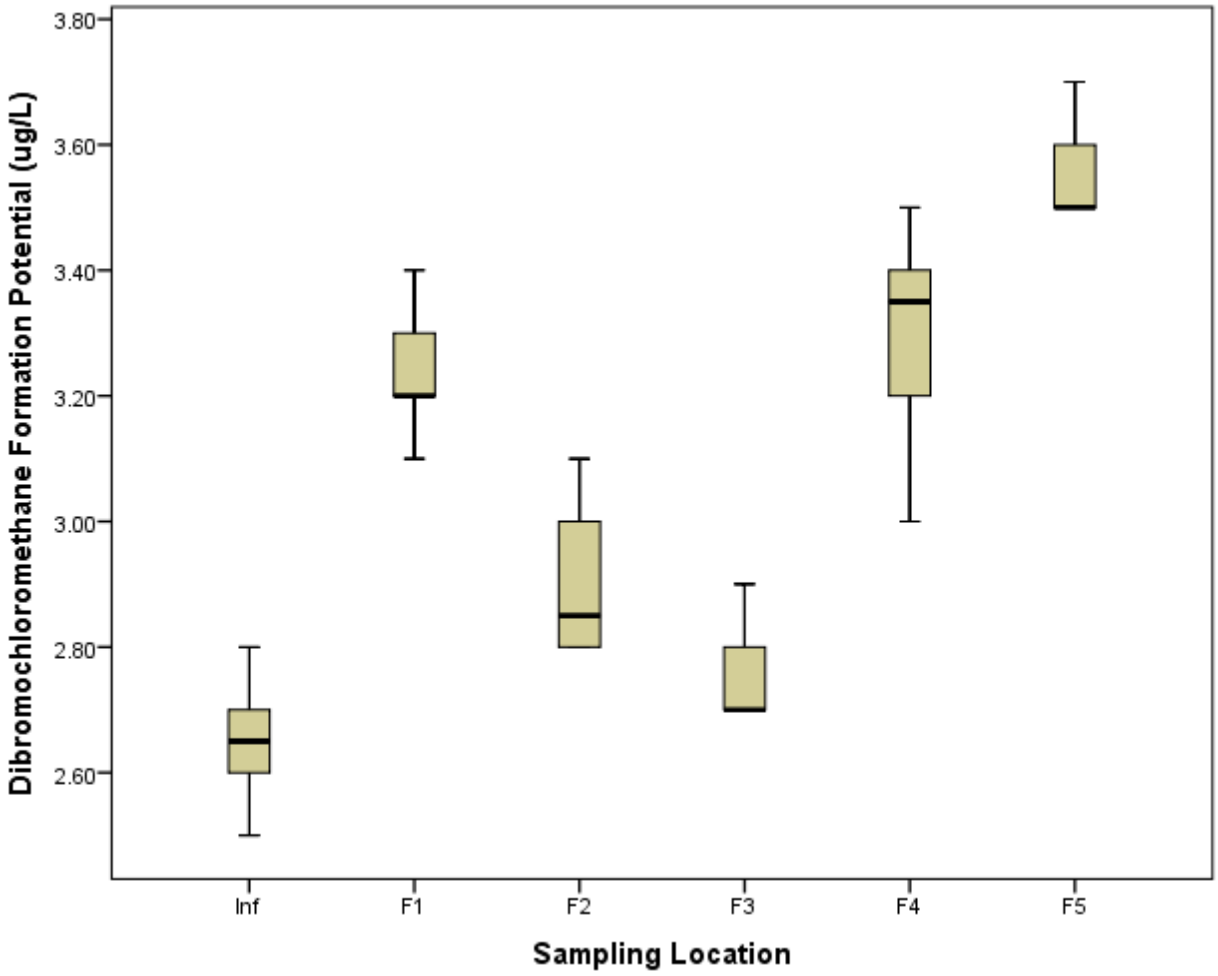

Figure D-52: Boxplot of dibromochloromethane formation potential data from June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

ANOVA diagnostics

Table D-27: Results from Levene's test for ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

F	df1	df2	Sig.
.651	5	26	6.630E-001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

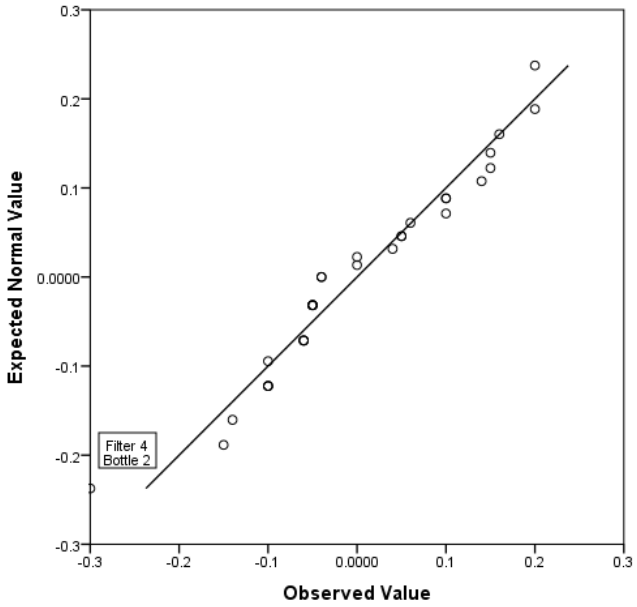

Figure D-53: Normal probability plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

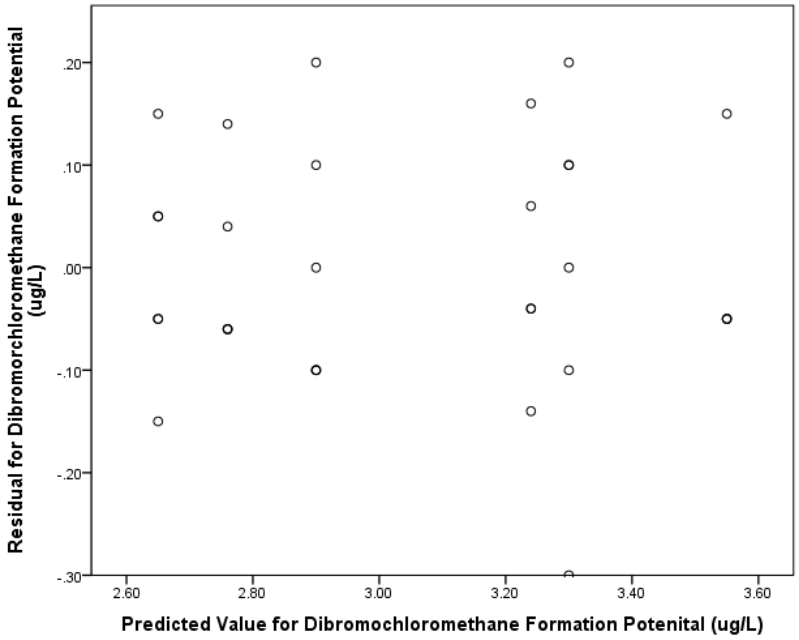

Figure D-54: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event versus the predicted values (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

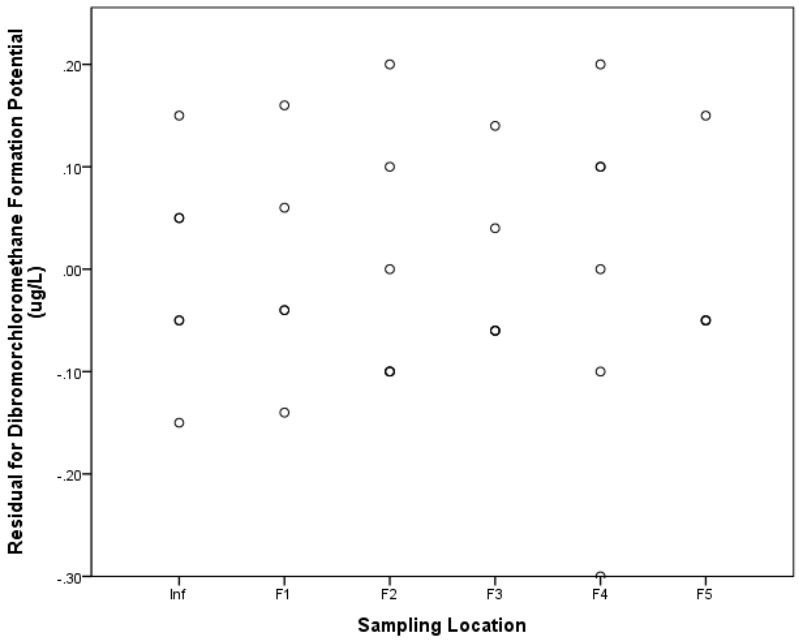

Figure D-55: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event versus the sampling location (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

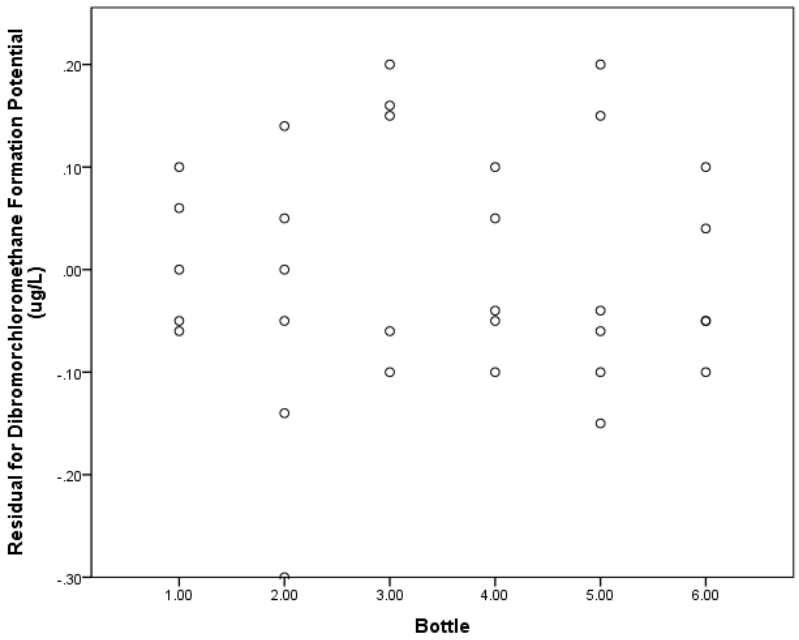

Figure D-56: Plot of residuals from ANOVA on dibromochloromethane formation potential data from June 10, 2013 sampling event versus the bottle number (Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

Multiple comparison results

Table D-28: Detailed multiple comparison results from analysis of dibromochloromethane formation potential data from June 10, 2013 sampling event (Tukey's Test; Data associated with Filter 1 Bottle 6, Filter 3 Bottle 4, Filter 5 Bottle 1, and Filter 5 Bottle 3 excluded)

Test	(I) Filter	(J) Filter	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey's HSD	F1	F2	0.340*	0.0759	1.677E-003	0.107	0.573
		F3	0.480*	0.0793	2.938E-005	0.236	0.724
		F4	-0.060	0.0759	9.668E-001	-0.293	0.173
		F5	-0.310*	0.0841	1.211E-002	-0.569	-0.051
		Inf	0.590*	0.0759	4.303E-007	0.357	0.823
	F2	F1	-0.340*	0.0759	1.677E-003	-0.573	-0.107
		F3	0.140	0.0759	4.572E-001	-0.093	0.373
		F4	-0.400*	0.0724	1.133E-004	-0.622	-0.178
		F5	-0.650*	0.0810	2.338E-007	-0.899	-0.401
		Inf	0.250*	0.0724	2.106E-002	0.028	0.472
	F3	F1	-0.480*	0.0793	2.938E-005	-0.724	-0.236
		F2	-0.140	0.0759	4.572E-001	-0.373	0.093
		F4	-0.540*	0.0759	2.091E-006	-0.773	-0.307
		F5	-0.790*	0.0841	1.107E-008	-1.049	-0.531
		Inf	0.110	0.0759	6.983E-001	-0.123	0.343
	F4	F1	0.060	0.0759	9.668E-001	-0.173	0.293
		F2	0.400*	0.0724	1.133E-004	0.178	0.622
		F3	0.540*	0.0759	2.091E-006	0.307	0.773
		F5	-0.250*	0.0810	4.832E-002	-0.499	-0.001
		Inf	0.650*	0.0724	2.725E-008	0.428	0.872
	F5	F1	0.310*	0.0841	1.211E-002	0.051	0.569
		F2	0.650*	0.0810	2.338E-007	0.401	0.899
		F3	0.790*	0.0841	1.107E-008	0.531	1.049
		F4	0.250*	0.0810	4.832E-002	0.001	0.499
		Inf	0.900*	0.0810	3.235E-010	0.651	1.149
	Inf	F1	-0.590*	0.0759	4.303E-007	-0.823	-0.357
		F2	-0.250*	0.0724	2.106E-002	-0.472	-0.028
		F3	-0.110	0.0759	6.983E-001	-0.343	0.123
		F4	-0.650*	0.0724	2.725E-008	-0.872	-0.428
		F5	-0.900*	0.0810	3.235E-010	-1.149	-0.651

Based on observed means.

*The mean difference is significant at the .05 level.

Amount of chlorine added to samples at the beginning of the THMFP tests

June 6, 2013 sampling event

Table D-29: Amount of chlorine added to samples at the beginning of THMFP tests for the June 6, 2013 sampling event

Location	Bottle	Sample Date	Amount of Chlorine Added	Units	MDL
F1	1	2013-06-06	68	mg/L	0.02
F1	2	2013-06-06	107	mg/L	0.02
F1	3	2013-06-06	97.2	mg/L	0.02
F2	1	2013-06-06	97.2	mg/L	0.02
F2	2	2013-06-06	97.2	mg/L	0.02
F2	3	2013-06-06	97.2	mg/L	0.02
F3	1	2013-06-06	97.2	mg/L	0.02
F3	2	2013-06-06	107	mg/L	0.02
F3	3	2013-06-06	48.6	mg/L	0.02
F4	1	2013-06-06	97.2	mg/L	0.02
F4	2	2013-06-06	48.6	mg/L	0.02
F4	3	2013-06-06	68	mg/L	0.02
F5	1	2013-06-06	97.2	mg/L	0.02
F5	2	2013-06-06	97.2	mg/L	0.02
F5	3	2013-06-06	58.3	mg/L	0.02
Inf	1	2013-06-06	97.2	mg/L	0.02
Inf	2	2013-06-06	58.3	mg/L	0.02
Inf	3	2013-06-06	107	mg/L	0.02

June 10, 2013 sampling event

Table D-30: Amount of chlorine added to the samples at the beginning of THMFP tests for the June 10, 2013 sampling event

Location	Bottle	Sample Date	Amount of Chlorine Added	Unit	MDL
F1	1	2013-06-10	243	mg/L	0.02
F1	2	2013-06-10	243	mg/L	0.02
F1	3	2013-06-10	243	mg/L	0.02
F1	4	2013-06-10	243	mg/L	0.02
F1	5	2013-06-10	243	mg/L	0.02
F1	6	2013-06-10	97.2	mg/L	0.02
F2	1	2013-06-10	204	mg/L	0.02
F2	2	2013-06-10	243	mg/L	0.02
F2	3	2013-06-10	146	mg/L	0.02
F2	4	2013-06-10	214	mg/L	0.02
F2	5	2013-06-10	243	mg/L	0.02
F2	6	2013-06-10	243	mg/L	0.02
F3	1	2013-06-10	243	mg/L	0.02
F3	2	2013-06-10	243	mg/L	0.02
F3	3	2013-06-10	243	mg/L	0.02
F3	4	2013-06-10	146	mg/L	0.02
F3	5	2013-06-10	243	mg/L	0.02
F3	6	2013-06-10	243	mg/L	0.02
F4	1	2013-06-10	214	mg/L	0.02
F4	2	2013-06-10	243	mg/L	0.02
F4	3	2013-06-10	194	mg/L	0.02
F4	4	2013-06-10	243	mg/L	0.02
F4	5	2013-06-10	243	mg/L	0.02
F4	6	2013-06-10	243	mg/L	0.02
F5	1	2013-06-10	243	mg/L	0.02
F5	2	2013-06-10	243	mg/L	0.02
F5	3	2013-06-10	117	mg/L	0.02
F5	4	2013-06-10	243	mg/L	0.02
F5	5	2013-06-10	194	mg/L	0.02
F5	6	2013-06-10	194	mg/L	0.02
Inf	1	2013-06-10	292	mg/L	0.02
Inf	2	2013-06-10	292	mg/L	0.02
Inf	3	2013-06-10	243	mg/L	0.02
Inf	4	2013-06-10	243	mg/L	0.02
Inf	5	2013-06-10	292	mg/L	0.02
Inf	6	2013-06-10	243	mg/L	0.02

Final free chlorine concentrations at the end of the THMFP tests

June 6, 2013 sampling event

Table D-31: Final free chlorine concentrations at the end of the THMFP tests for the June 6, 2013 sampling event

Location	Bottle	Sample Date	Final Free Chlorine Concentration	Unit	MDL
F1	1	2013-06-06	5.5	mg/L	0.02
F1	2	2013-06-06	4.6	mg/L	0.02
F1	3	2013-06-06	4.0	mg/L	0.02
F2	1	2013-06-06	3.3	mg/L	0.02
F2	2	2013-06-06	7.8	mg/L	0.02
F2	3	2013-06-06	3.5	mg/L	0.02
F3	1	2013-06-06	3.4	mg/L	0.02
F3	2	2013-06-06	3.9	mg/L	0.02
F3	3	2013-06-06	1.1	mg/L	0.02
F4	1	2013-06-06	4.6	mg/L	0.02
F4	2	2013-06-06	1.7	mg/L	0.02
F4	3	2013-06-06	3.9	mg/L	0.02
F5	1	2013-06-06	4.1	mg/L	0.02
F5	2	2013-06-06	5.1	mg/L	0.02
F5	3	2013-06-06	3.5	mg/L	0.02
Inf	1	2013-06-06	18	mg/L	0.02
Inf	2	2013-06-06	0.41	mg/L	0.02
Inf	3	2013-06-06	16	mg/L	0.02

June 10, 2013 sampling event

Table D-32: Final free chlorine concentrations at the end of the THMFP tests for the June 10, 2013 sampling event

Location	Bottle	Sample Date	Final Free Chlorine Concentration	Unit	MDL
F1	1	2013-06-10	18	mg/L	0.02
F1	2	2013-06-10	19	mg/L	0.02
F1	3	2013-06-10	18	mg/L	0.02
F1	4	2013-06-10	20	mg/L	0.02
F1	5	2013-06-10	20	mg/L	0.02
F1	6	2013-06-10	4.8	mg/L	0.02
F2	1	2013-06-10	15	mg/L	0.02
F2	2	2013-06-10	18	mg/L	0.02
F2	3	2013-06-10	10	mg/L	0.02
F2	4	2013-06-10	15	mg/L	0.02
F2	5	2013-06-10	18	mg/L	0.02
F2	6	2013-06-10	18	mg/L	0.02
F3	1	2013-06-10	22	mg/L	0.02
F3	2	2013-06-10	18	mg/L	0.02
F3	3	2013-06-10	20	mg/L	0.02
F3	4	2013-06-10	9.0	mg/L	0.02
F3	5	2013-06-10	17	mg/L	0.02
F3	6	2013-06-10	18	mg/L	0.02
F4	1	2013-06-10	17	mg/L	0.02
F4	2	2013-06-10	20	mg/L	0.02
F4	3	2013-06-10	15	mg/L	0.02
F4	4	2013-06-10	19	mg/L	0.02
F4	5	2013-06-10	20	mg/L	0.02
F4	6	2013-06-10	20	mg/L	0.02
F5	1	2013-06-10	20	mg/L	0.02
F5	2	2013-06-10	20	mg/L	0.02
F5	3	2013-06-10	6.0	mg/L	0.02
F5	4	2013-06-10	19	mg/L	0.02
F5	5	2013-06-10	14	mg/L	0.02
F5	6	2013-06-10	14	mg/L	0.02
Inf	1	2013-06-10	20	mg/L	0.02
Inf	2	2013-06-10	32	mg/L	0.02
Inf	3	2013-06-10	16	mg/L	0.02
Inf	4	2013-06-10	12	mg/L	0.02
Inf	5	2013-06-10	22	mg/L	0.02
Inf	6	2013-06-10	16	mg/L	0.02

Appendix E

Maltose and Acetate Biodegradation Test Data

Contents

This appendix contains TOC results from the acetate and maltose biodegradation tests, in tabular form.

Structure of the Appendix

The first two tables contain TOC data from the acetate and maltose biodegradation tests conducted using inoculum from the UW pilot plant. The next two tables contain TOC data from the acetate and maltose biodegradation tests conducted using inoculum from the Toronto pilot plant.

TOC Results from Biodegradation Tests Using Inoculum from the UW Pilot Plant

Table E-1: Acetate TOC Data from the biodegradation test using the inoculum from the pilot plant at location 1

Days since inoculation	Vial #	Average TOC Concentration (µg/L)	Standard Deviation (µg/L)	99% Confidence Interval (+/- µg/L)	Number of measurements
-[1]	1	3287	6	33	3
-[1]	2	3270	10	57	3
-[1]	3	3273	21	119	3
0	1	2740	0	0	3
0	2	2547	6	33	3
0	3	2420	20	115	3
0	4	2260	26	152	3
1	1	1110	17	99	3
1	2	937	6	33	3
1	3	960	10	57	3
1	4	917	15	88	3
3	1	667	15	88	3
3	2	697	21	119	3
3	3	683	21	119	3
3	4	643	15	88	3
5	1	507	6	33	3
5	2	580	10	57	3
5	3	520	10	57	3
5	4	553	6	33	3
7	1	483	12	66	3
7	2	503	15	88	3
7	3	477	6	33	3
7	4	-	-	-	-

1. TOC concentration analyzed before inoculation

Table E-2: Maltose TOC Data from the biodegradation test using the inoculum from the UW pilot plant

Days since inoculation	Vial #	Average TOC Concentration (µg/L)	Standard Deviation (µg/L)	99% Confidence Interval (+/- µg/L)	Number of measurements
-[1]	1	3397	25	144	3
-[1]	2	3407	15	88	3
-[1]	3	3423	12	66	3
0	1	3417	6	33	3
0	2	3457	6	33	3
0	3	3397	12	66	3
0	4	3387	12	66	3
1	1	3390	0	0	3
1	2	3373	6	33	3
1	3	3390	10	57	3
1	4	3390	10	57	3
3	1	1807	12	66	3
3	2	1623	29	165	3
3	3	1393	15	88	3
3	4	1370	26	152	3
5	1	1060	10	57	3
5	2	850	0	0	3
5	3	917	15	88	3
5	4	1110	10	57	3
7	1	983	12	66	3
7	2	1047	15	88	3
7	3	953	21	119	3
7	4	-	-	-	3

1. TOC concentration analyzed before inoculation

TOC Results from Biodegradation Tests Using Inoculum from the Toronto Pilot Plant

Table E-3: Acetate TOC Data from the biodegradation test using the inoculum from the Toronto pilot plant

Days since inoculation	Vial #	Average TOC Concentration (µg/L)	Standard Deviation (µg/L)	99% Confidence Interval (+/- µg/L)	Number of measurements
-[1]	1	3183	6	33	3
-[1]	2	3167	12	66	3
0	1	3463	12	66	3
0	2	3680	0	0	3
0	3	3763	6	33	3
0	4	3617	15	88	3
1	1	4010	10	57	3
1	2	3553	12	66	3
1	3	3847	12	66	3
1	4	3553	6	33	3
5	1	953	21	119	3
5	2	923	21	119	3
5	3	1060	36	207	3
5	4	943	38	217	3

1. TOC concentration analyzed before inoculation

Table E-4: Maltose TOC Data from the biodegradation test using the inoculum from the Toronto pilot plant

Days since inoculation	Vial #	Average TOC Concentration (µg/L)	Standard Deviation (µg/L)	99% Confidence Interval (+/- µg/L)	Number of measurements
-[1]	1	3163	12	66	3
-[1]	2	3210	10	57	3
0	1	3937	6	33	3
0	2	3550	0	0	3
0	3	4223	15	88	3
0	4	3583	6	33	3
1	1	3670	10	57	3
1	2	3800	10	57	3
1	3	3383	6	33	3
1	4	3620	10	57	3
5	1	2220	17	99	3
5	2	2510	26	152	3
5	3	3150	36	207	3
5	4	2973	15	88	3

1. TOC concentration analyzed before inoculation

Appendix F
Maltose and Acetate Adsorption Data

Contents

This appendix contains results from the acetate and maltose adsorption tests. The average TOC concentrations for various masses of GAC, at equilibrium, are presented. For the interested reader, the mass of carbon present in each jar at equilibrium, the mass of carbon adsorbed, and the mass adsorbed per mass GAC have been calculated and are provided; additional plots presenting this data are also provided.

Structure of the Appendix

The data and plots from adsorption tests conducted using virgin wood-based GAC are presented, followed by the data and plots from adsorption tests conducted using the coal-based GAC from the UW pilot plant.

Adsorption Tests Using Virgin Wood-Based GAC

Table F-1: Adsorption test results for the adsorption of acetate on virgin wood-based GAC

Sample Description	GAC mass	Water type[3]	Sample volume	Reaction time	Equilibrium TOC Concentration[4]							Estimated values			
					Average		Standard deviation		n[5]	99% Confidence interval[6]		mass of carbon in sample[7]	mass of carbon adsorbed[8]	mass adsorbed/mass GAC	
	(g)		(L)	(hrs)	(µg/L)	(mg/L)	(µg/L)	(mg/L)		(µg/L)	(mg/L)	µg	µg	µg/g	mg/g
Process blank (process contamination check)[1]	0.0000	Ultrapure	0.200	2	66.68	0.06668	2.922	0.002922	9	3.268	0.003268	13.34	-	-	-
GAC contamination check[1]	0.0493	Ultrapure	0.200	2	131.89	0.13189	2.315	0.002315	9	2.590	0.002590	26.38	-	-	-
Test solution (~10 mg/L-C acetate)	0.0000	Test	0.200	2	10100.00	10.10000	0.000	0.000000	9	0.000	0.000000	2020.00	-	-	-
Isotherm point 1	0.0011	Test	0.200	2	10000.00	10.00000	0.000	0.000000	9	0.000	0.000000	2000.00	20.00	18181.82	18.18
Isotherm point 2	0.0026	Test	0.200	2	10033.33	10.03333	50.000	0.050000	9	55.923	0.055923	2006.67	13.33	5128.21	5.13
Isotherm point 3	0.0079	Test	0.200	2	10100.00	10.10000	0.000	0.000000	9	0.000	0.000000	2020.00	0.00	0.00	0.00
Isotherm point 4	0.0107	Test	0.200	2	10300.00	10.30000	0.000	0.000000	9	0.000	0.000000	2060.00	-40.00	-3738.32	-3.74
Isotherm point 5	0.0243	Test	0.200	2	10100.00	10.10000	0.000	0.000000	9	0.000	0.000000	2020.00	0.00	0.00	0.00
Isotherm point 6	0.0493	Test	0.200	2	10100.00	10.10000	0.000	0.000000	6	0.000	0.000000	2020.00	0.00	0.00	0.00
Time test (4 hrs vs 2 hrs)[1,2]	0.0106	Test	0.200	4	10300.00	10.30000	0.000	0.000000	9	0.000	0.000000	2060.00	-40.00	-3773.58	-3.77

1. Quality control sample.
2. Compare results from this sample to isotherm point 4 to review the impact of time on the results.
3. Ultrapure water was produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada).
4. TOC concentrations measured on a Sievers M9 TOC analyzer (GE Analytics, Boulder, Colorado). TOC concentrations reported in µg/L and converted to mg/L.
5. Number of measurements.
6. 99% confidence interval calculated using a t-distribution.
7. Estimated mass of carbon in the sample at equilibrium was calculated by multiplying the volume of the sample by the TOC concentration at equilibrium.
8. Estimated mass of carbon adsorbed was calculated by subtracting the mass of carbon present in the sample from the mass of carbon present in the test solution sample.

Table F-2: Adsorption test results for the adsorption of maltose on virgin wood-based GAC

Samples Description	GAC mass	Water type[3]	Sample volume	Reaction time	Equilibrium TOC Concentration[4]							Estimated Values			
					Average		Standard deviation		n[5]	99% Confidence interval[6]		mass of carbon in sample[7]	mass of carbon adsorbed[8]	mass adsorbed/mass GAC	
	(g)		(L)	(hrs)	(µg/L)	(mg/L)	(µg/L)	(mg/L)		(µg/L)	(mg/L)	(µg)	(µg)	(µg/g)	(mg/g)
Process blank (process contamination check)[1]	0	Ultrapure	0.200	2	55.04	0.05504	1.897	0.001897	9	2.122	0.002122	11.01	-	-	-
GAC contamination check[1]	0.0508	Ultrapure	0.200	2	143.33	0.14333	2.598	0.002598	9	2.906	0.002906	28.67	-	-	-
Test solution (~10 mg/L-C maltose)	0.0000	Test	0.200	2	10577.78	10.57778	44.096	0.044096	9	49.320	0.049320	2115.56	-	-	-
Isotherm point 1	0.0012	Test	0.200	2	10511.11	10.51111	33.333	0.033333	9	37.282	0.037282	2102.22	13.33	11111.11	11.11
Isotherm point 2	0.0026	Test	0.200	2	10488.89	10.48889	60.093	0.060093	9	67.211	0.067211	2097.78	17.78	6837.61	6.84
Isotherm point 3	0.0078	Test	0.200	2	10411.11	10.41111	33.333	0.033333	9	37.282	0.037282	2082.22	33.33	4273.50	4.27
Isotherm point 4	0.0099	Test	0.200	2	10311.11	10.31111	33.333	0.033333	9	37.282	0.037282	2062.22	53.33	5387.21	5.39
Isotherm point 5	0.0256	Test	0.200	2	10122.22	10.12222	139.443	0.139443	9	155.962	0.155962	2024.44	91.11	3559.03	3.56
Isotherm point 6	0.0509	Test	0.200	2	9552.22	9.55222	17.873	0.017873	9	19.990	0.019990	1910.44	205.11	4029.69	4.03
Time test (4 hrs vs 2 hrs)[1,2]	0.0104	Test	0.200	4	10322.22	10.32222	44.096	0.044096	9	49.320	0.049320	2064.44	51.11	4914.53	4.91

1. Quality control sample.
2. Compare results from this sample to isotherm point 4 to review the impact of time on the results.
3. Ultrapure water was produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada).
4. TOC concentrations measured on a Sievers M9 TOC analyzer (GE Analytics, Boulder, Colorado). TOC concentrations reported in µg/L and converted to mg/L.
5. Number of measurements.
6. 99% confidence interval calculated using a t-distribution.
7. Estimated mass of carbon in the sample at equilibrium was calculated by multiplying the volume of the sample by the TOC concentration at equilibrium.
8. Estimated mass of carbon adsorbed was calculated by subtracting the mass of carbon present in the sample from the mass of carbon present in the test solution sample.

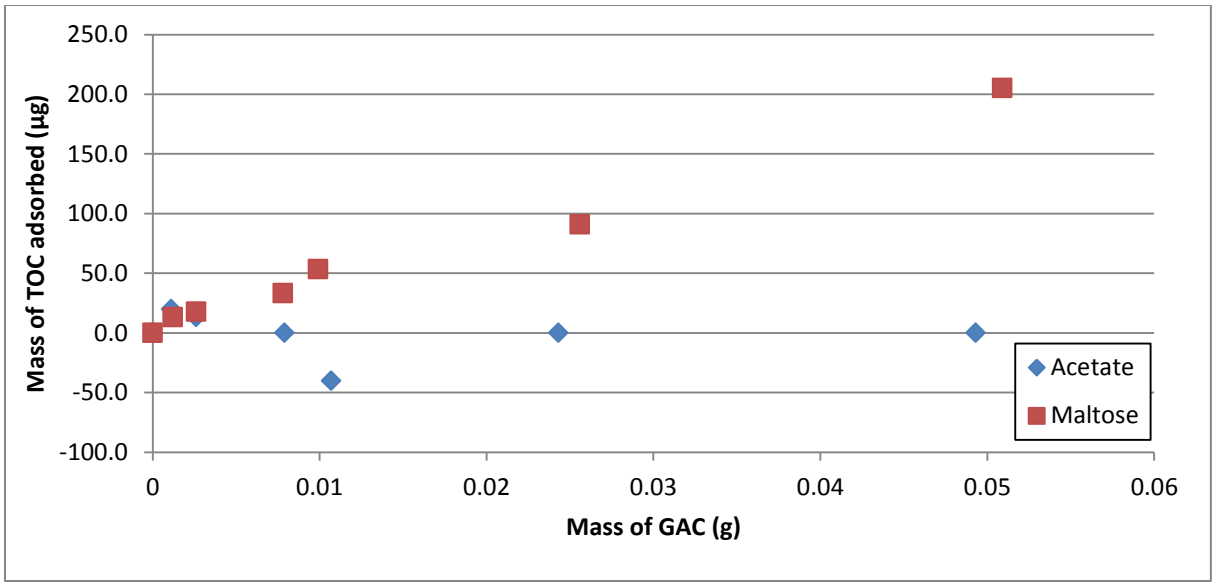

Figure F-1: Mass of acetate and maltose adsorbed onto virgin wood-based GAC for various masses of GAC

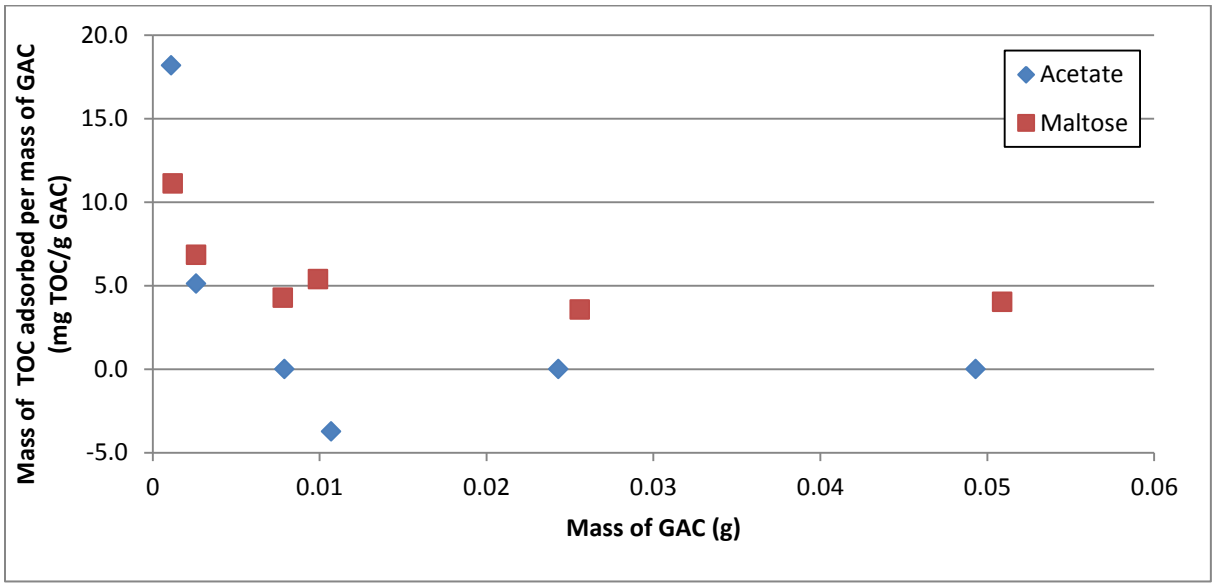

Figure F-2: Mass of TOC adsorbed/mass of GAC for acetate and maltose on virgin wood-based GAC

Adsorption Tests Using the Coal-Based GAC from the UW Pilot Plant

Table F-3: Adsorption test results for the adsorption of acetate on coal-based GAC from the UW pilot plant

Samples Description	GAC mass	Water type[3]	Sample volume	Reaction time	Equilibrium TOC Concentration[4]							Estimated Values			
					Average		Standard deviation		n[5]	99% Confidence interval[6]		mass of carbon in sample[7]	mass of carbon adsorbed[8, 9]	mass adsorbed/mass GAC[9]	
	(g)		L	(hrs)	(µg/L)	(mg/L)	(µg/L)	(mg/L)		(µg/L)	(mg/L)	(µg)	(µg)	(µg/g)	(mg/g)
Process blank (process contamination check)[1]	0.0000	Ultrapure	0.200	2	46.92	0.04692	1.975	0.001975	12	1.771	0.001771	9.38	-	-	-
GAC contamination check[1]	0.3006	Ultrapure	0.200	2	4094.17	4.09417	16.765	0.016765	12	15.031	0.015031	818.83	-	-	-
Test solution (~15 mg/L-C acetate)	0.0000	Test	0.200	2	15066.67	15.06667	49.237	0.049237	12	44.144	0.044144	3013.33	-	-	-
Isotherm point 1	0.0011	Test	0.200	2	15133.33	15.13333	77.850	0.077850	12	69.798	0.069798	3026.67	-13.33	-12121.21	-12.12
Isotherm point 2	0.0025	Test	0.200	2	15150.00	15.15000	52.223	0.052223	12	46.822	0.046822	3030.00	-16.67	-6666.67	-6.67
Isotherm point 3	0.0076	Test	0.200	2	15191.67	15.19167	51.493	0.051493	12	46.167	0.046167	3038.33	-25.00	-3289.47	-3.29
Isotherm point 4	0.0108	Test	0.200	2	15275.00	15.27500	86.603	0.086603	12	77.645	0.077645	3055.00	-41.67	-3858.02	-3.86
Isotherm point 5	0.0255	Test	0.200	2	15516.67	15.51667	57.735	0.057735	12	51.763	0.051763	3103.33	-90.00	-3529.41	-3.53
Isotherm point 6	0.0502	Test	0.200	2	15841.67	15.84167	51.493	0.051493	12	46.167	0.046167	3168.33	-155.00	-3087.65	-3.09
Isotherm point 7	0.1008	Test	0.200	2	16233.33	16.23333	49.237	0.049237	12	44.144	0.044144	3246.67	-233.33	-2314.81	-2.31
Isotherm point 8	0.2002	Test	0.200	2	17791.67	17.79167	66.856	0.066856	12	59.941	0.059941	3558.33	-545.00	-2722.28	-2.72
Isotherm point 9	0.3002	Test	0.200	2	18891.67	18.89167	79.296	0.079296	12	71.094	0.071094	3778.33	-765.00	-2548.30	-2.55
Time test (4 hrs vs 2 hrs)[1,2]	0.0502	Test	0.200	4	15883.33	15.88333	57.735	0.057735	12	51.763	0.051763	3176.67	-163.33	-3253.65	-3.25
Replicate of Isotherm point 5[1]	0.026	Test	0.200	2	15475.00	15.47500	62.158	0.062158	12	55.729	0.055729	3095.00	-81.67	-3177.69	-3.18
Replicate of Isotherm point 7[1]	0.100	Test	0.200	2	16575.00	16.57500	75.378	0.075378	12	67.581	0.067581	3315.00	-301.67	-3013.65	-3.01
Replicate of Isotherm point 9[1]	0.300	Test	0.200	2	18466.67	18.46667	65.134	0.065134	12	58.397	0.058397	3693.33	-680.00	-2265.16	-2.27

1. Quality control sample.
2. Compare results from this sample to isotherm point 6 to review the impact of time on the results.
3. Ultrapure water was produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada).
4. TOC concentrations measured on a Sievers M9 TOC analyzer (GE Analytics, Boulder, Colorado). TOC concentrations reported in µg/L and converted to mg/L.
5. Number of measurements.
6. 99% confidence interval calculated using a t-distribution.
7. Estimated mass of carbon in the sample at equilibrium was calculated by multiplying the volume of the sample by the TOC concentration at equilibrium.
8. Estimated mass of carbon adsorbed was calculated by subtracting the mass of carbon present in the sample from the mass of carbon present in the test solution sample.
9. A negative value indicates that carbon was released and not adsorbed.

Table F-4: Adsorption test results for the adsorption of maltose on coal-based GAC from the UW pilot plant

Sample description	GAC mass	Water type[3]	Sample volume	Reaction time	Equilibrium TOC Concentration[4]							Estimated Values			
					Average		Standard deviation		n[5]	99% Confidence intervals[6]		mass of carbon in sample[7]	mass of carbon adsorbed[8]	mass adsorbed/mass GAC[9]	
	(g)		(L)	(hrs)	(µg/L)	(mg/L)	(µg/L)	(mg/L)		(µg/L)	(mg/L)	(µg)	(µg)	(µg/g)	(mg/g)
Process blank (process contamination check)[1]	0.0000	Ultrapure	0.200	2	68.58	0.06858	9.821	0.009821	12	8.805	0.008805	13.72	-	-	-
GAC contamination check[1]	0.3012	Ultrapure	0.200	2	3668.33	3.66833	43.240	0.043240	12	38.768	0.038768	733.67	-	-	-
Test solution (~15 mg/L-C maltose)	0.0000	Test	0.200	2	15025.00	15.02500	62.158	0.062158	12	55.729	0.055729	3005.00	-	-	-
Isotherm point 1	0.0011	Test	0.200	2	14908.33	14.90833	66.856	0.066856	12	59.941	0.059941	2981.67	23.33	21212.12	21.21
Isotherm point 2	0.0026	Test	0.200	2	14916.67	14.91667	57.735	0.057735	12	51.763	0.051763	2983.33	21.67	8333.33	8.33
Isotherm point 3	0.0077	Test	0.200	2	14766.67	14.76667	115.470	0.115470	12	103.527	0.103527	2953.33	51.67	6709.96	6.71
Isotherm point 4	0.0099	Test	0.200	2	14608.33	14.60833	28.868	0.028868	12	25.882	0.025882	2921.67	83.33	8417.51	8.42
Isotherm point 5	0.0250	Test	0.200	2	14158.33	14.15833	66.856	0.066856	12	59.941	0.059941	2831.67	173.33	6933.33	6.93
Isotherm point 6	0.0497	Test	0.200	2	13300.00	13.30000	73.855	0.073855	12	66.216	0.066216	2660.00	345.00	6941.65	6.94
Isotherm point 7	0.1003	Test	0.200	2	11950.00	11.95000	52.223	0.052223	12	46.822	0.046822	2390.00	615.00	6131.61	6.13
Isotherm point 8	0.2005	Test	0.200	2	10258.33	10.25833	66.856	0.066856	12	59.941	0.059941	2051.67	953.33	4754.78	4.75
Isotherm point 9	0.3005	Test	0.200	2	9273.33	9.27333	26.400	0.026400	12	23.670	0.023670	1854.67	1150.33	3828.06	3.83
Time test (4 hrs vs 2 hrs)[1,2]	0.0499	Test	0.200	4	13008.33	13.00833	28.868	0.028868	12	25.882	0.025882	2601.67	403.33	8082.83	8.08
Replicate of Isotherm point 5[1]	0.0253	Test	0.200	2	14091.67	14.09167	51.493	0.051493	12	46.167	0.046167	2818.33	186.67	7378.13	7.38
Replicate of Isotherm point 7[1]	0.1008	Test	0.200	2	12016.67	12.01667	38.925	0.038925	12	34.899	0.034899	2403.33	601.67	5968.92	5.97

1. Quality control sample.
2. Compare results from this sample to isotherm point 6 to review the impact of time on the results.
3. Ultrapure water was produced using a Milli-Q UV Plus water system with a QPak 2 cartridge (EMD Millipore, Canada).
4. TOC concentrations measured on a Sievers M9 TOC analyzer (GE Analytics, Boulder, Colorado). TOC concentrations reported in µg/L and converted to mg/L.
5. Number of measurements.
6. 99% confidence interval calculated using a t-distribution.
7. Estimated mass of carbon in the sample at equilibrium was calculated by multiplying the volume of the sample by the TOC concentration at equilibrium.
8. Estimated mass of carbon adsorbed was calculated by subtracting the mass of carbon present in the sample from the mass of carbon present in the test solution sample.
9. Estimated mass of carbon adsorbed/mass GAC was calculated by dividing the mass of carbon adsorbed by the GAC mass that was present in the sample.

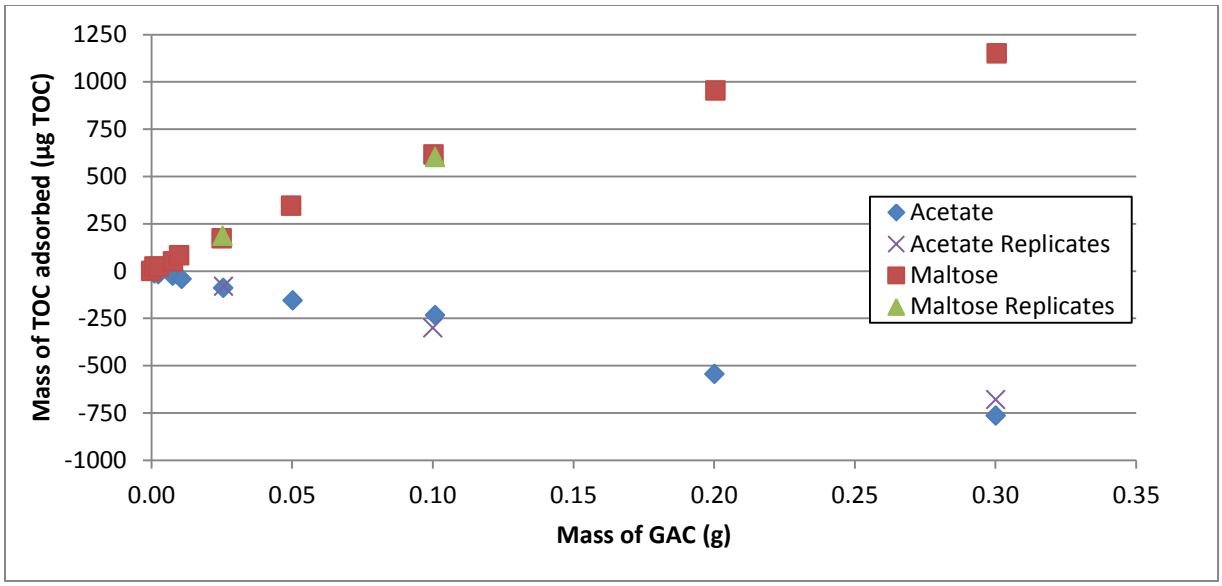

Figure F-3: Mass of acetate and maltose adsorbed onto coal-based GAC from the UW pilot plant for various masses of GAC

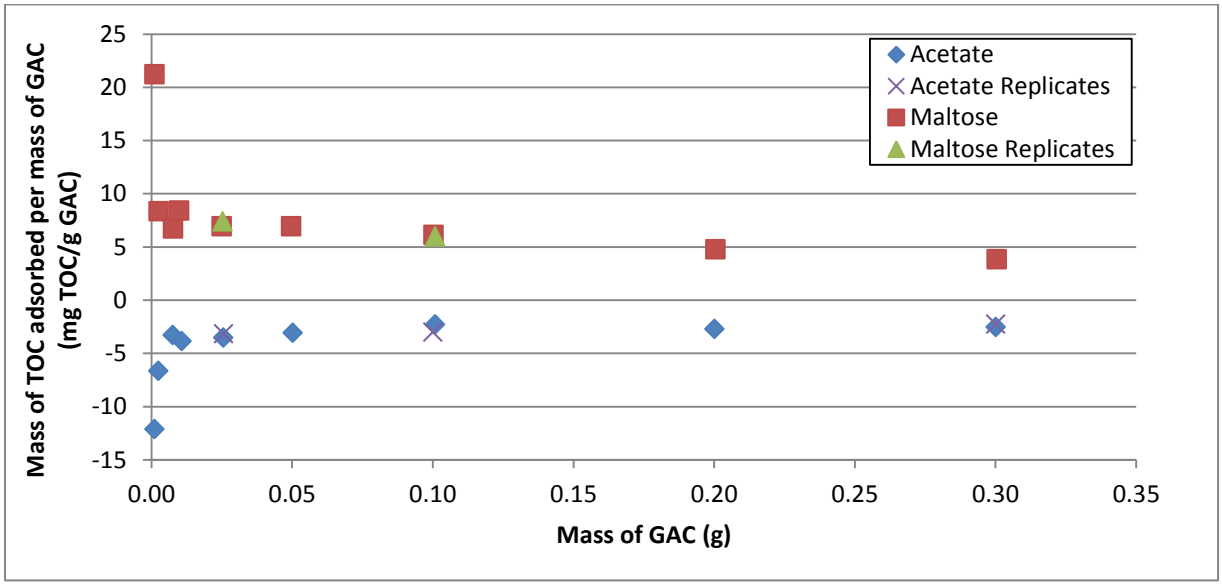

Figure F-4: Mass of TOC adsorbed/mass of GAC for acetate and maltose on coal-based GAC from the UW pilot plant

Appendix G
Example Calculations Related to Spike Experiments

Contents

This appendix contains example calculations related to the spike experiments conducted at UW. Example calculations for the correction of the influent TOC analyzer concentrations, the calculation of TOC removal, and the calculation of IC production are provided.

Structure of the Appendix

A subset of the TOC and IC data collected from the influent and effluent TOC analyzers, from the first spike experiment conducted at the UW pilot plant, is provided in two tables. The results from the May 13, 2015 comparison of the influent and effluent TOC analyzers are also re-presented for ease of reference. Example calculations for the correction of the influent TOC analyzer concentrations are presented, followed by a table showing the corrected values for the data. Finally, example TOC removal and IC production calculations are provided.

Raw TOC and IC Data

Table G-1 provides influent total organic carbon [TOC] and inorganic carbon [IC] data collected on May 13, 2015 from 14:28 to 15:32. Table G-2 provides effluent data for the same time period. This subset of the TOC and IC data was chosen because it captures the increase in concentration due to the first acetate spike conducted at the UW pilot plant and, thus, provides a range of measured concentrations. In these tables, the reference number provides a unique identifier for each data point.

Table G-1: Select Influent TOC and IC data

Reference Number	Date and time of analysis	TOC (µg/L)	IC (µg/L)
10231	13-May-2015 14:28	3260	899
10232	13-May-2015 14:30	3250	899
10233	13-May-2015 14:32	3240	897
10234	13-May-2015 14:34	3230	896
10235	13-May-2015 14:36	3240	897
10236	13-May-2015 14:38	3230	896
10237	13-May-2015 14:40	3230	896
10238	13-May-2015 14:42	3230	894
10239	13-May-2015 14:44	3230	894
10240	13-May-2015 14:46	3220	895
10241	13-May-2015 14:48	3220	895
10242	13-May-2015 14:50	3220	895
10243	13-May-2015 14:52	3230	894
10244	13-May-2015 14:54	3230	896
10245	13-May-2015 14:56	3220	895
10246	13-May-2015 14:58	3220	895
10247	13-May-2015 15:00	3230	896
10248	13-May-2015 15:02	3230	896
10249	13-May-2015 15:04	3240	895
10250	13-May-2015 15:06	3320	895
10251	13-May-2015 15:08	3580	895
10252	13-May-2015 15:10	4280	895
10253	13-May-2015 15:12	5360	895
10254	13-May-2015 15:14	6380	896
10255	13-May-2015 15:16	7180	898
10256	13-May-2015 15:18	7690	898
10257	13-May-2015 15:20	7950	898
10258	13-May-2015 15:22	8170	899
10259	13-May-2015 15:24	8310	899
10260	13-May-2015 15:26	8330	899
10261	13-May-2015 15:28	8370	899
10262	13-May-2015 15:30	8440	900
10263	13-May-2015 15:32	8460	898

Table G-2: Select Effluent TOC and IC data

Reference Number	Date and time of analysis	TOC (µg/L)	IC (µg/L)
27009	13-May-2015 14:28	1030	2840
27010	13-May-2015 14:30	1080	2810
27011	13-May-2015 14:32	1110	2790
27012	13-May-2015 14:34	1140	2760
27013	13-May-2015 14:36	1170	2750
27014	13-May-2015 14:38	1190	2750
27015	13-May-2015 14:40	1200	2740
27016	13-May-2015 14:42	1200	2740
27017	13-May-2015 14:44	1210	2720
27018	13-May-2015 14:46	1210	2730
27019	13-May-2015 14:48	1220	2720
27020	13-May-2015 14:50	1220	2720
27021	13-May-2015 14:52	1220	2710
27022	13-May-2015 14:54	1220	2710
27023	13-May-2015 14:56	1220	2710
27024	13-May-2015 14:58	1220	2700
27025	13-May-2015 15:00	1220	2710
27026	13-May-2015 15:02	1230	2710
27027	13-May-2015 15:04	1240	2710
27028	13-May-2015 15:06	1240	2700
27029	13-May-2015 15:08	1230	2700
27030	13-May-2015 15:10	1230	2690
27031	13-May-2015 15:12	1240	2700
27032	13-May-2015 15:14	1270	2700
27033	13-May-2015 15:16	1360	2710
27034	13-May-2015 15:18	1630	2720
27035	13-May-2015 15:20	2330	2730
27036	13-May-2015 15:22	3030	2740
27037	13-May-2015 15:24	3810	2770
27038	13-May-2015 15:26	4460	2780
27039	13-May-2015 15:28	4840	2790
27040	13-May-2015 15:30	5330	2800
27041	13-May-2015 15:32	5530	2790

Table G-3 shows the results from the comparisons of the influent and effluent TOC analyzers on the same set of synthetic samples. Figure G-1 shows the difference in TOC analyzer concentration plotted versus the reading on the influent TOC analyzer.

Table G-3: Results from comparisons of the effluent and influent TOC analyzers on the same synthetic samples. Comparisons conducted on May 13, 2015, after the first spike experiment.

Analyte	Approximate concentration of sample (µg/L)	Average reading on: Effluent TOC analyzer (µg/L)	Influent TOC analyzer (µg/L)	Difference (Effluent-Influent) (µg/L)
TOC	1000	1109	1074	35
	3000	3234	3041	192
	5000	5327	4971	356
	10000	10718	9866	852
	15000	15936	14886	1050
IC	1000	1082	1062	20
	3000	3076	3044	32
	5000	5015	5015	0
	10000	9954	9906	47
	15000	14807	14800	7

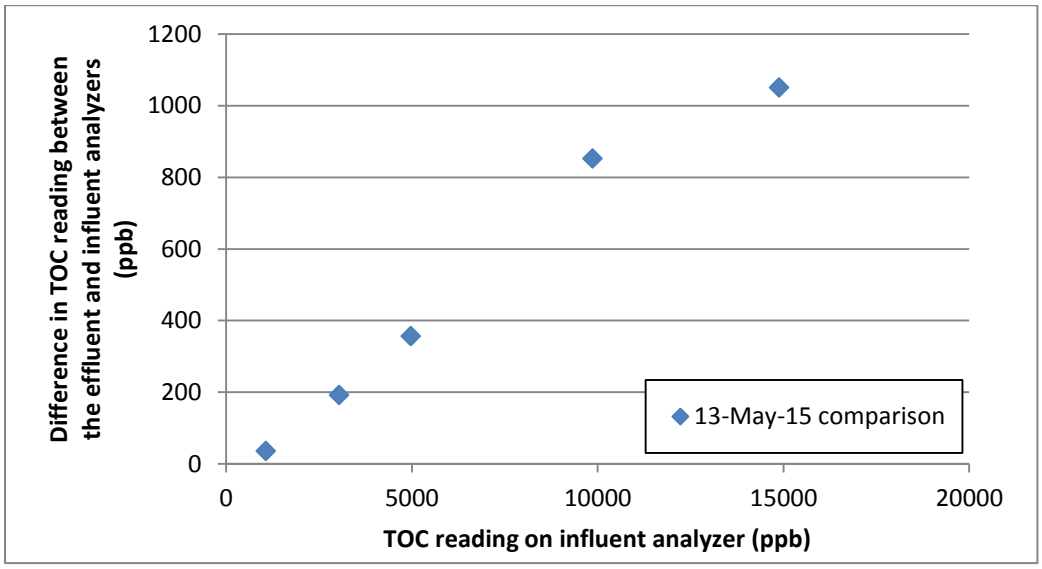

Figure G-1: Difference in TOC reading between influent and effluent analyzers plotted versus reading on the influent TOC analyzer (May 13, 2015 and May 29, 2015 comparisons)

Influent TOC analyzer readings were corrected to match effluent TOC analyzer readings. In order to match the influent readings to the effluent readings, the difference in TOC analyzer reading was estimated using linear point-to-point interpolation. The influent TOC reading was then adjusted by the difference. To illustrate the calculation procedure, the influent TOC concentration associated with influent reading number 10231 is calculated.

The raw TOC reading for influent reading 10231 was 3260 µg/L. A priori, the difference in reading between the effluent and influent TOC analyzers for this data point is unknown. However, when the reading 3260 µg/L is compared to the TOC analyzer comparison results listed in Table G-3, it can be seen that this reading falls between the 3041 µg/L and 4971µg/L readings measured on the influent TOC analyzer. Differences in TOC reading between the effluent and influent TOC analyzer are known for the 3041 µg/L and 4971 µg/L readings; therefore, the difference in TOC reading between the effluent and influent TOC analyzers for 3260 µg/L can be estimated using linear interpolation.

The difference in TOC reading between the effluent and influent TOC analyzers was 192 µg/L for the 3041 µg/L reading and was 356 µg/L for the 4971 µg/L reading (see Table G-3 & Figure G-1). The equation of the line that can be drawn between these points is calculated using this data. The equation of the line is shown in Equation G-1.

$$y = 0.08484x - 65.89 \qquad \textbf{(Equation G-1)}$$

Where y is the difference in TOC reading between the effluent and influent TOC analyzer in µg/L and x is the raw (uncorrected) influent TOC reading in µg/L. The difference in TOC reading between the effluent and influent TOC analyzer, for a reading of 3260 µg/L, can be calculated using Equation G-1 and is 211 µg/L. The corrected influent TOC concentration is then calculated using Equation G-2:

$$z = y + x \qquad \textbf{(Equation G-2)}$$

Where z is the corrected influent TOC concentration, y is the difference in reading between the effluent and influent TOC analyzers, and x is the raw (uncorrected) reading on the influent TOC analyzer. The corrected TOC concentration for TOC reading 10231, therefore, is:

$$\begin{aligned} z &= y + x \\ &= 3260\ \mu g/L + 211\ \mu g/L \\ &= 3471\ \mu g/L \end{aligned} \qquad \textbf{(Equation G-3)}$$

The same general procedure was used to correct all influent TOC concentrations. Table G-4 (following page) provides the corrected influent TOC values, the interpolated difference in TOC reading, and the slope and intercept values used to calculate the difference in TOC reading for all TOC values presented in Table G-1.

Table G-4: Corrected Influent TOC values

Raw Data			Values used to calculate corrected TOC			Corrected TOC (µg/L)
Reference Number	Date and time of analysis	TOC (µg/L)	Slope	Intercept	Calculated Difference[1] (µg/L)	
10231	13-May-2015 14:28	3260	0.08484	-65.89	211	3471
10232	13-May-2015 14:30	3250	0.08484	-65.89	210	3460
10233	13-May-2015 14:32	3240	0.08484	-65.89	209	3449
10234	13-May-2015 14:34	3230	0.08484	-65.89	208	3438
10235	13-May-2015 14:36	3240	0.08484	-65.89	209	3449
10236	13-May-2015 14:38	3230	0.08484	-65.89	208	3438
10237	13-May-2015 14:40	3230	0.08484	-65.89	208	3438
10238	13-May-2015 14:42	3230	0.08484	-65.89	208	3438
10239	13-May-2015 14:44	3230	0.08484	-65.89	208	3438
10240	13-May-2015 14:46	3220	0.08484	-65.89	207	3427
10241	13-May-2015 14:48	3220	0.08484	-65.89	207	3427
10242	13-May-2015 14:50	3220	0.08484	-65.89	207	3427
10243	13-May-2015 14:52	3230	0.08484	-65.89	208	3438
10244	13-May-2015 14:54	3230	0.08484	-65.89	208	3438
10245	13-May-2015 14:56	3220	0.08484	-65.89	207	3427
10246	13-May-2015 14:58	3220	0.08484	-65.89	207	3427
10247	13-May-2015 15:00	3230	0.08484	-65.89	208	3438
10248	13-May-2015 15:02	3230	0.08484	-65.89	208	3438
10249	13-May-2015 15:04	3240	0.08484	-65.89	209	3449
10250	13-May-2015 15:06	3320	0.08484	-65.89	216	3536
10251	13-May-2015 15:08	3580	0.08484	-65.89	238	3818
10252	13-May-2015 15:10	4280	0.08484	-65.89	297	4577
10253	13-May-2015 15:12	5360	0.10131	-147.78	395	5755
10254	13-May-2015 15:14	6380	0.10131	-147.78	499	6879
10255	13-May-2015 15:16	7180	0.10131	-147.78	580	7760
10256	13-May-2015 15:18	7690	0.10131	-147.78	631	8321
10257	13-May-2015 15:20	7950	0.10131	-147.78	658	8608
10258	13-May-2015 15:22	8170	0.10131	-147.78	680	8850
10259	13-May-2015 15:24	8310	0.10131	-147.78	694	9004
10260	13-May-2015 15:26	8330	0.10131	-147.78	696	9026
10261	13-May-2015 15:28	8370	0.10131	-147.78	700	9070
10262	13-May-2015 15:30	8440	0.10131	-147.78	707	9147
10263	13-May-2015 15:32	8460	0.10131	-147.78	709	9169

1. Estimated difference between the reading on the effluent analyzer and the reading on the influent analyzer

Calculation of TOC Removal and IC Production

Once the influent TOC values were corrected, TOC removal through the filters was calculated. TOC removal was calculated as the difference between the influent and effluent TOC concentrations. It was found that it took approximately 10 minutes for water to travel from the influent TOC sampling port to the effluent TOC sampling port[1]. Therefore, the TOC removal was calculated by subtracting each effluent TOC measurement from the corrected influent TOC measurement taken *10 minutes prior* to the effluent TOC measurement to ensure that the TOC removal was calculated for the same aliquot of water; i.e.

$$TOCR_t = CorInfTOC_{t-10\ \text{min}} - EffTOC_t \qquad \textbf{(Equation G-4)}$$

Where $TOCR_t$ is the calculated TOC removal for time t, $CorInfTOC_{t\text{-}10\ min}$ is the corrected influent TOC concentration measured 10 minutes prior to time t, and $EffTOC_t$ is the effluent concentration measured at time t.

To provide an example of the TOC removal calculations, the TOC removal associated at time 14:38 on May 13, 2015 was calculated. The effluent TOC concentration measured at 14:38 on May 13, 2015 was 1190 µg/L (TOC reading number 27014 in Table G-2). The corrected influent TOC concentration measured ten minutes prior to the effluent TOC reading was 3471 µg/L (TOC reading number 10231 in Table G-4). Therefore, the TOC removal at 14:38 can be calculated as follows:

$$\begin{aligned} TOCR_t &= CorInfTOC_{t-10\ \text{min}} - EffTOC_t \\ &= 3471\ \mu g/L - 1190\ \mu g/L \\ &= 2281\ \mu g/L \end{aligned} \qquad \textbf{(Equation G-5)}$$

Inorganic carbon production was calculated in the same way as TOC removal except that the influent IC concentration was subtracted from the effluent IC concentration. i.e.

$$ICPr_t = EffIC_t - InfIC_{t-10\ \text{min}} \qquad \textbf{(Equation G-6)}$$

[1] This was determined based on inspection of the TOC data and TOC removal data. It was found that effluent TOC spikes started and stopped approximately 10 minutes after the same spike was observed to start or stop in the filter influent. Using a 10 minute delay also minimized artificial increases in the calculated TOC removal (using delays shorter or longer than 10 minutes resulted in in TOC removal during the start of a TOC spike and resulted in unstable removal values).

Where $ICPr_t$ is the IC production calculated at time t, $EffIC_t$ is the effluent IC concentration at time t, and $InfIC_{t\text{-}10\ min}$ is the influent inorganic concentration measured 10 minutes prior to time t. Therefore, the IC production at the same time (14:38 on May 13, 2015) is:

$$ICPr_t = EffIC_t - InfIC_{t-10\ \text{min}} = 2750\ \mu g/L - 899\ \mu g/L = 1851\ \mu g/L \quad \textbf{(Equation G-7)}$$

It should be noted that the influent IC concentration was subtracted from the effluent IC concentration because inorganic carbon production was of interest and not inorganic carbon removal. Inorganic carbon (i.e. CO_2) can be produced from the oxidation of TOC. Therefore, given that TOC is removed by biological action in biofilters, at least some IC production can be expected.

Table G-5 (next page) summarizes the calculated TOC removal and IC production for the data set presented in Tables G-2 and G-4.

Table G-5: Calculated TOC removal and IC production for data presented in Tables H-2 and H-4

Date and Time of measurements	Influent		Effluent		TOC Removal	IC Production
	Corrected TOC (µg/L)	IC (µg/L)	TOC (µg/L)	IC (µg/L)	(µg/L)	(µg/L)
13-May-2015 14:28	3471	899	1030	2840	-	-
13-May-2015 14:30	3460	899	1080	2810	-	-
13-May-2015 14:32	3449	897	1110	2790	-	-
13-May-2015 14:34	3438	896	1140	2760	-	-
13-May-2015 14:36	3449	897	1170	2750	-	-
13-May-2015 14:38	3438	896	1190	2750	2281	1851
13-May-2015 14:40	3438	896	1200	2740	2260	1841
13-May-2015 14:42	3438	894	1200	2740	2249	1843
13-May-2015 14:44	3438	894	1210	2720	2228	1824
13-May-2015 14:46	3427	895	1210	2730	2239	1833
13-May-2015 14:48	3427	895	1220	2720	2218	1824
13-May-2015 14:50	3427	895	1220	2720	2218	1824
13-May-2015 14:52	3438	894	1220	2710	2218	1816
13-May-2015 14:54	3438	896	1220	2710	2218	1816
13-May-2015 14:56	3427	895	1220	2710	2207	1815
13-May-2015 14:58	3427	895	1220	2700	2207	1805
13-May-2015 15:00	3438	896	1220	2710	2207	1815
13-May-2015 15:02	3438	896	1230	2710	2208	1816
13-May-2015 15:04	3449	895	1240	2710	2198	1814
13-May-2015 15:06	3536	895	1240	2700	2187	1805
13-May-2015 15:08	3818	895	1230	2700	2197	1805
13-May-2015 15:10	4577	895	1230	2690	2208	1794
13-May-2015 15:12	5755	895	1240	2700	2198	1804
13-May-2015 15:14	6879	896	1270	2700	2179	1805
13-May-2015 15:16	7760	898	1360	2710	2176	1815
13-May-2015 15:18	8321	898	1630	2720	2188	1825
13-May-2015 15:20	8608	898	2330	2730	2247	1835
13-May-2015 15:22	8850	899	3030	2740	2725	1845
13-May-2015 15:24	9004	899	3810	2770	3069	1874
13-May-2015 15:26	9026	899	4460	2780	3300	1882
13-May-2015 15:28	9070	899	4840	2790	3481	1892
13-May-2015 15:30	9147	900	5330	2800	3278	1902
13-May-2015 15:32	9169	898	5530	2790	3320	1891

Appendix H
Mass Balance on a Closed Biofilter

Contents

This appendix contains a mass balance illustrating that carbon stored in the filter is being utilized and released as inorganic carbon (i.e. bioregeneration and/or net decay of biomass is occurring) when the production of inorganic carbon exceeds the removal of TOC by a closed biofilter. The likely cause of the increased organic carbon is also discussed.

Definitions and Symbols

In this appendix, the term "closed" biofilter indicates a biofilter that is closed to the atmosphere. It is not meant to exclude water from flowing through the biofilter (i.e. being pumped into the influent side of the filter via tubing and allowed flow out of effluent tubing on the effluent side of the biofilter).

The following symbols will be used:

Symbol	Description
TCi	Total mass of carbon present in the filter influent
TCe	Total mass of carbon present in the filter effluent
TOCi	Mass of organic carbon present in the filter influent
TOCe	Mass of organic carbon present in the filter effluent
ICi	Mass of inorganic carbon present in the filter influent
ICe	Mass of inorganic carbon present in the filter effluent

Mass Balance

Consider the following closed biofilter:

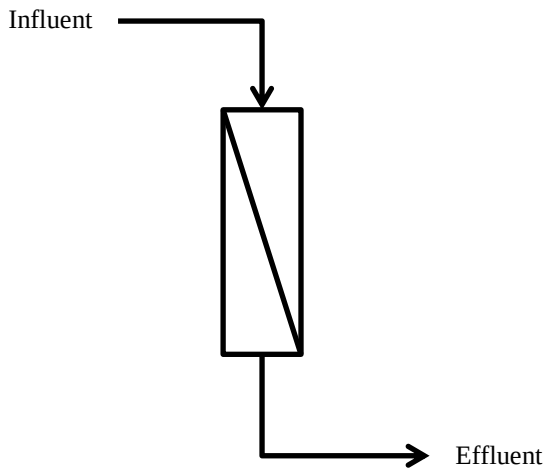

Figure H-1: Schematic of a closed biofilter

Assume that the biofilter is being fed water containing organic and inorganic carbon. Also assume that the carbon in the water and in the filter is either in an organic or inorganic form. Finally, since the biofilter is closed, assume that carbon is not lost from the system through the air and can only enter or exit the system through the influent or effluent.

In such a system, the total accumulation of carbon in the biofilter at any given point in time is equal to the mass of carbon entering in biofilter minus the mass of carbon exiting the biofilter,. i.e.

$$Accumulation = TCi - TCe \qquad \textbf{(Equation H-1)}$$

The total mass of carbon entering the biofilter is equal to the mass of organic carbon in the biofilter influent plus the mass of inorganic carbon in the biofilter influent. The total mass of carbon exiting the biofilter is equal to the mass of organic carbon in the biofilter effluent plus the mass of inorganic carbon in the biofilter effluent. Therefore, Equation H-1 can be rewritten as:

$$Accumulation = (TOCi + ICi) - (TOCe + ICe) \qquad \textbf{(Equation H-2)}$$

Equation H-2 can be rearranged as follows:

$$\begin{aligned} Accumulation &= (TOCi + ICi) - (TOCe + ICe) \\ &= TOCi + ICi - TOCe - ICe \\ &= (TOCi - TOCe) + (ICi - ICe) \end{aligned} \qquad \textbf{(Equation H-3)}$$

The difference between the influent and effluent TOC is the TOC removal. The difference between the influent and effluent IC is the IC removal.

The mass of IC produced by the biofilter is defined as the difference between the mass of IC in the effluent and the mass of IC in the influent. Therefore:

$$IC\ production = ICe - ICi \qquad \textbf{(Equation H-4)}$$

and it can be shown that:

$$\begin{aligned} IC\ production &= ICe - ICi \\ &= -(ICi - ICe) && \textbf{(Equation H-5)} \\ &= -IC\ removal && \textbf{(Equation H-6)} \end{aligned}$$

Rearranging equation H-5 and inserting it into equation H-3 gives:

$$\begin{aligned} Accumulation &= (TOCi - TOCe) + (-IC\ Production) \\ &= (TOCi - TOCe) + \big(-(ICe - ICi)\big) \\ &= (TOCi - TOCe) - (ICe - ICi) \end{aligned} \qquad \textbf{(Equation H-7)}$$

Equation H-7 indicates that the accumulation of carbon in a closed biofilter is equal to the TOC removal minus the IC production. If the IC production is equal to the TOC removal, the accumulation of organic carbon in the biofilter will be zero; this indicates that there is no net storage of organic carbon in the biofilter. If the IC production is less than the TOC removal, the accumulation of carbon in the biofilter will be positive; the positive accumulation indicates that some of the organic carbon that is removed is stored in the biofilter. If the IC production is greater than the TOC removal, the accumulation of carbon in the biofilter will be negative. In this case, the negative accumulation indicates that carbon stored in the filter is leaving the filter in the form of inorganic carbon.

The most likely cause of stored organic carbon leaving a biofilter in the form of inorganic carbon is the oxidation of organic carbon to CO_2 by biological action. It is well known that heterotrophic bacteria can oxidize biodegradable organic carbon to CO_2. It is also known that organic carbon can be adsorbed to GAC, thus storing it in the biofilter (this can occur when the GAC in the biofilter is virgin and, as this study has shown, can even occur when the GAC has been used for extended periods of time). Additional,

it is theoretically possible for organic carbon to be stored in the biofilter when it is utilized as a carbon source to create biomass. Conversion of either of these forms of stored organic carbon (i.e. adsorbed organic carbon or organic carbon incorporated into biomass) to CO_2 by biological action would increase the mass of inorganic carbon mass in the effluent and thus, result in increased inorganic carbon production. If a sufficient amount of stored organic carbon is converted to CO_2 by biological action at a given point in time, the IC production will exceed the TOC removal.

It is conceptually possible for the inorganic carbon concentration in the effluent to increase via release of stored inorganic carbon. However, this is unlikely (at least in this study) because there was no evidence of net inorganic carbon storage observed (inorganic carbon was always produced). Therefore, it is most likely that when inorganic carbon production exceeded TOC removal that the increased inorganic carbon was due to the oxidation of stored organic carbon to CO_2 by biological action.

Finally, it should be noted that the mass balance shown above was written using the mass of carbon; however, the same analysis can be done using concentrations measured in thus study. The mass of carbon is equal to the concentration multiplied by the volume of water. During this study a constant flow rate was used and concentrations were measured at equally spaced time steps; therefore, the volume of water passed through the filter was constant for each time step. The mass of carbon entering, stored, and exiting the filter at each time step, therefore, was directly proportional to the measured TOC and IC concentrations. Analysis of the amount of TOC removed, IC produced, and carbon stored can thus be conducted using TOC and IC concentrations directly without converting them to masses.