**UV-vis spectroscopy as a tool for the detection of residual
polymer and optimization of polymer dose in drinking water
treatment applications**

By

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ABSTRACT

The optimization of polymer dose during the coagulation and flocculation stages of drinking water treatment remains a challenge for treatment plants. Incorrect polymer dosage can lead to either inadequate flocculation or the restabilization of flocs, filter or membrane clogging downstream, potential health effects due to the toxicity of polymers, and increased polymer costs. Analytical methods are not suitable for on-site monitoring and optimization of polymer dose, and it is particularly challenging to accurately detect and measure very low polymer concentrations in drinking water. This study employed an in-line and real-time UV-vis spectrophotometer to measure the polymer concentration in raw and treated water by correlating polymer concentration to the absorbance at 190nm and introduced a new approach to improve the sensitivity and detection limit of the method through altering the path length. In addition, the method was used to determine the optimum polymer dose required for treatment to prevent the addition of excess polymer during coagulation/flocculation. The method has the potential for development into a full-scale optimization system.

LIST OF ABBREVIATIONS

A	Absorbance
AU	Absorbance units
C	Concentration
CD	Charge density
CST	Capillary suction time
ECH	Epichlorohydrin
EPA	Environmental Protection Agency (United States)
GC	Gas chromatography
H-Bond	Hydrogen bond
HPLC	High-performance liquid chromatography
I	Intensity
I_o	Incident intensity
L	Path length
MS	Mass spectrometry
MW	Molecular weight
NOM	Natural organic matter
NTU	Nephelometric Turbidity Units
PAM	Polyacrylamide
PDADMAC	Polydiallyldimethylammonium chloride
PDA	Photometric dispersion analyzer
PL sensor	Power line sensor
RI	Refractive index
RSD	Relative standard deviation
SCD	Streaming current detection
SEC	Size exclusion chromatography
T	Transmittance
UV-vis	Ultraviolet-visible
ε	Molar absorptivity
ξ	Zeta potential
θ	Fractional surface coverage

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CHAPTER 1: INTRODUCTION

The majority of water sources utilized for drinking water contain some concentration of dissolved impurities comprised of minerals, gases, and organic compounds that alter the chemical (biological and chemical oxygen demand, pH, total organic carbon), physical (turbidity, temperature, colour) and biological characteristics of water (1). Safe drinking water is essential to human health, which is why every drinking water source undergoes some form of purification prior to consumption. Various treatment methods are employed to render water safe and appealing to drink, which are dependent on the above listed characteristics of the water source. A major issue regarding the treatment of surface waters is the substantial seasonal variation in the physical characteristic of turbidity (2).

Of all the methods used for the production of safe drinking water; the application of chemical coagulants such as ferric chloride, and both alum and polyelectrolyte polymers have proven to increase the efficiency of suspended solid (colloid) separation from water matrices, decreasing turbidity (3). Drinking water treatment systems frequently make use of a variety of different polymers, typically polyelectrolytes, during the coagulation and flocculation stages of the treatment process. These polymers act as either primary coagulants or flocculant aids to improve efficiency of the coagulation and flocculation stages by lowering coagulant dose, decreasing the ionic load of the treated water, improving the settling of slow-settling flocs in low-temperatures, improving settleability and toughness of flocs, decreasing operating costs, and increasing treatment facility

capacity (4) (5) (6). The polymers bridge the microfloc formed by coagulation, agglomerating smaller particles into larger ones (7).

Polymers function most effectively within an optimum dose range, which is dependent on the properties of the water sample in which they will be used. Dosing polymer at a concentration less than optimum (under-dosing) renders the chemical ineffective, as there is not an adequate concentration of polymer present with respect to the concentration of suspended colloids in the water (5). Dosing polymer at a concentration greater than optimum (overdosing) leads to the production of *residual polymer* left suspended in solution post-treatment; which constitutes any polymer that was not adsorbed onto particulate matter during the coagulation-flocculation process, and often contains monomer units as well as other contaminants that may have been present in the original polymer.

The presence of residual polymer has proven to cause many operational and environmental issues. The viscous nature of dissolved polymer has been shown to cause issues with the clogging of filter beds and filter head loss in wastewater sludge applications, which is also suspected to affect water treatment applications (8). In addition, overdosing can lead to the restabilization of flocs, breaking the flocs, and allowing particulates and contaminants to re-enter the water matrix (3). Overdosing also leads to a larger sludge yield, which increases disposal costs and is undesirable. Furthermore, polymer addition can be a very expensive addition to municipal drinking water treatment if not dosed correctly. In terms of environmental concerns, polyelectrolyte products used for water treatment applications often contain detectable amounts of certain contaminants such as monomer and unreacted

chemicals used to form the monomer, which are toxic to humans and fauna (9). The monomer units have been shown to be more toxic than the polymers themselves, thus the World Health Organization (WHO) has set maximum dosage limits for polymers in water treatment that are usually <50mg/L for polydiallyldimethylammonium chloride (PDADMAC) polymer, <20mg/L epichlorohydrin (ECH/DMA) polymers and <1.0 mg/L for polyacrylamide (PAM) polyelectrolytes in the USA (10).

The detection of residual polymer and the optimization of polymer dose continues to be a major challenge for drinking water treatment facilities. Differences in source water characteristics such as; pH, temperature, coagulant type, concentration of suspended particles present, as well as the upstream treatment systems can alter the optimum dosage concentration significantly (11). The source, composition charge, particle size, particle shape, and density of the suspended particles present in the source water also vary considerably; with the correct dosage of polymer being contingent upon these variables. The majority of drinking water treatment plants tend to use operators for the manual adjustment of polymer dose based on major changes noticed in settleability or seasonal turbidity changes in source water (12). The optimum dose is most often pre-determined using a jar test method seasonally. This method is limited seeing that is only dependant on supernatant turbidity, which reaches a minimum at optimum dose. Although this is a good approximation, the turbidity does not vary beyond optimum polymer dose and does not give an indication of how much polymer is overdosed, often leading to overdosing. This results in higher polymer costs, ineffective coagulation-flocculation, and an excess release of residual polymer downstream, which is then discharged into the environment.

There is a clear need for the development of a reliable system that can sensitively produce real-time measurements of residual polymer dose during drinking water treatment, and ideally develop a feedforward or feedback control loop for the optimization of polymer dose in-line. Some of the methods that have been suggested for this purpose include the development of a feedforward control system that optimizes coagulant dose based on continuous measurement of raw water quality through parameters such as turbidity (13) (14), conductivity, NOM removal, and/or surface charge (15). The development of a feedback control system that optimizes coagulant dose based on raw or dosed water quality is another method that has been studied; with the use of streaming current detection (SCD) being most common for this application (16) (17) (18). The use of online sensors that (19)analyze the size and shape of floc formation have also been applied in research, such as the use of a photometric dispersion analyzer (PDA) that measures turbidity and turbidity fluctuations after coagulant addition via a fiber-optical monitor (20) (21); but have not been tested in practice. Other very sensitive methods of measuring polymer dose in water treatment applications in a laboratory setting include high-performance liquid chromatography (HPLC) and electron-gas capture chromatography; however, these methods are impractical for in-line use.

Although these methods have been studied extensively, they did not find successful applications in drinking water treatment facilities due to a variety of reasons. The complexity and capacity required to carry out the method, the lack of instruments designed for full-scale application, the fluctuation of source water characteristics impacting the sensitivity of the method, and lastly the difficulties with replicability of results in the field

have led to little progress in further development of these methods. Moreover, the bulk of the research available for these methods is based on wastewater applications. In drinking water applications, particulate matter is present in far lower concentrations, and there are very few approaches that analyze finished drinking water parameters for real-time control purposes (15).

Ultraviolet-visible light (UV-vis) spectroscopy is a method that has been proposed for the measurement of polyacrylamide polymers in water and wastewater applications using an in-line spectrophotometer (22). Al Momani and Örmeci have conducted research on this method, with results indicating that the concentration of residual polyacrylamide polymers in water and wastewater matrices can be correlated to the absorbance of the dosed water at a wavelength of around 190nm, with quite low detection limits ($<0.1\text{mg/L}$). Further research by Al Momani and Örmeci investigated the optimization of sludge conditioning and dewatering based on residual polymer in the dewatering supernatant through the use of UV-vis spectrophotometry (23). The results of this study indicated that the optimum polymer dose for sludge dewatering could be correlated to the lowest filtrate absorbance at or around 191.5nm. Although these results demonstrate that UV-vis spectroscopy is a viable method for the in-line determination of optimum polymer dose, little work has been done on the application of this method for drinking water treatment.

Research Objectives

The principle objectives of this research are to improve the sensitivity of UV-vis spectroscopy as a method of monitoring and optimizing polymer dose in drinking water treatment applications, and test whether it can confidently measure these low concentrations in the presence of other constituents in-line and real time.

Firstly, this study explores the effect of path length, particles, and additional drinking water treatment chemicals present in water on the sensitivity of UV-vis spectroscopy as a method for the detection of residual polymer in drinking water treatment applications. This is done to conclude whether the polymer detection sensitivity can be improved by manipulating these parameters, improving the linear correlation between residual polymer concentration and absorbance, as well as determine where the unit would be best suited for in-line monitoring during drinking water treatment. Figure 1 below illustrates the potential for residual polymer monitoring using this method in a drinking water treatment application.

Figure 1: UV-vis spectroscopy as a tool for the in-line and real time monitoring of residual polymer in drinking water treatment applications schematic

Secondly, this study aims to determine whether UV-vis spectroscopy has potential as a tool for the optimization of polymer dose in-line and real time during drinking water treatment.

The relationship between absorbance and residual polymer concentration post-settling in the optimum dose range is explored, and the potential to create a feedback control loop using this relationship in drinking water treatment applications is determined. Figure 2 below illustrates this optimization application in a drinking water treatment settling.

Figure 2: UV-vis spectroscopy as a tool for the in-line and real time optimization of residual polymer in drinking water treatment applications schematic

In order to study these objectives, this research has been divided into four main experimental phases:

Phase 1: Effect of path length on polymer detection using UV-vis spectroscopy

The first phase of the experiment was designed to compare the effect of path length on polymer detection sensitivity using both an in-line and desktop spectrophotometer. This phase also allowed for a comparison in functionality and sensitivity between both the in-line and desktop spectrophotometers. In addition, effect of polymer dose range was also accounted for.

The main purpose behind comparing different path lengths was to determine the effect this alteration would have on the sensitivity of UV-vis spectroscopy as a method for the detection of residual polymer in drinking water sample matrices. The Beer-Lambert law (*equation 5*) is the governing principle behind UV-vis spectroscopy and assumes that the absorbance and the path length of the sample cuvette are directly proportional. Increasing the path length of the sample cuvette allows the incident light more opportunity to interact with the molecules of interest present in the sample, thus increasing the final absorbance reading and enabling a higher detection sensitivity. Contrastingly, a decrease in path length has also been shown to yield more sensitive result in certain applications, due to the theory that a longer path length allows for more light scattering and a decrease in sensitivity, especially for solutions with very low concentrations (24). In addition, a shorter path length typically reduces the absorbance (increasing the transmittance) hence reducing the incident light required to achieve a reliable result. This removes the need to dilute the sample, which is often necessary to achieve an absorbance within the working range of the unit.

An in-line spectrophotometer was used to compare the effect of altering the path length between 2mm, 4mm and 8mm for an anionic polyelectrolyte polymer used for potable water treatment. These results were then compared to those produced using a desktop spectrophotometer with a typical 1cm path length. When altering the path length, the absorbance results are normalized to be comparable to that of a 1cm path length, thus changing the working range with regard to each different flow cell. Using the in-line spectrophotometer, the 2mm path length has a working range of 0-6.5 A.U., the 4mm path length has a working range of 0-3.25 A.U., and the 8mm path length has a working range

of 0-1.6 A.U. Using the results from this phase, an optimum path length could be determined for the polymer in question for the subsequent phases.

Phase 2: Effect of filtration and dilution on polymer detection using UV-vis spectroscopy

The second phase of the experiment was designed to analyze the effect of particles present in water on the sensitivity of UV-vis spectroscopy as a method of measuring residual polymer in drinking water treatment applications. This was done by analyzing the effects of filtration and dilution on polymer detection sensitivity, using both an in-line and desktop spectrophotometer on the relationship between polymer concentration and sample absorbance.

Particles present in the solution can often interfere with the accuracy of the UV-vis absorbance reading when trying to identify a particular constituent, as they can absorb or scatter the incident light. Comparing results for samples with particles (unfiltered) and without particles (filtered) using both a 1cm path length and a shorter path length was carried out to observe the effect that the path length had on UV-vis absorbance sensitivity in the presence of particles. A shorter path length yields less opportunity for the particles to interact with the incident light, as is thought to produce more sensitive results. Dilution of samples was also analyzed to observe the same effect when the particles present were reduced in concentration, rather than eliminated completely. This was performed on both an in-line and desktop spectrophotometer at both high and low polymer dose ranges for comparison purposes. This was done using the optimum path length for the in-line UV-vis spectrophotometer determined from phase one.

Phase 3: Effect of Actiflo® treatment process on polymer detection using UV-Vis spectroscopy

The third phase of the experiment was designed to determine the effect of drinking water treatment process chemicals on the sensitivity of UV-vis spectroscopy as a method of detecting residual polymer post drinking water treatment and determine whether or not the method would be viable in a full-scale drinking water treatment setting. This was done by analyzing the effects of the chemical additives used during the Actiflo® coagulation and decantation treatment process, on the linear relationship between polymer concentration and sample absorbance.

Similarly to particles present in solution, additional treatment chemicals can often interfere with the accuracy of the UV-vis absorbance reading when trying to identify a particular constituent, as they can absorb or scatter the incident light. Comparing results for samples with and without additional treatment chemicals present using both a 1cm path length and a shorter path length was carried out to observe the effect that the path length had on UV-vis absorbance sensitivity in the presence of particles. A shorter path length yields less opportunity for the chemicals to interact with the incident light, as is thought to produce more sensitive results. This was performed on both an in-line and desktop spectrophotometer at both high and low polymer dose ranges for comparison purposes. This was again done using the optimum path length for the in-line UV-vis spectrophotometer determined from phase one.

Phase 4: Determination of optimum polymer dose using UV-vis spectroscopy

The fourth phase of the experiment was designed to determine the viability of UV-vis spectroscopy as an in-line real time method for the determination of optimum polymer dose for a given drinking water source. As previously mentioned, optimum polymer dose in drinking water treatment is typically identified using a jar test. If polymer is dosed less than optimally, it does not function effectively and the sample will contain a higher number of non-settled particles, contributing to the supernatant turbidity. As optimum dose is approached, there are limited particles left in the solution and the supernatant turbidity will decrease until it reaches a minimum once optimum dose is reached. Beyond this dose, turbidity will remain at a constant minimum.

Al Momani and Örmeci demonstrated in a previous study that polymer, when dosed optimally, will produce a minimum absorbance in sludge centrate applications using UV-vis spectroscopy. Similarly to turbidity, when polymer is underdosed it does not function effectively and the sample will contain a higher number of non-settled particles, contributing to the supernatant absorbance. As polymer dose is increased and optimum dose is approached, the polymer will incrementally remove more particulate matter present in the sample and the supernatant absorbance will decrease until it reaches a minimum value at the optimum dose. Beyond this dose, any excess polymer added remains suspended in solution as residual, which contributes to an increase in absorbance. This is an advantage of using UV-vis spectroscopy as opposed to a traditional jar test for optimum dose determination, as it gives a better indication of polymer overdosing through absorbance increase.

This theory was tested using potable water samples of varying turbidity using a cationic and an anionic polymer, as well as with Actiflo® chemical addition. This was done to observe the effects of turbidity variance (number of particles present), polymer type, and chemical additives on the sensitivity of this method for optimum dose determination using both an in-line and desktop spectrophotometer. The optimum dose results based on absorbance measurements were compared with preliminary settling test and turbidity measurements, as well as particle count data for each sample to observe if the minimum absorbance corresponded to the same polymer dose as the minimum turbidity and particle concentration.

1.2 Thesis layout

Chapter 1

Chapter one introduces the topic of the thesis, highlights the need for the study and presents the research objectives of the study.

Chapter 2

Chapter two provides a literature review outlining relevant background information pertaining to the topic of the thesis in order to give the reader the capacity to follow the thesis.

Chapter 3

Chapter three provides a description of the materials and methods used to carry out the experiments performed during this thesis in order to study the outlined research objectives.

Chapter 4

Chapter four presents the results and analysis of all four experimental phases of the study as outlined above. Absorbance spectra are presented for all datasets to demonstrate the relationship between absorbance trends and polymer dose. In addition, plots of the linear relationship between polymer concentration and absorbance at 190nm are also included to compare the linearity of this relationship between samples. The results of the fourth experimental phase also present settling test results, turbidity results, and particle concentration results for all datasets completed during this experimental phase. Chapter four also discusses other analytical methods that have been studied for the determination of optimum polymer dose in water treatment applications, and how these methods compare to UV-vis spectroscopy in terms of viability, sensitivity and applicability.

Chapter 5

Chapter five provides concluding statements based on the findings of this study, as well as recommendations for future work.

It is our hope that the work done to accomplish the principle objective of this study will contribute to the overall improvement of polymer dosing and efficiency in drinking water treatment applications. The development of a simple, sensitive and direct method for the in-line determination of optimum polymer dose in drinking water treatment applications will aid facilities not only in improving treatment performance; but also in reducing and ideally eliminating the release of toxic polyelectrolyte polymers into the environment.

CHAPTER 2: LITERATURE REVIEW

2.1 *Applications of polymers in drinking water treatment*

Drinking water treatment processes are of the most fundamental industrial processes carried out in anthropologically in our world today. These processes exist to provide us with readily available water that is safe to drink, free of any unpleasant tastes or odors, cost-effective to produce, free of viruses and pathogens, and ultimately safe for public health (25) (26). Although the drinking water treatment process can vary depending on the source water, the basic unit processes remain generally the same. An overview of the typical drinking water unit operations is depicted below in Figure 3. Firstly, source water, either surface or groundwater, is subjected to a coagulation and flocculation stage, which is typically considered a chemical treatment. Afterwards, the water undergoes a sedimentation stage followed by some form of filtration, both of which are considered physical treatments. Finally, the water is disinfected by either physical or chemical means to ensure it is free of any residual bacteria, viruses and/or protozoa before entering the distribution system (26) (27).

Figure 3: *General drinking water treatment processes*

During the coagulation and/or flocculation stages of drinking water treatment, water-soluble polymers are sometimes added as primary coagulants, or as coagulant/flocculant

aids (4) (5) (6). The principle function of coagulation is to reduce the repulsive potential of the electrical double layer of colloids suspended in the water source in such a manner that micro-particles can begin formation. These micro-particles can then collide with one another and form larger structures known as *flocs* in the subsequent flocculation stage (28). The overall goal of the coagulation and flocculation stage in drinking water treatment is to reduce turbidity, remove unpleasant colour and remove pathogens by pulling the particles together and increasing their size and weight; allowing them to be settled out or filtered out more effectively (28). Polymers have been shown to improve the coagulation and flocculation stages by lowering coagulant dose, decreasing the ionic load of the treated water, improving the settling of slow-settling flocs in low-temperatures, improving settleability and toughness of flocs, decreasing operating costs and increasing treatment facility capacity (5) (4). The polymers chosen for this purpose are typically synthetic in nature, although there are a number of organic products that are also of interest for this application. These polymers can be broadly categorized as polyelectrolytes (either *anionic*, *cationic*, or *non-ionic*) (5). The polymer molecules themselves are constructed of monomer units linked together as either linear chains or branched three-dimensional networks. The majority of those used in water treatment applications are linear chain structures with a minimum degree of branching (3). The number of repeating monomers in the chain known as the *degree of polymerization*. The product of the *degree of polymerization* and the molecular weight (MW) of the monomer yields the MW of the polymer. In general, low MW cationic polymers are used as coagulants or coagulant aids; whereas high molecular weight polyelectrolytes or non-ionic polymers are used as flocculants (3).

2.2 Mechanisms of polymer function

In drinking water treatment applications, there are two main mechanisms of coagulation by which a polymer can function: *polymer bridging* and *charge neutralization* (29). Both of these mechanisms are strongly dependant on the adsorption of the polymer onto the suspended colloidal surface. This adsorption can only occur if there is some sort of affinity between the colloidal surface and the polymer chain that is greater than the loss of entropy attributed to polymer adsorption (28). This adsorption can occur through several different methods, the main of which being a combination of *electrostatic interaction* and *van der Waals attraction* (5) (4).

Electrostatic interaction occurs when polyelectrolytes with a charge opposite to that of the colloid surface adsorb by simple means of electrostatic attraction. Most colloidal particles in aqueous suspension are negatively charged, depending on the chemistry of the solution. A colloidal dispersion, however, does not have any charge regardless of the charge attributed to the particles themselves. In order for this electroneutrality to exist, the colloidal charge must be counterbalanced by counter ions present in the aqueous solution. This compact, fixed layer of counter ions surrounding the colloid is known as the Stern layer and is depicted in Figure 4 below. Surrounding this Stern layer, a more diffused layer of counter ions exists (Gouy-Chapman layer). Together, the Stern layer and the diffuse layer form what is called the *electrical double layer*.

Figure 4: A negative colloidal particle with its electrostatic field demonstrating the electrical double layer (Forbes, E., Chryss, A., *Clays in the Minerals Processing Value Chain*, 2017)

A shear plane exists between the Stern layer and the diffuse layer and is thought to be located a minute distance beyond the Stern layer that encloses the volume of bound water that moves with the particle. The electrostatic potential that exists between this bound water and the bulk liquid surrounding it is said to exist at this shear plane and is known as the *zeta potential* (ξ). The zeta potential is of particular importance, as it is the only measurable potential and provides a good approximation of the unmeasurable surface potential. Moving outwardly from the shear plane into the diffuse layer, the zeta potential decreases (3). The electrical double layer model allows for the determination of the stability of a colloidal solution. The interaction between two similarly charged colloidal particles is prevented as their diffuse layers overlap and their Stern layers repel one another, preventing

aggregation. The magnitude of this repulsive force is dependent on the surface potential of the particles, or the zeta potential (3).

Polyelectrolytes with a higher MW will be more effective for absorption by electrostatic interaction as they offer more ionic groups for attraction, however even low MW polymers are capable of at minimum neutralizing the particles surface charge (5). In drinking water treatment applications, natural organic matter (NOM) is most often negatively charged, and therefore cationic polyelectrolytes are often preferred in application. Polymer adsorption can also occur through *hydrogen bonding* and *ion binding*. Certain polymers, such as polyacrylamide (PAM), have the capability to form hydrogen (H)-bonds with particles that have suitable bonding sites. For example, silica oxides have surface hydroxyl groups that are capable of forming H-bonds with the amide groups present in a PAM molecule (30). Ion binding occurs in instances where there is a large concentration of divalent metal ions and Ca^+ . It is theorized that these ions act as ‘bridges’ between anionic polymers and negatively charged particles, allowing for ion binding to occur despite electrostatic repulsion (31). Regardless of the adsorption mechanism, Figure 5 below depicts the general accepted model for an adsorbed polymer consists of three assumed segment categories:

- *trains* – polymer segments directly attached to the particle surface,
- *loops* – polymer segments erecting between trains along the particle surface,
- *tails* – polymer segment ends that protrude from the particle surface into solution.

Figure 5: adsorbed polymer model

2.2.1 Polymer bridging

The first main coagulation mechanism, as previously mentioned, is known as *polymer bridging*. Bridging occurs when the polymer adsorbs to the particle in such a way that allows for a sufficient number of tails and loops to attach to those alike surrounding it. A schematic of this mechanism is illustrated below in Figure 6.

Figure 6: Polymer bridging mechanism schematic (Singh, H. et al., *High-technology materials based on modified polysaccharides*, 2009)

In order for bridging to occur, there must be an adequate number of unoccupied sites on the particle adjacent to that of another particle with an adsorbed polymer. If the particle is too highly covered with polymer, it is considered *reestablished* and bridging cannot occur. Alternatively, if there is insufficient polymer coverage then bridging also becomes impossible since the proper contingency cannot occur, which infers the idea of an *optimum*

polymer dose for maximum bridging. Early studies on optimum dose suggested that 50% fractional surface coverage (θ) corresponds to the optimum polymer dose by means of the following equation: $\theta (1 - \theta)$ (32). Due to difficulties accurately measuring particle surface coverage, studies that are more modern have shown that the optimum dosage occurs when essentially the entire polymer is adsorbed, implying that the optimum dose be proportional to aqueous particle concentration. This value is typically 1.0 mg of polymer per gram of suspended solids (5). High MW polyelectrolytes with a variable charge density (CD) have proven to be most effective for bridging applications, since they have less bulky branch groups to hinder available sites, but also have longer chains to allow for ample bridging. With regard to CD, a cationic polyelectrolyte with roughly 30% anionic groups is most effective as the anionic groups allow for a degree of electrostatic repulsion, expanding the chains and encouraging bridging.

2.2.2 *Charge neutralization*

In most water matrices, suspended impurities are negatively charged, making cationic polymers most effective due to their electrostatic adsorption ability facilitating their attraction onto the particles. This adsorption causes the particles to take on a neutral charge, or even undergo a charge reversal. This has been theorized as *charge neutralization*, the idea that particles are able to coagulate and flocculate by merely reducing the electrostatic repulsion between them through polymer addition (5). Typically, cationic polyelectrolytes with a low MW and high CD are best suited for this application in water treatment, as they are able to neutralize the particle charge and adsorb in a flatter configuration on the particle surface due to the lack of bulky groups along their chain (29). Another extension of charge

neutralization that can occur is the *electrostatic patch* mechanism. The basic concept of this mechanism is that if a high CD cationic polymer adsorbs onto a low CD anionic particle, the distance between negatively charged sites on the particle may be so far that the charged segments of the polymer cannot physically reach them all and, in turn, cannot attain overall neutrality. This then creates ‘patches’ of positive charge over the particle surface while leaving some uncovered negatively charged sites, allowing for particle attachment to occur via electrostatic attraction between the two oppositely charged sites.

2.3 Operational and environmental disadvantages of polymer in drinking water treatment

Although the use of polymer in drinking water treatment applications does have many benefits when implemented properly, there are also some important operational and environmental disadvantages to consider. Polymer toxicity is one factor that has caused concern in recent years, especially with regard to their use in drinking water treatment. In general, most anionic and non-ionic polyelectrolytes are of low toxicity to humans and aquatic life. However, most cationic polyelectrolytes are acutely toxic to humans, animals and aquatic flora and fauna when they are present within the range of 0.1 – 1.0. mg/L (33). In addition, polyelectrolyte products used for water treatment applications often contain detectable amounts of certain contaminants such as monomer and unreacted chemicals used to form the monomer (9). The monomer units have proven to be more toxic than the polymers themselves because their smaller molecular structure allows them to be more readily adsorbed into the gastrointestinal tract and lymphoid tissues, especially with regard to acrylamide products (34). Although the monomer poses much more of a risk than the

polymers themselves, measuring individual monomers post-water treatment can be very difficult, and it is therefore best practice to consider any toxic hazard on the basis of the applied dose of the polymer. For this reason, the World Health Organization (WHO) has set maximum dosage limits for polymers in water treatment that are usually <50mg/L for Polydiallyldimethylammonium chloride (PDADMAC) polymer, <20mg/L Epichlorohydrin (ECH/DMA) polymers and <1.0 mg/L for polyacrylamide (PAM) polyelectrolytes in the USA (10).

Dosing the correct volume of polymer for a given water treatment application is an important factor in the process not only to meet regulation, but also for operational reasons. Under conditions where a polymer has been overdosed, particles may become restabilized by the adsorption of excess polymer. When the concentration of polymer is higher than that needed for flocculation, the particle surface becomes entirely covered by adsorbed polymer, leaving little to no available opportunity for the bridging or charge neutralization mechanisms to occur (3). This then results in not only poor flocculation performance, but also an excess of *residual polymer* in the water. Residual polymer constitutes any polymer that was not adsorbed onto suspended colloidal matter during the coagulation/flocculation process, and often contains monomer units as well as other contaminants that may have been present in the original polymer (5).

An excess in residual polymer can also cause many operational issues downstream, as well as toxicity issues upon release (35). As filtration most often follows polymer addition, excess residual polymer has proven to cause issues with the clogging of filter beds and

filter head loss in wastewater sludge applications, which is also suspected to affect water treatment applications (8). One of the most widely used polyelectrolytes in drinking water treatment applications is polyacrylamide (PAM), which degrades into its acrylamide monomer of higher toxicity if left in aqueous solution. The US EPA limit for PAM in drinking water treatment applications is 1.0mg/L. At a monomer content of 0.05%, this corresponds to a maximum theoretical concentration of 0.5 µg/l of the monomer in water. Practical concentrations may be lower by a factor of 2–3. This applies to the anionic and non-ionic polyacrylamides, but residual levels from cationic polyacrylamides may be higher (10).

In addition to this, as much as an under-dose of polymer can affect the flocculation quality, an overdose can as well. As previously mentioned, restabilization of flocculated particles can occur when the polymer dose exceeds its optimum value, breaking the flocs and allowing particulates and contaminants to re-enter the water matrix (3). Overdosing also leads to a larger sludge yield, which increases disposal costs and is undesirable. Furthermore, polymer addition can be a very expensive addition to municipal drinking water treatment if not dosed correctly. BASF Inc., the manufacturer of the Magnafloc polymer analyzed in this study, reported a unit price of 1.36USD – 1.62USD/kg polymer in 2016. Although the savings a plant achieves in additional chemical use and filter backwash reduction are high, they typically will only outweigh the added cost of the polymer if the polymer is dosed optimally. In example, a water treatment plant in South Africa reported a 30% decrease in unit cost upon switching from alum to a polymeric coagulant, despite a 10% yearly inflation rate (36).

2.4 *Current Polymer Dose Monitoring Systems in Drinking Water Treatment*

It is apparent that a quick and feasible method for monitoring the dosage of polymer is a vital need for water treatment facilities in order to ensure they are operating at optimal conditions, minimizing the release of residual polymer, and abiding by the set dosage limits. As it currently stands, many municipal water treatment facilities do not have any means of monitoring their polymer dosages on site, leading to operators frequently overdosing (31). There are a number of analytical methods that have been proven successful for the quantitative determination of polyelectrolytes in water, however they are typically quite extensive, time consuming and require specific skill capacities and laboratory access. A few of the most common methods used in practice include gas chromatography (GC), high-performance liquid chromatography (HPLC), mass spectrometry (MS) or a combination of these methods (22). Aside from these separation methods, a few other possibilities have been explored for the quantitative determination of polymers in water treatment, the main of which are summarized in Table 1. All of the below mentioned monitoring techniques are laboratory based aside from turbidimetry, which has the potential to be executed in-line however is not sensitive enough for the accurate detection of residual polymer in drinking water treatment applications due to the very low turbidity of drinking water sources and very low polymer dose concentrations.

Table 1: Current methods for polymer monitoring in drinking water treatment applications

Polymer monitoring system	Description
1 Colloid titration	Based on the titration of a cationic polyelectrolyte with an anionic polyelectrolyte (or vice versa) in the presence of an endpoint indicator (37). This method is not very sensitive, can be easily affected by other electrolytes in solution, and is not very practical to perform in-line in an industrial setting.
2 Streaming current detection (SCD)	Streaming current is defined as a measurable electric current that is generated by a mass water, which is forced to flow past a network of fixed shear plane surfaces. The measurable current is proportional to the charge remaining after polymer addition. This allows for the monitoring of the net residual charge balance of the water, the positive charge representing the coagulant and the negative charge representing the suspended solids. Following the reduction of the negative surface charge on the particles as polymer is added, the optimum dose can be correlated with charge neutrality (38).
3 Turbidimetry	There are a few different turbidimetric methods used for polymer detection in solution, however each begin with the addition of a reagent that reacts with the polymer to produce an insoluble complex. This complex most often remains suspended in solution and is measured by light scattering, a turbidimeter or spectrophotometer. These methods require large sample volumes and are of limited use for the detection of acrylamide polymers in brine solutions where interactions with sodium

	chloride, iron, calcium and anionic surfactants cause detection interference (37).
4 Rheology/Viscosity	Rheological characteristics of the solution have been shown to also have the capacity to measure polymer concentration. One method that has been studied requires that the solution viscosity vary proportionally with polymer concentration. These methods lack practicability in practice seeing that any change in temperature, ionic strength, polymer degree of hydrolysis, pH, MW distribution or shear rate will have some impact on the solutions overall viscosity. This makes isolating the polymers effects on solution viscosity essentially impossible in non-ideal conditions (37).
5 Size exclusion chromatography (SEC)	SEC achieves a measurement by separating the polymer from low MW impurities through a filtration column with a specified pore size. This separated solution can then be further analyzed by ultraviolet (UV) or refractive index (RI) detectors, RI being more sensitive than UV. This method is capable of measuring any UV absorbing polymer in contaminated solutions, however its sensitivity is greatly affected by the polymer's degree of hydrolysis, as well as any divalent ions or salts present in solution (as they affect the hydrodynamic volume of the polymer). This method is also quite slow, typically only three to five samples per hour (37).

2.5 *UV-Vis spectroscopy as a polymer dose monitoring method*

Ultraviolet-visible light (UV-Vis) spectroscopy is a simple, easy to use technology that has potential application as a method for the detection and optimization of residual polymer in drinking water treatment. Gibbons and Örmeci have shown this method to be successful in the determination of polymer concentrations in both water and sludge centrate samples (39). Al Momani and Örmeci also studied the use of UV-Vis spectroscopy for the measurement of residual polyacrylamide polymers in drinking water using an in-line UV-vis spectrophotometer. This study showed that the absorbance reading of a sample dosed with a predetermined polymer concentration at 191.5nm was able to form a strong linear correlation with the concentration of polyacrylamide present in the given sample ($R^2 > 0.97$). The study was also able to determine the detection limits of the UV-Vis spectrophotometer to be 0.05mg/L of polymer in distilled water, and between 0.07mg/L to 1.35mg/L for water and wastewater samples depending on the polymer type and water quality (22).

2.5.1 *Overview of UV-Vis spectroscopy*

All optical spectroscopy technologies function based on the Bohr-Einstein frequency relationship, shown below in Equation 1. This relationship correlates the molecular energy states of a given molecule (E_i) to the frequency of the electromagnetic radiation (ν) using a proportionality constant known as Planck's constant (h).

$$\Delta E = E_2 - E_1 = h\nu$$

Equation 1: Bohr-Einstein frequency relationship

In spectroscopy applications, the frequency can be related to the velocity of light in a vacuum (c) divided its wavelength (λ), thus replacing the frequency value in Equation 1 to give Equation 2, where ($\tilde{\nu}$) is known as the wavenumber (40).

$$\Delta E = E_2 - E_1 = \frac{hc}{\lambda} = hc\tilde{\nu} \quad \text{Equation 2: Bohr-Einstein frequency relationship}$$

In the ultraviolet to visible light range, the wavelength ranges from ~190nm to 800nm, depending on the spectrophotometer. A complete schematic of the electromagnetic spectrum wavelengths for light photons, depicted below in Figure 7.

Figure 7: Electromagnetic spectrum schematic (National Geographic, 2018)

The basic concept of UV-Vis spectroscopy is based on the interaction of light with a given medium, where the radiant light can be either absorbed, transmitted, scattered, reflected or excite fluorescence. UV-Vis spectrophotometry is concerned with the transmission and absorption of light radiation through a sample medium and is typically used as a quantitative analysis method for determining the amount of a compound in a solution. A light source that produces visible light, typically a tungsten bulb, and a light source that produces ultraviolet light, typically a deuterium bulb, are used to transmit an incident

number of light photons, or incident intensity (I_o), over their respective wavelength ranges through a monochromator to a sample cuvette of a specific width or path length (l). This is accomplished under conditions that aim to keep any reflection, scatter, and fluorescence effects to a minimum. A visual representation of the internal workings of a spectrophotometer is depicted below in Figure 8. From here, the number of light photons transmitted, or intensity of the light beam transmitted through the sample (I), is then analyzed by a detector to produce a resulting absorbance value (41).

Figure 8: UV-Vis spectrophotometer internal workings schematic (Sigma Aldrich, USA)

The ratio of incident intensity and transmitted intensity gives an indication of what fraction of light entering the sample was able to pass through the sample. This value is referred to as transmittance (T) as described in Equation 3.

$$T = \frac{I_o}{I}$$

Equation 3: Transmittance

Using transmittance, we can mathematically define absorbance (A) as the negative log of transmittance, as depicted in Equation 4 below. Absorbance is a direct measurement of the amount of light that was absorbed by the sample for a given wavelength.

$$A = -\log_{10} \left(\frac{I_o}{I} \right) = -\log_{10}(T)$$

Equation 4: Absorbance

Using these two values we can now define the Beer-Lambert Law, defined as Equation 5, which forms the mathematical-physical basis of spectroscopy in the ultraviolet and visible light regions and is the principle by which spectrophotometry is possible. This law is valid under two main assumptions:

- **Assumption 1:** The absorbance is directly proportional to the concentration of the sample solution. This is described in the relationship below, where (A) is the measured absorbance and (C) is the sample concentration.

$$A \propto C$$

- **Assumption 2:** The absorbance is also directly proportional to the path length (l) of the cuvette holding the sample. This is depicted in the relationship below.

$$A \propto l$$

Using these two assumptions combined with Equation 4, as well as the molar absorptivity (ϵ) as a linear relation coefficient, we can derive the equation for the Beer-Lambert law, relating the sample absorbance to the concentration of the sample.

$$A = -\log_{10} \left(\frac{I_o}{I} \right) = \epsilon l C$$

Equation 5: Beer-Lambert Law

2.6 *Determination of optimum polymer dose*

The effectiveness of a polymer for coagulation and flocculation processes is dependent on the type of polymer used, the dosage, the pH of the solution, as well as the concentration and nature of the organic compounds present in the water matrix (19). Focusing on parameters that can be controlled, maintaining the polymer dose at an optimal level during treatment is a method of maintaining effectiveness that would be beneficial for operation, however is not as straight forward to implement as simply selecting the correct polymer. The organic compounds present in the influent are constantly subject to change, which in turn reflects on the optimum polymer dose required for treatment.

The standard method for the optimization of coagulant and/or flocculant dose in water, wastewater and sludge applications in the jar test, and has been for over half a century (42) (43). Jar testing is a pilot-scale simulation of a coagulation/flocculation process that is performed in order to determine the most effective dosage of a given coagulant or flocculant for a particular water treatment operation (44). This method involves dosing the polymer at varying concentrations to identical water samples and observing their settling time simultaneously. The optimum dose typically corresponds to the fastest settling time, the heaviest floc, as well as the lowest supernatant turbidity reading (44). Capillary suction time (CST) tests, settling tests and filtration tests are also frequented for optimizing polymer dose in wastewater and sludge applications, however these methods are typically not feasible for the low polymer doses in drinking water applications (45) (46). Although the jar (settling) test is an effective method for estimating optimum polymer dose in drinking water, it is not practical to execute these tests in-line continuously during the

treatment process, as they require laboratory access and time to complete. If this method is applied in operation it can be timely to execute and is often only done seasonally, leading to inaccurate optimum dosages based on the changing water matrix in between the performance of the jar tests.

UV-vis spectroscopy is a potential method for the in-line optimization of polymer dosage for drinking water applications. Al Momani and Örmeci were able to use this method to determine the optimal polymer dose range for sludge dewatering in-line by establishing a relationship between the optimum polymer dose and the UV-vis absorbance readings of the sludge filtrate at 191.5nm, which correspond to the concentration of residual polymer in the filtrate (23). The optimum dose was first determined using standard methods, namely capillary suction time (CST) tests and filtration tests, which was then used to determine a relationship between the filtrate absorbance at 191.5nm and the optimum dose. This method was successful in demonstrating this relationship, exhibiting a decrease in filtrate absorbance in the under-dose range as polymer dose is increased, and an increase in filtrate absorbance in the over-dose range as polymer dose was increased. The optimal dosage range corresponded to the minimum filtrate absorbance reading at 191.5 nm (the curve forming a 'U' or 'V' shape), indicating that the real-time optimization of polymer addition using UV-vis spectroscopy has the potential to be applied at wastewater treatment plants. This is an advantage of UV-vis spectroscopy over traditional jar testing because where turbidity would remain constant beyond optimum dose; absorbance would increase, making the optimum dose more detectable. Salam, Örmeci and Simms also studied this method for the determination of the optimum polymer dose in the dewatering of oil sands

tailings, and a similar relationship was acquired, the sample absorbance at 190nm was found to correlate linearly with the residual polymer concentration in the tailings water (47). This same relationship may also have the potential to be applied to drinking water applications by firstly determining the optimal polymer dose using the jar test method and measuring the supernatant turbidity, and then correlating these results to the minimum supernatant absorbance at 190nm using UV-vis spectroscopy.

2.7 *Actiflo® treatment process*

To test the objectives of this study, a drinking water treatment process that utilizes polyacrylamide polymer during the coagulation and flocculation stage was chosen for analysis. In this case, the Actiflo® enhanced coagulation drinking water treatment process utilized by the Casselman municipal drinking water treatment facility in Casselman, ON was mimicked for laboratory purposes. This facility treats their source water using the Actiflo® clarifying process followed by the Dunsenflo® filtration unit, both of which are manufactured by Veolia Water Technologies, Inc. At the Casselman facility, potassium permanganate (KMnO₄) is added to the raw water initially in order to oxidize any iron and/or manganese that may be present. Afterwards, a polyaluminum sulphate coagulant manufactured by Kemira Inc., known PASS-10, is dosed into the inlet stream before the water enters the clarifier. These constituents are mixed in a coagulation mixing tank to destabilize colloidal materials. Following this mixing, the water is sent to an injection tank where an anionic polyacrylamide polymer manufactured by BASF Canada Inc. known as Magnafloc LT27AG is added, along with microsand to assist in weighing down the flocs that will be formed and facilitate settling later on. These constituents are mixed gently to

accelerate the bridging mechanism between pin flocs, suspended solids and microsand. After a maturation period, the water is sent to the decantation tank where the sand and now formed flocs are settled out. This effluent is then sent to the Dunsenflo® filtration unit, where any remaining suspended particulates are filtered through a combination of sand and anthracite (48). A complete schematic of the Actiflo® clarifying process and the Dunsenflo® filtration unit is outlined in Figure 9.

Figure 9: Actiflo clarification process and Dunsenflo filtration unit schematic (Casselman Treatment Facility, 2016)

CHAPTER 3: MATERIALS AND METHODS

3.1 *Polymers*

In the first, second and third phases of experiments, an anionic polyacrylamide polymer known as Magnafloc LT27AG manufactured by BASF Inc. was used due to the fact that it is the primary polymer used in the Actiflo® treatment process carried out at the Casselman drinking water treatment facility, located in Casselman, ON. In the final phase of experiments, a cationic polyacrylamide polymer known as Hydrex 3661 manufactured by Veolia Inc. was also tested in order to ensure the determination of optimum polymer dose using the proposed method was viable for both a cationic and anionic polymer. Both of these polymers are typical for potable water treatment use (22). A summary of relevant characteristics of each polymer are listed in Table 2.

Table 2: Polymer Characteristics

Polymer	Type	Charge	Product Use	Appearance	Density (kg/m ³)
Magnafloc LT27AG	Polyacrylamide	Anionic	Potable water treatment	Crystalline Powder	750
Hydrex 3661	Polyacrylamide	Cationic	Potable water treatment	Crystalline Powder	600-900

3.2 *Preparation of polymer stock solution*

Stock solutions of both the anionic and cationic polymers were prepared at 400mg/L concentrations for sample spiking purposes. Firstly, 0.20g of crystalline polymer weighed using a lab scale (Sartorius BP2215 model). Using a jar testing apparatus (Phipps and Bird, USA), the granulated polymer was added to 500mL of deionized water and mixed at 220

RPM for 5 minutes. Afterwards, the stirring speed was reduced to 125 RPM for 55 minutes. If any large flocs were visible in the solution, a hand mixer (Braun, Germany) was used post-mixing for 10-second pulse intervals as needed to produce a well-mixed, homogenous solution. The solution was then left to mature for a minimum of 1 hour prior to experimental use. This procedure produced a well-dissolved polymer solution for both polymers. Fresh polymer stock solutions were prepared weekly over the course of the experiment.

3.3 *Water samples*

Source waters vary in physical and chemical characteristics; therefore, a variation of water matrices was used throughout the duration of the experiment. During the first phase of the experiment, deionized water was used as a control in order to compare the effect of path length on residual polymer detection, as well as the difference in sensitivity and detection limits between desktop and in-line spectrophotometers. The second and third phases of the experiment aimed to determine the effects of filtration and dilution, as well as the Actiflo® treatment process chemical additives the sensitivity of UV-vis spectroscopy for residual polymer detection. This was achieved using raw water collected from the Rideau River in Ottawa, ON, and deionized water as a controlled comparison. The Rideau River water used for the second and third phases of the experiment had an average turbidity of 17NTU. The fourth phase of the experiment aimed to use UV-vis spectroscopy to determine the optimum polymer dose for a given water sample. For this purpose, raw water from the Rideau River in Ottawa, ON was collected at both high turbidity (4000-9000 NTU) and low turbidity (200-600 NTU).

3.4 Sample preparation

Samples were prepared for this study in four main experimental phases, as depicted below in Figure 10. Each of these phases is further explained in the following subsections.

Figure 10: Experimental phase outline schematic

3.4.1 Phase 1

Samples for the first phase of the experiment were prepared by spiking deionized water with the prepared Magnafloc LT24AG polymer (400mg/L stock solution) at both a high concentration range (0-3 mg/L) and a low concentration range (0-1 mg/L) to prepare 400mL samples of each polymer dose. For the high concentration range samples (0-3 mg/L), polymer stock solution was pipetted into the prepared sample beakers in increments of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 mL. For the low concentration range samples (0-1 mg/L), polymer solution was pipetted into the prepared sample beakers in increments of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 mL. After polymer addition, the samples were mixed for 1 minute using a jar test apparatus (Phipps and Bird, USA) at 125RPM, prior to being used for absorbance measurements.

3.4.2 Phase 2

Samples for the second phase of the experiment were prepared using water collected from the Rideau River on Carleton University Campus in Ottawa, ON. Samples of Rideau River water with turbidity measurements of 6.8 NTU and 3.2 NTU were collected; half of each was set aside for filtration. These sample sets were prepared using raw Rideau River water, filtered Rideau River water, diluted Rideau River water, as well Rideau River water that was both filtered and diluted. Each sample was prepared by spiking the water with the prepared Magnafloc LT24AG polymer (400mg/L stock solution) at both a high concentration range (0-3 mg/L) and a low concentration range (0-1 mg/L) to prepare 400mL samples of each polymer dose. For the high concentration range samples (0-

3mg/L), polymer solution was pipetted into the prepared sample beakers in increments of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0mL. For the low concentration range samples (0-1 mg/L), polymer solution was pipetted into the prepared sample beakers in increments of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0mL.

3.4.2.1 Dilution and filtration of samples

The second phase of the experiment analyzed the effects of suspended particulates through dilution of the samples. The raw water samples were diluted using deionized water after polymer addition and before absorbance measurements. The following dilution procedure was used. Firstly, 400mL samples of Rideau River water were spiked with polymer at both a high concentration range (0-3 mg/L) and a low concentration range (0-1 mg/L) in increments of 0.5 mg/L and 0.1 mg/L, respectively. The sample and polymer mixtures were then mixed for 1 minute using a jar test apparatus (Phipps and Bird, USA) at 125RPM, and an absorbance spectrum of each sample was measured. Afterwards, each sample was diluted using deionized water at a ratio of 1:1, and their absorbance spectra were measured a second time.

The second phase of the experiment also explored the effects of suspended particulates through filtration of the samples. The raw water samples were filtered using a Whatman 0.45µm filter paper (Sigma Aldrich, USA) prior to polymer addition and absorbance measurements. In the instances where filtration and dilution were combined on the sample, the raw water samples were filtered first and then the dilution procedure was carried out.

Table 3 below outlines the filtration and dilution scheme of the samples prepared during phase 2.

Table 3: Phase 2 sample summary

Magnafloc LT27AG Polymer Dose Range	Raw Rideau River Water Turbidity (NTU)	Filtration	Dilution
High Range (0-3 mg/L)	6.8		
		x	
			x
		x	x
Low Range (0-1 mg/L)	3.2		
		x	
			x
		x	x

3.4.3 Phase 3

The third phase of the experiment required the imitation of the Actiflo® enhanced coagulation treatment process utilized by the Casselman drinking water treatment facility in Casselman, ON. These samples were prepared using water collected from the Rideau River on Carleton University Campus in Ottawa, ON with a turbidity of 32.0 NTU, as well as deionized water as a controlled comparison. These samples were prepared by mimicking the full-scale enhanced coagulation process at a laboratory scale, adding each chemical in the same succession and dosage as would be done during full-scale operation. Each sample maintained a constant concentration of the Actiflo® treatment process chemicals, varying only the concentration of polymer as well as the concentration of sodium hydroxide necessary to achieve a neutral pH.

Each 400mL sample was prepared by firstly adding potassium permanganate acquired from the Casselman treatment facility to the raw sample at a dose of 1.0mg/L in order to oxidize any iron or manganese present in the water. This is the typical dose for drinking water treatment purposes as reported by the United States Environmental Protection Agency (US EPA). The potassium permanganate is supplied in powder form, and therefore 0.0004g had to be weighed using a weighing scale (Sartorius BP2215 model) for each sample. Following this, a polyaluminium silicate sulphate (PASS-10) coagulant manufactured by Kemira Inc. (Helsinki, Finland) acquired from the Casselman treatment facility was added to each sample at a dose of 50mg/L, a typical dosage as reported by the Casselman treatment facility. The PASS-10 coagulant is supplied as a solution and was therefore added to each sample by pipetting 40.8µL to each sample. The Magnafloc LT27AG polymer (400mg/L stock solution) was then dosed to the samples at both a high concentration range (0-3.0mg/L) and a low concentration range (0-1.0mg/L), along with 0.80g of microsand to aid in settling by facilitating the formation of larger, heavier flocs. Table 4 summarizes all chemicals used for the Actiflo® treatment process.

Table 4: Actiflo treatment process additives summary

Treatment Additive	Dosage concentration
Magnafloc LT27AG polymer	400mg/L stock in 0-1mg/L and 0-3.0mg/L concentration ranges
PASS-10 Coagulant	50mg/L
Microsand	2kg/m ³
Potassium Permanganate	1.0mg/L
Sodium Hydroxide	As needed to reach pH of 7.0

For the high concentration range samples (0-3 mg/L), polymer solution was pipetted into the prepared sample beakers in increments of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 mL. For the low concentration range samples (0-1 mg/L), polymer solution was pipetted into the prepared sample beakers in increments of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 mL. Following the addition of the chemicals and polymer, the samples were mixed for two minutes using a jar test apparatus (Phipps and Bird, USA) at 125RPM. Post-mixing, a pH meter (ThermoFisher Scientific, Waltham, US) was used to measure the pH of each sample. A 1N solution of sodium hydroxide (NaOH) was then added in increments of 15 μ L as needed to neutralize the pH in accordance with the process carried out at the Casselman treatment facility. On average, 100 μ L of NaOH solution was added to each sample in order to achieve a pH of seven. The samples were then left to settle for thirty minutes, again in accordance with the sedimentation process carried out at the Casselman treatment facility. The supernatant of each settled sample was then used for absorbance measurements.

3.4.4 Phase 4

Samples for the fourth phase of the experiment were prepared using Rideau River water collected from the Carleton University Campus in Ottawa, ON. The water was to be analyzed at both a very high turbidity, and a lower turbidity. For this purpose, a clay-like soil was added until the desired turbidity was reached. The high turbidity samples ranged from 4000 - 9000NTU, and the low turbidity samples ranged from 200 -600NTU.

For both the high and low turbidity water samples, a series of settling test trials were performed to determine the optimum polymer dose range for both the Magnafloc LT27AG

as well as the Hydrex 3661 polymers. These trials were done by firstly measuring 200mL of raw Rideau River water and spiking with polymer solution in increments of 1.0mg/L. After spiking, the samples were mixed for 1 minute using a jar test apparatus (Phipps and Bird, USA) at 125RPM. The mixed samples were then left to settle, and the apparent turbidity of each sample was observed while the settling time was being recorded. The range of dosages that reached an apparent clarity in the least amount of settling time were selected as the *optimum polymer dose range*. Once this range was determined, a series of polymer doses were chosen to represent this optimum dose range, an over dose range, and an under-dose range. Combining all of these ranges, a sample set was created for both the high and low turbidity Rideau River water samples, for both the Magnafloc LT27AG and Hydrex 3661 polymers.

3.4.4.1 Settling tests

In order to determine the precise optimum dose of each polymer at each turbidity, a proper settling test was carried out based on the pre-determined ranges from the earlier performed trials. The procedure for the settling tests was as follows. Firstly, 400mL samples of each polymer dosage determined during the trial period were prepared by spiking the raw water with the prepared polymer solution to reach the desired sample concentration. This was done using both the Magnafloc LT27AG polymer (400mg/L stock solution) as well as the Hydrex 3661 polymer (400mg/L stock solution). After spiking, the samples were mixed simultaneously for 2 minutes at 125RPM using a jar test apparatus (Phipps and Bird, USA). Immediately after mixing, 50mL of the combined solution was pipetted from the sample beakers into clear, plastic 50mL flasks. The flasks were then mixed once more for 10

seconds before settling. The settling time was recorded as all of the samples settled simultaneously. During the settling process, the samples were observed until the first of the set reached maximum clarity and the settling ended. At this point the settling time was recorded and the interfaces of all samples were measured in the 50mL flasks. The supernatant was then extracted from each sample of varying polymer dose using a pipette and set aside for turbidity measurements, absorbance measurements as well as particle counts.

This settling process was repeated using the Actiflo® treatment process, following the same procedure as that of the phase 3 sample preparations. The Actiflo® treatment chemicals were added to the high turbidity Rideau River water samples prior to performing the settling tests. Again, prior to performing the proper settling test procedure, a series of settling test trials were performed to determine the optimum polymer dose range for the Magnafloc LT27AG polymer in the same method as for that without the addition of the Actiflo® chemicals. The Actiflo® treatment process was only tested for the MagnaflocLT27AG polymer, as it is the polymer used for the process at the Casselman water treatment facility. The proper settling test procedure was then followed, and the supernatant was again extracted from each sample of varying polymer dose using a pipette and set aside for turbidity measurements, absorbance measurements as well as particle counts.

3.5 Analytical Methods

3.5.1 Turbidity measurements

Phase 4 of the experiment utilized turbidity measurements of the settled sample supernatants to compare polymer effectiveness and determine the optimum dose. The procedure for measuring the turbidity is as follows. Supernatant collected from the settling test samples in phase 4 were transferred into clean, individual HACH turbidity test tubes. A HACH (HACH Co., USA) turbidimeter was calibrated according to factory instructions prior to each set of tests. The samples were then inverted in the HACH tubes 10 times immediately before inserting the tubes into the turbidimeter. The meter was then read and documented when the value displayed remained at a value ± 5 NTU. This entire process was carried out three times per sample, and the average of the three values was taken as the sample's overall turbidity value.

3.5.2 UV-Vis Spectroscopy Absorbance measurements

Absorbance measurements were taken for all samples in phases 1 through 4 using both an in-line UV-Vis spectrophotometer, as well as a desktop UV-vis spectrophotometer. The samples were divided after preparation to ensure an equal comparison between absorbance values on each spectrophotometer; 10mL of each sample was reserved for use in the desktop unit and the remaining 390mL was reserved for use in the in-line unit. Absorbance spectrums were read for each sample from 189.5nm - 800nm for the in-line unit, and 190nm - 800nm for the desktop unit based on the spectral capabilities of each spectrophotometer. It has been determined that the polymers chosen for analysis in this experiment show a

maximum absorbance at 190nm, and these values were therefore taken as the overall result value for each sample concentration (Gibbons & Örmeci, 2013). The in-line UV-Vis spectrophotometer (Real Spectrum Platinum Series) is manufactured by Real Tech Inc. (Ontario, Canada) and allows for a real-time analysis of the sample's absorbance across the entire spectrum of ultraviolet and/or visible light (189.5 nm – 800 nm). Figure 11 below illustrates the inner workings of the in-line spectrophotometer.

Figure 11: In-line spectrophotometer (Real Tech Inc.)

The experimental setup consisted of the in-line spectrophotometer mounted onto a wall in the Civil and Environmental Engineering lab located at Carleton University in Ottawa, ON. The spectrophotometer itself includes a tungsten lamp as the visible light source, a deuterium lamp as the ultraviolet light source, a PL sensor for interpreting absorbance measurements (Real Tech Inc., ON), a dehumidifier (EvaDry, Tampa, US), a pump and

tubing for inlet/outlet sample flow, and a quartz flow cell (Real Tech Inc., ON). The flow cells used were in path lengths of 2mm, 4mm and 8mm, and were also supplied by Real Tech Inc. Each flow cell was able to detect polymer at various levels of precision in deionized water, the 2mm path length had an average standard deviation of ± 0.0027 A.U., the 4mm path length had an average standard deviation of ± 0.0007 A.U., and the 8mm path length had an average standard deviation of ± 0.0012 A.U. between absorbance measurements for a given polymer concentration. The desktop UV-vis spectrophotometer (Cary-100 Bio series) is manufactured by Varian Inc./Agilent Technologies (USA). The desktop spectrophotometer is a double beam unit equipped with a tungsten halogen visible light source with a quartz window, a deuterium arc ultraviolet light source, and is centrally controlled by an external computer. The experimental set up consists of the unit itself and the external computer source, and a 10mm Hellma quartz cuvette (Hellma Canada Ltd., Canada) which was loaded into the sample holder located inside the unit.

The procedure for running a sample through the in-line spectrophotometer is as follows. Firstly, the unit was equipped with a flow cell of desired path length depending on the nature of the experiment. During phase one, the flow cell was changed between 2mm, 4mm and 10mm for both the high polymer concentration range (0-3 mg/L) and low polymer concentration range (0-1mg/L) sample sets. This was also altered on the systems internal software by changing the 'path length' field to the corresponding value for each flow cell. Once the desired flow cell was installed, the unit was turned on and allotted a minimum of 30 minutes to run through distilled water in accordance with the equipment's start-up procedure. The wavelength range was set from 189nm – 350nm on the systems internal

software. Afterwards, the unit was zeroed with deionized water before beginning any sample analysis. This was done by allowing the deionized water to run through for a minimum of 10 minutes prior to executing the programs 'zero' function. The absorbance values were then observed for 2 consecutive readings prior to beginning analysis to ensure the spectrophotometer was properly zeroed. Samples prepared earlier were then mixed with a stirring stick in a beaker for 30 seconds prior to being loaded onto the inlet tubing of the spectrophotometer. The sample was then allowed to run through the machine for 3 minutes, with the outlet being diverted into a waste beaker. After 3 minutes, the deionized water had been flushed out and the sample occupied all tubing volume. At this point, the outlet was diverted back into the inlet sample beaker to allow for a recycle of sample through the machine. This was done to accommodate the sample volume capacity necessary for the unit to analyze the sample a minimum of 3 consecutive analysis cycles. Each sample cycle requires 1 minute and 55 seconds. The average of these three absorbance readings is reported as the absorbance for each respective sample in the results. After 3 analysis cycles, the sample was removed from the inlet and replaced with deionized water for one full cycle to flush out any sample from the units tubing. After this flushing cycle, the next sample was loaded onto the inlet and the procedure was repeated until all samples in the set had been analyzed. Samples were analyzed in order from lowest to highest polymer concentration. After every sample set was complete, the unit was given another 10 minutes to run through deionized water and was re-zeroed prior to beginning to analyze a new sample set.

The procedure for running a sample through the desktop UV-Vis spectrophotometer is as follows. Firstly, the unit was powered on for a minimum of 1 hour prior to analysis in accordance with the machines start-up procedure in order to give the lamps sufficient time to warm up. The software was set to 'double-beam' setting and the wavelength range was set from 190nm – 800nm. Afterwards, the clean quartz cuvette was filled with 4mL of deionized water and loaded into the unit. The 'zero' function was initiated through the system software located on the external computer source. Once zeroed, the cuvette was removed, and any residual water present on the cuvette was dried by means of a compressed air canister to eliminate the possibility of any sample dilution. Samples prepared earlier were then mixed with a stirring stick in a beaker for 30 seconds prior to being poured into the cuvette for analysis. It was ensured that the sample fill the cuvette at minimum $\frac{3}{4}$ of the way full, in accordance with the spectrophotometers outlined operating procedure. The sample cuvette was then wiped using a Kim wipe to ensure no dust was present on the quartz walls and was then loaded into the machine where an absorbance spectrum was produced. This measurement was repeated twice per sample, and the reported absorbance measurements are the average of these replicates. After each sample, the cuvette was rinsed with deionized water and dried using the air canister before loading the next sample. This procedure was repeated until all samples within a given sample set had been analyzed, after which point the unit was re-zeroed before beginning a new sample set. Samples were analyzed in order from lowest to highest polymer concentration.

3.5.3 Particle counts

Particle counts of samples produced in phase 4 were carried out using a Dynamic Particle Analyzer (BP-4100-HEV model) manufactured by BrightWell Technologies INC (Ottawa, ON). This unit is capable of analyzing both sub-visible and visible particles. Micro-Flow Imaging™ (MFI) technology is used in this unit to allow for the rapid measurement of particle size, count, concentration and morphology. The flow cell used (BP-4100-FC-400-UN, Brightwell Technologies Inc.) was able to detect particles sized from 100µm - 400µm. The experimental set-up consisted of the particle counter itself, a beaker of deionized water that had also been filtered through a vacuum filtration system using Whatman 0.45µm filter paper (Sigma Aldrich, USA) in order to eliminate any possible false particles, a pumping mechanism, an external computer with the system software and the flow cell. The procedure for particle counts was conducted as follows. Firstly, the filtered deionized water was allowed to pump through the system for a minimum of 2 minutes in order to flush the flow cell of any potential particles. A cleaning solution (50% PCC54 detergent by volume) was then introduced into the inlet and allowed to flush through the system for another 2 minutes, followed by a final flush of deionized water for 1 minute. The systems cleanliness check was then used to ensure the flow cell was clean enough to be used for analysis. The sample in question was then loaded into the inlet tube and a stirring mechanism was initiated at a speed setting of 3 in order to maintain particle suspension. The sample was then run through the system based on a volume of 0.22 mL/min in accordance with the software's recommendation for the flow cell used. For each sample set, a cleaning procedure was followed between samples to ensure accurate particle readings. After the sample had finished its analysis, deionized water was allowed to run through the system

for one minute, followed by another minute of the cleaning solution and then a final minute flush of deionized water. The successive sample was then loaded into the inlet and the procedure was repeated until the entire set had been completed.

3.6 Statistics

3.6.1 Absorbance readings

All absorbance measurements were taken a minimum of three repetitions per sample. The average of these three readings at each wavelength was then taken as the overall absorbance reading for the production of the absorbance spectra. A minimum of seven data points were recorded at each polymer concentration range. The maximum absorbance values for each concentration recorded at a 190nm wavelength from the absorbance spectra were then used to create a linear correlation representing the absorbance-polymer concentration relationship established for each data set. The polymer concentration used for the linear correlation plots refers to the concentration of polymer dosed in the original sample, not the residual polymer concentration post settling. The error bars on these linear correlations represent the standard deviation between the three repetitions of each absorbance measurement for the respective sample concentration.

CHAPTER 4: RESULTS & DISCUSSION

4.1 Effect of path length on polymer detection using UV-vis spectroscopy

4.1.1 UV-vis absorbance spectra

The effect of path length on the detection sensitivity using UV-Vis spectroscopy for the detection of residual polymer was assessed using both a high range of Magnafloc polymer concentration (0 – 3 mg/L) as well as a low range (0–1 mg/L) in deionized water under the above-mentioned increments and conditions. Each concentration range was analyzed using both the desktop spectrophotometer using a 10mm path length quartz flow cell, and the in-line spectrophotometer using the 2mm, 4mm and 8mm path length flow cells. The results were then compared to establish which path length produced the most sensitive absorbance results, as well as to compare the sensitivity between both the desktop and in-line spectrophotometers. Absorbance readings were taken from 190nm to 350nm. Figures 12a and 12b below represent the absorbance spectra for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration range respectively using the desktop spectrophotometer and a 10mm flow cell.

Figure 12: Absorbance spectra of Magnafloc LT27AG polymer in deionized water using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 13a and 13b represent the absorbance spectra for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration using the in-line spectrophotometer and a 2mm flow cell. The flow cell was then increased to 4mm and the same readings were taken, as represented by Figures 14a and 14b. Finally, the flow cell was increased to 8mm and the absorbance spectra were reproduced under these conditions, as represented by Figures 15a and 15b. Previous studies by Al Momani and Örmeci as well as Gibbons and Örmeci showed no significant absorbance readings beyond 240nm, which was also in accordance with the results shown in Figures 12 through 15. Therefore, only results from 190nm to 250nm are presented in the absorbance spectra for this phase of the experiment.

Figure 13: Absorbance spectra of Magnafloc LT27AG polymer in deionized water using an in-line spectrophotometer with a 2mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figure 14: Absorbance spectra of Magnafloc LT27AG polymer in deionized water using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figure 15: Absorbance spectra of Magnafloc LT27AG polymer in deionized water using an in-line spectrophotometer with an 8mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 12 through 15 demonstrate that as the concentration of Magnafloc LT27AG polymer was increased, the corresponding absorbance reading also increased. This was true for both the desktop and in-line spectrophotometers at the 2mm, 4mm, 8mm and 10mm path lengths for both the high and low polymer concentration ranges. The highest absorbance value in all cases was measured at 190nm, which is in accordance with a previous study performed by Al Momani and Örmeci (22), which found a maximum absorbance value of polymer in a variety of water matrices (sludge centrate, raw water, clarified water and distilled water) to occur at 191.5nm when using an in-line UV-vis spectrophotometer. As the wavelength increases, the absorbance values decrease, tending to hover around zero with no significant absorbance readings beyond 240nm between the variable polymer concentrations.

Upon firstly analyzing the shape of the absorbance spectra for the high concentration range, it is clear from Figure 12a that the 2mm path length in the in-line spectrophotometer yields

a quite turbulent absorbance spectra when compared to the other path lengths. Figures 13a and 15a demonstrate that as the path length was increased, the variance in absorbance became smoother and more linear. There was also less noise at the higher wavelengths when the path length was increased, as can be observed when comparing Figure 13a to 15a. The same is true for the shape of the absorbance spectra at the low concentration range, as can be see when comparing Figure 13b to Figures 14b and 15b. The shape of the absorbance spectra curve produced by the desktop unit showed very similar results, however the unit did always pick up some background around 254nm, consistent with the wavelength at which organic matter absorbs light the most effectively (49) (50). It should be noted that the desktop unit is a double-beam UV-vis spectrophotometer, meaning the light-source can be diffracted through both the sample cell and a reference cell containing a sample solution containing no polymer. The absorbance attributed to the reference cell is measured simultaneously and is then subtracted as background from the overall reading attributed to the sample cell, which then reports the absorbance value attributed to the polymer only. As the quartz cells used for the purpose of this experiment had been used previously for other experiments, there is the possibility that some residual organic matter from previous experiments was permanently present on the cell and was therefore not removed as background, which would explain the slight peak around 254nm.

Analyzing the magnitude of the absorbance values at 190nm for each concentration between path lengths on the in-line unit at the high concentration range, it can be observed from Figure 15a that the 8mm path length was able to detect the highest absorbance readings for every different polymer concentration sample. The results show that as the

path length increased, the absorbance values for each polymer concentration increased as well. In addition to this, it is also notable that as the path length increased, the incremental difference in absorbance readings between polymer concentrations increased as well. Table 5 below summarizes this absorbance spectra data for the high concentration range. Although it would appear that the 8mm path length is most sensitive, it is also important to take into consideration the standard deviation between the incremental differences in absorbance. A larger standard deviation would indicate a less linear relationship between polymer concentration and absorbance at 190nm. From the standard deviation of these values indicated in Table 5, it is apparent that at the increase in absorbance occurring using the 8mm path length deviates most of the three path length variations, suggesting the absorbance-concentration relationship may be weaker for this path length when compared to the 4mm path length. The 2mm path length yielded the lowest standard deviation between absorbance increments, however it also was not able to detect a very strong absorbance when compared to the other path lengths and the shape of the absorbance spectra was very turbulent. When comparing the in-line results to the desktop unit results at the high concentration range, a background of approximately 0.300 A.U. is present due to the double-beam technology explained previously. In order to compare these values accurately with the in-line unit values, this background absorbance was subtracted from each of the sample absorbance values and the differences are listed in Table 5 below. From the desktop spectrophotometer results, it can be determined that the 10mm path length flow cell in the desktop unit was able to detect a maximum absorbance for each concentration higher than the 4mm path length and lower than the 8mm path length, however quite comparable to the two. The average incremental increase of 0.0215 A.U. was also in

between that of the 4mm and 8mm path lengths using the in-line unit, which were 0.0102 A.U. and 0.0481 A.U. respectively. The standard deviation of the incremental absorbance measurements was 0.0052 A.U., comparable to that of the 8mm path length which was 0.0058 A.U.

When analyzing the magnitude of the absorbance values at 190nm for each concentration between path lengths on the in-line unit at the low concentration range, it can be observed from Figure 12b that the 4mm path length was able to detect the highest absorbance values for each different polymer concentration sample. These results differ from those of the higher concentration range, which indicated that an increase in path length coordinated with an increase in absorbance value for a given concentration. In the case of the low concentration range, the 8mm path length detected a lower absorbance reading than that of the 4mm path length, as is observed when comparing Figure 14b to Figure 15b. Table 6 below summarizes this absorbance spectra data for the low concentration range. From this data, it can be observed that the 4mm path length also offered the largest average incremental increase in absorbance at 190nm of 0.0023 A.U. between the different concentrations of polymer. The standard deviation of 0.0016 A.U. between these values was quite low as well. The 8mm path length showed a decrease in average incremental absorbance at 190nm with a value of 0.0015 A.U. when compared to the 4mm path length. This data suggests that at very low polymer concentrations, the 4mm path length actually performed better than the 8mm path length. When comparing these results to that of the desktop unit in the low concentration range, the results are very consistent with that of the 4mm path length in the in-line unit, with an average incremental absorbance increase at

190nm of 0.004 A.U., associated with a standard deviation of 0.003 A.U. Table 6 shows that at very low concentrations, however, the desktop unit appears to be far less sensitive than the in-line unit. The average incremental absorbance values at 190nm between 0 mg/L of polymer up to 1.0 mg/L fluctuates from a minimum of 0.019 A.U. to 0.093 A.U., indicating that the relationship between concentration and absorbance is less linear. When comparing these values to that of the in-line unit using the 4mm path length, the average incremental increase in absorbance at 190nm remains far steadier with a minimum of 0.0010 A.U. and a maximum of 0.0027 A.U. The standard deviation of these values between the in-line unit and the desktop unit of 0.0016 A.U. and 0.0027 A.U., respectively, further indicates this point.

Table 5: Summary of absorbance spectra data results at 190nm for path length comparison using the desktop and in-line spectrophotometers at the high concentration range of Magnafloc LT27AG polymer (0-3 mg/L)

Concentration	Desktop Unit 10mm path length			In-line Unit 2mm path length		In-line Unit 4mm path length		In-line Unit 8mm path length	
	Raw	Absorbance	Incremental	Absorbance	Incremental	Absorbance	Incremental	Absorbance	Incremental
	Absorbance	Less	Absorbance		Absorbance		Absorbance		Absorbance
		Background	Increase		Increase		Increase		Increase
0.0	0.2902	0.0000		-0.00013		-0.00010		0.00025	
0.5	0.3167	0.0265	0.0265	0.00172	0.0019	0.01055	0.0106	0.04445	0.0442
1.0	0.3322	0.0420	0.0155	0.00692	0.0052	0.02109	0.0105	0.09271	0.0483
1.5	0.3573	0.0671	0.0251	0.01007	0.0031	0.02959	0.0085	0.14560	0.0529
2.0	0.3733	0.0830	0.0160	0.01753	0.0075	0.03966	0.0101	0.19218	0.0466
2.5	0.3999	0.1097	0.0266	0.02161	0.0041	0.05057	0.0109	0.23270	0.0405
3.0	0.4194	0.1292	0.0195	0.03237	0.0108	0.06111	0.0105	0.28907	0.0564
		Average		Average		Average		Average	
		Incremental	0.0215	Incremental	0.0054	Incremental	0.0102	Incremental	0.0481
		Increase		Increase		Increase		Increase	
		STDV of		STDV of		STDV of		STDV of	
		Incremental	0.00519	Incremental	0.00324	Incremental	0.00088	Incremental	0.00576
		Increase		Increase		Increase		Increase	

Table 6: Summary of absorbance spectra data results at 190nm for path length comparison using the desktop and in-line spectrophotometers at the low concentration range of Magnafloc LT27AG polymer (0-1 mg/L)

Concentration	Desktop Unit 10mm path length			In-line Unit 2mm path length		In-line Unit 4mm path length		In-line Unit 8mm path length	
	Raw	Absorbance	Incremental	Absorbance	Incremental	Absorbance	Incremental	Absorbance	Incremental
	Absorbance	Less Background	Absorbance Increase		Absorbance Increase		Absorbance Increase		Absorbance Increase
0.0	0.29162	0.0000		-0.00016		0.00000		-0.00003	
0.1	0.29521	0.00358	0.0036	0.01952	0.0197	0.00238	0.0024	-0.00003	0.0000
0.2	0.29327	0.00165	0.0019	0.01949	0.0000	0.00502	0.0026	-0.00045	0.0004
0.3	0.29634	0.00471	0.0031	0.01856	0.0009	0.00623	0.0012	0.00270	0.0032
0.4	0.30287	0.01124	0.0065	0.01571	0.0028	0.00832	0.0021	0.00412	0.0014
0.5	0.29914	0.00751	0.0037	0.01725	0.0015	0.00973	0.0014	0.00557	0.0015
0.6	0.30270	0.01107	0.0036	0.01975	0.0025	0.01224	0.0025	0.00752	0.0020
0.7	0.30608	0.01446	0.0034	0.01929	0.0005	0.01324	0.0010	0.00886	0.0013
0.8	0.30395	0.01233	0.0021	0.02031	0.0010	0.01507	0.0018	0.00947	0.0006
0.9	0.31322	0.02160	0.0093	0.02397	0.0037	0.01778	0.0027	0.01218	0.0027
1.0	0.32023	0.02861	0.0070	0.02292	0.0011	0.02315	0.0000	0.01451	0.0023
	Average			Average		Average		Average	
		Incremental	0.0044	Incremental	0.0034	Incremental	0.0018	Incremental	0.0015
		Increase		Increase		Increase		Increase	
	STDV of			STDV of		STDV of		STDV of	
		Incremental	0.00271	Incremental	0.00118	Incremental	0.00101	Incremental	0.00076
		Increase		Increase		Increase		Increase	

4.1.2 Linear correlations

The results from Figures 12 through 15 above demonstrate that the absorbance values at a 190nm wavelength were highest for all samples on both the in-line spectrophotometer and the desktop spectrophotometer. This is in accordance with a previous study performed by Al Momani and Örmeci (22), which found a maximum absorbance value of polymer in a variety of water matrices (sludge centrate, raw water, clarified water and distilled water) to occur at 191.5nm when using an in-line UV-vis spectrophotometer. In order to further analyze this relationship and determine which path length offered the most sensitive results, a linear correlation of the absorbance-polymer concentration data was done for all datasets. Figures 16a and 16b below represent the positive linear correlation between the polymer concentration and absorbance readings using the desktop spectrophotometer at the 0-3 mg/L and the 0-1 mg/L concentration ranges respectively. The polymer concentration for these and all subsequent linear correlations refers to the dosed concentration in the sample.

Figure 16: Linear correlation of the absorbance-polymer concentration data of Magnafloc LT27AG in deionized water at 190nm using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 17a and 17b represent the linear correlation of the absorbance-polymer concentration data using the in-line spectrophotometer and the 2mm flow cell at the 0-mg/L and 0-1 mg/L polymer concentration ranges respectively. Again, the absorbance-polymer concentration data was plotted using this same linear correlation method for both the 4mm and 8mm flow cells using the in-line spectrophotometer. Figures 18a and 18b below represent this data using the 4mm flow cell at both the high and low concentration ranges, respectively, and Figures 19a and 19b represent the 8mm flow cell at both the high and low concentration ranges, respectively.

Figure 17: Linear correlation of the absorbance-polymer concentration data of Magnafloc LT27AG in deionized water at 190nm using an in-line spectrophotometer with a 2mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figure 18: Linear correlation of the absorbance-polymer concentration data of Magnafloc LT27AG in deionized water at 190nm using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figure 19: Linear correlation of the absorbance-polymer concentration data of Magnafloc LT27AG in deionized water at 190nm using an in-line spectrophotometer with an 8mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 16 through 19 demonstrate that at a 190nm wavelength, UV-vis spectroscopy is capable of demonstrating a quite strong linear correlation between the polymer concentration in a given solution and its absorbance reading at both high and low concentration ranges. All linear correlations depicted in Figures 16 through 19 denote an incremental increase in absorbance readings as the polymer concentration increases in solution with deionized water. These results are consistent with those reported by a similar study done by Al Momani and Örmeci, as well as Gibbons and Örmeci (22).

Upon analysis of the linear correlation curves of the desktop and in-line UV-vis spectrophotometers, some comparisons can be made. Both spectrophotometers were able to form very strong linear correlations ($R^2 > 0.99$) between the absorbance values and the polymer concentration in the high concentration range (0-3 mg/L), as depicted in Figures 16a, 17a, 18a and 19a. From the linear correlation curve in Figure 16b, it is apparent that the desktop spectrophotometer is less sensitive in detecting polymer in the low concentration range (0-1 mg/L) than the in-line spectrophotometer based on the R^2 value of 0.861 A.U. and the quite low slope of 0.0242. Figures 18b and 19b demonstrate that the in-line unit was able to form quite a strong linear correlation ($R^2 = 0.97$) between polymer concentration and absorbance values for the low concentration range using the 4mm and 8mm flow cells, whereas the desktop unit was not. At the higher concentration range (0-3 mg/L), however, the desktop spectrophotometer was capable of detecting the full range of concentrations and formed a strong linear correlation ($R^2 = 0.997$). A full summary of the coefficient of determinations can be observed below in Table 7.

It was previously noted that the desktop unit is a double beam spectrophotometer, meaning the light-source can be diffracted through both the sample cell and a reference cell containing a sample solution containing no polymer, which is then subtracted from the sample reading as background. As there are variances between the flow cell used for the sample and the flow cell used for reference, the zero value that is reported for the desktop unit hovers around an approximate value of 0.300 A.U. For the purpose of comparing the in-line unit to the desktop unit, this value was subtracted from all maximum absorbance values reported by the desktop unit at 190nm and are listed above in Tables 5 and 6. For the purpose of comparison between spectrophotometers, these absorbance values will be used. When comparing these values, the desktop unit and the in-line unit are in agreeance at the low concentration range, with a maximum absorbance value at 1.0mg/L of ~0.020 A.U., as is visible in Table 6. At the higher concentration however, the desktop unit was able to detect a stronger absorbance reading for the 3.0mg/L than that of the in-line unit using the 2mm and 4mm flow cells, as is visible in Table 5. When the 8mm flow cell was used, the in-line unit was able to detect a much higher absorbance value at the 3.0 mg/L concentration of 0.289 A.U.

As was previously mentioned, the in-line unit is capable of utilizing different flow cells, each with a different path length. The path length is a critical parameter in the Beer-Lambert law stated in equation 5, which is the main governing principle of UV-vis spectroscopy. The path length was varied between 2mm, 4mm and 8mm using the in-line unit for both the high concentration sample range and the low concentration sample range in order to analyze and compare absorbance values and sensitivity between path lengths.

The 2mm path length was not effective in detecting low concentrations of polymer, offering a weak linear correlation ($R^2=0.442$) as can be seen in Figure 17b. The 4mm and 8mm path lengths were able to form much stronger linear correlations, both with R^2 values of ~ 0.970 , as depicted in Figures 18b and 19b. Tables 7 and 8 below depicts a full summary of the coefficient of determinations at both the high and low polymer concentration range, respectively.

Table 7: Summary of coefficient of determinations for desktop and in-line UV-vis spectrophotometers at a high Magnafloc LT27AG polymer concentration range (0-3 mg/L)

UV-vis spectrophotometer model	Path length (mm)	Coefficient of determination R^2
Desktop	10	0.997
In-Line	2	0.959
In-Line	4	0.999
In-Line	8	0.999

Table 8: Summary of coefficient of determinations for desktop and in-line UV-vis spectrophotometers at a low Magnafloc LT27AG polymer concentration range (0-1 mg/L)

UV-vis spectrophotometer model	Path length (mm)	Coefficient of determination R^2
Desktop	10	0.861
In-Line	2	0.442
In-Line	4	0.975
In-Line	8	0.969

In order to perform a full comparison of the path lengths and determine which is most sensitive for the detection of residual polymer in drinking water treatment, the absorbance readings themselves, shape of the absorbance spectra, slope of the linear correlation as well as the incremental increase between absorbance readings associated with each concentration were analyzed and compared against each other. At the high concentration

range, the 4mm path length did offer the lowest detection limit, however the maximum absorbance value, smooth absorbance spectra and large incremental absorbance increase at 190nm demonstrated by the 8mm path length yields the conclusion that it might offer the most sensitive results for the concentration range of 0 – 3 mg/L. At the low concentration range, the detection limits of all path lengths using the in-line unit were marginally different. When comparing the shape of the absorbance spectra, it is clear that the 2mm path length creates a very turbulent curve, deterring from its use in this case. The 4mm and 8mm path lengths both offer smoother curve shapes, however the 4mm path length is capable of detecting a higher absorbance value for a given concentration at the 0 – 1 mg/L concentration range than the 8mm path length. The average incremental increase between absorbance values at the 4mm path length was also larger (0.0010 A.U.) than that of the 8mm path length (0.0007 A.U.), as stated in Table 7. When then comparing the R^2 values of the absorbance-concentration linear correlations, the 4mm path length was also slightly more linear ($R^2 = 0.98$) when compared to that of the 8mm path length ($R^2=0.97$). The combination of these results infers that the 4mm path length offered the most sensitive results at the low concentration range of 0 – 1 mg/L of polymer. Seeing that the maximum dosage limits for PAM polyelectrolytes in drinking water treatment is currently set to <1.0 mg/L by the National Sanitation Foundation, the path length that is most sensitive for the detection of polymers at this low range was to be chosen for the remainder of the experiments, this being the 4mm path length.

4.2 Effect of particles on polymer detection using UV-vis spectroscopy

4.2.1 UV-vis absorbance spectra

The effect of suspended particulate matter present in surface waters on the sensitivity of UV-vis spectroscopy as a method for the detection of residual polymer was assessed at both a high concentration range of Magnafloc LT27AG polymer (0 – 3 mg/L) as well as a low concentration range (0 – 1 mg/L). Water samples collected from the Rideau River in Ottawa, Ontario, Canada were prepared in four different methods: filtered through a 0.45µm filter, diluted (1:1) with deionized water, both filtered and diluted (1:1) with deionized water, as well as unfiltered and undiluted. These prepared samples were spiked with polymer at both the high and low concentration ranges and were analyzed using both the desktop spectrophotometer using a 10mm path length quartz flow cell, and the in-line spectrophotometer using a 4mm path length flow cell. Results between the four types of prepared samples were then compared to establish the effect of particulate matter present in the sample on the sensitivity of UV-vis spectroscopy as a detection method for residual polymer, as well as to compare this sensitivity between both the desktop and in-line spectrophotometers. Figures 20a and 20b below represent the absorbance spectra for the 0-3.0mg/L and 0-1.0mg/L polymer concentration ranges respectfully using the desktop spectrophotometer in an unfiltered and undiluted Rideau River water sample. Figures 21a and 21b below represent the absorbance spectra for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration ranges respectfully using a 4mm path length flow cell and the in-line spectrophotometer in the same unfiltered and undiluted Rideau River water sample. As the change in absorbance is very small between polymer concentrations, Figures 20 and 21

below include a smaller scale graph overlaid to demonstrate the incremental increases in absorbance, although very minor.

Figure 20: Absorbance spectra of Magnafloc LT27AG polymer in unfiltered and undiluted Rideau River water with a turbidity of 6.8 NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figure 21: Absorbance spectra of Magnafloc LT27AG polymer in unfiltered and undiluted Rideau River water with a turbidity of 6.8 NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

A portion of the same bulk Rideau River water sample was then filtered through a $0.45\mu\text{m}$ filter on a different date, and the polymer concentrations were once again dosed at both the high and low concentration ranges. The raw Rideau River water sample had a turbidity of 6.8NTU, however after filtration this turbidity measured 0.15NTU. The purpose of the filtration was to remove suspended particulate matter present in the water and observe the effect this had on the sensitivity of UV-vis spectroscopy for the detection of residual polymer. Once again, the samples at both the high and low concentration ranges were analyzed using both the desktop and in-line UV-vis spectrophotometers. Figures 22a and 22b below represent the absorbance spectra for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration ranges respectfully using a 10mm path length flow cell and the desktop spectrophotometer in a filtered and undiluted Rideau River water sample.

Figure 22: Absorbance spectra of Magnafloc LT27AG polymer in filtered ($0.45\mu\text{m}$) and undiluted Rideau River water with an initial turbidity of 6.8NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 23a and 23b below represent the absorbance spectra for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration ranges respectfully using a 4mm path length flow cell and the in-line spectrophotometer in the same filtered (0.45 μ m) and undiluted Rideau River water sample.

Figure 23: Absorbance spectra of Magnafloc LT27AG polymer in filtered (0.45 μ m) and undiluted Rideau River water with an initial turbidity of 6.8NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 20 and 21 demonstrate that the presence of particulate matter in the raw water sample did not affect the ability of UV-vis spectroscopy to detect residual polymer at 190nm. The absorbance spectra for these samples using both the in-line and desktop units followed the expected trend and maintained the expected shape. Figure 20 did indicate that the presence of particulate matter in the sample increased the maximum absorbance values quite substantially using the desktop unit at both the high and low concentration ranges when compared to that in the deionized water sample as seen in Figure 14. In deionized water, the 3.0 mg/L sample denoted an absorbance value of 0.4194 A.U. with the

background included using the desktop spectrophotometer. The raw river water sample, however, read an absorbance value of 2.3568 A.U. using the same spectrophotometer, depicted in Figure 20a. The same increase was observed for the low concentration range as well, as can be seen in Figure 20b. When analyzing the absorbance results of the raw water samples read using the in-line unit (Figures 21a and 21b), an increase in absorbance was also observed in the presence of particles. Figures 21a and 21b demonstrate that at both the high and low concentration ranges, the particulate matter present in the raw water sample caused the absorbance values at 190nm to increase toward 1.0 AU. Although these absorbance values are higher than those read in deionized water, they are still within the acceptable absorbance working range of 0 to 1.0 AU. This infers that the in-line unit would be better suited for detecting polymer in the presence of surface water particulate matter than the desktop unit, as the desktop unit would require substantial dilution to decrease the absorbance values within the acceptable working range.

Figures 22 and 23 demonstrate that post-filtration, the removal of particulate matter present in the raw surface water sample had a very marginal effect on the absorbance values reported at 190nm by each spectrophotometer at both the high and low polymer concentration sample ranges. Filtered samples analyzed by the desktop unit, as represented by Figures 22a and 22b, resulted in absorbance spectra with an almost identical shape as the raw water samples, as represented by Figures 20a and 20b. When comparing the absorbance values between the filtered and raw samples at 190nm reported using the desktop unit, the filtered samples demonstrated little to no variation to the values reported by the raw water sample, indicating that particulate matter has little to no effect of the unit's

ability to detect residual polymer. When comparing this to Figures 23a and 23b, representing the absorbance spectra of the filtered samples reported by the in-line spectrophotometer, very similar results are shown. Again, the shape of the curves at both the high and low remains very similar to those resulted in the raw water sample, as represented by Figures 21a and 21b. Figure 23a, representing the high polymer concentration range in the filtered water sample, does show a slight gap between the maximum absorbance value at 190nm of the 0.5 mg/L sample to the 1.0 mg/L sample. As this gap is not observed in Figure 23b, representing the low polymer concentration range in the same filtered water sample, this can be attributed to an error in polymer dosing during sample preparation. When comparing the maximum absorbance values between the filtered and raw samples at 190nm reported using the in-line unit, the filtered samples demonstrated a slight increase in absorbance to that of the raw water samples. This effect is presumed to be because of the lack of particulate matter in the sample available for adsorption causes the polymer to remain suspended in solution as residual. The increase in residual polymer would lead to an increase in the reported absorbance value, which is observed comparing Figures 21a and 21b to Figures 23a and 23b. The fact that this effect is only observed using the in-line unit and not the desktop unit indicates that the in-line is capable of detecting polymer more sensitively, as it was able to measure this very slight increase in residual polymer concentration and demonstrate this through the absorbance spectra.

Another bulk sample of raw Rideau River water was then collected on another date, with a turbidity measuring 3.2NTU. Based on the absorbance reading for the high concentration range reporting a value between 2.0 A.U. and 2.5 A.U. using the desktop

spectrophotometer, the sample was diluted 1:1 with deionized water prior to polymer addition in an attempt to bring the absorbance down to a value within the common acceptable working absorbance range of 0 – 1.0 A.U. After dilution, the turbidity was decreased to a value of 1.2NTU. Another purpose of the dilution was to observe the effect of suspended particulate matter present in the raw water sample on the sensitivity of UV-vis spectroscopy as a method for the detection of residual polymer. As was done for the other datasets, the samples at both the high and low concentration ranges were analyzed using both the desktop and in-line UV-vis spectrophotometers. Figure 24 below represents the absorbance spectra for the 0 – 1 mg/L polymer concentration range using a 10mm path length flow cell and the desktop spectrophotometer in the unfiltered and diluted Rideau River water sample. The diluted high concentration range samples were not measured using the desktop unit, as the 1:1 dilution is still out of the units working range.

Figure 24: Absorbance spectra of Magnafloc LT27AG polymer in unfiltered Rideau River water diluted 1:1 with deionized water with an initial turbidity of 3.2NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration range of 0-1 mg/L

Figures 25a and 25b below represent the absorbance spectra for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges respectfully using a 4mm path length flow cell and the in-line spectrophotometer in the same unfiltered and diluted Rideau River water sample as the desktop unit above.

Figure 25: Absorbance spectra of Magnafloc LT27AG polymer in unfiltered Rideau River water diluted 1:1 with deionized water with an initial turbidity of 3.2NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

When comparing the absorbance spectra of the diluted water samples, shown in Figures 24, 25a and 25b, to that of the undiluted water samples, shown in Figures 20a, 20b, 21a and 21b; a similar curve shape is produced. As was expected, the maximum absorbance values at 190nm at both the high and low concentration ranges decreased to roughly half of what was demonstrated in the raw river water samples on both the desktop and the in-line spectrophotometers. Aside from this decrease in maximum absorbance, no other major differences in the absorbance spectra can be drawn from the dilution of the samples.

A portion of the bulk sample of raw Rideau River water measuring 3.2NTU turbidity was then filtered using a 0.45 μ m filter and also diluted 1:1 with deionized water prior to being dosed with Magnafloc LT27AG polymer at both the high and low concentration ranges. Again, this method was tested in order to observe the effects of suspended particulate matter present in the sample on the sensitivity of UV-vis spectroscopy for the detection of residual polymer. After dilution and filtration, the turbidity was decreased from 3.2NTU to 0.10NTU. Again, both the high and low concentration ranges were analyzed using both the desktop and in-line UV-vis spectrophotometers. Figure 26 represents the absorbance spectra for the 0–1 mg/L polymer concentration range using the desktop spectrophotometer in the filtered and diluted Rideau River water sample. Again, the filtered high concentration range samples were not measured using the desktop unit as the 1:1 dilution still rendered absorbance values outside the units working range.

Figure 26: Absorbance spectra of Magnafloc LT27AG polymer in filtered Rideau River water filtered with a 0.45 μ m filter and diluted 1:1 with deionized water with an initial turbidity of 3.2NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration range of 0-1mg/L

Figures 27a and 27b below represent the absorbance spectra for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration ranges respectfully using a 4mm path length flow cell and the in-line spectrophotometer in the same filtered and diluted Rideau River water sample as for the desktop unit above.

Figure 27: Absorbance spectra of Magnafloc LT27AG polymer in filtered Rideau River water filtered with a 0.45 μ m filter and diluted 1:1 with deionized water with an initial turbidity of 3.2NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3mg/L and (b) 0-1mg/L

When comparing the absorbance spectra of the filtered and diluted curves in Figures 26, 27a and 27b, to that of the raw river water absorbance spectra in Figures 20a, 20b, 21a and 21b; the shape is once again very similar. As was expected, the maximum absorbance values at 190nm at both the high and low concentration ranges was decreased to the lowest value of all four samples using both the desktop and in-line spectrophotometers. The filtration and dilution of the samples remove the majority of the particulate matter present in the sample, and thus the absorbance attributed to this suspended particulate matter is no longer visible on the absorbance spectra. This causes the overall absorbance to decrease.

Regardless of this, the incremental increases in polymer addition are still visible at 190nm in all cases, and the absorbance spectra curves retain their shape.

A full comparison of the peak absorbance values between the filtered samples, diluted samples, filtered and diluted samples, as well as the raw samples dosed with the high concentration range of polymer (0-3 mg/L) can be observed in Table 9 below. When analyzing the magnitude of the absorbance values at 190nm for each concentration in this range, it is apparent that that raw water measures the highest absorbance values at this wavelength for each concentration the desktop spectrophotometer, however the in-line spectrophotometer reports the highest absorbance values in filtered water when comparing the raw, filtered and diluted samples. This same trend in absorbance is observed in the samples dosed with the low concentration range of polymer (0-1 mg/L), which are summarized in Table 10 below. The increase in peak absorbance between the raw and filtered samples can be attributed to the fact that when particles are absent in the sample, the polymer remains suspended in solution rather than adsorbed onto the particles. When polymer absorbance occurs, a portion of the polymer now attributed to the particle will form clumps which increase in weight and may settle out of suspension in solution. Seeing that peak absorbance can be correlated with polymer concentration, this effect would be indicated by a decrease in absorbance as the settled polymer would no longer be suspended in solution and would not be detected by the spectrophotometer. This is observed using the in-line spectrophotometer, showing a lower absorbance in the raw water when particles are present and a higher absorbance in the filtered water where particles are absent. This effect is observed on the in-line spectrophotometer and not the desktop spectrophotometer

because, as was demonstrated in phase one of the results, the in-line spectrophotometer is capable of detecting residual polymer with more sensitivity than the desktop spectrophotometer. This indicates that this effect may not be visible on the desktop unit due to its lack of sensitivity.

Table 9: Summary of absorbance spectra data results for effect of particles on UV-Vis absorbance for the detection of residual polymer using the desktop and in-line spectrophotometers at the high concentration range of Magnafloc LT27AG polymer (0-3 mg/L)

Concentration	Raw Rideau River Sample				Filtered Rideau River Sample				Diluted Rideau River Sample		Filtered & Diluted Rideau River Sample	
	In-line		Desktop		In-line		In-line		In-line		In-line	
	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase
0	2.2845		1.0473		2.1886		0.9671		0.5153		0.5658	
0.5	2.2933	0.0088	1.0565	0.0093	2.1694	0.0192	0.9759	0.0088	0.5221	0.0067	0.5761	0.0103
1.0	2.3082	0.0149	1.0645	0.0080	2.1473	0.0221	1.1271	0.1512	0.5258	0.0037	0.5745	0.0015
1.5	2.3186	0.0104	1.0750	0.0104	2.1758	0.0284	1.1632	0.0361	0.5336	0.0079	0.5860	0.0115
2.0	2.3315	0.0129	1.0848	0.0099	2.1988	0.0231	1.1786	0.0153	0.5353	0.0017	0.5850	0.0011
2.5	2.3420	0.0105	1.0936	0.0088	2.2060	0.0072	1.1918	0.0132	0.5403	0.0050	0.5942	0.0093
3.0	2.3568	0.0148	1.1019	0.0082	2.2324	0.0264	1.2087	0.0169	0.5464	0.0061	0.6042	0.0100
Average												
Incremental Increase		0.0121		0.0091		0.0073		0.0403		0.0052		0.0064
STDV of Incremental Increase		0.0025		0.0009		0.0229		0.0551		0.0022		0.0060

Table 10: Summary of absorbance spectra data results for effect of particles on UV-Vis absorbance for the detection of residual polymer using the desktop and in-line spectrophotometers at the low concentration range of Magnafloc LT27AG polymer (0-1 mg/L)

Concentration	Raw Rideau River Sample				Filtered Rideau River Sample				Diluted Rideau River Sample				Filtered & Diluted Rideau River Sample			
	Desktop		In-line		Desktop		In-line		Desktop		In-line		Desktop		In-line	
	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase	ABS	ABS Increase
0	1.9261		0.8981		1.9616		1.0326		1.2809		0.4582		1.2094		0.4756	
0.1	1.9586	0.0324	0.9123	0.0142	1.9601	0.0014	1.0451	0.0125	1.2862	0.0053	0.4663	0.0081	1.2298	0.0204	0.4815	0.0059
0.2	1.9328	0.0258	0.9173	0.0050	1.9631	0.0029	1.0460	0.0008	1.2815	0.0047	0.4626	0.0037	1.2369	0.0071	0.4858	0.0043
0.3	1.9600	0.0272	0.9219	0.0046	1.9613	0.0018	1.0491	0.0032	1.2801	0.0014	0.4626	0.0000	1.2335	0.0034	0.4854	0.0004
0.4	1.9785	0.0185	0.9282	0.0063	1.9597	0.0016	1.0480	0.0011	1.3076	0.0275	0.4684	0.0058	1.2237	0.0098	0.4828	0.0026
0.5	1.9637	0.0148	0.9320	0.0038	1.9623	0.0025	1.0534	0.0054	1.2972	0.0104	0.4710	0.0026	1.2273	0.0036	0.4839	0.0011
0.6	1.9891	0.0255	0.9380	0.0060	1.9655	0.0032	1.0519	0.0015	1.2966	0.0006	0.4732	0.0022	1.2222	0.0052	0.4829	0.0010
0.7	1.9946	0.0055	0.9430	0.0050	1.9678	0.0024	1.0532	0.0013	1.3147	0.0181	0.4748	0.0017	1.2237	0.0015	0.4841	0.0012
0.8	2.0129	0.0183	0.9461	0.0031	1.9627	0.0052	1.0544	0.0013	1.3052	0.0095	0.4729	0.0019	1.2231	0.0006	0.4836	0.0004
0.9	2.0276	0.0147	0.9512	0.0051	1.9748	0.0121	1.0576	0.0032	1.3025	0.0028	0.4719	0.0010	1.2254	0.0023	0.4834	0.0002
1.0	2.0232	0.0044	0.9546	0.0034	1.9724	0.0024	1.0636	0.0060	1.3059	0.0035	0.4781	0.0062	1.2376	0.0122	0.4886	0.0052
Average Incremental Increase		0.0097		0.0056		0.0011		0.0031		0.0025		0.0020		0.0028		0.0013
STDV of Incremental Increase		0.0192		0.0032		0.0048		0.0041		0.0120		0.0038		0.0088		0.0029

4.2.2 Linear correlations

The results from Figures 20 through 27 above demonstrate that the absorbance values at a 190nm wavelength were highest for all samples on both the in-line spectrophotometer and the desktop spectrophotometer. These results remained valid regardless of dilution, filtration, or a combination of the two; indicating that suspended particulates present in the sample do not alter the wavelength at which the polymer is most highly detected by UV-vis spectroscopy. Figures 20 through 27 also demonstrate that the absorbance values maintain their incremental increase as polymer concentration is increased, as shown phase one of the results. In order to further analyze this relationship and determine the impact that suspended particulates present in raw water may have on UV-vis spectroscopy sensitivity for polymer detection, a linear correlation of the absorbance-polymer concentration data was done for all datasets.

Figures 28a and 28b below represent the positive linear correlation between the polymer concentration and absorbance values at 190nm using the desktop spectrophotometer at the 0-3 mg/L and the 0-1 mg/L concentration ranges in an unfiltered and undiluted Rideau River water sample respectively. Figures 29a and 29b below represent the linear correlation for the 0 – 3 mg/L and 0 – 1 mg/L polymer concentration ranges respectfully using a 4mm path length flow cell and the in-line spectrophotometer in the same unfiltered and undiluted Rideau River water sample as for the desktop unit.

Figure 28: Linear correlation of the absorbance-polymer concentration data of Magnafloc LT27AG in Rideau River water with a turbidity of 6.8NTU at 190nm using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3mg/L and (b) 0-1 mg/L

Figure 29: Linear correlation of the absorbance-polymer concentration data of Magnafloc LT27AG in Rideau River water with a turbidity of 6.8NTU at 190nm using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3mg/L and (b) 0-1mg/L

From these linear correlations, it is apparent that the presence of particles in the water sample did not hinder the ability of UV-Vis spectroscopy to detect the increase in polymer

concentration between the samples at both the high and low concentration ranges. Figures 28a and 28b, representing the absorbance values reported by the desktop unit, do correlate with a larger slope than that of the in-line unit measuring the same samples, represented by Figures 29a and 29b. The larger slope is an initial indication that the linear correlation between polymer concentration and absorbance may be detected more strongly using the desktop spectrophotometer, however there are other factors to be considered. Another notable difference between the two spectrophotometers is observed when comparing the linear correlations at the low concentration range. The error bars at each concentration in Figure 28b, representing the desktop unit absorbance values at this range, indicates that there is quite a large variance in absorbance readings for a given concentration. This variance is nowhere near as large for the same samples read using the in-line spectrophotometer, represented by Figure 29b. The large variance implies that the desktop unit has a larger variability for polymer detection at lower concentrations when compared to the in-line unit, which is quite meaningful as drinking water treatment applications require the detection of polymer at significantly low concentrations (>1.0 mg/L). The coefficient of determination is also stronger using the in-line unit ($R^2 = 0.976$) at the low concentration range when compared to the desktop unit ($R^2 = 0.905$).

Figures 30a and 30b below represent the linear correlation for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges respectfully using the desktop spectrophotometer in an undiluted Rideau River water sample filtered through a 0.45 μ m filter. Figures 31a and 31b below represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer

concentration ranges, respectively, using the in-line spectrophotometer under the same sample conditions as for the desktop spectrophotometer.

Figure 30: Linear correlation of Magnafloc LT27AG polymer in filtered ($0.45\mu\text{m}$) and undiluted Rideau River water with an initial turbidity of 6.8NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figure 31: Linear correlation of Magnafloc LT27AG polymer in filtered ($0.45\mu\text{m}$) and undiluted Rideau River water with an initial turbidity of 6.8NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

The filtration and removal of particles from the sample decreased the linear correlation between absorbance and polymer concentration at both the high and low concentration ranges on both spectrophotometers. The linear correlations were weaker using the desktop unit when compared to the in-line unit, indicated by the lower coefficient of determinations reported in Figures 30a and 30b when compared to those reported by Figures 31a and 31b. The slope of the linear correlations at the low concentration range was also lower on both spectrophotometers when sample filtration was implemented when compared to that of the raw water sample in Figures 28b and 29b. These results can be correlated with the differences in absorbance spectra between the raw water, in Figures 20 and 21, and the filtered water, in Figures 22 and 23. As was mentioned, the lack of particles in the water causes most of the polymer to remain suspended in solution as residual, contributing to an increase in maximum absorbance. However, the filtration may not have removed 100% of the particles present in the water, causing a discrepancy in sample uniformity. This would lead to the potential of some samples of a given polymer concentration containing more particles than another given polymer concentration. This discrepancy would cause certain samples to experience polymer settling more so than others, thus leading to the observed decrease in linear correlation. Despite the decrease, the in-line unit was still able to form quite a strong linear correlation between polymer concentration and absorbance at 190nm in the filtered water samples, at both the high polymer concentration range ($R^2 = 0.835$) and the low polymer concentration range ($R^2 = 0.844$).

Figure 32 below represents the linear correlation for the 0 – 1 mg/L polymer concentration range using a 10mm path length flow cell and the desktop spectrophotometer in an

unfiltered Rideau River water sample diluted 1:1 with deionized water. Figures 33a and 33b represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the in-line spectrophotometer under the same sample conditions as for the desktop spectrophotometer.

Figure 32: Linear correlation of Magnafloc LT27AG polymer in unfiltered Rideau River water diluted 1:1 with deionized water with an initial turbidity of 6.8NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration range of 0-1 mg/L

Figure 33: Linear correlation of Magnafloc LT27AG polymer in unfiltered Rideau River water diluted 1:1 with deionized water with an initial turbidity of 6.8NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

As expected, the 1:1 dilution of the sample with deionized water decreased the maximum absorbance of each sample to half of its value reported in the raw water samples. This may be necessary if the raw water absorbance values reported are outside the working range of the spectrophotometer which is 0 – 4 A.U., however the suggested range is 0 – 1 A.U. Dilution of the sample decreased the linear correlation between peak absorbance and polymer concentration quite significantly using the desktop spectrophotometer, as observed in Figure 32b ($R^2 = 0.620$) when compared to the raw water sample in Figure 28b ($R^2 = 0.925$). The in-line spectrophotometer, however, was still able to form quite a strong linear correlation post dilution at both the high and low concentration ranges, as observed by the linear correlation coefficients in Figure 33a ($R^2 = 0.987$) and Figure 33b ($R^2 = 0.819$).

Figure 34 below represents the linear correlation for the 0 – 1mg/L polymer concentration range using the desktop spectrophotometer in a Rideau River water sample both filtered through a 0.45 filter and diluted 1:1 with deionized water. Figures 35a and 35b represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the in-line spectrophotometer under the same sample conditions as that of the desktop unit.

Figure 34: Linear correlation of Magnafloc LT27AG polymer in filtered (0.45 μm) Rideau River water diluted 1:1 with deionized water with an initial turbidity of 3.2 NTU using a desktop spectrophotometer with a 10mm flow cell in the concentration range of 0-1 mg/L

Figure 35: Linear correlation of Magnafloc LT27AG polymer in filtered (0.45 μm) Rideau River water diluted 1:1 with deionized water with an initial turbidity of 3.2 NTU using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

As was expected, a 1:1 dilution of the samples with deionized water once again decreased the peak absorbance values to half their value reported in the raw water samples at both the high and low concentration ranges on both spectrophotometers. The addition of the filtration of the samples also decreased the linear correlation between the absorbance at

190nm and polymer concentration in all cases. The correlation was completely lost at the low concentration range using the desktop spectrophotometer, as observed in Figure 34 ($R^2 = 0.053$). The in-line spectrophotometer was still able to detect quite a strong linear correlation at the high concentration range, visible in Figure 35a ($R = 0.936$), however at the low concentration range the correlation also decreased substantially, visible in Figure 35b ($R^2 = 0.361$). Tables 11 and 12 below summarize the coefficient of determination values for all samples at both the high and low polymer concentration ranges, respectively.

Table 11: Summary of coefficient of determinations for desktop and in-line UV-vis spectrophotometers at a high Magnafloc LT27AG polymer concentration range (0-3 mg/L) in Rideau River water samples

UV-vis spectrophotometer model	Filtered	Diluted	Coefficient of determination R^2
Desktop Unit	No	No	0.997
In-Line Unit	No	No	0.999
Desktop Unit	Yes	No	0.513
In-Line Unit	Yes	No	0.835
In-Line Unit	No	Yes	0.987
In-Line Unit	Yes	Yes	0.936

Table 12: Summary of coefficient of determinations for desktop and in-line UV-vis spectrophotometers at a low Magnafloc LT27AG polymer concentration range (0-1 mg/L) in Rideau River water samples

UV-vis spectrophotometer model	Filtered	Diluted	Coefficient of determination R^2
Desktop Unit	No	No	0.905
In-Line Unit	No	No	0.976
Desktop Unit	Yes	No	0.616
In-Line Unit	Yes	No	0.844
Desktop Unit	No	Yes	0.620
In-Line Unit	No	Yes	0.819
Desktop Unit	Yes	Yes	0.053
In-Line Unit	Yes	Yes	0.361

4.3 Effect of water treatment process chemicals on polymer detection using UV-vis spectroscopy

4.3.1 UV-vis absorbance spectra

In order to assess the feasibility of UV-vis spectroscopy as a method of determining the residual polymer concentration during the drinking water treatment process, the impact of additional chemicals that may potentially be present during treatment on the sensitivity of UV-vis spectroscopy as a method for this purpose were examined. The Actiflo® enhanced coagulation process, manufactured by Veolia Water Technologies Inc. (Paris, France), employed at the Casselman drinking water treatment facility was chosen to be recreated at a laboratory scale for the purpose of this experiment, as it utilizes a variety of additional chemicals during its process. Firstly, before clarification, potassium permanganate is added to the raw water to oxidize any iron and/or manganese present. Following this, a polyaluminium silicate sulphate (PASS-10) coagulant manufactured by Kemira Inc. (Helsinki, Finland) is added to destabilize colloidal material as the water enters the clarifier. The water is then sent to an injection tank where the polymer, used as a flocculant in this case, is added along with microsand to aid in settling through the creation of larger, heavier flocs. The water is then mixed and sent to a decantation tank and left to settle for thirty minutes. Following this, the supernatant is sent to a Dunsenflo® filter, also manufactured by Veolia Water Technologies Inc., which is composed of anthracite and sand. Post-filtration, sodium hydroxide is added as needed to ensure the water maintains a neutral pH.

These chemicals were dosed into samples of both deionized water and Rideau River water samples at dosages in accordance with those reported by the Casselman Water Treatment facility. A full list of these dosage concentrations is reported in Table 4 found in Chapter 3: Materials and Methods, as well as a full description of sample preparation methodology. The dosage of potassium permanganate, PASS-10 coagulant, and microsand remained constant for all samples. The polymer dosages, however, varied between a high concentration range (0-3 mg/L) and a low concentration range (0-1 mg/L). The amount of sodium hydroxide also varied between samples and was dosed as needed in order to acquire a pH of 7 for each sample. Post mixing and settling, the supernatant of each sample was collected and used for absorbance measurements on both the desktop and in-line spectrophotometers. Figures 36a and 36b below represent the absorbance spectra for sample supernatant in the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectfully, using the desktop spectrophotometer in deionized water samples dosed with all Actiflo® process chemicals.

Figure 36: Absorbance spectra of Magnafloc LT27AG polymer in deionized water dosed with Actiflo® enhanced coagulation process chemicals using a desktop spectrophotometer with a 10 mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 37a and 37b below represent the absorbance spectra for sample supernatant in the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectfully, using the in-line spectrophotometer in the same deionized water samples as above dosed with all Actiflo® process chemicals.

Figure 37: Absorbance spectra of Magnafloc LT27AG polymer in deionized water dosed with Actiflo® enhanced coagulation process chemicals using an in-line spectrophotometer with a 4 mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

From observing Figures 36 and 37 it is apparent that the absorbance spectra maintain a peak absorbance at a 190nm wavelength despite the presence of the Actiflo® process chemicals in the deionized water samples. This trend was observed at both the high and low polymer concentration ranges using both the desktop spectrophotometer, Figures 36a and 36b, as well as the in-line spectrophotometer, Figures 37a and 37b. As observed in previous experimental phases, there were no significant deviations in absorbance beyond 250nm, which is why these values are not included in the results. In order to accurately model the full-scale Actiflo® enhanced coagulation treatment process, it was also essential

to work with raw water samples from a natural source. For this purpose, surface water collected from the Rideau River with a turbidity of 32NTU was used to prepare 400mL samples following the exact same procedure as was performed for the deionized water samples. Figures 38a and 38b below represent the absorbance spectra for sample supernatant in the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the desktop spectrophotometer in Rideau River water samples dosed with all Actiflo® process chemicals.

Figure 38: Absorbance spectra of Magnafloc LT27AG polymer in Rideau River (32.0 NTU) water dosed with Actiflo® enhanced coagulation process chemicals using a desktop spectrophotometer with a 10 mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 39a and 39b below represent the absorbance spectra for sample supernatant in the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the in-line spectrophotometer in the same Rideau River water samples as above dosed with all Actiflo® process chemicals.

Figure 39: Absorbance spectra of Magnafloc LT27AG polymer in Rideau River water (32.0 NTU) dosed with Actiflo® enhanced coagulation process chemicals using an in-line spectrophotometer with a 4 mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Again, the results from the samples prepared with Rideau River water produce an absorbance spectrum following the expected shape with a peak absorbance at 190nm. This trend was observed at both the high and low polymer concentration ranges using both the desktop spectrophotometer, Figures 38a and 38b, as well as the in-line spectrophotometer, Figures 39a and 39b. The peak absorbance values at 190nm were significantly higher for each polymer concentration than those reported in the deionized water samples, as is expected due to the increase in turbidity and the particulate matter in the raw water increasing the base absorbance of the sample.

A potential issue with the addition of the Actiflo® enhanced coagulation process chemicals would be their contribution to the peak absorbance value at 190nm compared to that of the polymer itself. In order to further investigate this potential impact, two samples of deionized water were dosed with the required dose of each potassium permanganate (1.0

mg/L) and the PASS-10 coagulant (50 mg/L). Each sample was mixed for two minutes using a jar tester at 125RPM and absorbance measurements were taken using both the desktop and in-line spectrophotometers. Figures 40a and 40b below represent the absorbance spectrum for these doses of potassium permanganate as well as PASS-10 coagulant, respectively, in the deionized water samples using a desktop spectrophotometer.

Figure 40: Absorbance spectra of (a) potassium permanganate and (b) PASS-10 coagulant in deionized water using a desktop spectrophotometer and a 10mm flow cell

Figures 41a and 41b below represent the absorbance spectrum for these doses of potassium permanganate as well as PASS-10 coagulant, respectively, in the same deionized water samples as above using an in-line spectrophotometer.

Figure 41: Absorbance spectra of (a) potassium permanganate and (b) PASS-10 coagulant in deionized water using a in-line spectrophotometer and a 4mm flow cell

From Figure 40a, the desktop spectrophotometer reports the peak absorbance of potassium permanganate in the deionized water sample at 190nm to be 0.5610 AU. When comparing this value to that of the lowest polymer concentration (0.10 mg/L) in deionized water containing all Actiflo® process chemicals, as reported in Figure 36b, the polymer containing sample reports a similar but slightly lower value of 0.5300 AU using the desktop unit. Analyzing the peak absorbance values at 190nm of each polymer concentration in the low range, represented by Figure 36b, the desktop unit is not able to differentiate between polymer concentrations as they increase when the Actiflo® process chemicals are present seeing that the potassium permanganate contributes to the peak absorbance more so than the polymer itself. This infers that the desktop unit would not be a reliable method of detecting residual polymer at a concentration of 3.0 mg/L or lower when potassium permanganate is present at the above-mentioned dosage. Comparatively, from Figure 41a, the in-line spectrophotometer reports the peak absorbance of potassium permanganate in deionized water at 190nm to be 0.1074 AU. When comparing this value to that of the lowest

polymer concentration (0.10 mg/L) in deionized water containing all Actiflo® process chemicals, as reported in Figure 36b, the polymer containing sample reports a much higher value of 0.3640 AU. This infers that the in-line spectrophotometer is sensitive enough to detect a significant difference in absorbance between potassium permanganate alone, and with residual polymer present in solution at concentrations as low as 0.10 mg/L.

From Figure 40b, the desktop spectrophotometer reports the peak absorbance of PASS-10 coagulant in deionized water at 190nm to be 0.3308 AU. Again, when comparing this value to that of the lowest polymer concentration (0.10 mg/L) in deionized water containing all Actiflo® process chemicals, as reported in Figure 36b, the polymer containing sample reports a much higher value of 0.5300 AU using the desktop unit. Similarly, when analyzing Figure 41b, the in-line spectrophotometer reports the peak absorbance of PASS-10 coagulant in deionized water at 190nm to be 0.1534 AU. Comparing this again to the peak absorbance at 190nm of the lowest polymer concentration (0.10 mg/L) in deionized water containing all Actiflo® process chemicals, Figure 37b, the in-line unit reports a peak absorbance value of 0.3640 A.U. Since the absorbance value of the PASS-10 coagulant in deionized water is significantly lower than that of the polymer containing sample as read by both spectrophotometers, it can be concluded that the PASS-10 coagulant does not impact the ability of either spectrophotometer to detect residual polymer in a solution containing both constituents.

4.3.2 Linear correlations

As was done for all other absorbance data gathered during the experimental procedure, linear correlations of peak absorbance data versus polymer concentration from Figures 36 to 39 were plotted in order to further analyze the absorbance-polymer concentration relationship and determine the impact that Actiflo process chemicals present in raw water may have on UV-vis spectroscopy sensitivity for residual polymer detection. Figures 42a and 42b below represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the desktop spectrophotometer in samples of deionized water containing all Actiflo® enhanced coagulation process chemicals.

Figure 42: Linear correlation of Magnafloc LT27AG polymer in deionized water dosed with Actiflo® enhanced coagulation process chemicals using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 43a and 43b below represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the in-line spectrophotometer in

the same samples of deionized water containing all Actiflo® enhanced coagulation process chemicals.

Figure 43: Linear correlation of Magnafloc LT27AG polymer in deionized water dosed with Actiflo® enhanced coagulation process chemicals using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

From Figures 42a and 42b, it is apparent that the desktop spectrophotometer was unable to form any meaningful correlation between polymer concentration and absorbance at either the high or low polymer concentration range in deionized water when Actiflo® process chemicals were present. As polymer concentration increases, the absorbance values reported by the desktop unit either remain fairly constant or decrease slightly forming a negative correlation overall. The coefficient of determinations for both polymer concentration ranges were also very weak, $R^2 = 0.033$ for the high concentration range and $R^2 = 0.107$ for the low concentration range. This infers that the desktop unit does not have the required sensitivity to accurately detect the absorbance value of residual polymer at concentrations of 3.0mg/L or lower in the presence of Actiflo® process chemicals. Comparatively, Figures 43a and 43b demonstrate that the in-line spectrophotometer was

able to form a meaningful positive correlation between polymer concentration and absorbance in deionized water with Actiflo® process chemicals present. At the high concentration range, Figure 43a, this positive linear correlation is quite strong a coefficient of determination of $R^2 = 0.843$, despite the presence of additional chemicals in solution. At the lower concentration range, Figure 43b, this correlation is still present but slightly weaker, as represented by the coefficient of determination of $R^2 = 0.553$.

Figures 44a and 44b below represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the desktop spectrophotometer in samples of Rideau River water with a turbidity of 32NTU containing all Actiflo® enhanced coagulation process chemicals.

Figure 44: Linear correlation of Magnafloc LT27AG polymer in Rideau River (32.0 NTU) water dosed with Actiflo® enhanced coagulation process chemicals using a desktop spectrophotometer with a 10mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

Figures 45a and 45b below represent the linear correlations for the 0 – 3mg/L and 0 – 1mg/L polymer concentration ranges, respectively, using the in-line spectrophotometer in samples of the same Rideau River water sample as above with a turbidity of 32NTU containing all Actiflo® enhanced coagulation process chemicals.

Figure 45: Linear correlation of Magnafloc LT27AG polymer in Rideau River (32.0 NTU) water dosed with Actiflo® enhanced coagulation process chemicals using an in-line spectrophotometer with a 4mm flow cell in the concentration ranges of (a) 0-3 mg/L and (b) 0-1 mg/L

From Figures 44a and 44b, it is clear to see that the desktop spectrophotometer again was unable to detect the increase in polymer concentration in the presence of Actiflo® process chemicals present in the Rideau River water sample. This is depicted by the lack of correlation between polymer concentration and absorbance at both polymer concentration ranges, with the high range indicating a coefficient of determination of $R^2 = 0.364$ and the low range being $R^2 = 0.155$. This is most likely due to the fact that the desktop spectrophotometer does not have the required sensitivity to detect the small concentrations of polymer in the presence of the potassium permanganate, which contributes to quite a

substantial background absorbance on this unit. Comparatively, from Figures 45a and 45b, the in-line unit was still able to form a slightly better positive linear correlation between polymer concentration and absorbance in the presence of Actiflo® process chemicals in a Rideau River water sample. The higher polymer concentration range, Figure 45a, showed a substantial decrease in this correlation ($R^2 = 0.449$) when compared to the same sample set in deionized water, as depicted in Figure 43a ($R^2 = 0.843$). This decrease in correlation is likely due to the increase in particulate matter present in the sample, as indicated by the increase in turbidity, contributing to an increase in background absorbance. The lower polymer concentration range formed a very similar correlation in Rideau River water, Figure 45b, as the same sample set in deionized water, Figure 43b. The coefficient of determination values were relatively similar, however the slope of the correlation did increase from 0.1941 in the deionized water sample to 1.0056 in the Rideau River water sample. These results not only indicate that the in-line unit is a more sensitive tool for the detection of residual polymer in drinking water treatment applications when compared to the desktop unit, but also that the correlation between residual polymer concentration and absorbance can still be detected at very low concentrations in the presence of additional process chemicals in raw water matrices.

4.4 Determination of optimum polymer dose in drinking water treatment using UV-vis spectroscopy

Two bulk water samples, one measuring a high turbidity and one measuring a low turbidity, were collected from the Rideau River in Ottawa, Ontario. Each sample was dosed with polymer, a Magnafloc LT27AG anionic polymer and a Hydrex 3661 cationic polymer, in concentration ranges both overdosing and under-dosing the optimum polymer dosage. The optimum polymer dose for each water sample was pre-determined using a preliminary settling test, and turbidity measurements of the supernatant were taken of each sample dosed with polymer concentrations within the optimum dose range. The samples were left to settle for a period of time relative to that required for the optimal dose to reach visible clarity, and the supernatant was then collected and used for UV-vis absorbance measurements on both an in-line spectrophotometer and a desktop spectrophotometer. A relationship between the optimum polymer dose and the supernatant absorbance at 190nm was established for both polymer types in both the high and low turbidity bulk water samples. In addition to this, a particle counter was also used to measure the particle counts of each sample of supernatant for each data set. This was done in order to further analyze the data and determine whether or not trends in the particle data corresponded to those of the turbidity data, as well as the absorbance data. In addition to this, the effect of Actiflo® enhanced coagulation process chemicals on the determination of optimum dose using UV-vis spectroscopy was also explored.

4.4.1 Magnafloc LT27AG Polymer

4.4.1.1 Settling tests

Magnafloc LT27AG is an anionic polyacrylamide polymer with an ultra-high molecular weight and a medium charge density. A preliminary settling test was performed on each different water matrices in order to determine the optimum polymer dose range based on apparent clarity of the supernatant and the fastest settling time. The samples, prepared in graduated cylinders, were overdosed and under-dosed with polymer relative to this optimum dose range and left to settle whilst being observed and timed simultaneously. Once a particular sample supernatant reached apparent clarity, the time was recorded, and this sample was assumed to contain the optimum polymer dosage. At this time, the supernatant of all other samples was collected to be used for turbidity measurements, and the interfaces of the sediment in each sample were also measured and recorded. Tables 13, 14 and 15 below represent the results of the settling tests for the high turbidity Rideau River water, the low turbidity Rideau River water, and the high turbidity Rideau River water also dosed with Actiflo® enhanced coagulation process chemicals.

Table 13: Settling test data for high turbidity (9172 NTU) Rideau River Water dosed with Magnafloc LT27AG polymer

Polymer Concentration (mg/L)	Interface (mm)	Supernatant Turbidity (NTU)
0.00	N/A	9172
0.10	2.0	595
0.50	2.0	252
1.00	2.0	185
1.50	3.0	157
2.00	6.0	140
3.00	6.0	178
4.00	3.0	190
5.00	4.0	209
Optimum Settling Time		170 seconds at 2.00mg/L polymer dose

Table 14: *Settling test data for low turbidity (260 NTU) Rideau River Water dosed with Magnafloc LT27AG polymer*

Polymer Concentration (mg/L)	Interface (mm)	Supernatant Turbidity (NTU)
0.00	N/A	260
0.05	~1.0	107
0.10	~1.0	108
0.50	~1.0	113
1.00	~1.0	114
1.50	~1.0	115
2.00	~1.0	110
3.00	~1.0	125
Optimum Settling Time		160 seconds at 0.05mg/L polymer dose

Table 15: *Settling test data for high turbidity (9000 NTU) Rideau River Water dosed Actiflo® enhanced coagulation process chemicals and Magnafloc LT27AG polymer*

Polymer Concentration (mg/L)	Interface (mm)	Supernatant Turbidity (NTU)
0.00	N/A	9000
0.05	2.0	980
0.10	2.0	965
0.50	4.0	385
1.00	3.0	373
2.00	3.0	392
4.00	2.0	462
6.00	2.0	516
8.00	2.0	525
Optimum Settling Time		266 seconds at 0.50mg/L polymer dose

From these preliminary settling test results, the optimum dose of Magnafloc LT27AG polymer water was determined to be 2.00mg/L for the high turbidity Rideau River, 0.05mg/L for the low turbidity Rideau River water, and 0.50mg/L for the high turbidity Rideau River water dosed with Actiflo® enhanced coagulation process chemicals. These results were based on apparent clarity of the supernatant and the fastest settling time.

4.4.1.2 Turbidity measurements

Samples of Rideau River water of both high and low turbidity were dosed with polymer both overdosing and under-dosing the optimum polymer dose range which was pre-determined through a preliminary settling test, as described above. The supernatant of the settled samples was collected and used for turbidity measurements, absorbance measurements as well as particle count measurements. In order to better visualize the relationship between turbidity and polymer dosage, the data was plotted in scatter plot form. Figure 46 below represents the turbidity data in relation to polymer concentration for the supernatant of high turbidity (9172NTU) Rideau River water samples dosed with polymer both over and under-dosing the preliminarily determined optimum dosage range.

Figure 46: Turbidity values corresponding to Magnafloc LT27AG polymer concentrations within the optimum dose range in the supernatant of a high turbidity (9172NTU) Rideau River water sample

Figure 47 below represents the turbidity data in relation to polymer concentration for the supernatant of low turbidity (260 NTU) Rideau River water samples dosed with polymer both over and under-dosing the preliminarily determined optimum dosage range.

Figure 47: Turbidity values corresponding to Magnafloc LT27AG polymer concentrations within the optimum dose range in the supernatant of a low turbidity (260 NTU) Rideau River water sample

Figure 48 below represents the turbidity data in relation to polymer concentration for the supernatant of high turbidity (9000 NTU) Rideau River water samples dosed with polymer both over and under-dosing the preliminarily determined optimum dosage range. In addition, each sample was also dosed with Actiflo® enhanced coagulation process chemicals in concentrations listed in Table 4 found in Chapter 3: Materials and Methods.

Figure 48: Turbidity values corresponding to Magnafloc LT27AG polymer concentrations within the optimum dose range in the supernatant of a high turbidity (9000 NTU) Rideau River water sample dosed with Actiflo® enhanced coagulation process chemicals

Figure 46, representing the relationship between turbidity and polymer concentration in the supernatant of a high turbidity (9172 NTU) Rideau River water sample, reports that the minimum turbidity (140 NTU) corresponds to the sample dosed with 2.0mg/L of polymer. This polymer concentration is in accordance with the preliminary value determined using the settling test. As was expected, an under-dose of polymer resulted in an increase in turbidity. This is due to the fact that polymer has a finite capacity for absorption; if there is an insufficient concentration of polymer available in the sample solution to properly coagulate the suspended particulates, more particles will remain in the supernatant post-settling and the turbidity will measure a higher value (5). As polymer dosage was increased toward the optimum value, the turbidity decreased accordingly. Again, this is expected seeing that an increase in polymer concentration implies an increase in capacity for absorption. In the overdose range, a slight increase in turbidity was observed, however the values measured only slightly higher than the minimum value associated with the optimum

dose. This is expected, as the optimum polymer dose corresponds to the concentration of polymer at which the maximum absorbance occurs. Beyond this dosage the polymer is no longer effective, and the removal of suspended particulates no longer increases, meaning the turbidity should remain fairly constant. The slight increase in turbidity can be attributed to the fact that the excess polymer in the overdose range will remain suspended in the supernatant as residual polymer, which contributes slightly to the overall turbidity.

Figure 47, representing the relationship between turbidity and polymer concentration in the supernatant of a low turbidity (260 NTU) Rideau River water sample, reports that the minimum turbidity (107 NTU) corresponds to the sample dosed with 0.05mg/L of Magnafloc polymer. The sample dosed with 0.10mg/L of polymer is only marginally more turbid (108 NTU). These concentration values coincide with the predetermined settling test estimates. The samples were not under-dosed beyond the value of 0.05mg/L as accurately measuring this volume of polymer is extremely difficult due to the viscous solution polymer forms with water. In the overdosed range, the turbidity once again increases with increasing polymer dose. There is the exception of the 2.0mg/L dosage, in which case the turbidity decreases suddenly to 110 NTU. This outlier may be due to an issue with the mixing of the bulk sample, which was mixed prior to preparing each sample of different polymer concentration in order to maintain suspension of particles and ensure each individual sample was created with water of equal turbidity. There is the possibility that the raw water collected to prepare the 2.0mg/L contained a less evenly distributed number of suspended particles, and in turn a lower initial turbidity than the other samples, leading to a lower turbidity overall after settling. These results indicate that in water matrices of

lower turbidity, determining the optimum polymer dose using turbidity measurements alone may not be a viable method for accurate results.

Figure 48, representing the relationship between turbidity and polymer concentration in the supernatant of a high turbidity (9000 NTU) Rideau River water sample dosed with Actiflo enhanced coagulation process chemicals, reports that the minimum turbidity (373 NTU) corresponds to a 1.00mg/L dosage of polymer. Again, this dosage corresponds to the optimum dose range that was predetermined using an initial settling test. In the under-dose range, the curve once again tends to the previously observed pattern of increased turbidity, which decreases as the polymer concentration is incremented towards optimal concentration. Beyond this optimum dosage, as polymer concentration is further increased into the overdose range, the turbidity follows the previously observed trend of increasing slightly. These results indicate that in highly turbid water matrices containing additional water treatment chemical constituents, the method of determining optimum polymer dose through turbidity measurements has viable potential using Magnafloc LT27AG polymer.

4.4.1.3 UV-vis absorbance spectra

In order to test the viability of using UV-vis spectrophotometry as a method of determining optimum polymer dose in drinking water treatment applications, the optimum dose results of the settling test and turbidity measurements were compared to the absorbance results produced by UV-vis spectroscopy using both a desktop and in-line spectrophotometer. The supernatant of the samples prepared for the settling tests and turbidity measurements was reserved and used for the UV-vis spectroscopy absorbance tests as well. Figures 49a and

49b below represent the absorbance spectra of the supernatant of high turbidity (9172NTU) Rideau River water samples dosed with Magnafloc polymer at concentrations both overdosing and under-dosing the optimum polymer dose range using a desktop and in-line spectrophotometer, respectively. Figures 50a and 50b below represent the absorbance spectra of the supernatant of low turbidity (260 NTU) Rideau River water samples dosed with Magnafloc polymer at concentrations both overdosing and under-dosing the optimum polymer dose range using a desktop and in-line spectrophotometer, respectively.

Figure 49: UV-vis absorbance spectra of Magnafloc LT27AG polymer in a sample of high turbidity (9172 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for identifying the samples optimum polymer dose

Figure 50: UV-vis absorbance spectra of Magnafloc LT27AG polymer in a sample of low turbidity (260 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for identifying the samples optimum polymer dose

As is observed in Figures 49 and 50, both the high and low turbidity Rideau River water samples resulted in absorbance spectra with the expected shape and peak absorbance at 190nm using both the desktop and in-line spectrophotometers. The peak absorbance values of the high turbidity samples were slightly higher on both spectrophotometers when compared to that of the low turbidity samples, which is expected as the increase in suspended particulates contributes to the absorbance value. There absorbance spectra curves of each different concentration are also more sparsely distributed than those in experimental phases one, two and three. This is also expected seeing that the polymer is overdosed and under-dosed relative to the optimum dose rather than dosed in equal incrementations as has been done for all previous experimental phases.

The same experiment was also conducted with Magnafloc polymer in a high turbidity (9000 NTU) Rideau River water sample dosed with Actiflo® enhanced coagulation

process chemicals in concentrations reported in Table 4 found in Chapter 3: Materials and Methods. Figures 51a and 51b below represent the absorbance spectra for the supernatant of these high turbidity Rideau River water samples treated with Actiflo® enhanced coagulation process chemicals using both the desktop and in-line spectrophotometers, respectively.

Figure 51: UV-vis absorbance spectra of Magnafloc LT27AG polymer in a sample of high turbidity (9000 NTU) Rideau River water dosed with Actiflo enhanced coagulation process chemicals using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for identifying the samples optimum polymer dose

Again, from Figure 51 it is apparent that even in the presence of Actiflo® enhanced coagulation process chemicals in a highly turbid water sample, the supernatant of the treated samples resulted in the expected shape and peak absorbance values at 190nm using both the desktop and in-line spectrophotometers. The curves were higher in peak absorbance than those of the samples not containing the Actiflo® process chemicals, which was expected as the chemicals do contribute to some of the overall absorbance of the sample. Regardless of this, a clear increase in absorbance at 190nm as well as an increase

and decrease in overall absorbance between the overdosed and under-dosed samples, respectively, is still observed in the presence the additional constituents added to each sample. These results, along with those in Figures 49 and 50, demonstrate that the use of UV-vis absorbance as a method for the detection of residual polymer can be replicated in water matrices of both high and low turbidity, with and without the addition of process chemicals.

4.4.1.4 *Linear correlations*

As was done for all other absorbance data gathered during the previous experimental phases, linear correlations of peak absorbance data versus polymer concentration from Figures 49, 50 and 51 were plotted in order to further analyze the absorbance-polymer concentration relationship and determine whether or not UV-vis spectroscopy is a method capable of observing the optimum polymer dose in each different water sample. The linear relationship between the polymer concentration and sample absorbance allows for the construction of a calibration curve to determine unknown polymer concentrations in a given water sample. Figures 52a and 52b below represent the linear correlations of high turbidity (9172 NTU) Rideau River water samples overdosed and under-dosed with Magnafloc polymer relative to the polymers predetermined optimum dosage range using both a desktop and in-line spectrophotometer, respectively.

Figure 52: Linear correlation of Magnafloc LT27AG absorbance at 190nm in high turbidity (9172 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for determination of the sample's optimum polymer dose

Figures 53a and 53b below represent the linear correlations of low turbidity (260 NTU) Rideau River water samples overdosed and under-dosed with Magnafloc polymer relative to the polymers predetermined optimum dosage range using both a desktop and in-line spectrophotometer, respectively.

Figure 53: Linear correlation of Magnafloc LT27AG absorbance at 190nm in low turbidity (260 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for determination of the sample's optimum polymer dose

Figures 54a and 54b below represent the linear correlations of high turbidity (9000 NTU) Rideau River water samples dosed with Actiflo process chemicals using both the desktop and in-line spectrophotometers, respectively. Again, these samples overdosed and underdosed with Magnafloc polymer relative to the polymers predetermined optimum dosage range.

Figure 54: Linear correlation of Magnafloc LT27AG absorbance at 190nm in high turbidity (9000 NTU) Rideau River water dosed with Actiflo® enhanced coagulation process chemicals using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for determination of the sample's optimum polymer dose

The linear correlations depicted in Figures 52, 53 and 54 demonstrate some very interesting and promising results for the use of UV-vis spectroscopy as a tool for the optimization of polymer dose in drinking water treatment applications. The results of the highly turbid water samples dosed with polymer, as seen in Figure 52, demonstrate that on both the desktop and in-line spectrophotometers, the lowest absorbance value, 2.220 A.U. on the desktop unit and 1.240 A.U. on the in-line unit, corresponds to the sample with a 2.0mg/L concentration of Magnafloc polymer. When comparing this value to that of the predetermined optimum dose done using a settling test, the value of 2.0mg/L remains

consistent. When the polymer concentration was lower than 2.0mg/L, or under-dosed, the sample dosed with a 0.10mg/L concentration of polymer resulted in an increase in absorbance values on both spectrophotometers, 2.940 A.U. for the desktop unit and 1.34mg/L on the Real tech unit. As the polymer dose concentration is further increased from 0.1mg/L towards 2.0mg/L, a steady decrease in absorbance is observed on both the desktop and in-line spectrophotometers. Beyond 2.0mg/L, or when the polymer is overdosed, again a steady increase in absorbance is observed until the maximum polymer dose of 5.0mg/L is reached, resulting in absorbance value increases to 2.470 A.U. on the desktop unit and 1.590 A.U. on the in-line unit. This is further observed in Figure 46, which depicts the turbidity data for the supernatant of the same sample set. The turbidity results also show a minimum value when the sample was dosed with 2.0mg/L of polymer, indicating that for the highly turbid water sample a polymer dose of 2.0mg/L resulted in the clearest supernatant after settling, and was thus dosed optimally with polymer. In addition, the turbidity results also show very similar trends to the absorbance results in the under-dosed range, indicating that as polymer dosage is increased towards an optimum concentration, the turbidity decreases steadily as well. In the overdosed range, however, the turbidity results neither increase nor decrease with increasing polymer concentration and instead remain fairly constant.

When observing Figures 53 and 54, for the low turbidity water sample and the high turbidity water sample dosed with Actiflo enhanced coagulation process chemicals, respectively, very similar results are demonstrated. In Figure 53, both spectrophotometers indicated that the lowest absorbance value, 2.170 A.U. using the desktop unit and 1.060

A.U. using the in-line unit, corresponded to the sample with a 0.10mg/L polymer concentration in Rideau River water with a low turbidity. This value is in accordance with the optimum dose predetermined using the preliminary settling tests, as well as within the range of the turbidity measurements for the supernatant of the same sample set presented in Figure 47. The turbidity measurements indicated that the lowest turbidity (107 NTU) corresponded to the sample dosed with 0.05mg/L of polymer, however the sample dosed with 0.10mg/L of polymer was only marginally more turbid (108 NTU). Moreover, Figure 54 demonstrates that both spectrophotometers reported a minimum supernatant absorbance value, 2.540 A.U. for the desktop unit and 1.120 A.U. for the in-line unit, corresponding to the sample with a 0.50mg/L polymer concentration. This value is in accordance with the optimum dose predetermined using the preliminary settling tests, as well as within the range of the turbidity measurements for the supernatant of the same sample set presented in Figure 48. The turbidity measurements indicated that the lowest turbidity (373 NTU) corresponded to the sample dosed with 1.0mg/L of polymer, however the sample dosed with 0.5mg/L of polymer was only marginally more turbid (385 NTU). Both Figures 53 and 54 also followed the same curve shape trends, showing a decrease in absorbance in the under-dose range until the optimum polymer dose is reached, at which point the overdose of polymer corresponds to an increase in absorbance.

The absorbance results presented in Figures 52, 53 and 54 and their accordance with the turbidity results presented in Figures 46, 47 and 48 demonstrate that the use of UV-vis spectroscopy as a method for the determination of optimum polymer dose is very

promising. These results also indicate that the method can be replicated in water matrices of both high and low turbidity, with and without the addition of process chemicals.

4.4.1.5 Total particle concentration

In order to further explore the trend between optimum polymer dose and minimum turbidity as well as minimum absorbance, particle counts were also measured from each sample of supernatant for all three water matrices using a Dynamic Particle Analyzer (BP-4100-HEV model) manufactured by BrightWell Technologies INC (Ottawa, ON). It was hypothesized that the optimum polymer dose should remove the greatest number of particles from the water sample, and therefore the supernatant should in turn contain a minimum number of particles at this polymer concentration. Figure 55 below represents the relationship between polymer concentration and particle concentration in the supernatant of a high turbidity (9172 NTU) Rideau River water sample.

Figure 55: Particle counts corresponding to Magnafloc LT27AG polymer concentrations within the optimum dose range in the supernatant of a high turbidity (9172 NTU) Rideau River water sample

Figures 56 and 57 below represent the relationship between polymer concentration and particle concentration in the supernatant of a low turbidity (260 NTU) Rideau River water sample and a high turbidity (9000 NTU) Rideau River water sample dosed with Actiflo® enhanced coagulation process chemicals, respectively.

Figure 56: Particle counts corresponding to Magnafloc LT27AG polymer concentrations within the optimum dose range in the supernatant of a low turbidity (260 NTU) Rideau River water sample

Figure 57: Particle counts corresponding to Magnafloc LT27AG polymer concentrations within the optimum dose range in the supernatant of a high turbidity (9000 NTU) Rideau River water sample dosed with Actiflo® enhanced coagulation process chemicals

Figure 55 illustrates that the lowest particle concentration (2.36×10^5 #particles/mL) coincides with the sample dosed with a polymer concentration of 2.0mg/L. This polymer concentration is in accordance with the optimum polymer dose determined through the preliminary settling test results depicted in Table 13, the turbidity results depicted in Figure 46, and the absorbance results depicted in Figure 52. The trends observed in all other results for this high turbidity water sample are once again observed in the particle count results, demonstrating an increase in total particle concentration (5.40×10^5 #particles/mL) in the under-dose range which then incrementally decreases as the polymer dose is increased towards the optimum concentration of 2.0mg/L. Beyond this concentration, as the polymer dose is increased, the total particle concentration then increases incrementally to a value of 3.76×10^5 #particles/mL corresponding to the maximum polymer dose of 5.0mg/L.

Figure 56 shows very similar trends in the low turbidity water sample, illustrating that the lowest total particle concentration (2.11×10^5 #particles/mL) corresponds to a polymer concentration of 0.10mg/L. This polymer concentration is in accordance with the optimum polymer dose determined using the UV-vis spectroscopy absorbance method depicted in Figure 53. The preliminary settling test, depicted in Table 14, and the turbidity results, depicted in Figure 47, suggested the optimum polymer dose be slightly lower at a concentration of 0.05mg/L. These preliminary results were likely not as sensitive as the absorbance and particle count results, as there was very marginal difference in turbidity between 0.10mg/L and 0.05mg/L concentrations of polymer; whereas there is a more noticeable distinction between the difference in absorbance (1.180 A.U. and 1.060 A.U.,

respectively, using the in-line unit) and the difference in particle concentration (2.94×10^5 #particles/mL and 2.11×10^5 #particles/mL, respectively) between the two concentrations.

Again, Figure 57 demonstrates very similar trends in the high turbidity water sample dosed with Actiflo® process chemicals, with results showing a minimum total particle concentration corresponding to a polymer concentration of 0.50mg/L. This polymer concentration is in accordance with the optimum polymer dose determined using the UV-vis spectroscopy absorbance method depicted in Figure 54. The preliminary settling test, depicted in Table 15, and the turbidity results, depicted in Figure 48, suggested the optimum polymer dose be slightly higher at a concentration of 1.0mg/L. Again, this variation is likely due to the fact that UV-vis spectroscopy and particle counting offer more sensitive results as there was very marginal difference in turbidity between 0.50mg/L and 1.0mg/L concentrations of polymer; whereas there is a more noticeable distinction between the difference in absorbance (1.120 A.U. and 1.390 A.U., respectively, using the in-line unit) and the difference in particle concentration (1.07×10^5 #particles/mL and 4.51×10^5 #particles/mL, respectively) between the two concentrations.

The fact that the particle count results between all three water sample matrices coincide with the absorbance results infers that UV-vis spectroscopy has the viability to be used as a tool for the optimization of polymer dose for Magnafloc LT27AG. The preliminary settling test and turbidity results are also in accordance with these results, furthering this inference. In addition, the ability of this method to succeed in a variety of different water matrices demonstrates replicability.

4.4.2 Hydrex 3661 Polymer

4.4.2.1 Settling tests

Hydrex 3661 is a cationic polyacrylamide polymer with a high molecular weight. This polymer was used to replicate the same experimental setup as was done for the Magnafloc LT27AG polymer, with the aim of testing the replicability of UV-vis spectroscopy as a method for determining the optimum polymer dose in both a high and low turbidity water sample using a polymer of opposing charge. Using the same method as was done using the Magnafloc LT27AG polymer, a preliminary settling test was performed on both high (4426 NTU) and low (546 NTU) turbidity water matrices in order to determine the optimum polymer dose range based on apparent clarity of the supernatant and the fastest settling time. Dissimilar to the tests performed using Magnafloc LT27AG, the experiments carried out using Hydrex 3661 were not performed in water matrices dosed with Actiflo® enhanced coagulation treatment chemicals due to the fact that this process specifies the use of Magnafloc LT27AG polymer only. Tables 16 and 17 below represent the results of the settling tests for the high turbidity Rideau River water and the low turbidity Rideau River water, respectively.

Table 16: *Settling test data for high turbidity (4426 NTU) Rideau River Water dosed with Hydrex 3661 polymer*

Polymer Concentration (mg/L)	Interface (mm)	Supernatant Turbidity (NTU)
0.00	N/A	4426
3.00	2.0	171
4.00	4.0	122
5.00	3.0	106
6.00	4.0	92
7.00	4.0	126
8.00	4.0	93
10.00	5.0	118
12.00	5.0	129
Optimum Settling Time		210 seconds at 8.00mg/L polymer dose

Table 17: *Settling test data for low turbidity (546 NTU) Rideau River Water dosed with Hydrex 3661 polymer*

Polymer Concentration (mg/L)	Interface (mm)	Supernatant Turbidity (NTU)
0.00	N/A	546
0.025	~1.0	395
0.05	~1.0	350
0.10	~1.0	325
0.50	~1.0	231
1.00	~1.0	155
2.00	2.0	113
4.00	2.0	98
6.00	~1.0	107
8.00	~1.0	90
10.00	~1.0	108
Optimum Settling Time		262 seconds at 2.00 mg/L polymer dose

From these preliminary settling test results, the optimum dose of Hydrex 3661 polymer was determined to be 8.0mg/L for the high turbidity Rideau River and 2.0mg/L for the low turbidity Rideau River water. These results were based on apparent clarity of the supernatant and the fastest settling time. The interface post-settling was quite variable in both the high and low turbidity water samples, and not much of a trend is observed.

4.4.2.2 Turbidity measurements

As was done for samples dosed with Magnafloc LT27AG polymer, the supernatant of the settled samples dosed with Hydrex 3661 polymer was collected and used for turbidity measurements, absorbance measurements as well as particle count measurements. In order to better visualize the relationship between turbidity and polymer dosage, the data was plotted in scatter plot form. Figures 58 and 59 below represent the turbidity data in relation to polymer concentration for the supernatant of the high turbidity (4426 NTU) and the low turbidity (546 NTU) Rideau River water samples dosed with polymer both over and under-dosing the preliminarily determined optimum dosage range, respectively.

Figure 58: Turbidity values corresponding to Hydrex 3661 polymer concentrations within the optimum dose range in a high turbidity (4426 NTU) Rideau River water sample supernatant

Figure 59: Turbidity values corresponding to Hydrex 3661 polymer concentrations within the optimum dose range in a low turbidity (546 NTU) Rideau River water sample supernatant

Figure 58, representing the relationship between turbidity and polymer concentration in the supernatant of a high turbidity (4426 NTU) Rideau River water sample, reports that the minimum turbidity (92 NTU) corresponds to the sample dosed with 6.0mg/L of polymer. This polymer concentration differs slightly from the preliminary value determined using the settling test, which determined the fastest settling time to occur at a polymer dose of 8.0mg/L. However, the turbidity between the 6.0mg/L sample (92 NTU) was only marginally less than that of the 8.0mg/L sample (93 NTU), implying that the turbidimeter does not possess the sensitivity to detect a substantial difference between these polymer dosages. As was expected, an under-dose of polymer resulted in an increase in turbidity. As polymer dosage was increased toward the optimum value, the turbidity decreased accordingly. At a polymer dose of 7.0mg/L, one incremental dose higher than the presumed optimum dose, a spike in turbidity was observed (126 NTU). Beyond 7.0mg/L, in the overdose range, the expected trend was observed and only a slight increase in turbidity was noted once again. This spike in turbidity at a polymer concentration of 7.0mg/L may once

again be attributed to the fact that the bulk sample, assumed to be homogeneous post-mixing, may have not settled for as long a period as the other samples in the set. This would lead to a potential higher initial turbidity of this specific sample, thus resulting in a higher turbidity post-settling test. Regardless of this spike, the remaining samples of varying polymer concentration tend to the expected trend.

Figure 59, representing the relationship between turbidity and polymer concentration in the supernatant of a low turbidity (546 NTU) Rideau River water sample, reports that the minimum turbidity (90 NTU) corresponds to the sample dosed with 8.0mg/L of Hydrex 3661 polymer. This concentration value differs from the predetermined settling test estimates, which suggested the optimum polymer dose should be in the range of 2.0mg/L for this particular water matrix. In the under-dose range, the turbidity once again follows the expected trend of decreasing with increasing polymer concentration. However, at 4.0mg/L, the turbidity rests at a value of 98 NTU, increasing only slightly to 107 NTU (at a 6.0mg/L polymer concentration) before reaching the minimum value of 90 NTU. In the overdosed range, the turbidity once again increases marginally with increasing polymer dose. Between 4.0mg/L and 10.0mg/L, the variance in turbidity veers only slightly and the exact optimum dose is suggestive. These results again indicate that in water matrices of lower turbidity, determining the optimum polymer dose using turbidity measurements alone may not be a viable method for accurate results in drinking water treatment applications.

4.4.2.3 UV-vis absorbance spectra

As was done for the samples prepared using Magnafloc LT27AG, the viability of using UV-vis spectrophotometry as a method of determining optimum polymer dose for cationic polymers in drinking water treatment applications was tested. This was again done by comparing the preliminary optimum dose results of the settling test and turbidity measurements to absorbance results produced through UV-vis spectroscopy using both a desktop and in-line spectrophotometer. The supernatant of the samples prepared for the settling tests and turbidity measurements was reserved and used for the UV-vis spectroscopy absorbance tests as well. Figures 60a and 60b below represent the absorbance spectra of the supernatant of high turbidity (4426 NTU) Rideau River water samples dosed with Hydrex 3661 polymer at concentrations both overdosing and under-dosing the optimum polymer dose range using a desktop and in-line spectrophotometer, respectively.

Figure 60: UV-vis absorbance spectra of Hydrex 3661 polymer in a sample of high turbidity (4426 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for identifying the samples optimum polymer dose

Figures 61a and 61b below represent the absorbance spectra of the supernatant of low turbidity (546 NTU) Rideau River water samples dosed with Hydrex 3661 polymer at concentrations both overdosing and under-dosing the optimum polymer dose range using a desktop and in-line spectrophotometer, respectively.

Figure 61: UV-vis absorbance spectra of Hydrex 3661 polymer in a sample of low turbidity (546 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for identifying the samples optimum polymer dose

As is observed in Figures 60 and 61, both the high and low turbidity Rideau River water samples resulted in absorbance spectra with the expected shape and peak absorbance at 190 nm using both the desktop and in-line spectrophotometers. The absorbance spectra curves of each different concentration are again more sparsely distributed than those in experimental phases one, two and three. This is expected, seeing that the polymer is overdosed and under-dosed relative to the optimum dose rather than dosed in equal increments as has been done for all previous experimental phases. This, in-turn, results in curves that increase un-uniformly between polymer concentrations.

4.4.2.4 Linear correlations

As for all other absorbance data gathered during the previous experimental phases, linear correlations of peak absorbance data versus polymer concentration from Figures 58 and 59 were plotted in order to further analyze the absorbance-polymer concentration relationship and determine whether or not UV-vis spectroscopy is a method capable of observing the optimum polymer dose in each different water sample. Figures 62a and 62b below represent the linear correlations of high turbidity (4426 NTU) Rideau River water samples overdosed and under-dosed with Hydrex 3661 polymer relative to the polymers predetermined optimum dosage range using both a desktop and in-line spectrophotometer, respectively.

Figure 62: Linear correlation of Hydrex 3661 polymer absorbance at 190nm in high turbidity (4426 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for determination of the sample's optimum polymer dose

Figures 63a and 63b below represent the linear correlations of low turbidity (546 NTU) Rideau River water samples overdosed and under-dosed with Hydrex 3661 polymer relative to the polymers predetermined optimum dosage range using both a desktop and in-line spectrophotometer, respectively.

Figure 63: Linear correlation of Hydrex 3661 polymer absorbance at 190nm in low turbidity (546 NTU) Rideau River water using a (a) desktop spectrophotometer and a (b) in-line spectrophotometer for determination of the sample's optimum polymer dose

The linear relationship between polymer concentration and absorbance at 190 nm of the highly turbid water sample (Figure 62) demonstrate very similar trends to those observed in a high turbidity sample dosed with Magnafloc LT27AG (Figure 52). Again, in the under-dose range, the absorbance decreases with increasing polymer concentration until it reaches a minimum value at 8.0mg/L on both spectrophotometers; 1.420 A.U. on the desktop unit and 0.630 A.U. on the in-line unit. This value is in accordance with the value estimated through the preliminary settling tests and turbidity results for this water sample. Beyond this concentration, as polymer dose increases, the absorbance again demonstrates an

increase in absorbance with increasing polymer concentration. This increase in absorbance is notably more prominent than the increase in turbidity for the same supernatant samples, observed in Figure 58. This is likely due to the fact that beyond the optimum dosage, the polymer is no longer effective and therefore remains suspended in the solution as residual rather than absorbing onto particulates present in the sample and settling out. UV-vis spectroscopy is able to detect this residual polymer increase with increasing dose, whereas the turbidity measurements are not able to detect this. Another notable difference are the results between spectrophotometers, the desktop unit spiking in absorbance at the 7.0mg/L sample (Figure 62a) and the in-line unit demonstrating more of the expected relationship (Figure 62b), implying the in-line unit has a higher detection sensitivity and is able to detect very slight changes in polymer dosage at a wavelength of 190 nm.

The linear relationship between polymer concentration and absorbance in a low turbidity water sample (Figure 63) again shows very similar trends as observed with previous samples used for this experiment. The minimum absorbance value at 190nm using the desktop unit measured 1.013 A.U. and is observed at a concentration of 4.0mg/L of polymer. This value differs slightly from that read using the in-line unit, which detected a minimum absorbance value (0.399 A.U.) corresponding to a polymer concentration of 2.0mg/L. Comparing the absorbance values at 190nm between 2.0mg/L and 4.0mg/L read using the desktop unit (Figure 63a) there is a very marginal difference of 0.003 A.U. Alternatively, when comparing these same values read using the in-line unit (Figure 63b) there is a more notable difference in absorbance of 0.038 A.U. between the 2.0mg/L and 4.0mg/L samples. Again, the ability of the in-line unit to detect a larger variance in

absorbance between samples of varying polymer concentration infers that this spectrophotometer is a more sensitive tool for the detection of residual polymer than the desktop unit. Using this logic, the optimum polymer dosage should therefore correspond to 2.0mg/L, as reported by the in-line spectrophotometer. In the under-dose and overdose ranges, both spectrophotometers demonstrate the expected trends as observed in previous samples. The optimum dosage value of 2.0mg/L determined using the UV-vis spectroscopy method differs from the optimum dose value of 8.0mg/L determined through the preliminary turbidity measurements; however, it is in accordance with the value of 2.0mg/L determined using the preliminary settling tests and settling time. As was previously noted, the turbidity test method of determining the optimum polymer dose lacks in sensitivity in the overdose range, whereas the UV-vis absorbance measurement method is able to detect residual polymer in the overdose range and indicate its presence in solution through an increase in absorbance. This results in a more obvious minimum absorbance reading as opposed to the more ambiguous minimum turbidity reading, which is likely why the absorbance measurements are in accordance with the settling test estimates for the optimum dosage of Hydrex 3661 in the low turbidity water sample.

The results of the linear relationship between polymer concentration and absorbance presented in Figures 62 and 63; and their accordance with the turbidity results presented in Figures 58 and 59 demonstrate that the use of UV-vis spectroscopy as a method for the determination of optimum polymer dose for cationic polymers is very promising. These results also indicate that the method can be replicated not only in water matrices of both high and low turbidity, but also using polymers of variable charge.

4.4.2.5 Total particle concentration

As was done for the samples prepared with Magnafloc LT27AG polymer, the trend between optimum polymer dose and minimum turbidity as well as minimum absorbance was compared to the total particle concentration of each sample of supernatant for both water matrices using a Dynamic Particle Analyzer (BP-4100-HEV model) manufactured by BrightWell Technologies INC (Ottawa, ON). It was hypothesized that the optimum polymer dose for the cationic polymer should again remove the greatest number of particles from the water sample, and therefore the supernatant should in turn contain a minimum number of particles at this polymer concentration. Figures 64 and 65 below represent the relationship between polymer concentration and particle concentration in the supernatant of a high turbidity (4426 NTU) and low turbidity (546 NTU) Rideau River water sample dosed with Hydrex 3661, respectively.

Figure 64: Particle counts corresponding to Hydrex 3661 polymer concentrations within the optimum dose range in a high turbidity (4426 NTU) Rideau River water sample supernatant

Figure 65: Particle counts corresponding to Hydrex 3661 polymer concentrations within the optimum dose range in a low turbidity (546 NTU) Rideau River water sample supernatant

Figure 64 illustrates that the lowest particle concentration (2.18×10^4 #particles/mL) coincides with the sample dosed with a polymer concentration of 7.0 mg/L. This polymer concentration is in range of the optimum polymer dose determined through the preliminary turbidity results depicted in Figure 58, and the absorbance results depicted in Figure 62; both of which suggested the optimum dose measure 8.0mg/L. The preliminary settling test, however, suggested that the optimum dose measure close to 6.0mg/L. This is slightly different from the other results, however the settling test is based on visual appearance and settling time only, meaning it is very much an estimate and leaves room for error. The trends observed in all other results for this high turbidity water sample are once again observed in the particle count results, demonstrating an incremental decrease in total particle concentration with increasing polymer concentration towards the optimum concentration of 7.0mg/L. At the 4.0mg/L polymer concentration, a slight decrease in total particle concentration is observed marginally outside of the trend. This may be due to

inadequate mixing of the sample prior to measuring total particle concentration, as the samples following tend back to the expected trend. Beyond the optimum concentration, as the polymer dose is increased, the total particle concentration then increases incrementally to a value of 1.19×10^5 #particles/mL corresponding to the maximum polymer dose of 12.0mg/L, following the expected trend based on previous results.

Figure 65 shows very similar trends in the low turbidity water sample, illustrating that the lowest total particle concentration (1.67×10^4 #particles/mL) corresponds to a polymer concentration of 1.0mg/L. This polymer concentration differs slightly with the optimum polymer dose of 2.0mg/L determined using the UV-vis spectroscopy absorbance method (Figure 63) and the preliminary settling test (Table 17) for the same sample. The preliminary turbidity results (Figure 59) suggested the optimum polymer dose be higher at a concentration of 8.0mg/L. Again, these preliminary results were likely not as sensitive as the absorbance and particle count results, as there was very marginal difference in turbidity between the 2.0mg/L and 10.0mg/L sample; whereas there is a more noticeable distinction between the difference in absorbance (0.453 A.U. and 0.599 A.U., respectively, using the in-line unit) and the difference in particle concentration (1.67×10^4 #particles/mL and 1.55×10^5 #particles/mL, respectively) between the two concentrations. The variance in optimum dose results between the particle concentration (1.0mg/L polymer) and the UV-vis absorbance (2.0mg/L polymer) suggests that the exact optimum dose lies in the range between these two concentrations.

The particle count results for the high and low turbidity water samples dosed with Hydrex 3661 coincide with the absorbance results, as was observed for the samples dosed with Magnafloc LT27AG. This infers that UV-vis spectroscopy has the viability to be used as a tool for the optimization of polymer dose for not only an anionic Magnafloc LT27AG polymer but can also be replicated using a cationic Hydrex 3661 polymer. In addition, the ability of this method to succeed in a variety of different water matrices further demonstrates replicability.

Table 18 below outlines a complete comparison of optimum dosages for both polymers in each water sample matrix determined using each of the four analytical methods. For both polymers in all water matrices, the more robust UV-vis spectroscopy and particle concentration method of determining optimum dose produced result in accordance with one another. There is a very slight discrepancy between the two methods using the Hydrex 3661 polymer, the total particle concentration resulting in an optimum dosage 1.0mg/L lower in both water samples. The settling test and turbidity measurements are also either in accordance or marginally variable to the UV-vis spectroscopy and particle concentration results for all samples and polymer types, with the exception of the turbidity results for the Hydrex 3661 polymer in the low turbidity water sample. The settling test and turbidity methods of determining optimum polymer dose are suitable to acquire a general polymer dose range, however the methods are quite rudimentary and are not expected to produce as precise of a result as UV-vis spectroscopy or total particle concentration

Table 18: Comparison of optimum polymer dosages determined using the four methods in all water samples

Polymer	Sample Type	Analytical Method			
		Settling Test	Turbidity	UV-vis absorbance	Total particle concentration
Magnafloc LT27AG	High Turbidity	2.00 mg/L	2.00 mg/L	2.00 mg/L	2.00 mg/L
Magnafloc LT27AG	Low Turbidity	0.05 mg/L	0.05 mg/L	0.10 mg/L	0.10 mg/L
Magnafloc LT27AG	Actiflo	0.50 mg/L	1.00 mg/L	0.50 mg/L	0.50 mg/L
Hydrex 3661	High Turbidity	8.00 mg/L	6.00 mg/L	8.00 mg/L	7.00 mg/L
Hydrex 3661	Low Turbidity	2.00 mg/L	8.00 mg/L	2.00 mg/L	1.00 mg/L

4.4.2 UV-vis absorbance as an in-line method for polymer optimization

The results of this phase of the study indicate that an in-line UV-vis spectrophotometer not only has the potential to be used as a tool for the detection, quantification and monitoring of residual polymer in drinking water treatment applications; but also as a method for the in-line real-time determination of optimum polymer dose necessary for drinking water treatment applications. UV-vis spectroscopy has proven to be a suitable method for this purpose, seeing that the process can be continuously automated, and the need for additional chemical reagents and/or dilution is eliminated.

There is the potential to create a feedback control loop that would correlate the absorbance value of the water post-coagulation and flocculation to the concentration of residual polymer present in the water sample. The output could then be used for the continuous adjustment of the polymer dose being added in real-time, ensuring efficient coagulation, reduced polymer costs, and a decrease in the concentration of residual polymer being released into environmental water sources. In order for this full-scale system to be implemented, a minimum search algorithm would need to be developed. This algorithm

would need to measure the change in slope between absorbance values coinciding with polymer concentrations as they vary, and minimize this slope through a polymer-dosing controller to maintain a constant optimum polymer dose. The development of this algorithm is outside the scope of this study, and will need to be explored through future work.

4.5 Discussion of UV-vis spectroscopy in comparison to other analytical methods for the detection of residual polymer in drinking water treatment applications

The results of experimental phases one, two and three demonstrate the viability of UV-vis spectroscopy as a sensitive method for the in-line detection of residual polymer in drinking water treatment applications, using the in-line spectrophotometer. These results also indicate that this method is suitable for water matrices containing particulate matter, as well as water matrices containing additional treatment chemicals used during drinking water treatment. As previously mentioned, the achievability of other analytical methods used for the detection of residual polymer in water treatment applications have also been explored.

High-performance liquid chromatography (HPLC) is an analytical method that has been researched extensively for the detection of residual acrylamide monomer in various water matrices. Brown and Read developed a HPLC/ultraviolet absorption detection procedure for the detection of acrylamide in samples of sea, river, potable and estuarine waters; as well as sewage and China clay works effluents. This method was able to achieve a detection range of 0.2-100 µg/L for acrylamide monomer, which at an assumed monomer content of

0.05% corresponds to a polyacrylamide concentration range of 4.0-2000 μ g/L (51). This procedure involves the bromination and extraction of α,β -dibromopropionamide with ethyl acetate, quantification using HPLC, and finally detection using ultraviolet detection, which is quite timely and impractical for use in-situ. Ver Vers developed a HPLC method using C₁₈ and ion-exchange columns in series for the determination of acrylamide and acrylic monomers in polymeric samples and detection limits were shown in the parts-per-billion range; however again this method is more suitable for studying polymer degradation and less applicable for in-situ residual polymer detection (52). Backe et al. also explored the use of large-volume injection hydrophilic-interaction liquid chromatography and tandem mass spectrometry for the determination of acrylamide residuals in environmental and drinking waters. Interestingly, this study found that the concentration of acrylamide leaving the drinking water plant (46ng/L) was about twice as high as that measured within the plant (21-27ng/L) (53). It is mentioned that this event was not isolated, and that samples from a separate water treatment plant showed similar results. This was attributed to the fact that acrylamide does not have a large affinity for sludge and sediment, and therefore is not significantly reduced through clarification and/or filtration processes (54). This large amount of residual polyacrylamide was suspected to be degraded to its acrylamide monomer form through disinfection (chloroamination) or fluoridation processes (53). The advantage of using HPLC for the detection of residual polymer in drinking water treatment applications is the methods capability of detecting extremely low limits of isolated acrylamide monomer. The US EPA limit for the release of polyacrylamide is 1.0mg/L, corresponding to an acrylamide monomer concentration of 0.005mg/L assuming a 0.05% monomer content. In terms of applicability, however, this method is quite cumbersome to

perform in-situ and requires that the plant have the capacity to execute these procedures routinely.

Electron-capture gas chromatography is another analytical method that has been frequented for the detected of residual acrylamide monomers post-drinking water treatment. Croll and Simkins used a combination of α,β -dibromopropionamide extraction using diethyl ether followed by analysis by electron-gas capture chromatography to detect residual acrylamide monomer in a river water sample. The detection limit of acrylamide monomer was found to be $0.1\mu\text{g/L}$, which, at an assumed acrylamide monomer content of 0.05%, results in a polyacrylamide detection limit of $2.0\mu\text{g/L}$ (55). Yamini et al. performed a study developing and validating a method using dispersive liquid-liquid microextraction coupled with electron-capture gas chromatography detection to detect ultra-trace amounts of acrylamide contaminant in water samples filtered through a $0.45\mu\text{m}$ filter. This method was able to form a correlation between acrylamide concentration and the response of ECD with a correlation of determination (R^2) of 0.9999, a relative standard deviation (RSD) of 3.6%, and a limit of detection of $0.001\mu\text{g/L}$ of acrylamide monomer, which corresponds to $0.02\mu\text{g/L}$ of polyacrylamide polymer at a monomer content of 0.05% (56). As is similar for the high-performance liquid chromatography method, electron-capture gas chromatography does have the advantage of extremely low detection limits of acrylamide monomer. Again, this method does require plants to have the capacity to carry out these extensive analytical methods, and the option of continuous monitoring is not viable as is with UV-vis spectroscopy as a method for the detection of residual polymer post-drinking water treatment.

4.6 Discussion of determination of optimum polymer dose

The use of UV-vis spectroscopy for the determination of optimum polymer dose is a method that has been previously examined for use in other industrial applications. Salam et al. explored the use of this method for the determination of optimum polymer dose in oil sands tailings. This study was very similar to that performed in this study on drinking water samples, however it was performed on oil sands tailings conditioned with an anionic A3338 (SNF Group, France) polymer dosed in both the under and overdose ranges. A capillary suction time (CST) test was performed on the conditioned samples as a comparison method to initially determine the optimum polymer dose for the tailings sample. Afterwards, a settling test was also performed on the conditioned samples. The supernatant of these settled samples was then used for UV-vis spectroscopy absorbance measurements, using a desktop spectrophotometer. The results of this study showed that the optimum polymer dose, determined by the lowest capillary suction time, aligned with the polymer dose that yielded the lowest absorbance value at 190nm (47). This experiment is quite similar to that performed on the drinking water samples in this study, however the trend in absorbance was instead correlated to the lowest particle concentration as well as the lowest turbidity measurements of the supernatant of the settled samples dosed with polymer. A CST test would not be appropriate for samples of drinking water, as these samples contain very little particulate matter and do not possess the necessary rheological characteristics to carry out a CST test. However, the correlation between minimum turbidity and particle concentration with minimum absorbance aligns very well with the results of the CST-absorbance results in the study done by Salam et al.

As was previously mentioned, Al Momani and Örmeci also conducted a similar study on the use of UV-vis spectroscopy as a method for the optimization of sludge dewatering. This study conditioned anaerobically digested sludge samples with various doses of a few different cationic and anionic polymers. In this case, CST tests were coupled with filtration tests to quantify the filtration rate of the conditioned sludge samples. The filtrate of these samples was then used to carry out UV-vis spectroscopy absorbance measurements using an in-line UV-vis spectrophotometer. The results of this study concluded that samples dosed with polymer in the optimum dose range correlated with those that exhibited the lowest capillary suction time, fastest filtration rate and minimum absorbance at a wavelength at or around 191.5nm (23). This study also showed that in the over and under-dose ranges, the absorbance and CST results tended to the same U or V-shape as was demonstrated in the results found using drinking water samples. Again, this study further indicates that a sample, whether it be sludge or drinking water, dosed with the optimum concentration of polymer will tend to a minimum absorbance value at or around 190nm.

The correspondence between these studies further demonstrates not only the replicability of UV-vis spectroscopy as a method for monitoring polymer dose, but also the wide range of applications this method has the potential to expand upon. The release of residual polymer into the environment has negative impacts regardless of industrial source, and the negative impacts of polymer overdose and under-dose are experienced in a plethora of different applications.

CHAPTER 6: CONCLUSION

The general conclusions determined from this study are as follows:

- The use of UV-vis spectroscopy as a method for the in-line detection of residual polyacrylamide polymer concentration was established in deionized water. The method was able to form a linear correlation between polymer concentration and absorbance at 190nm at both a high (0-3.0 mg/L) and low (0-1.0 mg/L) polymer concentration range. Linear correlation coefficients of 0.9990 and 0.9753 were attained for the relationship between polymer concentration and absorbance at 190nm for the high and low concentration ranges, respectively.
- The effect of path length on the sensitivity of in-line UV-vis spectroscopy as a method for the detection of residual polyacrylamide polymer in water was studied using dosed samples of deionized water. It was determined that a path length of 4mm rendered the most sensitive results at a low concentration range (0-1.0 mg/L) of polyacrylamide polymer when compared to a 2mm, 8mm, and 10mm path length; yielding a linear relationship between polymer concentration and absorbance at 190nm with a linear correlation coefficient of $R^2 = 0.9753$. At a higher concentration range (0-3.0 mg/L), the 4mm and 8mm path lengths performed similarly, yielding linear relationships with correlation coefficients of $R^2 = 0.9990$ and $R^2 = 0.9992$, respectively. Seeing that drinking water treatment requires the accurate detection of polymers at very low concentrations (<1.0 mg/L), the 4mm path length was chosen as most effective and was used for subsequent experimental phases.

- The effect of suspended particulates present in raw water samples on the viability of UV-vis spectroscopy as a method for the in-line detection of residual polymer in drinking water applications was studied. It was found that raw water samples still resulted in strong linear correlations between polymer concentration and absorbance at 190nm at both the high and low concentration ranges, with linear relation coefficients of $R^2 = 0.9990$ and $R^2 = 0.9757$, respectively. The samples were then filtered, diluted with deionized water, as well as a combination of both filtration and dilution. It was found that filtration and dilution decreased the strength of the linear correlation slightly, however a substantial linear relationship was still present at both the high and low concentration ranges using the in-line spectrophotometer. The in-line spectrophotometer was capable of producing linear correlations between polymer concentration and absorbance at 190nm of 0.8435 post-filtration, 0.8190 post dilution, and 0.3614 post-filtration and dilution at the low polymer dose range (0-1mg/L). At the high polymer dose range, the in-line unit was capable of attaining linear relation coefficients of 0.8352 post-filtration, 0.9856 post-dilution, and 0.9356 post-filtration and dilution.
- The effect of process chemicals on the sensitivity of UV-vis spectroscopy as a method for the in-line detection of residual polymer in drinking water treatment applications was also studied. The Actiflo® enhanced coagulation process was carried out lab scale using raw water samples, and a linear relationship between polymer concentration and absorbance at 190nm was still attainable using an in-line spectrophotometer at both the high and low concentration ranges. However, the linear relation coefficients did decrease in the presence of Actiflo® process

chemicals, reducing the linear relation coefficients to 0.4485 at the high concentration range and 0.5565 at the low concentration range using the in-line spectrophotometer, indicating that the sensitivity of the method is reduced.

- Finally, a relationship between the optimum polymer dosage and the absorbance of the dosed sample at 190nm was established in raw water samples of both high and low turbidity using both an anionic and cationic polyelectrolyte polymer. The constructed relationship formed a 'U' shape trend, with the minimum absorbance value corresponding to the optimum polymer dose. The optimum polymer dose indicated by the UV-vis absorbance method at 190 nm was in close agreement with optimum polymer concentration detected by common settling tests, turbidity tests, and total particle concentration. The in-line spectrophotometer determined an optimum anionic polymer dose of 0.1mg/L in the low turbidity water sample (2.11×10^5 #particles/mL), 2.0mg/L in the high turbidity water sample (2.36×10^5 #particles/mL), and 0.5mg/L in the high turbidity water sample dose with enhanced coagulation process chemicals (1.07×10^5 #particles/mL). The in-line spectrophotometer also determined an optimum cationic polymer dose of 8.0mg/L for the high turbidity water sample (2.19×10^4 #particles/mL), and 2.0mg/L for the low turbidity water sample (2.13×10^4 #particles/mL). In addition, seeing that this relationship was established using an in-line spectrophotometer, this relationship has the potential to be used to create a control loop for automatic adjustments of polymer dosed in drinking water in real-time.

APPENDICES

Appendix A: UV-vis absorbance data for experimental phase I

Magnaflow in deionized water (2018-01-18)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.042	0.042	0.042	0.042	0.044	0.042	0.042	0.043	0.042	0.044	0.044
249	0.045	0.046	0.045	0.046	0.047	0.046	0.046	0.047	0.046	0.047	0.047
248	0.048	0.049	0.048	0.049	0.050	0.049	0.049	0.050	0.049	0.050	0.050
247	0.052	0.052	0.052	0.052	0.054	0.052	0.052	0.053	0.052	0.054	0.054
246	0.055	0.056	0.055	0.056	0.057	0.055	0.055	0.056	0.055	0.057	0.057
245	0.058	0.059	0.058	0.058	0.060	0.058	0.058	0.059	0.058	0.060	0.060
244	0.060	0.061	0.061	0.061	0.062	0.061	0.061	0.062	0.061	0.062	0.062
243	0.062	0.063	0.063	0.063	0.065	0.063	0.063	0.064	0.063	0.064	0.064
242	0.064	0.065	0.064	0.064	0.066	0.064	0.064	0.065	0.064	0.066	0.066
241	0.065	0.065	0.065	0.065	0.067	0.065	0.065	0.066	0.065	0.067	0.067
240	0.065	0.066	0.065	0.066	0.067	0.065	0.065	0.066	0.065	0.067	0.067
239	0.065	0.066	0.065	0.065	0.067	0.065	0.065	0.066	0.065	0.067	0.067
238	0.064	0.065	0.064	0.065	0.066	0.064	0.064	0.065	0.065	0.066	0.066
237	0.063	0.064	0.063	0.064	0.065	0.063	0.063	0.064	0.063	0.065	0.065
236	0.062	0.062	0.062	0.062	0.064	0.062	0.061	0.063	0.062	0.063	0.063
235	0.060	0.061	0.060	0.060	0.062	0.060	0.060	0.061	0.060	0.062	0.062
234	0.058	0.059	0.058	0.058	0.060	0.058	0.058	0.059	0.058	0.060	0.060
233	0.056	0.057	0.056	0.056	0.058	0.056	0.056	0.057	0.056	0.058	0.058
232	0.054	0.055	0.054	0.054	0.056	0.054	0.054	0.055	0.054	0.056	0.056
231	0.052	0.053	0.052	0.052	0.054	0.052	0.052	0.053	0.052	0.054	0.054
230	0.051	0.051	0.051	0.051	0.053	0.050	0.050	0.051	0.051	0.052	0.052
229	0.049	0.050	0.049	0.049	0.051	0.049	0.049	0.050	0.049	0.051	0.051
228	0.047	0.048	0.048	0.048	0.050	0.047	0.047	0.048	0.048	0.049	0.049
227	0.046	0.047	0.046	0.046	0.049	0.046	0.046	0.047	0.046	0.048	0.048
226	0.045	0.046	0.045	0.045	0.048	0.045	0.045	0.046	0.045	0.047	0.047
225	0.045	0.046	0.045	0.045	0.047	0.045	0.045	0.045	0.045	0.047	0.047
224	0.045	0.046	0.045	0.045	0.047	0.044	0.044	0.045	0.045	0.047	0.047
223	0.045	0.046	0.045	0.045	0.047	0.045	0.045	0.046	0.045	0.047	0.047
222	0.046	0.047	0.046	0.046	0.048	0.046	0.046	0.047	0.046	0.048	0.048
221	0.047	0.048	0.047	0.047	0.050	0.047	0.047	0.048	0.047	0.049	0.049
220	0.049	0.050	0.049	0.049	0.052	0.049	0.049	0.050	0.049	0.051	0.051

219	0.051	0.053	0.052	0.052	0.054	0.052	0.052	0.053	0.052	0.054	0.054
218	0.055	0.056	0.055	0.055	0.058	0.055	0.055	0.056	0.055	0.057	0.057
217	0.058	0.060	0.058	0.059	0.061	0.058	0.059	0.059	0.058	0.061	0.061
216	0.062	0.064	0.063	0.063	0.066	0.062	0.063	0.064	0.062	0.065	0.065
215	0.067	0.068	0.067	0.067	0.070	0.067	0.067	0.068	0.067	0.069	0.070
214	0.071	0.073	0.072	0.072	0.075	0.072	0.072	0.073	0.072	0.074	0.075
213	0.077	0.078	0.077	0.077	0.080	0.077	0.077	0.078	0.077	0.080	0.080
212	0.082	0.084	0.082	0.083	0.086	0.083	0.083	0.084	0.082	0.085	0.086
211	0.088	0.090	0.088	0.089	0.092	0.089	0.089	0.090	0.088	0.091	0.092
210	0.094	0.096	0.095	0.095	0.099	0.095	0.095	0.096	0.095	0.098	0.098
209	0.100	0.102	0.101	0.102	0.105	0.101	0.101	0.102	0.101	0.104	0.105
208	0.107	0.109	0.107	0.108	0.111	0.108	0.108	0.108	0.107	0.110	0.111
207	0.113	0.115	0.113	0.114	0.118	0.114	0.114	0.115	0.113	0.116	0.118
206	0.119	0.121	0.119	0.120	0.124	0.120	0.120	0.121	0.119	0.122	0.124
205	0.125	0.126	0.125	0.126	0.130	0.125	0.125	0.126	0.125	0.128	0.130
204	0.130	0.132	0.130	0.131	0.135	0.131	0.131	0.132	0.130	0.134	0.136
203	0.135	0.137	0.135	0.136	0.141	0.136	0.136	0.137	0.135	0.139	0.141
202	0.141	0.142	0.141	0.142	0.146	0.141	0.141	0.142	0.141	0.145	0.147
201	0.146	0.147	0.146	0.147	0.151	0.147	0.146	0.148	0.146	0.150	0.153
200	0.151	0.153	0.151	0.152	0.156	0.152	0.151	0.153	0.151	0.156	0.159
199	0.156	0.158	0.156	0.157	0.162	0.157	0.157	0.158	0.157	0.162	0.165
198	0.161	0.163	0.161	0.162	0.167	0.162	0.162	0.164	0.162	0.167	0.172
197	0.167	0.168	0.167	0.167	0.173	0.168	0.168	0.170	0.168	0.174	0.179
196	0.172	0.174	0.173	0.173	0.179	0.175	0.175	0.177	0.175	0.182	0.187
195	0.180	0.182	0.180	0.181	0.187	0.183	0.183	0.186	0.184	0.191	0.197
194	0.191	0.193	0.191	0.193	0.199	0.194	0.196	0.199	0.197	0.204	0.210
193	0.201	0.203	0.202	0.204	0.210	0.206	0.208	0.210	0.209	0.216	0.223
192	0.220	0.223	0.222	0.224	0.230	0.226	0.228	0.232	0.230	0.238	0.245
191	0.251	0.254	0.252	0.255	0.262	0.258	0.261	0.264	0.261	0.271	0.278
190	0.292	0.295	0.293	0.296	0.303	0.299	0.303	0.306	0.304	0.313	0.320
CONC	0.000	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000
ABS AT 190nm	0.292	0.295	0.293	0.296	0.303	0.299	0.303	0.306	0.304	0.313	0.320
STDV	0.002	0.000	0.001	0.001	0.001	0.001	0.002	0.000	0.001	0.000	0.001

Magnaflow in deionized water (2018-02-02)											
In-line spectrophotometer (2mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	-0.0002	0.0195	0.0195	0.0186	0.0157	0.0172	0.0197	0.0193	0.0203	0.0240	0.0229
192.8	-0.0001	0.0106	0.0103	0.0087	0.0064	0.0065	0.0068	0.0070	0.0067	0.0076	0.0084
195.8	0.0009	0.0078	0.0057	0.0048	0.0031	0.0028	0.0007	0.0007	0.0025	0.0010	0.0014
198.9	-0.0001	0.0068	0.0039	0.0040	0.0009	0.0010	-0.0011	-0.0013	0.0005	-0.0013	-0.0012
201.9	-0.0008	0.0041	0.0019	0.0018	-0.0018	-0.0016	-0.0024	-0.0032	-0.0022	-0.0018	-0.0037
204.9	-0.0023	0.0025	0.0017	0.0002	-0.0021	-0.0040	-0.0044	-0.0039	-0.0050	-0.0029	-0.0048
208	-0.0008	0.0022	0.0022	0.0001	-0.0014	-0.0034	-0.0022	-0.0023	-0.0048	-0.0038	-0.0045
211	0.0007	0.0019	0.0015	-0.0009	-0.0013	-0.0028	-0.0029	-0.0032	-0.0037	-0.0045	-0.0048
214	0.0007	0.0017	-0.0003	-0.0014	-0.0023	-0.0026	-0.0047	-0.0047	-0.0042	-0.0053	-0.0053
217	-0.0008	0.0004	-0.0017	-0.0020	-0.0032	-0.0034	-0.0047	-0.0054	-0.0046	-0.0049	-0.0060
220	-0.0021	-0.0012	-0.0021	-0.0023	-0.0043	-0.0043	-0.0048	-0.0053	-0.0057	-0.0050	-0.0067
223.1	-0.0007	-0.0007	-0.0005	-0.0011	-0.0033	-0.0040	-0.0031	-0.0034	-0.0048	-0.0038	-0.0054
226.1	0.0006	0.0000	0.0001	-0.0015	-0.0027	-0.0039	-0.0030	-0.0029	-0.0039	-0.0037	-0.0043
229.1	0.0006	0.0007	0.0000	-0.0017	-0.0023	-0.0030	-0.0032	-0.0033	-0.0033	-0.0037	-0.0039
232.1	-0.0001	0.0000	-0.0012	-0.0021	-0.0029	-0.0026	-0.0036	-0.0041	-0.0034	-0.0037	-0.0047
235.1	-0.0008	-0.0010	-0.0016	-0.0016	-0.0025	-0.0023	-0.0034	-0.0041	-0.0028	-0.0032	-0.0049
238.1	-0.0007	0.0000	-0.0009	-0.0002	-0.0029	-0.0017	-0.0021	-0.0030	-0.0026	-0.0026	-0.0043
241.1	0.0015	0.0005	0.0006	0.0000	-0.0013	-0.0020	-0.0019	-0.0018	-0.0020	-0.0018	-0.0034
244.1	0.0016	0.0011	0.0007	-0.0011	-0.0018	-0.0035	-0.0022	-0.0020	-0.0029	-0.0029	-0.0034
247.1	-0.0001	0.0002	-0.0011	-0.0032	-0.0036	-0.0038	-0.0042	-0.0034	-0.0036	-0.0039	-0.0043
250.1	-0.0027	-0.0011	-0.0024	-0.0036	-0.0040	-0.0029	-0.0038	-0.0043	-0.0038	-0.0038	-0.0054
CONC	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
ABS at 190nm	-0.0002	0.0195	0.0195	0.0186	0.0157	0.0172	0.0197	0.0193	0.0203	0.0240	0.0229
STDV	0.0000	0.0027	0.0018	0.0020	0.0017	0.0000	0.0014	0.0007	0.0001	0.0016	0.0001

Magnaflow in deionized water (2018-02-14)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	0.0000	0.0024	0.0050	0.0062	0.0083	0.0097	0.0122	0.0132	0.0151	0.0178	0.0231
192.8	-0.0006	-0.0005	0.0003	0.0022	0.0030	0.0027	0.0053	0.0057	0.0063	0.0070	0.0107
195.8	0.0004	0.0014	0.0020	0.0023	0.0025	0.0037	0.0035	0.0042	0.0041	0.0057	0.0079
198.9	-0.0001	0.0009	0.0013	0.0010	0.0018	0.0021	0.0025	0.0028	0.0033	0.0040	0.0054
201.9	0.0000	-0.0008	-0.0007	-0.0003	-0.0001	-0.0003	0.0007	0.0005	0.0005	0.0005	0.0021
204.9	0.0007	0.0016	0.0017	0.0017	0.0011	0.0017	0.0014	0.0021	0.0018	0.0026	0.0025
208	-0.0003	0.0002	0.0004	0.0006	0.0009	0.0010	0.0013	0.0013	0.0014	0.0015	0.0022
211	-0.0003	-0.0003	-0.0007	-0.0002	-0.0001	-0.0006	0.0001	0.0001	-0.0002	-0.0002	0.0007
214	0.0003	0.0011	0.0013	0.0010	0.0007	0.0014	0.0008	0.0012	0.0011	0.0017	0.0015
217	-0.0005	-0.0009	-0.0008	-0.0009	-0.0006	-0.0003	-0.0004	-0.0005	-0.0005	-0.0011	-0.0002
220	0.0004	-0.0001	-0.0003	0.0000	0.0000	-0.0001	0.0000	-0.0001	-0.0001	-0.0003	0.0002
223.1	0.0001	0.0006	0.0009	0.0006	0.0005	0.0006	0.0006	0.0005	0.0003	0.0009	0.0008
226.1	-0.0003	-0.0007	-0.0011	-0.0009	-0.0007	-0.0005	-0.0007	-0.0011	-0.0008	-0.0013	-0.0006
229.1	0.0005	0.0006	0.0007	0.0007	0.0006	0.0003	0.0004	0.0005	0.0002	0.0002	0.0008
232.1	-0.0001	0.0000	0.0005	0.0000	-0.0001	0.0002	0.0001	-0.0002	-0.0002	0.0002	-0.0004
235.1	-0.0002	-0.0006	-0.0007	-0.0007	-0.0001	-0.0003	-0.0005	-0.0007	-0.0008	-0.0013	-0.0006
238.1	0.0009	0.0010	0.0010	0.0012	0.0009	0.0029	0.0010	0.0008	0.0007	0.0007	0.0007
241.1	-0.0002	-0.0002	-0.0003	-0.0005	-0.0006	-0.0001	-0.0005	-0.0006	-0.0010	-0.0004	-0.0009
244.1	-0.0004	-0.0004	-0.0008	-0.0006	-0.0003	-0.0005	-0.0008	-0.0010	-0.0008	-0.0013	-0.0007
247.1	0.0007	0.0008	0.0009	0.0009	0.0009	0.0003	0.0005	0.0008	0.0004	0.0003	0.0007
250.1	-0.0001	-0.0008	-0.0005	-0.0010	-0.0012	-0.0006	-0.0008	-0.0012	-0.0014	-0.0012	-0.0015
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS AT 190nm	0.000	0.002	0.005	0.006	0.008	0.010	0.012	0.013	0.015	0.018	0.023
STDV	0.001	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000

Magnaflow in deionized water (2018-02-07)											
In-line spectrophotometer (8mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	0.0000	0.0000	-0.0004	0.0027	0.0041	0.0056	0.0075	0.0089	0.0095	0.0122	0.0145
192.8	0.0000	-0.0003	-0.0006	0.0005	0.0011	0.0019	0.0030	0.0037	0.0040	0.0056	0.0067
195.8	0.0001	0.0001	-0.0003	0.0001	0.0003	0.0008	0.0012	0.0015	0.0013	0.0025	0.0029
198.9	-0.0003	-0.0003	-0.0011	-0.0001	-0.0003	-0.0002	-0.0001	0.0002	-0.0003	0.0005	0.0006
201.9	-0.0003	-0.0005	-0.0012	-0.0004	-0.0005	-0.0003	-0.0006	-0.0004	-0.0010	-0.0007	-0.0001
204.9	-0.0004	-0.0008	-0.0015	-0.0003	-0.0005	-0.0008	-0.0008	-0.0008	-0.0012	-0.0010	-0.0006
208	-0.0004	-0.0005	-0.0009	-0.0004	-0.0003	-0.0009	-0.0008	-0.0009	-0.0010	-0.0007	-0.0006
211	-0.0002	0.0001	-0.0001	-0.0003	-0.0004	-0.0006	-0.0006	-0.0006	-0.0007	-0.0005	-0.0005
214	0.0001	0.0006	0.0006	0.0001	0.0000	-0.0001	-0.0002	-0.0003	-0.0004	-0.0003	-0.0001
217	0.0000	0.0003	0.0005	-0.0001	-0.0002	-0.0001	-0.0003	-0.0005	-0.0006	-0.0006	-0.0005
220	-0.0001	-0.0001	0.0000	-0.0001	-0.0004	-0.0003	-0.0006	-0.0006	-0.0010	-0.0010	-0.0009
223.1	-0.0001	-0.0003	-0.0006	0.0000	-0.0005	-0.0004	-0.0006	-0.0007	-0.0011	-0.0010	-0.0010
226.1	-0.0001	0.0000	-0.0005	0.0003	-0.0001	-0.0004	-0.0005	-0.0006	-0.0008	-0.0005	-0.0008
229.1	-0.0005	-0.0001	-0.0005	-0.0002	-0.0004	-0.0006	-0.0006	-0.0008	-0.0012	-0.0008	-0.0008
232.1	-0.0003	0.0002	0.0000	-0.0002	-0.0002	-0.0004	-0.0005	-0.0006	-0.0009	-0.0008	-0.0005
235.1	0.0002	0.0006	0.0007	0.0000	0.0001	0.0000	-0.0001	-0.0006	-0.0004	-0.0006	-0.0002
238.1	0.0004	0.0004	0.0007	0.0002	0.0000	0.0001	-0.0001	-0.0004	-0.0004	-0.0006	-0.0004
241.1	0.0003	0.0004	0.0006	0.0003	0.0001	0.0000	-0.0001	-0.0004	-0.0005	-0.0004	-0.0006
244.1	-0.0001	0.0001	0.0002	0.0005	0.0001	-0.0003	-0.0003	-0.0004	-0.0007	-0.0003	-0.0008
247.1	-0.0003	0.0004	-0.0002	0.0005	0.0001	0.0000	-0.0001	-0.0004	-0.0006	-0.0003	-0.0005
250.1	-0.0006	0.0003	-0.0001	0.0002	0.0001	-0.0001	-0.0002	-0.0003	-0.0005	-0.0005	-0.0003
CONC	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
ABS at 190NM	0.0000	0.0000	-0.0004	0.0027	0.0041	0.0056	0.0075	0.0089	0.0095	0.0122	0.0145
STDV	0.0006	0.0002	0.0002	0.0001	0.0005	0.0003	0.0002	0.0001	0.0003	0.0008	0.0000

Magnaflow in deionized water (2018-01-08)							
Desktop spectrophotometer (1cm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
250	0.0420	0.0427	0.0420	0.0421	0.0430	0.0438	0.0423
249	0.0454	0.0463	0.0455	0.0456	0.0464	0.0475	0.0458
248	0.0487	0.0493	0.0486	0.0486	0.0497	0.0504	0.0489
247	0.0520	0.0529	0.0520	0.0520	0.0529	0.0538	0.0523
246	0.0553	0.0560	0.0551	0.0552	0.0562	0.0569	0.0554
245	0.0580	0.0589	0.0579	0.0581	0.0591	0.0597	0.0583
244	0.0605	0.0612	0.0603	0.0604	0.0616	0.0621	0.0609
243	0.0626	0.0633	0.0625	0.0627	0.0637	0.0641	0.0630
242	0.0641	0.0646	0.0639	0.0641	0.0651	0.0657	0.0644
241	0.0647	0.0656	0.0647	0.0649	0.0660	0.0666	0.0651
240	0.0651	0.0657	0.0651	0.0652	0.0662	0.0668	0.0655
239	0.0648	0.0655	0.0648	0.0649	0.0661	0.0667	0.0654
238	0.0641	0.0648	0.0640	0.0644	0.0652	0.0661	0.0646
237	0.0630	0.0637	0.0629	0.0631	0.0645	0.0649	0.0636
236	0.0614	0.0622	0.0615	0.0618	0.0629	0.0635	0.0623
235	0.0597	0.0606	0.0599	0.0601	0.0613	0.0618	0.0606
234	0.0579	0.0587	0.0580	0.0583	0.0592	0.0601	0.0588
233	0.0558	0.0568	0.0561	0.0564	0.0576	0.0582	0.0571
232	0.0539	0.0548	0.0541	0.0545	0.0558	0.0563	0.0551
231	0.0519	0.0529	0.0522	0.0526	0.0538	0.0545	0.0533
230	0.0502	0.0512	0.0505	0.0508	0.0521	0.0531	0.0516
229	0.0484	0.0496	0.0487	0.0492	0.0505	0.0514	0.0501
228	0.0470	0.0481	0.0474	0.0480	0.0492	0.0503	0.0489
227	0.0456	0.0469	0.0463	0.0469	0.0481	0.0492	0.0480
226	0.0447	0.0461	0.0454	0.0461	0.0474	0.0487	0.0474
225	0.0441	0.0456	0.0450	0.0458	0.0470	0.0484	0.0470
224	0.0440	0.0456	0.0450	0.0458	0.0471	0.0486	0.0474
223	0.0443	0.0461	0.0455	0.0463	0.0477	0.0493	0.0481
222	0.0451	0.0470	0.0465	0.0472	0.0488	0.0505	0.0493
221	0.0465	0.0485	0.0480	0.0488	0.0504	0.0523	0.0510
220	0.0484	0.0504	0.0501	0.0510	0.0528	0.0546	0.0535
219	0.0509	0.0532	0.0528	0.0537	0.0555	0.0577	0.0565
218	0.0538	0.0564	0.0561	0.0572	0.0590	0.0614	0.0602
217	0.0575	0.0601	0.0598	0.0610	0.0629	0.0655	0.0642
216	0.0616	0.0644	0.0641	0.0653	0.0676	0.0701	0.0690
215	0.0658	0.0689	0.0687	0.0701	0.0726	0.0752	0.0741

214	0.0709	0.0741	0.0738	0.0753	0.0780	0.0807	0.0798
213	0.0761	0.0792	0.0791	0.0806	0.0834	0.0864	0.0854
212	0.0814	0.0850	0.0849	0.0866	0.0897	0.0927	0.0919
211	0.0873	0.0909	0.0909	0.0929	0.0960	0.0994	0.0986
210	0.0936	0.0973	0.0975	0.0995	0.1028	0.1063	0.1056
209	0.0998	0.1035	0.1038	0.1062	0.1096	0.1133	0.1126
208	0.1061	0.1100	0.1102	0.1127	0.1166	0.1204	0.1198
207	0.1120	0.1162	0.1164	0.1193	0.1231	0.1274	0.1268
206	0.1181	0.1223	0.1226	0.1257	0.1299	0.1341	0.1339
205	0.1236	0.1279	0.1286	0.1319	0.1365	0.1409	0.1410
204	0.1288	0.1336	0.1342	0.1381	0.1430	0.1479	0.1482
203	0.1338	0.1388	0.1397	0.1442	0.1494	0.1547	0.1557
202	0.1387	0.1440	0.1454	0.1506	0.1561	0.1619	0.1636
201	0.1437	0.1495	0.1515	0.1574	0.1633	0.1699	0.1723
200	0.1482	0.1547	0.1574	0.1642	0.1706	0.1782	0.1818
199	0.1529	0.1601	0.1636	0.1718	0.1785	0.1874	0.1920
198	0.1574	0.1656	0.1701	0.1796	0.1872	0.1970	0.2032
197	0.1625	0.1721	0.1776	0.1887	0.1969	0.2084	0.2161
196	0.1682	0.1790	0.1856	0.1986	0.2077	0.2210	0.2305
195	0.1756	0.1876	0.1958	0.2107	0.2207	0.2356	0.2467
194	0.1865	0.2007	0.2102	0.2273	0.2382	0.2554	0.2684
193	0.1972	0.2133	0.2242	0.2434	0.2556	0.2746	0.2892
192	0.2171	0.2357	0.2482	0.2696	0.2827	0.3041	0.3206
191	0.2486	0.2708	0.2848	0.3081	0.3226	0.3465	0.3646
190	0.2902	0.3167	0.3322	0.3573	0.3733	0.3999	0.4194
CONC	0.0	0.5	1.0	1.5	2.0	2.5	3.0
ABS AT 190NM	0.2902	0.3167	0.3322	0.3573	0.3733	0.3999	0.4194
STDV	0.0017	0.0004	0.0011	0.0008	0.0002	0.0013	0.0004

Magnaflow in deionized water (2018-02-13)							
In-line spectrophotometer (2mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	-0.0001	0.0017	0.0069	0.0101	0.0175	0.0216	0.0324
192.8	0.0008	0.0010	0.0043	0.0047	0.0095	0.0116	0.0176
195.8	-0.0009	0.0007	0.0032	0.0035	0.0056	0.0083	0.0126
198.9	-0.0032	-0.0027	-0.0015	-0.0007	-0.0004	0.0022	0.0045
201.9	-0.0025	-0.0042	-0.0042	-0.0018	-0.0027	-0.0014	0.0010
204.9	-0.0016	-0.0036	-0.0050	-0.0036	-0.0038	-0.0038	-0.0010
208	0.0000	-0.0023	-0.0025	-0.0017	-0.0023	-0.0034	0.0000
211	0.0003	0.0006	-0.0004	-0.0012	-0.0002	-0.0015	0.0011
214	0.0003	0.0019	0.0009	-0.0013	0.0004	-0.0004	0.0005
217	-0.0015	-0.0002	-0.0005	-0.0025	-0.0010	-0.0009	0.0001
220	-0.0018	-0.0019	-0.0024	-0.0025	-0.0028	-0.0025	-0.0020
223.1	-0.0019	-0.0039	-0.0042	-0.0032	-0.0046	-0.0045	-0.0034
226.1	-0.0011	-0.0039	-0.0037	-0.0029	-0.0047	-0.0045	-0.0035
229.1	0.0002	-0.0009	-0.0017	-0.0012	-0.0021	-0.0030	-0.0018
232.1	0.0008	0.0007	0.0000	-0.0006	-0.0002	-0.0013	-0.0009
235.1	-0.0006	0.0020	0.0004	-0.0006	0.0001	-0.0010	-0.0008
238.1	-0.0010	0.0006	-0.0003	-0.0019	-0.0009	-0.0010	-0.0007
241.1	-0.0021	-0.0016	-0.0024	-0.0030	-0.0031	-0.0031	-0.0020
244.1	-0.0018	-0.0036	-0.0035	-0.0036	-0.0046	-0.0040	-0.0032
247.1	-0.0002	-0.0037	-0.0037	-0.0030	-0.0044	-0.0039	-0.0036
250.1	0.0015	-0.0010	-0.0013	-0.0001	-0.0017	-0.0025	-0.0021
CONC	0	0.5	1	1.5	2	2.5	3
ABS AT 190NM	-0.0001	0.0017	0.0069	0.0101	0.0175	0.0216	0.0324
STDV	0.0005	0.0011	0.0006	0.0005	0.0015	0.0018	0.0025

Magnaflow in deionized water (2018-02-09)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	-0.0001	0.0105	0.0211	0.0296	0.0397	0.0506	0.0611
192.8	0.0018	0.0065	0.0118	0.0179	0.0232	0.0296	0.0359
195.8	0.0019	0.0043	0.0064	0.0113	0.0141	0.0185	0.0214
198.9	0.0005	0.0021	0.0038	0.0070	0.0081	0.0108	0.0129
201.9	-0.0016	0.0004	0.0021	0.0037	0.0049	0.0069	0.0081
204.9	-0.0011	0.0007	0.0022	0.0027	0.0044	0.0055	0.0072
208	0.0011	0.0014	0.0027	0.0034	0.0043	0.0051	0.0067
211	0.0019	0.0019	0.0018	0.0034	0.0033	0.0042	0.0047
214	0.0001	0.0004	0.0005	0.0018	0.0015	0.0025	0.0028
217	-0.0016	-0.0010	-0.0004	0.0003	-0.0001	0.0012	0.0008
220	-0.0011	-0.0006	0.0007	0.0003	0.0002	0.0008	0.0013
223.1	0.0009	0.0005	0.0013	0.0011	0.0013	0.0013	0.0020
226.1	0.0012	0.0007	0.0005	0.0012	0.0008	0.0004	0.0012
229.1	0.0000	-0.0004	-0.0006	0.0000	-0.0004	-0.0004	0.0000
232.1	-0.0017	-0.0010	-0.0007	-0.0009	-0.0011	-0.0006	-0.0012
235.1	-0.0007	-0.0005	0.0003	-0.0003	-0.0005	0.0000	0.0001
238.1	0.0010	0.0003	0.0011	0.0007	0.0004	0.0004	0.0005
241.1	0.0017	0.0010	0.0008	0.0014	0.0011	0.0007	0.0010
244.1	-0.0002	-0.0009	-0.0011	-0.0005	-0.0005	-0.0012	-0.0010
247.1	-0.0019	-0.0017	-0.0011	-0.0013	-0.0014	-0.0017	-0.0016
250.1	-0.0004	-0.0008	0.0002	-0.0002	-0.0011	-0.0002	-0.0011
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	-0.00010	0.01055	0.02109	0.02959	0.03966	0.05057	0.06111
STDV	0.00069	0.00079	0.00109	0.00066	0.00063	0.00123	0.00031

Magnaflow in deionized water (2018-01-24)							
In-line spectrophotometer (8mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	0.0002	0.0445	0.0927	0.1456	0.1922	0.2327	0.2891
192.8	-0.0003	0.0281	0.0536	0.0849	0.1119	0.1372	0.1682
195.8	0.0002	0.0192	0.0325	0.0520	0.0687	0.0844	0.1009
198.9	-0.0003	0.0135	0.0216	0.0333	0.0435	0.0543	0.0633
201.9	-0.0012	0.0076	0.0134	0.0225	0.0273	0.0355	0.0426
204.9	-0.0019	0.0039	0.0079	0.0150	0.0189	0.0250	0.0312
208	-0.0015	0.0030	0.0065	0.0119	0.0141	0.0191	0.0245
211	-0.0010	0.0043	0.0066	0.0107	0.0123	0.0162	0.0205
214	-0.0006	0.0043	0.0056	0.0084	0.0104	0.0129	0.0150
217	0.0001	0.0058	0.0056	0.0074	0.0084	0.0109	0.0110
220	-0.0006	0.0036	0.0032	0.0049	0.0048	0.0065	0.0064
223.1	-0.0010	0.0024	0.0011	0.0016	0.0022	0.0034	0.0035
226.1	-0.0010	0.0014	-0.0003	0.0011	0.0001	0.0006	0.0020
229.1	-0.0007	0.0008	-0.0003	0.0002	-0.0006	-0.0004	0.0014
232.1	-0.0003	0.0015	0.0008	0.0001	0.0008	0.0004	0.0014
235.1	0.0003	0.0019	0.0014	-0.0001	0.0019	0.0015	0.0007
238.1	0.0011	0.0041	0.0026	0.0017	0.0025	0.0025	0.0021
241.1	0.0001	0.0030	0.0012	0.0013	0.0008	0.0018	0.0006
244.1	-0.0007	0.0018	0.0003	0.0006	-0.0009	-0.0001	-0.0006
247.1	-0.0012	-0.0005	-0.0013	-0.0012	-0.0028	-0.0036	-0.0022
250.1	-0.0001	0.0001	-0.0008	-0.0025	-0.0020	-0.0028	-0.0013
CONC	0.0	0.5	1.0	1.5	2.0	2.5	3.0
ABS at 190nm	0.0002	0.0445	0.0927	0.1456	0.1922	0.2327	0.2891
STDV	0.0004	0.0007	0.0038	0.0026	0.0046	0.0223	0.0009

Appendix B: UV-vis absorbance data for experimental phase 2

Magnaflow in unfiltered/undiluted Rideau River Water (6.8 NTU) (2018-02-23)							
Desktop spectrophotometer (1 cm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
250	0.2859	0.2850	0.2872	0.2859	0.2863	0.2866	0.2857
249	0.2918	0.2907	0.2931	0.2915	0.2920	0.2924	0.2915
248	0.2977	0.2966	0.2990	0.2975	0.2978	0.2983	0.2973
247	0.3036	0.3026	0.3048	0.3034	0.3038	0.3042	0.3032
246	0.3095	0.3084	0.3107	0.3093	0.3095	0.3101	0.3090
245	0.3153	0.3141	0.3165	0.3149	0.3154	0.3158	0.3148
244	0.3207	0.3197	0.3221	0.3205	0.3208	0.3212	0.3203
243	0.3258	0.3249	0.3272	0.3258	0.3260	0.3264	0.3255
242	0.3307	0.3298	0.3321	0.3307	0.3309	0.3314	0.3303
241	0.3354	0.3345	0.3367	0.3353	0.3356	0.3359	0.3350
240	0.3397	0.3388	0.3410	0.3396	0.3400	0.3404	0.3393
239	0.3439	0.3429	0.3452	0.3437	0.3441	0.3444	0.3435
238	0.3478	0.3468	0.3491	0.3477	0.3483	0.3485	0.3474
237	0.3517	0.3507	0.3530	0.3514	0.3520	0.3523	0.3513
236	0.3554	0.3546	0.3568	0.3553	0.3558	0.3561	0.3552
235	0.3593	0.3585	0.3607	0.3594	0.3598	0.3600	0.3592
234	0.3635	0.3627	0.3648	0.3635	0.3639	0.3642	0.3633
233	0.3681	0.3673	0.3693	0.3680	0.3686	0.3688	0.3680
232	0.3731	0.3722	0.3744	0.3734	0.3735	0.3738	0.3731
231	0.3786	0.3777	0.3798	0.3788	0.3791	0.3794	0.3787
230	0.3847	0.3838	0.3858	0.3850	0.3852	0.3854	0.3849
229	0.3915	0.3905	0.3928	0.3920	0.3921	0.3924	0.3918
228	0.3991	0.3979	0.4004	0.3995	0.3998	0.3999	0.3995
227	0.4076	0.4065	0.4088	0.4081	0.4083	0.4086	0.4081
226	0.4170	0.4158	0.4183	0.4176	0.4178	0.4180	0.4177
225	0.4274	0.4263	0.4288	0.4282	0.4284	0.4285	0.4283
224	0.4391	0.4381	0.4407	0.4400	0.4401	0.4404	0.4401
223	0.4520	0.4510	0.4536	0.4529	0.4531	0.4534	0.4532
222	0.4662	0.4652	0.4680	0.4673	0.4675	0.4678	0.4675
221	0.4818	0.4809	0.4835	0.4830	0.4832	0.4837	0.4833
220	0.4988	0.4979	0.5006	0.5000	0.5002	0.5006	0.5004
219	0.5170	0.5163	0.5189	0.5183	0.5188	0.5192	0.5189
218	0.5366	0.5359	0.5385	0.5379	0.5384	0.5387	0.5388

217	0.5571	0.5563	0.5591	0.5587	0.5594	0.5596	0.5598
216	0.5787	0.5782	0.5808	0.5804	0.5810	0.5814	0.5815
215	0.6011	0.6003	0.6033	0.6030	0.6036	0.6040	0.6043
214	0.6241	0.6236	0.6265	0.6261	0.6267	0.6275	0.6277
213	0.6478	0.6471	0.6501	0.6501	0.6505	0.6512	0.6519
212	0.6716	0.6713	0.6741	0.6742	0.6748	0.6755	0.6761
211	0.6960	0.6955	0.6987	0.6986	0.6993	0.7001	0.7009
210	0.7205	0.7198	0.7229	0.7232	0.7239	0.7248	0.7258
209	0.7449	0.7442	0.7476	0.7477	0.7485	0.7494	0.7504
208	0.7692	0.7684	0.7719	0.7723	0.7733	0.7739	0.7751
207	0.7934	0.7927	0.7963	0.7968	0.7978	0.7987	0.8002
206	0.8177	0.8171	0.8208	0.8215	0.8228	0.8234	0.8251
205	0.8423	0.8417	0.8461	0.8467	0.8480	0.8489	0.8509
204	0.8678	0.8675	0.8716	0.8728	0.8742	0.8752	0.8775
203	0.8945	0.8944	0.8990	0.9005	0.9023	0.9035	0.9064
202	0.9240	0.9239	0.9293	0.9311	0.9333	0.9348	0.9382
201	0.9564	0.9569	0.9627	0.9652	0.9679	0.9701	0.9737
200	0.9936	0.9947	1.0011	1.0043	1.0078	1.0104	1.0151
199	1.0376	1.0394	1.0466	1.0509	1.0548	1.0580	1.0638
198	1.0896	1.0922	1.1004	1.1053	1.1103	1.1145	1.1212
197	1.1543	1.1580	1.1672	1.1736	1.1796	1.1847	1.1925
196	1.2329	1.2380	1.2484	1.2557	1.2632	1.2690	1.2786
195	1.3309	1.3364	1.3485	1.3568	1.3655	1.3723	1.3835
194	1.4605	1.4717	1.4810	1.4903	1.5006	1.5085	1.5216
193	1.6052	1.6130	1.6276	1.6376	1.6491	1.6582	1.6731
192	1.7922	1.8010	1.8166	1.8272	1.8401	1.8500	1.8655
191	2.0340	2.0424	2.0587	2.0703	2.0832	2.0943	2.1113
190	2.2845	2.2933	2.3082	2.3186	2.3315	2.3420	2.3568
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	2.2845	2.2933	2.3082	2.3186	2.3315	2.3420	2.3568
STDV	0.0003	0.0018	0.0014	0.0050	0.0089	0.0083	0.0026

Magnaflow in unfiltered/undiluted Rideau River water (6.8 NTU) (2018-02-23)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	1.0473	1.0565	1.0645	1.0750	1.0848	1.0936	1.1019
192.8	0.8462	0.8542	0.8587	0.8659	0.8689	0.8738	0.8792
195.8	0.7659	0.7736	0.7756	0.7807	0.7836	0.7859	0.7888
198.9	0.6971	0.7038	0.7051	0.7073	0.7106	0.7123	0.7140
201.9	0.6445	0.6496	0.6502	0.6528	0.6545	0.6563	0.6581
204.9	0.5843	0.5890	0.5897	0.5923	0.5926	0.5943	0.5955
208	0.5260	0.5309	0.5314	0.5335	0.5343	0.5351	0.5354
211	0.4739	0.4787	0.4791	0.4795	0.4811	0.4819	0.4825
214	0.4301	0.4342	0.4340	0.4347	0.4352	0.4370	0.4374
217	0.3884	0.3922	0.3921	0.3932	0.3930	0.3940	0.3941
220	0.3594	0.3637	0.3637	0.3645	0.3650	0.3649	0.3651
223.1	0.3310	0.3355	0.3352	0.3358	0.3366	0.3368	0.3370
226.1	0.3110	0.3151	0.3150	0.3153	0.3152	0.3162	0.3164
229.1	0.2931	0.2970	0.2964	0.2969	0.2969	0.2977	0.2973
232.1	0.2792	0.2826	0.2823	0.2831	0.2838	0.2835	0.2831
235.1	0.2676	0.2718	0.2712	0.2715	0.2724	0.2724	0.2726
238.1	0.2601	0.2601	0.2634	0.2634	0.2632	0.2644	0.2644
241.1	0.2600	0.2562	0.2556	0.2565	0.2559	0.2564	0.2560
244.1	0.2472	0.2503	0.2504	0.2504	0.2512	0.2511	0.2503
247.1	0.2412	0.2452	0.2446	0.2445	0.2454	0.2452	0.2461
250.1	0.2365	0.2399	0.2393	0.2401	0.2396	0.2409	0.2406
CONC	0	0.5	1	1.5	2	2.5	3
ABS AT 190nm	1.0473	1.0565	1.0645	1.0750	1.0848	1.0936	1.1019
STDV	0.0021	0.0010	0.0024	0.0021	0.0006	0.0034	0.0013

Magnaflow in filtered/undiluted Rideau River water (6.8 NTU) (2018-02-28)							
Desktop spectrophotometer (1cm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
250	0.2503	0.2496	0.2445	0.2449	0.2436	0.2416	0.2408
249	0.2561	0.2554	0.2503	0.2505	0.2493	0.2472	0.2464
248	0.2618	0.2610	0.2558	0.2561	0.2548	0.2529	0.2519
247	0.2678	0.2668	0.2617	0.2620	0.2607	0.2586	0.2578
246	0.2735	0.2726	0.2673	0.2679	0.2663	0.2643	0.2635
245	0.2793	0.2781	0.2730	0.2734	0.2721	0.2699	0.2691
244	0.2846	0.2835	0.2783	0.2787	0.2772	0.2751	0.2743
243	0.2897	0.2887	0.2833	0.2838	0.2823	0.2802	0.2794
242	0.2946	0.2935	0.2880	0.2883	0.2871	0.2849	0.2840
241	0.2991	0.2980	0.2925	0.2928	0.2914	0.2892	0.2884
240	0.3033	0.3021	0.2967	0.2969	0.2955	0.2933	0.2925
239	0.3073	0.3061	0.3005	0.3009	0.2995	0.2973	0.2964
238	0.3112	0.3099	0.3042	0.3045	0.3032	0.3009	0.2999
237	0.3150	0.3136	0.3079	0.3082	0.3069	0.3045	0.3036
236	0.3187	0.3175	0.3118	0.3119	0.3107	0.3082	0.3073
235	0.3228	0.3214	0.3155	0.3158	0.3145	0.3121	0.3112
234	0.3270	0.3257	0.3198	0.3200	0.3187	0.3162	0.3154
233	0.3319	0.3304	0.3244	0.3249	0.3233	0.3209	0.3200
232	0.3371	0.3356	0.3295	0.3301	0.3287	0.3259	0.3252
231	0.3429	0.3414	0.3350	0.3357	0.3344	0.3317	0.3309
230	0.3493	0.3479	0.3415	0.3420	0.3407	0.3378	0.3372
229	0.3565	0.3548	0.3483	0.3490	0.3478	0.3449	0.3442
228	0.3643	0.3627	0.3561	0.3567	0.3554	0.3526	0.3520
227	0.3730	0.3714	0.3647	0.3654	0.3642	0.3613	0.3607
226	0.3827	0.3809	0.3744	0.3750	0.3738	0.3708	0.3702
225	0.3935	0.3919	0.3851	0.3856	0.3845	0.3816	0.3811
224	0.4053	0.4035	0.3966	0.3974	0.3962	0.3932	0.3927
223	0.4185	0.4166	0.4097	0.4103	0.4092	0.4062	0.4059
222	0.4326	0.4308	0.4236	0.4244	0.4234	0.4202	0.4198
221	0.4483	0.4465	0.4392	0.4401	0.4391	0.4360	0.4354
220	0.4651	0.4633	0.4558	0.4568	0.4557	0.4526	0.4522
219	0.4836	0.4818	0.4741	0.4752	0.4741	0.4711	0.4707
218	0.5029	0.5010	0.4933	0.4945	0.4935	0.4903	0.4899
217	0.5237	0.5218	0.5138	0.5152	0.5144	0.5113	0.5108
216	0.5452	0.5432	0.5349	0.5364	0.5357	0.5325	0.5319
215	0.5679	0.5657	0.5574	0.5590	0.5583	0.5551	0.5547

214	0.5909	0.5887	0.5801	0.5819	0.5812	0.5781	0.5777
213	0.6151	0.6127	0.6037	0.6059	0.6051	0.6019	0.6016
212	0.6389	0.6365	0.6274	0.6297	0.6290	0.6260	0.6257
211	0.6635	0.6611	0.6515	0.6541	0.6538	0.6505	0.6502
210	0.6879	0.6853	0.6755	0.6783	0.6779	0.6748	0.6744
209	0.7125	0.7098	0.6997	0.7030	0.7025	0.6994	0.6991
208	0.7368	0.7339	0.7235	0.7269	0.7266	0.7235	0.7232
207	0.7613	0.7583	0.7474	0.7513	0.7511	0.7481	0.7480
206	0.7856	0.7822	0.7710	0.7753	0.7753	0.7722	0.7724
205	0.8106	0.8070	0.7954	0.8001	0.8005	0.7974	0.7977
204	0.8360	0.8323	0.8199	0.8253	0.8262	0.8234	0.8240
203	0.8632	0.8592	0.8465	0.8528	0.8541	0.8515	0.8525
202	0.8927	0.8884	0.8752	0.8828	0.8850	0.8823	0.8841
201	0.9263	0.9218	0.9079	0.9169	0.9198	0.9176	0.9203
200	0.9644	0.9596	0.9447	0.9555	0.9597	0.9579	0.9616
199	1.0094	1.0046	0.9885	1.0015	1.0071	1.0059	1.0109
198	1.0613	1.0564	1.0393	1.0550	1.0617	1.0613	1.0681
197	1.1254	1.1198	1.1014	1.1197	1.1283	1.1288	1.1377
196	1.2006	1.1944	1.1748	1.1961	1.2064	1.2083	1.2193
195	1.2934	1.2858	1.2655	1.2895	1.3020	1.3054	1.3189
194	1.4185	1.4093	1.3877	1.4144	1.4294	1.4341	1.4509
193	1.5506	1.5392	1.5175	1.5464	1.5632	1.5697	1.5893
192	1.7258	1.7118	1.6897	1.7193	1.7387	1.7465	1.7692
191	1.9528	1.9356	1.9134	1.9436	1.9644	1.9738	1.9990
190	2.1886	2.1694	2.1473	2.1758	2.1988	2.2060	2.2324
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	2.1886	2.1694	2.1473	2.1758	2.1988	2.2060	2.2324
STDV	0.0494	0.0518	0.0432	0.0089	0.0219	0.0291	0.0153

Magnaflow in filtered/undiluted Rideau River water (6.8 NTU) (2018-02-28)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	0.9671	0.9759	1.1271	1.1632	1.1786	1.1918	1.2087
192.8	0.7810	0.7881	0.8619	0.8801	0.8829	0.8947	0.9038
195.8	0.7037	0.7072	0.7452	0.7561	0.7557	0.7631	0.7688
198.9	0.6391	0.6419	0.6742	0.6808	0.6789	0.6845	0.6872
201.9	0.5905	0.5946	0.6183	0.6216	0.6177	0.6233	0.6255
204.9	0.5333	0.5362	0.5644	0.5659	0.5631	0.5667	0.5692
208	0.4767	0.4785	0.5086	0.5108	0.5069	0.5110	0.5121
211	0.4258	0.4286	0.4582	0.4587	0.4809	0.4589	0.4591
214	0.3828	0.3856	0.4087	0.4100	0.4073	0.4094	0.4107
217	0.3427	0.3443	0.3659	0.3661	0.3626	0.3654	0.3655
220	0.3138	0.3160	0.3309	0.3301	0.3273	0.3297	0.3301
223.1	0.2846	0.2871	0.3009	0.3010	0.2988	0.2999	0.3004
226.1	0.2644	0.2658	0.2760	0.2757	0.2724	0.2747	0.2743
229.1	0.2469	0.2491	0.2576	0.2570	0.2543	0.2556	0.2556
232.1	0.2333	0.2351	0.2417	0.2416	0.2394	0.2399	0.2404
235.1	0.2227	0.2241	0.2307	0.2304	0.2272	0.2291	0.2283
238.1	0.2159	0.2174	0.2218	0.2211	0.2188	0.2198	0.2199
241.1	0.2091	0.2106	0.2138	0.2139	0.2116	0.2124	0.2130
244.1	0.2042	0.2051	0.2085	0.2085	0.2052	0.2069	0.2065
247.1	0.1990	0.1999	0.2036	0.2030	0.2011	0.2015	0.2018
250.1	0.1950	0.1965	0.1988	0.1988	0.1962	0.1972	0.1975
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	0.9671	0.9759	1.1271	1.1632	1.1786	1.1918	1.2087
STDV	0.0025	0.0041	0.0031	0.0043	0.0037	0.0055	0.0020

Magnaflow in unfiltered/diluted Rideau River water (6.8 NTU) (2018-02-23)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	0.5153	0.5221	0.5258	0.5336	0.5353	0.5403	0.5464
192.8	0.4212	0.4259	0.4280	0.4322	0.4339	0.4357	0.4383
195.8	0.3818	0.3856	0.3881	0.3907	0.3921	0.3943	0.3963
198.9	0.3473	0.3510	0.3530	0.3560	0.3556	0.3556	0.3588
201.9	0.3210	0.3250	0.3253	0.3279	0.3281	0.3283	0.3298
204.9	0.2933	0.2968	0.2971	0.2992	0.2995	0.2994	0.3006
208	0.2639	0.2666	0.2680	0.2697	0.2699	0.2688	0.2716
211	0.2370	0.2403	0.2411	0.2427	0.2421	0.2422	0.2438
214	0.2190	0.2179	0.2183	0.2197	0.2200	0.2196	0.2202
217	0.1947	0.1978	0.1979	0.1995	0.1994	0.1985	0.1998
220	0.1808	0.1829	0.1838	0.1851	0.1844	0.1840	0.1859
223.1	0.1648	0.1675	0.1680	0.1699	0.1692	0.1690	0.1693
226.1	0.1551	0.1574	0.1576	0.1589	0.1592	0.1585	0.1592
229.1	0.1465	0.1494	0.1495	0.1507	0.1503	0.1497	0.1511
232.1	0.1396	0.1419	0.1428	0.1440	0.1434	0.1428	0.1438
235.1	0.1328	0.1354	0.1360	0.1370	0.1370	0.1373	0.1367
238.1	0.1288	0.1321	0.1313	0.1323	0.1325	0.1321	0.1330
241.1	0.1260	0.1288	0.1283	0.1293	0.1294	0.1285	0.1301
244.1	0.1237	0.1255	0.1267	0.1274	0.1271	0.1269	0.1273
247.1	0.1205	0.1211	0.1221	0.1231	0.1227	0.1229	0.1235
250.1	0.1169	0.1197	0.1187	0.1200	0.1202	0.1195	0.1210
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190NM	0.5153	0.5221	0.5258	0.5336	0.5353	0.5403	0.5464
STDV	0.0003	0.0000	0.0000	0.0009	0.0000	0.0011	0.0006

Magnaflow in filtered/diluted Rideau River water (6.8 NTU) (2018-02-28)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	0.5658	0.5761	0.5745	0.5860	0.5850	0.5942	0.6042
192.8	0.4260	0.4339	0.4320	0.4395	0.4373	0.4423	0.4488
195.8	0.3643	0.3695	0.3690	0.3731	0.3700	0.3737	0.3791
198.9	0.3282	0.3331	0.3329	0.3345	0.3317	0.3338	0.3381
201.9	0.2997	0.3036	0.3035	0.3056	0.3020	0.3038	0.3117
204.9	0.2737	0.2760	0.2772	0.2777	0.2744	0.2756	0.2794
208	0.2458	0.2497	0.2498	0.2501	0.2471	0.2480	0.2513
211	0.2201	0.2234	0.2239	0.2242	0.2215	0.2220	0.2250
214	0.1966	0.1990	0.1999	0.1999	0.1969	0.1972	0.2004
217	0.1751	0.1782	0.1788	0.1787	0.1761	0.1765	0.1787
220	0.1572	0.1594	0.1604	0.1607	0.1580	0.1577	0.1603
223.1	0.1428	0.1453	0.1460	0.1456	0.1429	0.1432	0.1455
226.1	0.1301	0.1328	0.1335	0.1333	0.1310	0.1308	0.1330
229.1	0.1213	0.1233	0.1243	0.1241	0.1221	0.1215	0.1239
232.1	0.1139	0.1165	0.1166	0.1167	0.1143	0.1142	0.1162
235.1	0.1079	0.1100	0.1108	0.1107	0.1090	0.1086	0.1102
238.1	0.1043	0.1057	0.1067	0.1066	0.1047	0.1040	0.1061
241.1	0.1004	0.1033	0.1034	0.1032	0.1010	0.1010	0.1028
244.1	0.0975	0.0994	0.1002	0.1003	0.0985	0.0981	0.0997
247.1	0.0953	0.0969	0.0976	0.0977	0.0958	0.0951	0.0977
250.1	0.0933	0.0955	0.0959	0.0958	0.0938	0.0939	0.0954
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	0.5658	0.5761	0.5745	0.5860	0.5850	0.5942	0.6042
STDV	0.0014	0.0016	0.0013	0.0010	0.0007	0.0018	0.0024

Magnaflow in unfiltered/undiluted Rideau River water (3.2 NTU) (2018-03-21)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.2567	0.2649	0.2618	0.2642	0.2655	0.2643	0.2655	0.2669	0.2667	0.2676	0.2674
249	0.2624	0.2708	0.2676	0.2699	0.2713	0.2700	0.2712	0.2729	0.2725	0.2737	0.2734
248	0.2683	0.2765	0.2736	0.2759	0.2772	0.2759	0.2771	0.2788	0.2783	0.2795	0.2792
247	0.2741	0.2823	0.2794	0.2817	0.2831	0.2819	0.2831	0.2847	0.2845	0.2854	0.2851
246	0.2798	0.2880	0.2852	0.2875	0.2888	0.2876	0.2888	0.2904	0.2902	0.2912	0.2910
245	0.2854	0.2938	0.2909	0.2932	0.2946	0.2934	0.2944	0.2963	0.2961	0.2971	0.2968
244	0.2908	0.2991	0.2963	0.2986	0.3001	0.2989	0.3001	0.3018	0.3013	0.3024	0.3022
243	0.2958	0.3043	0.3015	0.3036	0.3051	0.3040	0.3051	0.3070	0.3066	0.3077	0.3074
242	0.3005	0.3091	0.3062	0.3084	0.3099	0.3087	0.3102	0.3118	0.3114	0.3126	0.3122
241	0.3048	0.3134	0.3106	0.3128	0.3144	0.3132	0.3145	0.3163	0.3159	0.3171	0.3167
240	0.3088	0.3176	0.3146	0.3170	0.3187	0.3172	0.3188	0.3205	0.3202	0.3212	0.3210
239	0.3126	0.3215	0.3185	0.3211	0.3225	0.3214	0.3227	0.3245	0.3241	0.3251	0.3250
238	0.3161	0.3252	0.3221	0.3245	0.3263	0.3250	0.3264	0.3282	0.3279	0.3289	0.3287
237	0.3196	0.3287	0.3256	0.3282	0.3298	0.3285	0.3301	0.3318	0.3315	0.3324	0.3324
236	0.3230	0.3322	0.3292	0.3316	0.3332	0.3320	0.3336	0.3354	0.3351	0.3362	0.3360
235	0.3266	0.3358	0.3326	0.3353	0.3370	0.3356	0.3371	0.3390	0.3386	0.3397	0.3396
234	0.3301	0.3396	0.3364	0.3391	0.3407	0.3393	0.3409	0.3428	0.3424	0.3435	0.3434
233	0.3342	0.3437	0.3404	0.3432	0.3448	0.3433	0.3451	0.3470	0.3467	0.3478	0.3476
232	0.3386	0.3483	0.3449	0.3479	0.3493	0.3478	0.3497	0.3516	0.3513	0.3523	0.3523
231	0.3434	0.3535	0.3498	0.3528	0.3543	0.3530	0.3547	0.3567	0.3563	0.3575	0.3573
230	0.3489	0.3590	0.3554	0.3585	0.3600	0.3585	0.3604	0.3623	0.3620	0.3633	0.3630
229	0.3550	0.3651	0.3615	0.3648	0.3663	0.3647	0.3668	0.3688	0.3685	0.3698	0.3694
228	0.3619	0.3723	0.3687	0.3720	0.3736	0.3719	0.3740	0.3761	0.3757	0.3771	0.3766
227	0.3696	0.3803	0.3766	0.3798	0.3814	0.3799	0.3821	0.3843	0.3838	0.3852	0.3847
226	0.3785	0.3893	0.3855	0.3889	0.3905	0.3890	0.3912	0.3931	0.3928	0.3944	0.3939
225	0.3883	0.3993	0.3952	0.3988	0.4004	0.3989	0.4011	0.4034	0.4029	0.4046	0.4040
224	0.3991	0.4104	0.4065	0.4101	0.4118	0.4102	0.4125	0.4147	0.4143	0.4160	0.4154
223	0.4112	0.4229	0.4188	0.4225	0.4241	0.4226	0.4250	0.4272	0.4270	0.4286	0.4281
222	0.4248	0.4368	0.4324	0.4363	0.4381	0.4364	0.4390	0.4413	0.4409	0.4428	0.4423
221	0.4396	0.4518	0.4475	0.4513	0.4532	0.4516	0.4541	0.4564	0.4560	0.4580	0.4574
220	0.4557	0.4684	0.4638	0.4680	0.4698	0.4683	0.4709	0.4732	0.4729	0.4747	0.4743
219	0.4731	0.4861	0.4814	0.4858	0.4876	0.4860	0.4888	0.4910	0.4908	0.4928	0.4924
218	0.4920	0.5053	0.5005	0.5050	0.5070	0.5053	0.5082	0.5106	0.5104	0.5123	0.5121
217	0.5117	0.5256	0.5207	0.5253	0.5273	0.5256	0.5285	0.5309	0.5308	0.5329	0.5326
216	0.5329	0.5470	0.5418	0.5466	0.5488	0.5471	0.5500	0.5525	0.5524	0.5544	0.5544

215	0.5543	0.5690	0.5637	0.5687	0.5709	0.5692	0.5721	0.5748	0.5747	0.5769	0.5769
214	0.5770	0.5919	0.5863	0.5918	0.5941	0.5922	0.5954	0.5980	0.5981	0.6001	0.6001
213	0.5996	0.6150	0.6095	0.6151	0.6175	0.6157	0.6187	0.6217	0.6216	0.6238	0.6240
212	0.6230	0.6389	0.6330	0.6389	0.6414	0.6397	0.6427	0.6457	0.6457	0.6480	0.6484
211	0.6465	0.6626	0.6566	0.6629	0.6653	0.6637	0.6668	0.6698	0.6701	0.6725	0.6729
210	0.6701	0.6867	0.6806	0.6871	0.6897	0.6878	0.6910	0.6942	0.6945	0.6969	0.6976
209	0.6937	0.7105	0.7043	0.7111	0.7138	0.7120	0.7153	0.7187	0.7187	0.7214	0.7219
208	0.7170	0.7342	0.7278	0.7347	0.7376	0.7359	0.7394	0.7428	0.7431	0.7456	0.7464
207	0.7402	0.7577	0.7509	0.7583	0.7616	0.7597	0.7632	0.7668	0.7671	0.7701	0.7707
206	0.7633	0.7811	0.7741	0.7816	0.7853	0.7834	0.7870	0.7908	0.7913	0.7943	0.7951
205	0.7866	0.8047	0.7972	0.8053	0.8092	0.8073	0.8111	0.8151	0.8156	0.8189	0.8195
204	0.8107	0.8291	0.8211	0.8298	0.8338	0.8319	0.8362	0.8402	0.8410	0.8445	0.8450
203	0.8352	0.8539	0.8455	0.8547	0.8592	0.8571	0.8618	0.8661	0.8671	0.8709	0.8712
202	0.8614	0.8805	0.8717	0.8814	0.8865	0.8843	0.8892	0.8939	0.8950	0.8993	0.8998
201	0.8899	0.9095	0.9001	0.9108	0.9160	0.9137	0.9193	0.9241	0.9260	0.9304	0.9310
200	0.9222	0.9423	0.9322	0.9438	0.9498	0.9472	0.9530	0.9584	0.9606	0.9655	0.9660
199	0.9591	0.9802	0.9691	0.9816	0.9882	0.9851	0.9924	0.9976	1.0004	1.0057	1.0066
198	1.0019	1.0236	1.0117	1.0254	1.0330	1.0296	1.0374	1.0432	1.0468	1.0527	1.0533
197	1.0536	1.0762	1.0633	1.0784	1.0866	1.0825	1.0920	1.0974	1.1022	1.1091	1.1117
196	1.1155	1.1392	1.1251	1.1415	1.1507	1.1460	1.1564	1.1626	1.1684	1.1763	1.1766
195	1.1935	1.2182	1.2027	1.2206	1.2314	1.2255	1.2380	1.2441	1.2514	1.2607	1.2590
194	1.2841	1.3104	1.2931	1.3129	1.3246	1.3180	1.3321	1.3387	1.3478	1.3578	1.3581
193	1.3952	1.4227	1.4042	1.4254	1.4389	1.4302	1.4471	1.4533	1.4650	1.4761	1.4765
192	1.5364	1.5665	1.5449	1.5684	1.5841	1.5738	1.5930	1.5990	1.6128	1.6263	1.6258
191	1.7201	1.7516	1.7278	1.7527	1.7705	1.7585	1.7809	1.7865	1.8026	1.8173	1.8210
190	1.9261	1.9586	1.9328	1.9600	1.9785	1.9637	1.9891	1.9946	2.0129	2.0276	2.0232
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	1.9261	1.9586	1.9328	1.9600	1.9785	1.9637	1.9891	1.9946	2.0129	2.0276	2.0232
STDV	0.0145	0.0523	0.0147	0.0428	0.0505	0.0196	0.0338	0.0311	0.0448	0.0432	0.0289

Magnaflow in unfiltered/undiluted Rideau River water (3.2 NTU) (2018-03-21)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	0.8981	0.9123	0.9173	0.9219	0.9282	0.9320	0.9380	0.9430	0.9461	0.9512	0.9546
192.8	0.7530	0.7614	0.7626	0.7648	0.7690	0.7716	0.7743	0.7763	0.7773	0.7814	0.7806
195.8	0.6882	0.6960	0.6942	0.6961	0.6983	0.7028	0.7034	0.7051	0.7046	0.7073	0.7076
198.9	0.6315	0.6372	0.6353	0.6370	0.6389	0.6413	0.6421	0.6436	0.6434	0.6445	0.6454
201.9	0.5843	0.5888	0.5874	0.5883	0.5902	0.5922	0.5924	0.5935	0.5928	0.5951	0.5943
204.9	0.5284	0.5338	0.5313	0.5323	0.5339	0.5377	0.5376	0.5385	0.5367	0.5391	0.5387
208	0.4751	0.4798	0.4780	0.4795	0.4809	0.4831	0.4834	0.4845	0.4832	0.4845	0.4842
211	0.4263	0.4305	0.4290	0.4298	0.4313	0.4337	0.4339	0.4352	0.4336	0.4354	0.4339
214	0.3837	0.3884	0.3863	0.3874	0.3886	0.3916	0.3922	0.3928	0.3905	0.3924	0.3919
217	0.3443	0.3485	0.3471	0.3481	0.3515	0.3513	0.3518	0.3531	0.3513	0.3521	0.3519
220	0.3168	0.3210	0.3198	0.3200	0.3217	0.3240	0.3242	0.3255	0.3231	0.3248	0.3235
223.1	0.2901	0.2941	0.2930	0.2938	0.2948	0.2975	0.2981	0.2983	0.2963	0.2973	0.2970
226.1	0.2721	0.2756	0.2745	0.2758	0.2774	0.2789	0.2792	0.2804	0.2781	0.2790	0.2786
229.1	0.2558	0.2609	0.2578	0.2584	0.2598	0.2623	0.2623	0.2637	0.2610	0.2625	0.2612
232.1	0.2421	0.2459	0.2449	0.2456	0.2468	0.2491	0.2501	0.2507	0.2480	0.2490	0.2485
235.1	0.2330	0.2368	0.2353	0.2363	0.2379	0.2392	0.2399	0.2407	0.2388	0.2392	0.2388
238.1	0.2257	0.2286	0.2279	0.2280	0.2291	0.2317	0.2321	0.2332	0.2305	0.2320	0.2305
241.1	0.2172	0.2207	0.2201	0.2218	0.2221	0.2242	0.2253	0.2260	0.2231	0.2235	0.2232
244.1	0.2136	0.2174	0.2159	0.2172	0.2184	0.2201	0.2205	0.2220	0.2194	0.2198	0.2196
247.1	0.2094	0.2113	0.2109	0.2111	0.2123	0.2153	0.2153	0.2166	0.2140	0.2154	0.2137
250.1	0.2035	0.2069	0.2062	0.2069	0.2086	0.2122	0.2112	0.2115	0.2094	0.2095	0.2091
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	0.8981	0.9123	0.9173	0.9219	0.9282	0.9320	0.9380	0.9430	0.9461	0.9512	0.9546
STDV	0.0048	0.0023	0.0031	0.0016	0.0016	0.0013	0.0011	0.0015	0.0010	0.0010	0.0012

Magnaflow in unfiltered/diluted Rideau River water (3.2 NTU) (2018-03-21)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	0.4582	0.4663	0.4626	0.4626	0.4684	0.4710	0.4732	0.4748	0.4729	0.4719	0.4781
192.8	0.3766	0.3830	0.3791	0.3785	0.3836	0.3855	0.3869	0.3870	0.3849	0.3865	0.3905
195.8	0.3410	0.3480	0.3431	0.3425	0.3479	0.3509	0.3505	0.3503	0.3482	0.3504	0.3545
198.9	0.3107	0.3174	0.3137	0.3122	0.3169	0.3178	0.3192	0.3192	0.3180	0.3179	0.3224
201.9	0.2873	0.2934	0.2896	0.2882	0.2924	0.2937	0.2942	0.2939	0.2954	0.2936	0.2973
204.9	0.2603	0.2665	0.2623	0.2611	0.2657	0.2662	0.2667	0.2661	0.2651	0.2675	0.2700
208	0.2343	0.2398	0.2366	0.2354	0.2389	0.2395	0.2398	0.2397	0.2391	0.2398	0.2433
211	0.2128	0.2157	0.2122	0.2106	0.2234	0.2153	0.2156	0.2147	0.2136	0.2147	0.2178
214	0.1890	0.1947	0.1911	0.1897	0.1931	0.1939	0.1941	0.1935	0.1927	0.1950	0.1972
217	0.1698	0.1750	0.1721	0.1703	0.1732	0.1739	0.1741	0.1738	0.1733	0.1741	0.1767
220	0.1594	0.1613	0.1581	0.1565	0.1593	0.1603	0.1605	0.1597	0.1590	0.1593	0.1624
223.1	0.1425	0.1478	0.1446	0.1428	0.1460	0.1465	0.1467	0.1457	0.1457	0.1463	0.1490
226.1	0.1342	0.1388	0.1362	0.1344	0.1371	0.1378	0.1379	0.1371	0.1369	0.1376	0.1400
229.1	0.1258	0.1306	0.1277	0.1260	0.1282	0.1294	0.1295	0.1287	0.1274	0.1278	0.1308
232.1	0.1193	0.1242	0.1212	0.1193	0.1219	0.1225	0.1226	0.1217	0.1213	0.1225	0.1247
235.1	0.1151	0.1193	0.1168	0.1152	0.1173	0.1178	0.1182	0.1169	0.1169	0.1178	0.1200
238.1	0.1111	0.1157	0.1133	0.1112	0.1136	0.1143	0.1143	0.1133	0.1128	0.1136	0.1162
241.1	0.1067	0.1114	0.1089	0.1064	0.1090	0.1095	0.1097	0.1085	0.1084	0.1092	0.1120
244.1	0.1057	0.1097	0.1075	0.1057	0.1078	0.1084	0.1084	0.1074	0.1074	0.1086	0.1103
247.1	0.1031	0.1075	0.1050	0.1030	0.1047	0.1060	0.1058	0.1048	0.1040	0.1053	0.1073
250.1	0.1001	0.1045	0.1021	0.0996	0.1021	0.1025	0.1030	0.1013	0.1018	0.1018	0.1049
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190NM	0.4582	0.4663	0.4626	0.4626	0.4684	0.4710	0.4732	0.4748	0.4729	0.4719	0.4781
STDV	0.0007	0.0014	0.0005	0.0010	0.0017	0.0008	0.0010	0.0023	0.0002	0.0003	0.0023

Magnaflow in unfiltered/diluted Rideau River water (3.2 NTU) (2018-03-21)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.1595	0.1608	0.1600	0.1602	0.1630	0.1610	0.1621	0.1677	0.1669	0.1641	0.1652
249	0.1644	0.1655	0.1648	0.1651	0.1678	0.1658	0.1669	0.1724	0.1718	0.1689	0.1699
248	0.1692	0.1704	0.1697	0.1699	0.1727	0.1706	0.1718	0.1774	0.1767	0.1738	0.1749
247	0.1742	0.1753	0.1747	0.1748	0.1775	0.1755	0.1766	0.1823	0.1816	0.1787	0.1797
246	0.1787	0.1799	0.1794	0.1794	0.1822	0.1801	0.1814	0.1871	0.1863	0.1834	0.1844
245	0.1832	0.1845	0.1839	0.1839	0.1865	0.1846	0.1858	0.1917	0.1909	0.1881	0.1889
244	0.1874	0.1886	0.1879	0.1880	0.1907	0.1888	0.1899	0.1958	0.1950	0.1921	0.1929
243	0.1912	0.1923	0.1917	0.1919	0.1944	0.1925	0.1937	0.1994	0.1987	0.1960	0.1969
242	0.1944	0.1957	0.1950	0.1953	0.1978	0.1959	0.1970	0.2030	0.2022	0.1992	0.2002
241	0.1973	0.1986	0.1979	0.1981	0.2007	0.1987	0.1999	0.2059	0.2052	0.2022	0.2031
240	0.1998	0.2011	0.2004	0.2006	0.2032	0.2013	0.2025	0.2084	0.2077	0.2048	0.2058
239	0.2020	0.2032	0.2025	0.2025	0.2054	0.2033	0.2047	0.2106	0.2099	0.2070	0.2080
238	0.2037	0.2050	0.2042	0.2045	0.2072	0.2052	0.2065	0.2125	0.2118	0.2087	0.2099
237	0.2054	0.2066	0.2058	0.2061	0.2088	0.2069	0.2080	0.2141	0.2134	0.2103	0.2115
236	0.2067	0.2080	0.2072	0.2074	0.2102	0.2083	0.2095	0.2155	0.2150	0.2118	0.2128
235	0.2080	0.2092	0.2085	0.2086	0.2116	0.2095	0.2107	0.2171	0.2162	0.2129	0.2144
234	0.2093	0.2106	0.2097	0.2100	0.2131	0.2108	0.2121	0.2183	0.2175	0.2145	0.2156
233	0.2107	0.2122	0.2111	0.2114	0.2146	0.2122	0.2136	0.2199	0.2191	0.2160	0.2174
232	0.2124	0.2139	0.2129	0.2131	0.2163	0.2140	0.2154	0.2216	0.2209	0.2177	0.2190
231	0.2144	0.2158	0.2148	0.2151	0.2185	0.2160	0.2173	0.2238	0.2230	0.2198	0.2212
230	0.2166	0.2181	0.2171	0.2173	0.2210	0.2182	0.2198	0.2262	0.2253	0.2221	0.2235
229	0.2193	0.2209	0.2198	0.2201	0.2239	0.2211	0.2225	0.2290	0.2281	0.2249	0.2263
228	0.2227	0.2241	0.2231	0.2232	0.2275	0.2243	0.2258	0.2323	0.2315	0.2281	0.2296
227	0.2265	0.2279	0.2269	0.2271	0.2316	0.2282	0.2297	0.2363	0.2353	0.2321	0.2334
226	0.2311	0.2325	0.2313	0.2315	0.2362	0.2326	0.2343	0.2408	0.2400	0.2365	0.2379
225	0.2362	0.2376	0.2364	0.2366	0.2416	0.2379	0.2395	0.2461	0.2453	0.2418	0.2432
224	0.2422	0.2438	0.2424	0.2427	0.2478	0.2439	0.2455	0.2523	0.2515	0.2479	0.2493
223	0.2490	0.2506	0.2492	0.2495	0.2550	0.2508	0.2526	0.2593	0.2583	0.2548	0.2564
222	0.2569	0.2585	0.2570	0.2573	0.2631	0.2587	0.2604	0.2672	0.2663	0.2629	0.2642
221	0.2656	0.2672	0.2657	0.2661	0.2720	0.2675	0.2693	0.2761	0.2749	0.2716	0.2730
220	0.2754	0.2771	0.2755	0.2757	0.2821	0.2774	0.2790	0.2860	0.2849	0.2815	0.2829
219	0.2861	0.2878	0.2861	0.2865	0.2930	0.2881	0.2899	0.2969	0.2958	0.2923	0.2940
218	0.2979	0.2996	0.2980	0.2983	0.3052	0.2999	0.3018	0.3090	0.3078	0.3042	0.3058
217	0.3105	0.3123	0.3105	0.3108	0.3180	0.3126	0.3143	0.3218	0.3203	0.3169	0.3184
216	0.3240	0.3257	0.3239	0.3242	0.3316	0.3261	0.3280	0.3354	0.3339	0.3305	0.3322
215	0.3380	0.3398	0.3379	0.3383	0.3460	0.3401	0.3420	0.3497	0.3481	0.3446	0.3462

214	0.3529	0.3547	0.3527	0.3531	0.3611	0.3549	0.3569	0.3647	0.3631	0.3595	0.3613
213	0.3681	0.3698	0.3677	0.3681	0.3767	0.3702	0.3722	0.3801	0.3785	0.3747	0.3768
212	0.3839	0.3856	0.3834	0.3838	0.3926	0.3861	0.3882	0.3961	0.3944	0.3907	0.3928
211	0.3997	0.4016	0.3994	0.3997	0.4089	0.4020	0.4043	0.4124	0.4105	0.4069	0.4087
210	0.4162	0.4179	0.4156	0.4159	0.4254	0.4183	0.4206	0.4290	0.4271	0.4233	0.4252
209	0.4323	0.4341	0.4318	0.4320	0.4421	0.4348	0.4370	0.4454	0.4437	0.4396	0.4416
208	0.4488	0.4506	0.4481	0.4485	0.4588	0.4511	0.4536	0.4621	0.4603	0.4559	0.4582
207	0.4649	0.4668	0.4643	0.4646	0.4752	0.4676	0.4700	0.4787	0.4769	0.4726	0.4746
206	0.4814	0.4832	0.4804	0.4808	0.4920	0.4839	0.4864	0.4957	0.4935	0.4889	0.4912
205	0.4976	0.4999	0.4971	0.4974	0.5090	0.5006	0.5032	0.5127	0.5103	0.5058	0.5079
204	0.5149	0.5168	0.5140	0.5142	0.5264	0.5179	0.5203	0.5302	0.5278	0.5232	0.5251
203	0.5324	0.5343	0.5313	0.5316	0.5442	0.5355	0.5381	0.5481	0.5458	0.5407	0.5430
202	0.5508	0.5527	0.5496	0.5499	0.5630	0.5540	0.5570	0.5672	0.5645	0.5595	0.5618
201	0.5705	0.5725	0.5693	0.5695	0.5834	0.5741	0.5772	0.5879	0.5850	0.5798	0.5821
200	0.5925	0.5944	0.5914	0.5916	0.6060	0.5967	0.5998	0.6107	0.6078	0.6024	0.6047
199	0.6174	0.6196	0.6163	0.6164	0.6318	0.6221	0.6256	0.6367	0.6334	0.6281	0.6308
198	0.6460	0.6481	0.6446	0.6448	0.6612	0.6511	0.6548	0.6664	0.6627	0.6573	0.6602
197	0.6801	0.6825	0.6789	0.6788	0.6966	0.6861	0.6913	0.7019	0.6979	0.6926	0.6969
196	0.7202	0.7227	0.7192	0.7189	0.7379	0.7272	0.7311	0.7434	0.7389	0.7336	0.7371
195	0.7717	0.7748	0.7709	0.7707	0.7907	0.7798	0.7825	0.7964	0.7916	0.7864	0.7887
194	0.8304	0.8336	0.8298	0.8294	0.8509	0.8399	0.8441	0.8569	0.8515	0.8465	0.8509
193	0.9038	0.9074	0.9035	0.9031	0.9256	0.9148	0.9189	0.9319	0.9259	0.9211	0.9262
192	1.0011	1.0052	1.0011	1.0000	1.0243	1.0133	1.0174	1.0310	1.0240	1.0197	1.0250
191	1.1289	1.1336	1.1292	1.1276	1.1542	1.1428	1.1496	1.1612	1.1532	1.1492	1.1580
190	1.2809	1.2862	1.2815	1.2801	1.3076	1.2972	1.2966	1.3147	1.3052	1.3025	1.3059
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS AT 190nm	1.2809	1.2862	1.2815	1.2801	1.3076	1.2972	1.2966	1.3147	1.3052	1.3025	1.3059
STDV	0.0023	0.0067	0.0048	0.0034	0.0062	0.0015	0.0052	0.0063	0.0010	0.0039	0.0056

Magnaflow in filtered/undiluted Rideau River Water (3.2 NTU) (2018-03-19)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.2542	0.2542	0.2538	0.2533	0.2538	0.2531	0.2539	0.2539	0.2538	0.2541	0.2535
249	0.2599	0.2598	0.2594	0.2590	0.2594	0.2588	0.2595	0.2595	0.2595	0.2596	0.2590
248	0.2657	0.2657	0.2653	0.2648	0.2651	0.2646	0.2653	0.2652	0.2652	0.2652	0.2648
247	0.2713	0.2713	0.2709	0.2705	0.2708	0.2702	0.2711	0.2709	0.2710	0.2711	0.2705
246	0.2770	0.2770	0.2766	0.2760	0.2764	0.2758	0.2766	0.2766	0.2765	0.2767	0.2761
245	0.2826	0.2824	0.2820	0.2816	0.2819	0.2814	0.2821	0.2820	0.2821	0.2821	0.2817
244	0.2878	0.2877	0.2873	0.2869	0.2872	0.2866	0.2874	0.2872	0.2873	0.2873	0.2869
243	0.2927	0.2926	0.2922	0.2918	0.2921	0.2915	0.2924	0.2923	0.2922	0.2924	0.2919
242	0.2974	0.2972	0.2969	0.2965	0.2969	0.2962	0.2969	0.2969	0.2968	0.2969	0.2965
241	0.3017	0.3016	0.3011	0.3007	0.3010	0.3005	0.3012	0.3012	0.3011	0.3012	0.3008
240	0.3057	0.3055	0.3051	0.3047	0.3050	0.3045	0.3053	0.3051	0.3051	0.3052	0.3048
239	0.3095	0.3093	0.3089	0.3085	0.3087	0.3083	0.3090	0.3088	0.3088	0.3089	0.3085
238	0.3129	0.3128	0.3125	0.3120	0.3123	0.3117	0.3125	0.3124	0.3124	0.3125	0.3120
237	0.3164	0.3163	0.3160	0.3155	0.3157	0.3152	0.3160	0.3160	0.3158	0.3160	0.3156
236	0.3199	0.3199	0.3195	0.3191	0.3193	0.3189	0.3196	0.3196	0.3194	0.3195	0.3190
235	0.3237	0.3236	0.3232	0.3227	0.3230	0.3224	0.3232	0.3232	0.3230	0.3232	0.3227
234	0.3278	0.3276	0.3273	0.3267	0.3268	0.3263	0.3271	0.3271	0.3269	0.3271	0.3266
233	0.3321	0.3320	0.3315	0.3311	0.3312	0.3308	0.3315	0.3315	0.3313	0.3315	0.3309
232	0.3370	0.3369	0.3365	0.3358	0.3360	0.3355	0.3361	0.3362	0.3360	0.3363	0.3358
231	0.3424	0.3423	0.3418	0.3412	0.3413	0.3408	0.3416	0.3416	0.3414	0.3416	0.3410
230	0.3485	0.3483	0.3478	0.3473	0.3473	0.3468	0.3475	0.3475	0.3474	0.3475	0.3470
229	0.3551	0.3551	0.3545	0.3540	0.3540	0.3535	0.3541	0.3541	0.3538	0.3540	0.3536
228	0.3626	0.3626	0.3620	0.3615	0.3614	0.3610	0.3616	0.3616	0.3613	0.3616	0.3610
227	0.3711	0.3711	0.3705	0.3699	0.3698	0.3692	0.3699	0.3699	0.3697	0.3699	0.3694
226	0.3804	0.3805	0.3799	0.3794	0.3792	0.3787	0.3792	0.3792	0.3789	0.3793	0.3786
225	0.3907	0.3910	0.3904	0.3898	0.3895	0.3889	0.3896	0.3895	0.3891	0.3895	0.3889
224	0.4022	0.4026	0.4020	0.4015	0.4011	0.4005	0.4011	0.4009	0.4006	0.4010	0.4003
223	0.4148	0.4154	0.4149	0.4142	0.4138	0.4132	0.4139	0.4136	0.4132	0.4136	0.4130
222	0.4288	0.4296	0.4290	0.4285	0.4279	0.4273	0.4279	0.4277	0.4273	0.4276	0.4269
221	0.4439	0.4450	0.4445	0.4437	0.4431	0.4425	0.4431	0.4429	0.4424	0.4427	0.4421
220	0.4604	0.4619	0.4613	0.4608	0.4599	0.4593	0.4598	0.4597	0.4591	0.4594	0.4586
219	0.4779	0.4799	0.4794	0.4786	0.4778	0.4772	0.4776	0.4775	0.4767	0.4772	0.4765
218	0.4971	0.4994	0.4988	0.4982	0.4972	0.4965	0.4969	0.4968	0.4961	0.4964	0.4957
217	0.5170	0.5197	0.5193	0.5185	0.5173	0.5167	0.5170	0.5169	0.5163	0.5165	0.5156
216	0.5380	0.5411	0.5406	0.5399	0.5386	0.5380	0.5383	0.5384	0.5374	0.5378	0.5369

215	0.5596	0.5631	0.5626	0.5619	0.5604	0.5599	0.5602	0.5602	0.5592	0.5597	0.5586
214	0.5821	0.5862	0.5856	0.5848	0.5832	0.5827	0.5829	0.5830	0.5820	0.5824	0.5812
213	0.6049	0.6092	0.6086	0.6079	0.6061	0.6056	0.6058	0.6060	0.6048	0.6052	0.6041
212	0.6281	0.6329	0.6322	0.6315	0.6297	0.6292	0.6294	0.6295	0.6284	0.6287	0.6276
211	0.6513	0.6564	0.6557	0.6551	0.6533	0.6526	0.6527	0.6530	0.6517	0.6522	0.6508
210	0.6748	0.6802	0.6795	0.6790	0.6768	0.6763	0.6764	0.6767	0.6752	0.6757	0.6743
209	0.6979	0.7036	0.7030	0.7024	0.7002	0.6996	0.6998	0.7002	0.6986	0.6991	0.6977
208	0.7210	0.7269	0.7263	0.7258	0.7235	0.7229	0.7231	0.7234	0.7219	0.7223	0.7209
207	0.7439	0.7500	0.7494	0.7487	0.7463	0.7457	0.7460	0.7464	0.7449	0.7453	0.7440
206	0.7665	0.7730	0.7723	0.7716	0.7695	0.7687	0.7692	0.7694	0.7679	0.7683	0.7669
205	0.7895	0.7960	0.7953	0.7948	0.7922	0.7917	0.7922	0.7925	0.7909	0.7915	0.7900
204	0.8137	0.8201	0.8194	0.8190	0.8165	0.8159	0.8164	0.8168	0.8151	0.8158	0.8143
203	0.8386	0.8450	0.8444	0.8438	0.8413	0.8408	0.8414	0.8420	0.8403	0.8411	0.8396
202	0.8657	0.8720	0.8716	0.8709	0.8685	0.8681	0.8689	0.8694	0.8677	0.8687	0.8671
201	0.8961	0.9019	0.9016	0.9009	0.8985	0.8980	0.8990	0.8995	0.8980	0.8993	0.8978
200	0.9311	0.9363	0.9361	0.9352	0.9330	0.9328	0.9341	0.9343	0.9329	0.9345	0.9331
199	0.9714	0.9758	0.9759	0.9747	0.9731	0.9728	0.9739	0.9747	0.9735	0.9753	0.9737
198	1.0183	1.0218	1.0219	1.0212	1.0192	1.0195	1.0211	1.0218	1.0202	1.0228	1.0216
197	1.0733	1.0764	1.0768	1.0758	1.0744	1.0748	1.0765	1.0773	1.0762	1.0791	1.0777
196	1.1381	1.1409	1.1414	1.1403	1.1392	1.1398	1.1417	1.1426	1.1418	1.1454	1.1441
195	1.2192	1.2212	1.2222	1.2214	1.2200	1.2210	1.2233	1.2246	1.2220	1.2279	1.2268
194	1.3127	1.3143	1.3157	1.3146	1.3135	1.3152	1.3175	1.3190	1.3183	1.3229	1.3217
193	1.4263	1.4275	1.4291	1.4280	1.4269	1.4288	1.4317	1.4334	1.4326	1.4384	1.4366
192	1.5714	1.5711	1.5730	1.5719	1.5708	1.5730	1.5763	1.5777	1.5802	1.5841	1.5819
191	1.7568	1.7568	1.7585	1.7565	1.7554	1.7580	1.7609	1.7630	1.7622	1.7697	1.7671
190	1.9616	1.9601	1.9631	1.9613	1.9597	1.9623	1.9655	1.9678	1.9627	1.9748	1.9724
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190NM	1.9616	1.9601	1.9631	1.9613	1.9597	1.9623	1.9655	1.9678	1.9627	1.9748	1.9724
STDV	0.0018	0.0027	0.0035	0.0038	0.0018	0.0075	0.0039	0.0049	0.0003	0.0117	0.0007

Magnaflow in filtered/undiluted Rideau River Water (3.2 NTU) (2018-03-19)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	1.0326	1.0451	1.0460	1.0491	1.0480	1.0534	1.0519	1.0532	1.0544	1.0576	1.0636
192.8	0.8172	0.8291	0.8292	0.8302	0.8298	0.8310	0.8315	0.8325	0.8303	0.8330	0.8362
195.8	0.7201	0.7332	0.7306	0.7319	0.7311	0.7311	0.7298	0.7322	0.7301	0.7316	0.7324
198.9	0.6571	0.6701	0.6665	0.6675	0.6663	0.6661	0.6637	0.6658	0.6655	0.6654	0.6657
201.9	0.6031	0.6137	0.6115	0.6122	0.6101	0.6118	0.6088	0.6104	0.6098	0.6100	0.6105
204.9	0.5501	0.5587	0.5575	0.5578	0.5560	0.5571	0.5556	0.5557	0.5556	0.5557	0.5561
208	0.4989	0.5070	0.5052	0.5057	0.5043	0.5047	0.5042	0.5048	0.5036	0.5043	0.5042
211	0.4511	0.4588	0.4563	0.4562	0.4557	0.4556	0.4544	0.4559	0.4548	0.4554	0.4556
214	0.4045	0.4106	0.4082	0.4085	0.4075	0.4083	0.4067	0.4081	0.4074	0.4082	0.4080
217	0.3599	0.3641	0.3623	0.3630	0.3618	0.3633	0.3618	0.3628	0.3627	0.3630	0.3630
220	0.3257	0.3288	0.3279	0.3280	0.3278	0.3283	0.3284	0.3284	0.3281	0.3287	0.3294
223.1	0.2981	0.3017	0.3001	0.3000	0.3005	0.3001	0.3001	0.3008	0.3002	0.3012	0.3014
226.1	0.2749	0.2781	0.2759	0.2762	0.2764	0.2766	0.2758	0.2769	0.2766	0.2776	0.2775
229.1	0.2567	0.2592	0.2574	0.2578	0.2580	0.2586	0.2575	0.2588	0.2585	0.2591	0.2589
232.1	0.2417	0.2436	0.2420	0.2424	0.2424	0.2435	0.2430	0.2433	0.2435	0.2441	0.2440
235.1	0.2307	0.2326	0.2314	0.2315	0.2317	0.2319	0.2321	0.2325	0.2323	0.2327	0.2327
238.1	0.2226	0.2248	0.2231	0.2228	0.2239	0.2235	0.2234	0.2242	0.2238	0.2242	0.2246
241.1	0.2161	0.2184	0.2163	0.2166	0.2171	0.2172	0.2164	0.2176	0.2169	0.2179	0.2179
244.1	0.2094	0.2108	0.2096	0.2103	0.2099	0.2112	0.2099	0.2109	0.2109	0.2114	0.2115
247.1	0.2036	0.2047	0.2042	0.2042	0.2040	0.2051	0.2048	0.2049	0.2049	0.2053	0.2054
250.1	0.1986	0.2005	0.1992	0.1987	0.1997	0.1990	0.1998	0.1999	0.2000	0.2000	0.2004
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	1.0326	1.0451	1.0460	1.0491	1.0480	1.0534	1.0519	1.0532	1.0544	1.0576	1.0636
STDV	0.0012	0.0006	0.0020	0.0007	0.0022	0.0013	0.0004	0.0013	0.0010	0.0019	0.0006

Magnaflow in filtered/diluted Rideau River Water (3.2 NTU) (2018-03-26)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	0.4756	0.4815	0.4858	0.4854	0.4828	0.4839	0.4829	0.4841	0.4836	0.4834	0.4886
192.8	0.3908	0.3953	0.3982	0.3978	0.3944	0.3965	0.3949	0.3957	0.3968	0.3962	0.3997
195.8	0.3542	0.3571	0.3591	0.3587	0.3561	0.3580	0.3560	0.3569	0.3587	0.3575	0.3605
198.9	0.3228	0.3255	0.3272	0.3271	0.3249	0.3270	0.3250	0.3252	0.3264	0.3258	0.3283
201.9	0.2984	0.3001	0.3036	0.3029	0.3008	0.3021	0.3009	0.3007	0.3010	0.3015	0.3033
204.9	0.2710	0.2731	0.2751	0.2744	0.2730	0.2731	0.2733	0.2732	0.2731	0.2740	0.2753
208	0.2427	0.2449	0.2458	0.2451	0.2433	0.2439	0.2438	0.2442	0.2445	0.2449	0.2469
211	0.2170	0.2187	0.2194	0.2186	0.2167	0.2179	0.2178	0.2178	0.2191	0.2185	0.2207
214	0.1929	0.1944	0.1947	0.1944	0.1930	0.1942	0.1937	0.1939	0.1949	0.1944	0.1963
217	0.1698	0.1713	0.1725	0.1719	0.1710	0.1716	0.1714	0.1716	0.1717	0.1721	0.1734
220	0.1556	0.1578	0.1584	0.1573	0.1571	0.1567	0.1574	0.1575	0.1571	0.1579	0.1590
223.1	0.1421	0.1436	0.1443	0.1432	0.1430	0.1427	0.1433	0.1434	0.1438	0.1441	0.1452
226.1	0.1327	0.1346	0.1340	0.1334	0.1328	0.1330	0.1335	0.1337	0.1347	0.1345	0.1356
229.1	0.1243	0.1261	0.1250	0.1248	0.1241	0.1246	0.1249	0.1252	0.1259	0.1257	0.1268
232.1	0.1171	0.1182	0.1184	0.1182	0.1176	0.1182	0.1183	0.1180	0.1182	0.1191	0.1196
235.1	0.1116	0.1129	0.1134	0.1135	0.1130	0.1129	0.1130	0.1131	0.1128	0.1138	0.1145
238.1	0.1078	0.1086	0.1094	0.1087	0.1084	0.1082	0.1091	0.1086	0.1091	0.1132	0.1103
241.1	0.1035	0.1053	0.1050	0.1041	0.1038	0.1038	0.1048	0.1049	0.1055	0.1049	0.1063
244.1	0.1011	0.1040	0.1024	0.1019	0.1013	0.1015	0.1022	0.1023	0.1031	0.1029	0.1035
247.1	0.0991	0.1008	0.1003	0.1000	0.1000	0.1001	0.1005	0.1000	0.1004	0.1010	0.1010
250.1	0.0971	0.0989	0.0991	0.0984	0.0983	0.0986	0.0988	0.0989	0.0981	0.0993	0.0999
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS AT 190nm	0.4756	0.4815	0.4858	0.4854	0.4828	0.4839	0.4829	0.4841	0.4836	0.4834	0.4886
STDV	0.0028	0.0000	0.0008	0.0004	0.0003	0.0008	0.0008	0.0009	0.0004	0.0015	0.0003

Magnaflow in filtered/diluted Rideau River Water (3.2 NTU) (2018-03-26)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.1502	0.1519	0.1532	0.1525	0.1523	0.1506	0.1509	0.1516	0.1513	0.1513	0.1524
249	0.1548	0.1565	0.1579	0.1572	0.1569	0.1552	0.1557	0.1563	0.1558	0.1559	0.1570
248	0.1595	0.1613	0.1624	0.1618	0.1617	0.1600	0.1603	0.1611	0.1607	0.1607	0.1619
247	0.1641	0.1659	0.1672	0.1666	0.1663	0.1646	0.1649	0.1658	0.1653	0.1654	0.1665
246	0.1685	0.1705	0.1719	0.1711	0.1707	0.1691	0.1694	0.1704	0.1700	0.1698	0.1711
245	0.1729	0.1746	0.1760	0.1754	0.1752	0.1732	0.1738	0.1747	0.1741	0.1741	0.1753
244	0.1769	0.1786	0.1800	0.1793	0.1792	0.1772	0.1777	0.1787	0.1781	0.1782	0.1794
243	0.1805	0.1822	0.1837	0.1829	0.1829	0.1807	0.1812	0.1822	0.1817	0.1817	0.1830
242	0.1835	0.1853	0.1868	0.1861	0.1858	0.1838	0.1844	0.1855	0.1849	0.1848	0.1860
241	0.1863	0.1881	0.1896	0.1887	0.1887	0.1867	0.1871	0.1882	0.1876	0.1876	0.1888
240	0.1887	0.1905	0.1919	0.1912	0.1911	0.1888	0.1895	0.1905	0.1899	0.1898	0.1912
239	0.1908	0.1924	0.1939	0.1931	0.1930	0.1909	0.1914	0.1925	0.1919	0.1919	0.1931
238	0.1924	0.1939	0.1956	0.1948	0.1947	0.1925	0.1930	0.1941	0.1935	0.1934	0.1947
237	0.1938	0.1954	0.1971	0.1962	0.1962	0.1939	0.1943	0.1954	0.1947	0.1947	0.1962
236	0.1949	0.1966	0.1984	0.1974	0.1973	0.1950	0.1955	0.1967	0.1960	0.1959	0.1973
235	0.1962	0.1979	0.1995	0.1986	0.1986	0.1963	0.1967	0.1978	0.1972	0.1970	0.1985
234	0.1975	0.1990	0.2008	0.1998	0.1998	0.1974	0.1979	0.1991	0.1984	0.1982	0.1998
233	0.1988	0.2005	0.2023	0.2012	0.2011	0.1987	0.1993	0.2005	0.1998	0.1996	0.2011
232	0.2002	0.2020	0.2039	0.2028	0.2029	0.2005	0.2010	0.2021	0.2013	0.2011	0.2029
231	0.2022	0.2040	0.2059	0.2049	0.2047	0.2023	0.2028	0.2039	0.2032	0.2031	0.2047
230	0.2045	0.2062	0.2083	0.2072	0.2071	0.2046	0.2051	0.2064	0.2056	0.2052	0.2070
229	0.2071	0.2091	0.2112	0.2098	0.2098	0.2075	0.2078	0.2091	0.2083	0.2080	0.2099
228	0.2102	0.2124	0.2144	0.2133	0.2131	0.2108	0.2111	0.2123	0.2115	0.2113	0.2132
227	0.2139	0.2163	0.2184	0.2173	0.2170	0.2145	0.2148	0.2162	0.2155	0.2151	0.2171
226	0.2186	0.2210	0.2230	0.2219	0.2216	0.2191	0.2194	0.2209	0.2200	0.2196	0.2217
225	0.2237	0.2262	0.2282	0.2274	0.2269	0.2244	0.2246	0.2261	0.2252	0.2249	0.2271
224	0.2297	0.2324	0.2345	0.2335	0.2330	0.2306	0.2308	0.2323	0.2314	0.2310	0.2332
223	0.2366	0.2394	0.2416	0.2405	0.2400	0.2375	0.2377	0.2392	0.2384	0.2379	0.2402
222	0.2444	0.2474	0.2496	0.2488	0.2479	0.2457	0.2456	0.2473	0.2465	0.2459	0.2483
221	0.2531	0.2562	0.2584	0.2577	0.2567	0.2543	0.2545	0.2560	0.2552	0.2547	0.2571
220	0.2628	0.2662	0.2686	0.2678	0.2668	0.2644	0.2644	0.2661	0.2653	0.2646	0.2671
219	0.2735	0.2769	0.2793	0.2786	0.2775	0.2754	0.2751	0.2770	0.2760	0.2754	0.2780
218	0.2855	0.2890	0.2914	0.2908	0.2894	0.2874	0.2871	0.2892	0.2883	0.2874	0.2900
217	0.2977	0.3016	0.3041	0.3035	0.3018	0.2999	0.2996	0.3018	0.3007	0.2999	0.3026
216	0.3112	0.3152	0.3176	0.3171	0.3156	0.3135	0.3131	0.3154	0.3144	0.3136	0.3163

215	0.3250	0.3290	0.3317	0.3312	0.3293	0.3275	0.3270	0.3294	0.3282	0.3276	0.3302
214	0.3396	0.3440	0.3465	0.3462	0.3441	0.3424	0.3419	0.3444	0.3431	0.3423	0.3451
213	0.3545	0.3589	0.3616	0.3613	0.3591	0.3573	0.3567	0.3592	0.3579	0.3573	0.3598
212	0.3698	0.3745	0.3772	0.3770	0.3746	0.3730	0.3721	0.3748	0.3736	0.3729	0.3755
211	0.3853	0.3900	0.3929	0.3927	0.3902	0.3887	0.3876	0.3905	0.3890	0.3882	0.3910
210	0.4009	0.4058	0.4088	0.4088	0.4061	0.4046	0.4034	0.4063	0.4050	0.4040	0.4069
209	0.4167	0.4215	0.4247	0.4245	0.4217	0.4202	0.4189	0.4220	0.4205	0.4196	0.4224
208	0.4323	0.4371	0.4406	0.4403	0.4375	0.4359	0.4345	0.4375	0.4362	0.4353	0.4383
207	0.4476	0.4525	0.4561	0.4558	0.4529	0.4512	0.4498	0.4529	0.4513	0.4504	0.4535
206	0.4632	0.4678	0.4717	0.4713	0.4684	0.4666	0.4651	0.4682	0.4667	0.4657	0.4689
205	0.4784	0.4829	0.4871	0.4865	0.4837	0.4817	0.4800	0.4832	0.4817	0.4807	0.4839
204	0.4941	0.4989	0.5031	0.5025	0.4996	0.4977	0.4960	0.4992	0.4976	0.4963	0.4999
203	0.5097	0.5148	0.5193	0.5187	0.5156	0.5137	0.5116	0.5149	0.5133	0.5122	0.5158
202	0.5266	0.5320	0.5367	0.5358	0.5327	0.5311	0.5288	0.5322	0.5305	0.5292	0.5332
201	0.5447	0.5503	0.5554	0.5544	0.5510	0.5493	0.5470	0.5504	0.5487	0.5474	0.5516
200	0.5650	0.5713	0.5766	0.5754	0.5722	0.5704	0.5680	0.5715	0.5698	0.5684	0.5730
199	0.5879	0.5949	0.6006	0.5993	0.5959	0.5942	0.5918	0.5952	0.5934	0.5919	0.5974
198	0.6146	0.6223	0.6282	0.6269	0.6232	0.6218	0.6190	0.6226	0.6207	0.6193	0.6254
197	0.6460	0.6548	0.6608	0.6593	0.6554	0.6543	0.6515	0.6551	0.6532	0.6518	0.6584
196	0.6832	0.6930	0.6995	0.6980	0.6934	0.6928	0.6897	0.6934	0.6916	0.6902	0.6975
195	0.7300	0.7410	0.7479	0.7463	0.7410	0.7410	0.7380	0.7413	0.7393	0.7385	0.7466
194	0.7848	0.7976	0.8042	0.8028	0.7967	0.7976	0.7937	0.7969	0.7956	0.7952	0.8036
193	0.8524	0.8667	0.8737	0.8717	0.8654	0.8666	0.8626	0.8659	0.8642	0.8644	0.8737
192	0.9438	0.9596	0.9668	0.9648	0.9571	0.9590	0.9549	0.9579	0.9563	0.9571	0.9676
191	1.0645	1.0825	1.0897	1.0873	1.0785	1.0815	1.0766	1.0794	1.0778	1.0795	1.0908
190	1.2094	1.2298	1.2369	1.2335	1.2237	1.2273	1.2222	1.2237	1.2231	1.2254	1.2376
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS AT 19NM	1.2094	1.2298	1.2369	1.2335	1.2237	1.2273	1.2222	1.2237	1.2231	1.2254	1.2376
STDV	0.0010	0.0009	0.0053	0.0035	0.0031	0.0042	0.0010	0.0037	0.0033	0.0017	0.0027

Appendix C: UV-vis absorbance data for experimental phase 3

Magnaflow in deionized water with Actiflo process chemicals (2018-05-08)							
Desktop spectrophotometer (1cm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
250	0.1892	0.1892	0.1749	0.1669	0.1609	0.1551	0.1599
249	0.1943	0.1939	0.1795	0.1714	0.1654	0.1594	0.1648
248	0.1993	0.1986	0.1840	0.1758	0.1697	0.1635	0.1690
247	0.2048	0.2034	0.1887	0.1803	0.1741	0.1679	0.1737
246	0.2102	0.2081	0.1931	0.1844	0.1784	0.1721	0.1782
245	0.2152	0.2124	0.1975	0.1885	0.1825	0.1761	0.1825
244	0.2201	0.2162	0.2014	0.1918	0.1861	0.1797	0.1864
243	0.2246	0.2199	0.2048	0.1952	0.1894	0.1831	0.1898
242	0.2290	0.2232	0.2078	0.1978	0.1921	0.1859	0.1929
241	0.2327	0.2258	0.2104	0.2000	0.1944	0.1883	0.1956
240	0.2363	0.2282	0.2125	0.2017	0.1962	0.1904	0.1977
239	0.2397	0.2302	0.2142	0.2029	0.1978	0.1920	0.1996
238	0.2426	0.2316	0.2155	0.2038	0.1987	0.1931	0.2009
237	0.2453	0.2327	0.2163	0.2043	0.1994	0.1939	0.2018
236	0.2478	0.2336	0.2168	0.2045	0.1996	0.1945	0.2026
235	0.2500	0.2344	0.2170	0.2043	0.1996	0.1947	0.2030
234	0.2521	0.2346	0.2170	0.2040	0.1995	0.1949	0.2032
233	0.2539	0.2349	0.2169	0.2037	0.1994	0.1950	0.2034
232	0.2559	0.2353	0.2167	0.2033	0.1992	0.1949	0.2036
231	0.2577	0.2354	0.2167	0.2029	0.1990	0.1948	0.2036
230	0.2592	0.2358	0.2166	0.2027	0.1988	0.1949	0.2039
229	0.2608	0.2360	0.2165	0.2023	0.1989	0.1949	0.2041
228	0.2622	0.2364	0.2167	0.2024	0.1990	0.1950	0.2045
227	0.2634	0.2368	0.2169	0.2025	0.1993	0.1954	0.2049
226	0.2646	0.2373	0.2174	0.2030	0.1996	0.1959	0.2056
225	0.2656	0.2381	0.2183	0.2035	0.2004	0.1965	0.2063
224	0.2667	0.2391	0.2192	0.2046	0.2015	0.1972	0.2074
223	0.2679	0.2402	0.2207	0.2060	0.2026	0.1986	0.2087
222	0.2690	0.2420	0.2225	0.2079	0.2044	0.2001	0.2109
221	0.2706	0.2439	0.2248	0.2101	0.2064	0.2021	0.2132
220	0.2725	0.2463	0.2277	0.2132	0.2091	0.2046	0.2159
219	0.2747	0.2494	0.2312	0.2167	0.2122	0.2076	0.2194
218	0.2776	0.2530	0.2352	0.2207	0.2161	0.2112	0.2235

217	0.2812	0.2572	0.2396	0.2254	0.2203	0.2152	0.2282
216	0.2854	0.2619	0.2447	0.2306	0.2251	0.2200	0.2334
215	0.2900	0.2672	0.2504	0.2361	0.2305	0.2251	0.2391
214	0.2957	0.2731	0.2566	0.2423	0.2365	0.2310	0.2454
213	0.3023	0.2798	0.2635	0.2490	0.2432	0.2374	0.2526
212	0.3100	0.2873	0.2712	0.2564	0.2504	0.2444	0.2606
211	0.3188	0.2955	0.2795	0.2642	0.2581	0.2522	0.2692
210	0.3286	0.3045	0.2885	0.2726	0.2665	0.2605	0.2788
209	0.3394	0.3142	0.2983	0.2814	0.2755	0.2695	0.2889
208	0.3510	0.3245	0.3088	0.2907	0.2849	0.2792	0.2999
207	0.3639	0.3356	0.3201	0.3005	0.2950	0.2896	0.3119
206	0.3775	0.3474	0.3321	0.3109	0.3058	0.3004	0.3247
205	0.3922	0.3607	0.3460	0.3226	0.3175	0.3125	0.3392
204	0.4077	0.3742	0.3603	0.3345	0.3300	0.3252	0.3546
203	0.4239	0.3889	0.3763	0.3475	0.3433	0.3388	0.3718
202	0.4411	0.4048	0.3937	0.3616	0.3577	0.3537	0.3905
201	0.4593	0.4223	0.4130	0.3771	0.3735	0.3698	0.4114
200	0.4785	0.4410	0.4339	0.3938	0.3908	0.3875	0.4341
199	0.4985	0.4610	0.4570	0.4121	0.4093	0.4063	0.4590
198	0.5188	0.4819	0.4812	0.4315	0.4294	0.4262	0.4852
197	0.5400	0.5046	0.5076	0.4527	0.4502	0.4477	0.5137
196	0.5617	0.5280	0.5349	0.4748	0.4726	0.4699	0.5432
195	0.5864	0.5551	0.5666	0.5011	0.4974	0.4960	0.5769
194	0.6078	0.5791	0.5944	0.5246	0.5222	0.5191	0.6069
193	0.6333	0.6078	0.6272	0.5530	0.5504	0.5472	0.6413
192	0.6648	0.6421	0.6652	0.5875	0.5843	0.5809	0.6814
191	0.7070	0.6873	0.7141	0.6331	0.6308	0.6258	0.7318
190	0.7602	0.7426	0.7722	0.6892	0.6821	0.6817	0.7920
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	0.7602	0.7426	0.7722	0.6892	0.6821	0.6817	0.7920
STDV	0.0013	0.0010	0.0006	0.0019	0.0035	0.0008	0.0017

Magnaflow in deionized water with Actiflo process chemicals (2018-05-08)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	0.4596	0.5261	0.5835	0.5589	0.5846	0.6120	0.7226
192.8	0.4060	0.4693	0.5177	0.5076	0.5342	0.5639	0.6541
195.8	0.3743	0.4362	0.4851	0.4831	0.5114	0.5378	0.6194
198.9	0.3441	0.4124	0.4586	0.4644	0.4928	0.5178	0.5889
201.9	0.3280	0.3991	0.4429	0.4525	0.4795	0.5022	0.5671
204.9	0.3177	0.3884	0.4310	0.4462	0.4703	0.4940	0.5573
208	0.3098	0.3780	0.4187	0.4322	0.4598	0.4817	0.5427
211	0.3086	0.3745	0.4119	0.4238	0.4509	0.4744	0.5327
214	0.3062	0.3676	0.3998	0.4140	0.4414	0.4630	0.5195
217	0.3035	0.3581	0.3917	0.4035	0.4315	0.4527	0.5038
220	0.2981	0.3506	0.3824	0.3930	0.4209	0.4409	0.4935
223.1	0.2876	0.3410	0.3693	0.3835	0.4087	0.4282	0.4777
226.1	0.2747	0.3327	0.3585	0.3723	0.3963	0.4166	0.4681
229.1	0.2609	0.3219	0.3543	0.3662	0.3890	0.4056	0.4573
232.1	0.2522	0.3137	0.3443	0.3591	0.3825	0.3980	0.4477
235.1	0.2445	0.3103	0.3389	0.3557	0.3774	0.3913	0.4421
238.1	0.2372	0.3061	0.3349	0.3521	0.3726	0.3880	0.4366
241.1	0.2337	0.3021	0.3339	0.3499	0.3716	0.3865	0.4339
244.1	0.2297	0.3012	0.3336	0.3502	0.3727	0.3869	0.4341
247.1	0.2280	0.2994	0.3339	0.3509	0.3755	0.3896	0.4349
250.1	0.2255	0.3003	0.3356	0.3517	0.3800	0.3954	0.4363
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	0.4596	0.5261	0.5835	0.5589	0.5846	0.6120	0.7226
STDV	0.0081	0.0021	0.0014	0.0009	0.0047	0.0033	0.0047

Magnaflow in deionized water with Actiflo process chemicals (2018-04-25)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.1647	0.1498	0.1541	0.1464	0.1370	0.1345	0.1240	0.1239	0.1365	0.1332	0.1248
249	0.1674	0.1511	0.1551	0.1473	0.1384	0.1355	0.1245	0.1250	0.1374	0.1343	0.1256
248	0.1701	0.1529	0.1568	0.1487	0.1403	0.1365	0.1253	0.1257	0.1386	0.1358	0.1265
247	0.1732	0.1546	0.1584	0.1501	0.1423	0.1377	0.1266	0.1272	0.1398	0.1375	0.1275
246	0.1764	0.1566	0.1598	0.1515	0.1445	0.1388	0.1275	0.1281	0.1412	0.1390	0.1285
245	0.1799	0.1585	0.1615	0.1530	0.1466	0.1402	0.1285	0.1293	0.1426	0.1407	0.1298
244	0.1835	0.1605	0.1630	0.1545	0.1491	0.1414	0.1298	0.1305	0.1441	0.1423	0.1308
243	0.1873	0.1628	0.1647	0.1558	0.1515	0.1427	0.1308	0.1316	0.1453	0.1440	0.1321
242	0.1917	0.1651	0.1662	0.1573	0.1543	0.1442	0.1318	0.1328	0.1467	0.1456	0.1332
241	0.1963	0.1674	0.1678	0.1588	0.1571	0.1456	0.1329	0.1338	0.1479	0.1473	0.1344
240	0.2012	0.1700	0.1696	0.1602	0.1603	0.1471	0.1342	0.1351	0.1495	0.1491	0.1355
239	0.2065	0.1728	0.1713	0.1617	0.1635	0.1485	0.1353	0.1366	0.1510	0.1509	0.1368
238	0.2120	0.1757	0.1730	0.1633	0.1668	0.1498	0.1365	0.1379	0.1525	0.1527	0.1381
237	0.2178	0.1787	0.1746	0.1648	0.1706	0.1513	0.1377	0.1392	0.1540	0.1545	0.1393
236	0.2237	0.1817	0.1765	0.1662	0.1740	0.1528	0.1389	0.1403	0.1553	0.1562	0.1406
235	0.2296	0.1847	0.1783	0.1679	0.1777	0.1542	0.1400	0.1416	0.1571	0.1579	0.1418
234	0.2357	0.1879	0.1800	0.1694	0.1813	0.1555	0.1411	0.1429	0.1584	0.1596	0.1429
233	0.2417	0.1910	0.1816	0.1710	0.1851	0.1569	0.1423	0.1441	0.1599	0.1613	0.1442
232	0.2476	0.1940	0.1833	0.1726	0.1887	0.1585	0.1435	0.1454	0.1614	0.1630	0.1455
231	0.2533	0.1970	0.1852	0.1742	0.1921	0.1599	0.1449	0.1466	0.1629	0.1647	0.1470
230	0.2587	0.1999	0.1867	0.1758	0.1955	0.1613	0.1461	0.1480	0.1642	0.1664	0.1483
229	0.2638	0.2026	0.1885	0.1774	0.1985	0.1627	0.1473	0.1492	0.1655	0.1681	0.1496
228	0.2683	0.2049	0.1901	0.1790	0.2014	0.1643	0.1486	0.1505	0.1669	0.1696	0.1509
227	0.2721	0.2071	0.1917	0.1806	0.2040	0.1656	0.1498	0.1518	0.1684	0.1713	0.1522
226	0.2754	0.2090	0.1935	0.1821	0.2060	0.1669	0.1510	0.1529	0.1697	0.1728	0.1533
225	0.2781	0.2105	0.1949	0.1835	0.2077	0.1682	0.1521	0.1539	0.1711	0.1743	0.1546
224	0.2800	0.2118	0.1965	0.1851	0.2092	0.1695	0.1533	0.1552	0.1723	0.1757	0.1558
223	0.2813	0.2127	0.1982	0.1866	0.2101	0.1708	0.1543	0.1564	0.1736	0.1773	0.1569
222	0.2822	0.2135	0.1999	0.1881	0.2108	0.1722	0.1556	0.1573	0.1749	0.1788	0.1582
221	0.2825	0.2142	0.2016	0.1897	0.2112	0.1733	0.1568	0.1588	0.1764	0.1806	0.1594
220	0.2827	0.2146	0.2035	0.1913	0.2115	0.1746	0.1580	0.1600	0.1780	0.1823	0.1608
219	0.2828	0.2152	0.2052	0.1929	0.2118	0.1760	0.1593	0.1614	0.1794	0.1841	0.1621
218	0.2831	0.2158	0.2073	0.1946	0.2121	0.1774	0.1608	0.1628	0.1812	0.1860	0.1637
217	0.2831	0.2163	0.2094	0.1965	0.2124	0.1790	0.1622	0.1644	0.1830	0.1880	0.1651
216	0.2839	0.2170	0.2113	0.1984	0.2129	0.1806	0.1637	0.1659	0.1847	0.1902	0.1669

215	0.2849	0.2178	0.2135	0.2002	0.2136	0.1822	0.1653	0.1676	0.1868	0.1924	0.1684
214	0.2869	0.2191	0.2159	0.2022	0.2147	0.1842	0.1668	0.1694	0.1887	0.1950	0.1701
213	0.2897	0.2207	0.2184	0.2043	0.2163	0.1863	0.1687	0.1712	0.1908	0.1978	0.1722
212	0.2937	0.2228	0.2209	0.2067	0.2189	0.1886	0.1705	0.1733	0.1934	0.2010	0.1742
211	0.2990	0.2256	0.2241	0.2092	0.2219	0.1913	0.1730	0.1755	0.1963	0.2047	0.1768
210	0.3056	0.2290	0.2273	0.2123	0.2259	0.1943	0.1753	0.1782	0.1997	0.2089	0.1795
209	0.3140	0.2330	0.2311	0.2154	0.2308	0.1983	0.1780	0.1812	0.2032	0.2137	0.1826
208	0.3235	0.2378	0.2354	0.2191	0.2366	0.2025	0.1811	0.1846	0.2074	0.2195	0.1860
207	0.3348	0.2433	0.2403	0.2232	0.2434	0.2079	0.1844	0.1885	0.2126	0.2262	0.1902
206	0.3475	0.2497	0.2456	0.2278	0.2513	0.2141	0.1885	0.1930	0.2184	0.2340	0.1949
205	0.3619	0.2572	0.2523	0.2332	0.2601	0.2215	0.1929	0.1983	0.2253	0.2435	0.2006
204	0.3778	0.2654	0.2596	0.2396	0.2705	0.2306	0.1984	0.2049	0.2339	0.2551	0.2074
203	0.3956	0.2753	0.2689	0.2473	0.2823	0.2411	0.2048	0.2124	0.2436	0.2687	0.2154
202	0.4147	0.2858	0.2790	0.2557	0.2948	0.2536	0.2121	0.2211	0.2551	0.2843	0.2245
201	0.4354	0.2975	0.2907	0.2652	0.3088	0.2679	0.2202	0.2308	0.2683	0.3025	0.2352
200	0.4574	0.3107	0.3040	0.2761	0.3242	0.2842	0.2301	0.2424	0.2833	0.3233	0.2475
199	0.4805	0.3245	0.3189	0.2884	0.3406	0.3025	0.2410	0.2552	0.3002	0.3465	0.2614
198	0.5039	0.3390	0.3345	0.3015	0.3576	0.3222	0.2527	0.2691	0.3185	0.3717	0.2762
197	0.5281	0.3549	0.3522	0.3163	0.3757	0.3444	0.2666	0.2849	0.3388	0.3996	0.2939
196	0.5526	0.3710	0.3713	0.3318	0.3939	0.3674	0.2803	0.3017	0.3604	0.4287	0.3107
195	0.5760	0.3891	0.3926	0.3501	0.4140	0.3931	0.2961	0.3208	0.3848	0.4611	0.3303
194	0.5991	0.4060	0.4128	0.3676	0.4325	0.4176	0.3134	0.3393	0.4079	0.4913	0.3509
193	0.6232	0.4259	0.4361	0.3881	0.4535	0.4452	0.3332	0.3614	0.4343	0.5245	0.3740
192	0.6517	0.4509	0.4651	0.4143	0.4798	0.4773	0.3582	0.3885	0.4659	0.5621	0.4025
191	0.6909	0.4858	0.5032	0.4499	0.5153	0.5203	0.3961	0.4271	0.5086	0.6118	0.4433
190	0.7315	0.5300	0.5495	0.4945	0.5592	0.5643	0.4315	0.4679	0.5524	0.6547	0.4809
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	0.7315	0.5300	0.5495	0.4945	0.5592	0.5643	0.4315	0.4679	0.5524	0.6547	0.4809
STDV	0.0033	0.0014	0.0011	0.0015	0.0013	0.0037	0.0018	0.0036	0.0039	0.0022	0.0012

Magnaflow in deionized water with Actiflo process chemicals (2018-04-25)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	0.4821	0.3640	0.4128	0.4258	0.4974	0.5271	0.4624	0.4803	0.5395	0.6894	0.5579
192.8	0.4119	0.3244	0.3675	0.3885	0.4550	0.4653	0.4289	0.4454	0.4884	0.6025	0.5146
195.8	0.3622	0.3007	0.3414	0.3668	0.4278	0.4298	0.4095	0.4241	0.4596	0.5470	0.4891
198.9	0.3170	0.2787	0.3196	0.3496	0.4039	0.4022	0.3944	0.4070	0.4387	0.5096	0.4705
201.9	0.2846	0.2661	0.3074	0.3387	0.3876	0.3870	0.3882	0.3963	0.4247	0.4852	0.4570
204.9	0.2650	0.2564	0.2958	0.3286	0.3748	0.3735	0.3811	0.3866	0.4142	0.4706	0.4473
208	0.2564	0.2515	0.2870	0.3192	0.3674	0.3644	0.3714	0.3769	0.4048	0.4578	0.4399
211	0.2582	0.2489	0.2800	0.3125	0.3622	0.3582	0.3632	0.3714	0.3955	0.4479	0.4308
214	0.2588	0.2492	0.2725	0.3052	0.3586	0.3493	0.3538	0.3627	0.3870	0.4377	0.4214
217	0.2592	0.2455	0.2655	0.2972	0.3492	0.3418	0.3455	0.3548	0.3780	0.4261	0.4102
220	0.2553	0.2431	0.2600	0.2910	0.3444	0.3344	0.3388	0.3467	0.3687	0.4152	0.4015
223.1	0.2462	0.2342	0.2543	0.2849	0.3321	0.3290	0.3337	0.3396	0.3603	0.4059	0.3920
226.1	0.2336	0.2254	0.2484	0.2773	0.3185	0.3192	0.3245	0.3305	0.3513	0.3958	0.3827
229.1	0.2171	0.2172	0.2423	0.2711	0.3067	0.3121	0.3197	0.3246	0.3446	0.3867	0.3737
232.1	0.2013	0.2097	0.2366	0.2654	0.2934	0.3067	0.3124	0.3181	0.3377	0.3797	0.3672
235.1	0.1874	0.2018	0.2320	0.2608	0.2867	0.3015	0.3073	0.3142	0.3329	0.3727	0.3628
238.1	0.1776	0.1964	0.2288	0.2581	0.2792	0.2991	0.3046	0.3126	0.3303	0.3687	0.3589
241.1	0.1660	0.1920	0.2252	0.2549	0.2721	0.2949	0.3010	0.3098	0.3266	0.3625	0.3557
244.1	0.1609	0.1889	0.2233	0.2530	0.2689	0.2936	0.2994	0.3082	0.3251	0.3594	0.3553
247.1	0.1579	0.1877	0.2236	0.2529	0.2668	0.2934	0.2998	0.3093	0.3259	0.3604	0.3562
250.1	0.1540	0.1863	0.2222	0.2517	0.2672	0.2932	0.2987	0.3085	0.3268	0.3580	0.3559
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	0.4821	0.3640	0.4128	0.4258	0.4974	0.5271	0.4624	0.4803	0.5395	0.6894	0.5579
STDV	0.0221	0.0014	0.0162	0.0024	0.0164	0.0240	0.0177	0.0228	0.0221	0.0061	0.0175

Magnaflow in Rideau River water with Actiflo process chemicals (2018-04-11)							
Desktop spectrophotometer (1cm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
250	0.3813	0.2770	0.3372	0.3373	0.3479	0.3635	0.3312
249	0.3837	0.2790	0.3396	0.3397	0.3502	0.3662	0.3335
248	0.3865	0.2814	0.3419	0.3422	0.3526	0.3691	0.3361
247	0.3893	0.2837	0.3446	0.3450	0.3555	0.3721	0.3386
246	0.3922	0.2863	0.3475	0.3479	0.3586	0.3753	0.3416
245	0.3953	0.2891	0.3505	0.3507	0.3619	0.3789	0.3446
244	0.3985	0.2920	0.3534	0.3539	0.3654	0.3825	0.3477
243	0.4023	0.2953	0.3571	0.3576	0.3693	0.3867	0.3514
242	0.4063	0.2990	0.3610	0.3616	0.3736	0.3912	0.3552
241	0.4107	0.3030	0.3651	0.3662	0.3783	0.3962	0.3595
240	0.4156	0.3075	0.3699	0.3713	0.3835	0.4017	0.3643
239	0.4209	0.3125	0.3752	0.3766	0.3891	0.4076	0.3697
238	0.4267	0.3180	0.3809	0.3827	0.3954	0.4142	0.3754
237	0.4330	0.3243	0.3872	0.3893	0.4022	0.4212	0.3815
236	0.4400	0.3310	0.3942	0.3964	0.4095	0.4290	0.3885
235	0.4474	0.3384	0.4017	0.4041	0.4175	0.4374	0.3958
234	0.4557	0.3463	0.4098	0.4127	0.4264	0.4463	0.4041
233	0.4648	0.3551	0.4189	0.4220	0.4358	0.4560	0.4130
232	0.4745	0.3648	0.4287	0.4319	0.4462	0.4667	0.4229
231	0.4851	0.3752	0.4393	0.4429	0.4573	0.4780	0.4334
230	0.4964	0.3865	0.4506	0.4548	0.4691	0.4903	0.4450
229	0.5089	0.3985	0.4629	0.4673	0.4819	0.5033	0.4573
228	0.5221	0.4117	0.4762	0.4809	0.4956	0.5175	0.4707
227	0.5367	0.4258	0.4907	0.4954	0.5102	0.5327	0.4852
226	0.5523	0.4411	0.5062	0.5112	0.5261	0.5490	0.5010
225	0.5693	0.4576	0.5228	0.5281	0.5431	0.5664	0.5178
224	0.5875	0.4754	0.5411	0.5464	0.5614	0.5852	0.5364
223	0.6072	0.4945	0.5607	0.5660	0.5809	0.6055	0.5562
222	0.6287	0.5154	0.5819	0.5871	0.6022	0.6270	0.5777
221	0.6515	0.5375	0.6045	0.6097	0.6246	0.6503	0.6006
220	0.6759	0.5614	0.6289	0.6338	0.6488	0.6751	0.6253
219	0.7018	0.5865	0.6545	0.6594	0.6740	0.7013	0.6511
218	0.7291	0.6133	0.6816	0.6863	0.7011	0.7292	0.6788
217	0.7573	0.6410	0.7098	0.7145	0.7291	0.7579	0.7075
216	0.7867	0.6698	0.7392	0.7438	0.7581	0.7882	0.7373

215	0.8168	0.6995	0.7691	0.7739	0.7881	0.8191	0.7679
214	0.8480	0.7303	0.8005	0.8049	0.8191	0.8512	0.7996
213	0.8794	0.7612	0.8320	0.8364	0.8506	0.8838	0.8316
212	0.9114	0.7932	0.8639	0.8686	0.8828	0.9171	0.8642
211	0.9433	0.8250	0.8962	0.9010	0.9152	0.9506	0.8969
210	0.9756	0.8573	0.9289	0.9336	0.9482	0.9850	0.9297
209	1.0078	0.8895	0.9614	0.9663	0.9812	1.0192	0.9625
208	1.0403	0.9223	0.9944	0.9996	1.0147	1.0543	0.9958
207	1.0729	0.9555	1.0276	1.0328	1.0485	1.0900	1.0293
206	1.1063	0.9896	1.0618	1.0676	1.0833	1.1270	1.0636
205	1.1399	1.0237	1.0965	1.1025	1.1192	1.1649	1.0986
204	1.1747	1.0598	1.1325	1.1388	1.1564	1.2049	1.1346
203	1.2108	1.0968	1.1698	1.1763	1.1957	1.2471	1.1725
202	1.2492	1.1364	1.2100	1.2165	1.2374	1.2927	1.2131
201	1.2898	1.1781	1.2526	1.2594	1.2818	1.3419	1.2563
200	1.3341	1.2241	1.2994	1.3063	1.3308	1.3957	1.3039
199	1.3826	1.2745	1.3500	1.3573	1.3841	1.4548	1.3563
198	1.4368	1.3305	1.4070	1.4142	1.4433	1.5203	1.4149
197	1.4986	1.3940	1.4716	1.4791	1.5105	1.5939	1.4817
196	1.5719	1.4692	1.5476	1.5554	1.5886	1.6805	1.5611
195	1.6495	1.5482	1.6268	1.6349	1.6744	1.7689	1.6435
194	1.7453	1.6457	1.7255	1.7334	1.7733	1.8763	1.7454
193	1.8536	1.7553	1.8346	1.8428	1.8847	1.9942	1.8579
192	1.9859	1.8885	1.9674	1.9762	2.0201	2.1317	1.9952
191	2.1499	2.0514	2.1300	2.1390	2.1833	2.2953	2.1608
190	2.3269	2.2299	2.3052	2.3140	2.3562	2.4627	2.3364
CONC	0	0.5	1	1.5	2	2.5	3
ABS AT 190nm	2.3269	2.2299	2.3052	2.3140	2.3562	2.4627	2.3364
STDV	0.0010	0.0014	0.0011	0.0001	0.0021	0.0033	0.0048

Magnaflow in Rideau River water with Actiflo process chemicals (2018-04-11)							
In-line spectrophotometer (4mm path length)							
Wavelength (nm)	0 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	2.5 mg/L	3.0 mg/L
189.8	1.2269	1.1044	1.1190	1.1445	1.1875	1.2565	1.3818
192.8	1.0693	0.9443	0.9566	0.9827	1.0169	1.0801	1.1806
195.8	0.9956	0.8743	0.8837	0.9071	0.9346	0.9962	1.0880
198.9	0.9238	0.8010	0.8128	0.8355	0.8601	0.9150	1.0000
201.9	0.8596	0.7363	0.7483	0.7712	0.7937	0.8496	0.9285
204.9	0.7846	0.6637	0.6752	0.6961	0.7175	0.7714	0.8467
208	0.7088	0.5912	0.6023	0.6227	0.6438	0.6941	0.7654
211	0.6409	0.5254	0.5345	0.5572	0.5774	0.6267	0.6918
214	0.5827	0.4687	0.4768	0.4985	0.5186	0.5652	0.6286
217	0.5268	0.4154	0.4237	0.4445	0.4647	0.5086	0.5691
220	0.4912	0.3810	0.3905	0.4105	0.4298	0.4729	0.5304
223.1	0.4559	0.3468	0.3554	0.3741	0.3934	0.4353	0.4912
226.1	0.4314	0.3238	0.3396	0.3502	0.3689	0.4082	0.4648
229.1	0.4127	0.3048	0.3142	0.3315	0.3479	0.3880	0.4434
232.1	0.3973	0.2913	0.2985	0.3146	0.3313	0.3716	0.4261
235.1	0.3856	0.2793	0.2873	0.3041	0.3191	0.3583	0.4133
238.1	0.3785	0.2728	0.2810	0.2971	0.3125	0.3517	0.4051
241.1	0.3724	0.2672	0.2753	0.2898	0.3049	0.3452	0.3973
244.1	0.3651	0.2622	0.2702	0.2853	0.2994	0.3400	0.3913
247.1	0.3619	0.2570	0.2668	0.2820	0.2964	0.3371	0.3866
250.1	0.3595	0.2553	0.2651	0.2787	0.2942	0.3357	0.3842
CONC	0	0.5	1	1.5	2	2.5	3
ABS at 190nm	1.2269	1.1044	1.1190	1.1445	1.1875	1.2565	1.3818
STDV	0.0222	0.0209	0.0142	0.0139	0.0060	0.0014	0.0062

Magnaflow in Rideau River water with Actiflo process chemicals (2018-04-30)											
Desktop spectrophotometer (1cm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
250	0.4355	0.3409	0.3250	0.2998	0.2938	0.3184	0.2773	0.2677	0.2908	0.2919	0.3126
249	0.4405	0.3434	0.3271	0.3017	0.2957	0.3206	0.2794	0.2695	0.2929	0.2937	0.3148
248	0.4458	0.3457	0.3293	0.3037	0.2978	0.3230	0.2813	0.2715	0.2949	0.2954	0.3166
247	0.4517	0.3482	0.3316	0.3056	0.3000	0.3254	0.2832	0.2735	0.2970	0.2974	0.3189
246	0.4583	0.3510	0.3341	0.3079	0.3023	0.3281	0.2856	0.2758	0.2995	0.2996	0.3213
245	0.4658	0.3539	0.3367	0.3104	0.3048	0.3310	0.2880	0.2784	0.3021	0.3021	0.3238
244	0.4741	0.3569	0.3395	0.3131	0.3075	0.3340	0.2905	0.2806	0.3047	0.3044	0.3265
243	0.4831	0.3603	0.3427	0.3158	0.3105	0.3373	0.2932	0.2834	0.3076	0.3072	0.3295
242	0.4931	0.3638	0.3458	0.3187	0.3136	0.3407	0.2960	0.2864	0.3108	0.3103	0.3326
241	0.5041	0.3673	0.3495	0.3222	0.3170	0.3445	0.2993	0.2897	0.3143	0.3135	0.3361
240	0.5161	0.3717	0.3534	0.3258	0.3208	0.3485	0.3029	0.2933	0.3180	0.3175	0.3399
239	0.5294	0.3761	0.3578	0.3299	0.3250	0.3531	0.3069	0.2973	0.3223	0.3214	0.3440
238	0.5433	0.3811	0.3624	0.3344	0.3295	0.3579	0.3110	0.3017	0.3269	0.3261	0.3486
237	0.5584	0.3863	0.3676	0.3393	0.3346	0.3632	0.3158	0.3065	0.3320	0.3311	0.3536
236	0.5740	0.3922	0.3732	0.3447	0.3402	0.3690	0.3211	0.3118	0.3374	0.3366	0.3592
235	0.5908	0.3987	0.3796	0.3507	0.3462	0.3754	0.3271	0.3178	0.3435	0.3428	0.3653
234	0.6081	0.4058	0.3865	0.3574	0.3529	0.3825	0.3336	0.3244	0.3502	0.3495	0.3721
233	0.6264	0.4138	0.3942	0.3649	0.3604	0.3904	0.3410	0.3320	0.3579	0.3570	0.3797
232	0.6451	0.4224	0.4028	0.3732	0.3690	0.3990	0.3492	0.3403	0.3662	0.3655	0.3880
231	0.6640	0.4321	0.4124	0.3826	0.3784	0.4087	0.3583	0.3495	0.3757	0.3749	0.3973
230	0.6834	0.4429	0.4231	0.3930	0.3891	0.4195	0.3686	0.3599	0.3860	0.3855	0.4078
229	0.7028	0.4551	0.4351	0.4046	0.4008	0.4315	0.3801	0.3716	0.3977	0.3972	0.4198
228	0.7223	0.4683	0.4483	0.4176	0.4137	0.4448	0.3928	0.3845	0.4107	0.4102	0.4330
227	0.7419	0.4833	0.4629	0.4319	0.4283	0.4597	0.4069	0.3987	0.4253	0.4247	0.4475
226	0.7612	0.4993	0.4791	0.4479	0.4442	0.4756	0.4226	0.4146	0.4412	0.4405	0.4635
225	0.7806	0.5173	0.4970	0.4653	0.4619	0.4937	0.4400	0.4319	0.4589	0.4581	0.4811
224	0.8000	0.5368	0.5162	0.4845	0.4812	0.5131	0.4588	0.4510	0.4780	0.4774	0.5004
223	0.8195	0.5580	0.5375	0.5054	0.5023	0.5343	0.4798	0.4718	0.4990	0.4983	0.5214
222	0.8394	0.5809	0.5603	0.5280	0.5248	0.5572	0.5020	0.4944	0.5217	0.5208	0.5442
221	0.8598	0.6056	0.5850	0.5524	0.5493	0.5819	0.5263	0.5186	0.5461	0.5454	0.5686
220	0.8807	0.6317	0.6112	0.5783	0.5752	0.6079	0.5519	0.5445	0.5719	0.5713	0.5944
219	0.9027	0.6595	0.6389	0.6058	0.6027	0.6356	0.5792	0.5717	0.5997	0.5987	0.6220
218	0.9255	0.6885	0.6679	0.6345	0.6313	0.6646	0.6077	0.6004	0.6285	0.6274	0.6505
217	0.9496	0.7185	0.6978	0.6644	0.6611	0.6948	0.6374	0.6301	0.6584	0.6573	0.6805
216	0.9743	0.7491	0.7281	0.6943	0.6912	0.7255	0.6675	0.6603	0.6890	0.6878	0.7109
215	1.0007	0.7802	0.7588	0.7249	0.7219	0.7567	0.6979	0.6909	0.7198	0.7184	0.7418

214	1.0279	0.8110	0.7897	0.7554	0.7529	0.7879	0.7282	0.7215	0.7508	0.7493	0.7728
213	1.0570	0.8419	0.8207	0.7859	0.7836	0.8193	0.7590	0.7521	0.7818	0.7799	0.8040
212	1.0871	0.8721	0.8506	0.8157	0.8137	0.8501	0.7888	0.7820	0.8125	0.8100	0.8345
211	1.1186	0.9019	0.8800	0.8448	0.8429	0.8803	0.8184	0.8115	0.8423	0.8397	0.8642
210	1.1515	0.9300	0.9081	0.8728	0.8711	0.9096	0.8463	0.8396	0.8715	0.8680	0.8929
209	1.1855	0.9571	0.9354	0.8995	0.8981	0.9383	0.8737	0.8667	0.8998	0.8956	0.9202
208	1.2207	0.9827	0.9608	0.9249	0.9236	0.9658	0.8995	0.8923	0.9268	0.9217	0.9465
207	1.2571	1.0070	0.9850	0.9492	0.9478	0.9926	0.9242	0.9169	0.9532	0.9470	0.9718
206	1.2938	1.0303	1.0082	0.9719	0.9706	1.0187	0.9480	0.9401	0.9786	0.9713	0.9958
205	1.3326	1.0528	1.0308	0.9944	0.9934	1.0453	0.9715	0.9633	1.0047	0.9952	1.0194
204	1.3715	1.0746	1.0528	1.0161	1.0152	1.0722	0.9946	0.9859	1.0301	1.0192	1.0424
203	1.4126	1.0968	1.0748	1.0378	1.0372	1.1004	1.0184	1.0089	1.0575	1.0437	1.0664
202	1.4547	1.1196	1.0974	1.0606	1.0602	1.1302	1.0433	1.0331	1.0856	1.0697	1.0913
201	1.4993	1.1440	1.1222	1.0852	1.0849	1.1631	1.0702	1.0592	1.1171	1.0980	1.1188
200	1.5470	1.1713	1.1498	1.1127	1.1127	1.2001	1.1007	1.0886	1.1519	1.1296	1.1494
199	1.5981	1.2028	1.1815	1.1446	1.1447	1.2427	1.1357	1.1221	1.1924	1.1665	1.1849
198	1.6521	1.2393	1.2181	1.1813	1.1828	1.2909	1.1762	1.1612	1.2384	1.2084	1.2271
197	1.7114	1.2846	1.2634	1.2267	1.2276	1.3487	1.2256	1.2088	1.2938	1.2595	1.2746
196	1.7770	1.3377	1.3171	1.2806	1.2822	1.4151	1.2833	1.2648	1.3574	1.3193	1.3325
195	1.8563	1.4087	1.3879	1.3514	1.3509	1.4995	1.3587	1.3387	1.4396	1.3961	1.4026
194	1.9373	1.4856	1.4655	1.4297	1.4318	1.5874	1.4398	1.4181	1.5261	1.4787	1.4895
193	2.0351	1.5843	1.5642	1.5279	1.5311	1.6973	1.5425	1.5190	1.6336	1.5828	1.5925
192	2.1558	1.7085	1.6894	1.6537	1.6571	1.8296	1.6702	1.6458	1.7655	1.7119	1.7211
191	2.3085	1.8717	1.8537	1.8171	1.8250	1.9977	1.8359	1.8113	1.9331	1.8786	1.8948
190	2.4698	2.0563	2.0376	2.0027	1.9995	2.1781	2.0204	1.9954	2.1158	2.0626	2.0586
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	2.4698	2.0563	2.0376	2.0027	1.9995	2.1781	2.0204	1.9954	2.1158	2.0626	2.0586
STDV	0.0006	0.0006	0.0013	0.0004	0.0101	0.0009	0.0011	0.0002	0.0040	0.0033	0.0022

Magnaflow in Rideau River water with Actiflo process chemicals (2018-04-30)											
In-line spectrophotometer (4mm path length)											
Wavelength (nm)	0 mg/L	0.1 mg/L	0.2 mg/L	0.3 mg/L	0.4 mg/L	0.5 mg/L	0.6 mg/L	0.7 mg/L	0.8 mg/L	0.9 mg/L	1.0 mg/L
189.8	1.9749	1.4671	1.4476	1.3916	1.4135	1.6155	1.5992	1.5924	1.7580	1.8040	1.8432
192.8	1.6527	1.2702	1.2544	1.2035	1.2191	1.3828	1.3854	1.3809	1.5226	1.5720	1.6127
195.8	1.4881	1.1783	1.1654	1.1169	1.1316	1.2759	1.2902	1.2951	1.4130	1.4711	1.5117
198.9	1.3186	1.0852	1.0723	1.0245	1.0381	1.1619	1.1920	1.2002	1.3076	1.3675	1.4109
201.9	1.1873	0.9973	0.9844	0.9383	0.9531	1.0696	1.0997	1.1107	1.2134	1.2734	1.3176
204.9	1.0610	0.8882	0.8776	0.8352	0.8460	0.9612	0.9915	1.0033	1.0996	1.1602	1.2035
208	0.9567	0.7797	0.7695	0.7264	0.7392	0.8465	0.8800	0.8934	0.9874	1.0465	1.0864
211	0.8746	0.6827	0.6714	0.6302	0.6409	0.7465	0.7789	0.7908	0.8832	0.9414	0.9803
214	0.8106	0.5997	0.5887	0.5490	0.5589	0.6644	0.6927	0.7058	0.7950	0.8517	0.8916
217	0.7425	0.5219	0.5118	0.4732	0.4833	0.5838	0.6118	0.6266	0.7130	0.7665	0.8064
220	0.6931	0.4736	0.4649	0.4266	0.4358	0.5329	0.5616	0.5756	0.6591	0.7120	0.7529
223.1	0.6320	0.4273	0.4176	0.3804	0.3896	0.4858	0.5113	0.5244	0.6082	0.6590	0.6993
226.1	0.5789	0.3978	0.3890	0.3513	0.3616	0.4552	0.4802	0.4946	0.5732	0.6234	0.6648
229.1	0.5247	0.3744	0.3660	0.3289	0.3379	0.4298	0.4536	0.4678	0.5471	0.5942	0.6349
232.1	0.4815	0.3566	0.3490	0.3136	0.3215	0.4126	0.4373	0.4505	0.5296	0.5760	0.6167
235.1	0.4462	0.3447	0.3372	0.3030	0.3105	0.4007	0.4251	0.4387	0.5162	0.5619	0.6019
238.1	0.4193	0.3360	0.3285	0.2936	0.3011	0.3908	0.4177	0.4294	0.5083	0.5532	0.5920
241.1	0.3988	0.3289	0.3233	0.2871	0.2950	0.3860	0.4130	0.4235	0.5039	0.5494	0.5872
244.1	0.3849	0.3232	0.3175	0.2823	0.2902	0.3811	0.4086	0.4193	0.4991	0.5455	0.5840
247.1	0.3715	0.3176	0.3121	0.2789	0.2841	0.3766	0.4068	0.4173	0.4953	0.5402	0.5804
250.1	0.3640	0.3130	0.3077	0.2736	0.2800	0.3723	0.4012	0.4128	0.4917	0.5395	0.5764
CONC	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
ABS at 190nm	0.2040	1.4671	1.4476	1.3916	1.4135	1.6155	1.5992	1.5924	1.7580	1.8040	1.8432
STDV	1.9749	0.0190	0.0138	0.0100	0.0200	0.0027	0.0089	0.0145	0.0132	0.0107	0.0128

Appendix D: UV-vis absorbance data for experimental phase 4

Magnaflow determination of optimum dose in high turbidity Rideau River water (9172 NTU)									
Desktop spectrophotometer (1cm path length)									
Wavelength (nm)	0 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	3.0 mg/L	4.0 mg/L	5.0 mg/L
250	10.0000	1.1642	0.7094	0.5758	0.5172	0.4846	0.5375	0.5774	0.6468
249	10.0000	1.1705	0.7150	0.5814	0.5229	0.4901	0.5430	0.5830	0.6528
248	10.0000	1.1767	0.7211	0.5871	0.5285	0.4956	0.5485	0.5887	0.6585
247	10.0000	1.1826	0.7267	0.5927	0.5341	0.5011	0.5540	0.5944	0.6645
246	10.0000	1.1887	0.7324	0.5982	0.5395	0.5065	0.5594	0.5996	0.6702
245	10.0000	1.1943	0.7380	0.6035	0.5445	0.5114	0.5646	0.6049	0.6755
244	10.0000	1.1999	0.7431	0.6085	0.5496	0.5163	0.5695	0.6099	0.6807
243	10.0000	1.2052	0.7481	0.6130	0.5543	0.5209	0.5741	0.6147	0.6856
242	10.0000	1.2102	0.7526	0.6176	0.5586	0.5252	0.5781	0.6190	0.6901
241	10.0000	1.2148	0.7571	0.6219	0.5627	0.5293	0.5823	0.6230	0.6945
240	10.0000	1.2194	0.7611	0.6258	0.5666	0.5330	0.5862	0.6270	0.6987
239	10.0000	1.2237	0.7654	0.6297	0.5702	0.5365	0.5898	0.6308	0.7025
238	10.0000	1.2277	0.7693	0.6332	0.5738	0.5400	0.5934	0.6343	0.7064
237	10.0000	1.2320	0.7733	0.6370	0.5774	0.5434	0.5970	0.6380	0.7102
236	10.0000	1.2365	0.7772	0.6409	0.5811	0.5470	0.6004	0.6415	0.7141
235	10.0000	1.2411	0.7814	0.6447	0.5849	0.5506	0.6043	0.6456	0.7183
234	10.0000	1.2460	0.7859	0.6491	0.5890	0.5545	0.6084	0.6498	0.7230
233	10.0000	1.2516	0.7911	0.6538	0.5936	0.5591	0.6129	0.6544	0.7279
232	10.0000	1.2575	0.7966	0.6592	0.5988	0.5640	0.6180	0.6596	0.7333
231	10.0000	1.2640	0.8029	0.6650	0.6046	0.5698	0.6238	0.6654	0.7396
230	10.0000	1.2715	0.8097	0.6714	0.6110	0.5760	0.6303	0.6718	0.7467
229	10.0000	1.2796	0.8174	0.6789	0.6185	0.5832	0.6375	0.6793	0.7542
228	10.0000	1.2887	0.8261	0.6874	0.6267	0.5913	0.6458	0.6876	0.7629
227	10.0000	1.2990	0.8358	0.6968	0.6358	0.6003	0.6549	0.6969	0.7725
226	10.0000	1.3106	0.8466	0.7072	0.6461	0.6104	0.6651	0.7072	0.7832
225	10.0000	1.3229	0.8586	0.7186	0.6576	0.6218	0.6768	0.7187	0.7952
224	10.0000	1.3365	0.8716	0.7317	0.6703	0.6344	0.6893	0.7315	0.8082
223	10.0000	1.3516	0.8860	0.7456	0.6843	0.6481	0.7033	0.7454	0.8228
222	10.0000	1.3680	0.9017	0.7613	0.6997	0.6630	0.7184	0.7606	0.8384
221	10.0000	1.3858	0.9189	0.7781	0.7162	0.6797	0.7349	0.7774	0.8554
220	10.0000	1.4048	0.9372	0.7960	0.7340	0.6973	0.7529	0.7954	0.8739
219	10.0000	1.4250	0.9566	0.8153	0.7531	0.7159	0.7719	0.8145	0.8932

218	10.0000	1.4463	0.9771	0.8354	0.7733	0.7358	0.7922	0.8346	0.9138
217	10.0000	1.4682	0.9986	0.8566	0.7940	0.7567	0.8131	0.8557	0.9351
216	10.0000	1.4907	1.0205	0.8782	0.8156	0.7779	0.8346	0.8773	0.9573
215	10.0000	1.5144	1.0430	0.9004	0.8377	0.7999	0.8568	0.8996	0.9798
214	10.0000	1.5377	1.0660	0.9232	0.8604	0.8222	0.8795	0.9220	1.0029
213	10.0000	1.5612	1.0893	0.9461	0.8832	0.8449	0.9023	0.9452	1.0262
212	10.0000	1.5851	1.1125	0.9694	0.9060	0.8675	0.9254	0.9679	1.0499
211	10.0000	1.6091	1.1357	0.9921	0.9289	0.8901	0.9483	0.9909	1.0734
210	10.0000	1.6326	1.1585	1.0148	0.9515	0.9124	0.9708	1.0134	1.0964
209	10.0000	1.6561	1.1810	1.0373	0.9736	0.9344	0.9934	1.0360	1.1193
208	10.0000	1.6790	1.2031	1.0592	0.9958	0.9558	1.0154	1.0580	1.1419
207	10.0000	1.7016	1.2249	1.0810	1.0174	0.9773	1.0373	1.0801	1.1644
206	10.0000	1.7246	1.2472	1.1031	1.0395	0.9991	1.0596	1.1024	1.1873
205	10.0000	1.7469	1.2694	1.1252	1.0616	1.0209	1.0823	1.1251	1.2108
204	10.0000	1.7707	1.2921	1.1483	1.0849	1.0439	1.1058	1.1490	1.2359
203	10.0000	1.7955	1.3166	1.1723	1.1097	1.0683	1.1311	1.1747	1.2628
202	10.0000	1.8221	1.3432	1.1991	1.1367	1.0949	1.1590	1.2032	1.2923
201	10.0000	1.8519	1.3733	1.2295	1.1674	1.1255	1.1907	1.2360	1.3270
200	10.0000	1.8867	1.4074	1.2642	1.2026	1.1605	1.2275	1.2738	1.3669
199	10.0000	1.9267	1.4473	1.3044	1.2433	1.2017	1.2700	1.3176	1.4130
198	10.0000	1.9756	1.4956	1.3533	1.2931	1.2512	1.3218	1.3703	1.4683
197	10.0000	2.0345	1.5560	1.4147	1.3536	1.3119	1.3859	1.4366	1.5368
196	10.0000	2.1057	1.6220	1.4814	1.4256	1.3838	1.4556	1.5082	1.6105
195	10.0000	2.1898	1.7093	1.5689	1.5119	1.4694	1.5468	1.6014	1.7059
194	10.0000	2.2922	1.8121	1.6728	1.6153	1.5731	1.6528	1.7097	1.8158
193	10.0000	2.4226	1.9404	1.8019	1.7455	1.7030	1.7846	1.8437	1.9514
192	10.0000	2.5979	2.1143	1.9761	1.9188	1.8772	1.9607	2.0221	2.1300
191	10.0000	2.7679	2.2827	2.1470	2.0910	2.0488	2.1320	2.1956	2.3024
190	10.0000	2.9400	2.4575	2.3220	2.2645	2.2220	2.3049	2.3675	2.4706

Magnaflow determination of optimum dose in high turbidity Rideau River water (9172 NTU)									
In-line spectrophotometer (4mm path length)									
Wavelength (nm)	0 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	3.0 mg/L	4.0 mg/L	5.0 mg/L
189.8	3.75	1.3422	1.3376	1.3296	1.2400	1.2364	1.3480	1.4491	1.5923
192.8	3.75	1.1556	1.1411	1.1278	1.0451	1.0380	1.1349	1.2153	1.3343
195.8	3.75	1.0782	1.0575	1.0398	0.9619	0.9548	1.0464	1.1160	1.2249
198.9	3.75	1.0084	0.9835	0.9618	0.8888	0.8804	0.9672	1.0328	1.1328
201.9	3.75	0.9567	0.9261	0.9009	0.8316	0.8231	0.9066	0.9694	1.0639
204.9	3.75	0.8926	0.8593	0.8337	0.7664	0.7580	0.8388	0.8972	0.9885
208	3.75	0.8351	0.7981	0.7688	0.7065	0.6972	0.7741	0.8310	0.9185
211	3.75	0.7844	0.7425	0.7118	0.6506	0.6422	0.7177	0.7721	0.8576
214	3.75	0.7413	0.6954	0.6622	0.6048	0.5954	0.6705	0.7223	0.8046
217	3.75	0.6986	0.6506	0.6153	0.5606	0.5501	0.6237	0.6745	0.7555
220	3.75	0.6741	0.6208	0.5853	0.5322	0.5220	0.5949	0.6457	0.7240
223.1	3.75	0.6457	0.5899	0.5540	0.5034	0.4926	0.5640	0.6127	0.6912
226.1	3.75	0.6273	0.5687	0.5321	0.4818	0.4715	0.5414	0.5898	0.6671
229.1	3.75	0.6096	0.5502	0.5126	0.4644	0.4530	0.5222	0.5697	0.6468
232.1	3.75	0.5985	0.5363	0.4988	0.4526	0.4402	0.5084	0.5547	0.6308
235.1	3.75	0.5902	0.5267	0.4885	0.4420	0.4296	0.4980	0.5433	0.6195
238.1	3.75	0.5831	0.5180	0.4801	0.4345	0.4218	0.4888	0.5359	0.6113
241.1	3.75	0.5795	0.5120	0.4729	0.4282	0.4156	0.4822	0.5278	0.6048
244.1	3.75	0.5766	0.5069	0.4675	0.4232	0.4096	0.4766	0.5222	0.5984
247.1	3.75	0.5707	0.5029	0.4633	0.4195	0.4052	0.4719	0.5170	0.5932
250.1	3.75	0.5683	0.4993	0.4585	0.4149	0.4010	0.4672	0.5134	0.5886

Magnaflow determination of optimum dose in low turbidity Rideau River water (260 NTU)								
Desktop spectrophotometer (1cm path length)								
Wavelength (nm)	0 mg/L	0.05 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	3.0 mg/L
250	0.5943	0.4553	0.3972	0.4065	0.4084	0.4135	0.4531	0.4298
249	0.5993	0.4606	0.4026	0.4117	0.4138	0.4188	0.4586	0.4351
248	0.6048	0.4658	0.4081	0.4171	0.4191	0.4243	0.4639	0.4407
247	0.6101	0.4712	0.4135	0.4226	0.4246	0.4298	0.4696	0.4461
246	0.6153	0.4765	0.4188	0.4280	0.4301	0.4352	0.4749	0.4517
245	0.6204	0.4818	0.4242	0.4333	0.4353	0.4405	0.4804	0.4568
244	0.6253	0.4867	0.4290	0.4384	0.4404	0.4456	0.4851	0.4619
243	0.6299	0.4914	0.4339	0.4432	0.4450	0.4504	0.4900	0.4668
242	0.6342	0.4958	0.4383	0.4476	0.4495	0.4549	0.4944	0.4712
241	0.6381	0.4998	0.4424	0.4519	0.4537	0.4591	0.4987	0.4755
240	0.6419	0.5037	0.4463	0.4558	0.4576	0.4630	0.5026	0.4795
239	0.6454	0.5074	0.4498	0.4595	0.4612	0.4668	0.5064	0.4834
238	0.6487	0.5106	0.4532	0.4632	0.4647	0.4703	0.5099	0.4869
237	0.6518	0.5138	0.4565	0.4666	0.4680	0.4737	0.5134	0.4904
236	0.6548	0.5170	0.4596	0.4697	0.4710	0.4767	0.5166	0.4935
235	0.6579	0.5201	0.4628	0.4729	0.4743	0.4802	0.5198	0.4967
234	0.6609	0.5233	0.4660	0.4762	0.4777	0.4834	0.5231	0.5000
233	0.6642	0.5268	0.4694	0.4796	0.4811	0.4871	0.5267	0.5037
232	0.6678	0.5304	0.4731	0.4833	0.4849	0.4907	0.5304	0.5075
231	0.6716	0.5344	0.4770	0.4873	0.4889	0.4949	0.5346	0.5117
230	0.6758	0.5386	0.4813	0.4916	0.4933	0.4992	0.5391	0.5162
229	0.6802	0.5434	0.4860	0.4964	0.4980	0.5042	0.5440	0.5211
228	0.6853	0.5486	0.4910	0.5015	0.5033	0.5093	0.5492	0.5264
227	0.6908	0.5541	0.4968	0.5072	0.5091	0.5152	0.5551	0.5323
226	0.6969	0.5605	0.5030	0.5133	0.5153	0.5216	0.5615	0.5389
225	0.7036	0.5674	0.5099	0.5202	0.5224	0.5287	0.5687	0.5462
224	0.7109	0.5749	0.5174	0.5277	0.5301	0.5366	0.5764	0.5539
223	0.7192	0.5833	0.5258	0.5362	0.5384	0.5452	0.5851	0.5626
222	0.7280	0.5924	0.5349	0.5454	0.5477	0.5546	0.5945	0.5723
221	0.7378	0.6026	0.5450	0.5554	0.5581	0.5649	0.6050	0.5826
220	0.7483	0.6135	0.5560	0.5664	0.5690	0.5762	0.6163	0.5943
219	0.7599	0.6253	0.5677	0.5784	0.5810	0.5883	0.6286	0.6066
218	0.7724	0.6380	0.5805	0.5911	0.5939	0.6013	0.6417	0.6200
217	0.7854	0.6514	0.5939	0.6048	0.6076	0.6154	0.6558	0.6343
216	0.7992	0.6654	0.6080	0.6190	0.6220	0.6299	0.6705	0.6492

215	0.8136	0.6802	0.6228	0.6340	0.6370	0.6451	0.6858	0.6648
214	0.8287	0.6955	0.6383	0.6498	0.6528	0.6611	0.7020	0.6811
213	0.8443	0.7115	0.6542	0.6662	0.6692	0.6778	0.7187	0.6983
212	0.8604	0.7282	0.6710	0.6832	0.6862	0.6950	0.7362	0.7159
211	0.8772	0.7452	0.6880	0.7009	0.7035	0.7130	0.7544	0.7343
210	0.8944	0.7627	0.7057	0.7191	0.7214	0.7311	0.7725	0.7530
209	0.9121	0.7808	0.7239	0.7379	0.7399	0.7500	0.7918	0.7724
208	0.9299	0.7991	0.7423	0.7570	0.7589	0.7689	0.8113	0.7921
207	0.9486	0.8181	0.7614	0.7769	0.7783	0.7890	0.8314	0.8126
206	0.9681	0.8380	0.7811	0.7976	0.7988	0.8096	0.8526	0.8341
205	0.9882	0.8588	0.8021	0.8194	0.8207	0.8319	0.8746	0.8569
204	1.0097	0.8808	0.8242	0.8425	0.8436	0.8554	0.8984	0.8813
203	1.0335	0.9053	0.8485	0.8675	0.8688	0.8811	0.9245	0.9085
202	1.0597	0.9321	0.8756	0.8954	0.8973	0.9100	0.9540	0.9389
201	1.0899	0.9634	0.9068	0.9272	0.9300	0.9432	0.9878	0.9741
200	1.1253	0.9998	0.9434	0.9641	0.9681	0.9821	1.0275	1.0151
199	1.1677	1.0437	0.9868	1.0082	1.0138	1.0282	1.0742	1.0637
198	1.2185	1.0953	1.0386	1.0607	1.0677	1.0828	1.1297	1.1216
197	1.2826	1.1605	1.1043	1.1253	1.1349	1.1505	1.1999	1.1940
196	1.3587	1.2421	1.1822	1.2069	1.2183	1.2347	1.2822	1.2790
195	1.4510	1.3347	1.2765	1.2997	1.3140	1.3296	1.3811	1.3801
194	1.5693	1.4568	1.3978	1.4213	1.4386	1.4542	1.5063	1.5084
193	1.7116	1.6022	1.5426	1.5667	1.5863	1.6015	1.6551	1.6602
192	1.8881	1.7827	1.7222	1.7462	1.7685	1.7819	1.8375	1.8437
191	2.1244	2.0228	1.9615	1.9858	2.0099	2.0208	2.0779	2.0837
190	2.3323	2.2312	2.1700	2.1923	2.2152	2.2256	2.2794	2.2847

Magnaflow determination of optimum dose in low turbidity Rideau River water (260 NTU)								
In-line spectrophotometer (4mm path length)								
Wavelength (nm)	0 mg/L	0.05 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	1.5 mg/L	2.0 mg/L	3.0 mg/L
189.8	1.3154	1.1800	1.0548	1.1990	1.1453	1.1588	1.2220	1.2211
192.8	1.0748	0.9507	0.8489	0.9651	0.9226	0.9300	0.9851	0.9765
195.8	0.9792	0.8562	0.7669	0.8703	0.8317	0.8387	0.8885	0.8794
198.9	0.9068	0.7810	0.7009	0.7918	0.7600	0.7667	0.8102	0.8004
201.9	0.8546	0.7296	0.6550	0.7377	0.7106	0.7160	0.7573	0.7494
204.9	0.8043	0.6810	0.6093	0.6865	0.6626	0.6673	0.7078	0.6990
208	0.7623	0.6399	0.5710	0.6441	0.6223	0.6270	0.6671	0.6579
211	0.7266	0.6026	0.5393	0.6072	0.5881	0.5930	0.6340	0.6223
214	0.6972	0.5699	0.5114	0.5762	0.5586	0.5641	0.6023	0.5919
217	0.6654	0.5392	0.4821	0.5441	0.5281	0.5336	0.5705	0.5609
220	0.6442	0.5178	0.4621	0.5213	0.5074	0.5120	0.5482	0.5389
223.1	0.6192	0.4939	0.4396	0.4969	0.4844	0.4883	0.5246	0.5157
226.1	0.6023	0.4752	0.4233	0.4794	0.4671	0.4711	0.5074	0.4983
229.1	0.5858	0.4556	0.4061	0.4606	0.4482	0.4533	0.4895	0.4797
232.1	0.5714	0.4407	0.3928	0.4451	0.4333	0.4387	0.4746	0.4648
235.1	0.5604	0.4284	0.3818	0.4316	0.4215	0.4265	0.4612	0.4520
238.1	0.5501	0.4192	0.3721	0.4209	0.4118	0.4162	0.4510	0.4427
241.1	0.5440	0.4106	0.3637	0.4119	0.4033	0.4075	0.4422	0.4341
244.1	0.5407	0.4045	0.3586	0.4066	0.3976	0.4023	0.4382	0.4286
247.1	0.5350	0.3974	0.3518	0.3984	0.3900	0.3963	0.4314	0.4225
250.1	0.5301	0.3922	0.3463	0.3925	0.3840	0.3901	0.4245	0.4163

Magnaflow optimum dose determination high turbidity Rideau River water with Actiflo process chemicals								
Desktop spectrophotometer (1cm path length)								
Wavelength (nm)	0.05 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	2.0 mg/L	4.0 mg/L	6.0 mg/L	8.0 mg/L
250	2.0896	1.5218	0.9666	0.9870	1.0274	1.1188	1.2840	1.2828
249	2.0952	1.5275	0.9722	0.9926	1.0331	1.1244	1.2901	1.2890
248	2.1015	1.5331	0.9779	0.9985	1.0390	1.1303	1.2966	1.2954
247	2.1076	1.5391	0.9837	1.0043	1.0448	1.1363	1.3029	1.3019
246	2.1126	1.5449	0.9892	1.0101	1.0504	1.1421	1.3093	1.3082
245	2.1184	1.5501	0.9948	1.0155	1.0562	1.1477	1.3154	1.3144
244	2.1233	1.5552	1.0001	1.0207	1.0613	1.1530	1.3212	1.3202
243	2.1288	1.5603	1.0051	1.0259	1.0665	1.1583	1.3272	1.3260
242	2.1334	1.5648	1.0096	1.0306	1.0712	1.1630	1.3325	1.3316
241	2.1376	1.5688	1.0140	1.0351	1.0755	1.1676	1.3376	1.3366
240	2.1420	1.5730	1.0183	1.0393	1.0798	1.1721	1.3426	1.3417
239	2.1461	1.5766	1.0219	1.0432	1.0838	1.1760	1.3476	1.3464
238	2.1490	1.5803	1.0256	1.0470	1.0876	1.1798	1.3520	1.3508
237	2.1534	1.5837	1.0290	1.0505	1.0911	1.1835	1.3565	1.3552
236	2.1570	1.5871	1.0323	1.0541	1.0945	1.1871	1.3607	1.3598
235	2.1605	1.5905	1.0355	1.0573	1.0980	1.1904	1.3651	1.3640
234	2.1639	1.5938	1.0388	1.0608	1.1013	1.1941	1.3695	1.3684
233	2.1677	1.5973	1.0420	1.0644	1.1048	1.1980	1.3740	1.3731
232	2.1722	1.6007	1.0456	1.0680	1.1085	1.2018	1.3787	1.3778
231	2.1766	1.6047	1.0494	1.0719	1.1124	1.2057	1.3839	1.3828
230	2.1812	1.6086	1.0534	1.0760	1.1167	1.2101	1.3890	1.3883
229	2.1859	1.6130	1.0575	1.0804	1.1210	1.2149	1.3948	1.3939
228	2.1917	1.6185	1.0620	1.0853	1.1259	1.2196	1.4010	1.4001
227	2.1971	1.6243	1.0671	1.0903	1.1312	1.2252	1.4073	1.4065
226	2.2029	1.6294	1.0722	1.0960	1.1367	1.2310	1.4142	1.4135
225	2.2101	1.6359	1.0780	1.1022	1.1429	1.2372	1.4217	1.4212
224	2.2171	1.6428	1.0842	1.1086	1.1496	1.2442	1.4296	1.4293
223	2.2256	1.6506	1.0913	1.1160	1.1568	1.2518	1.4386	1.4383
222	2.2339	1.6585	1.0990	1.1240	1.1648	1.2600	1.4480	1.4476
221	2.2433	1.6677	1.1073	1.1329	1.1736	1.2693	1.4583	1.4583
220	2.2532	1.6776	1.1164	1.1423	1.1830	1.2788	1.4693	1.4697
219	2.2643	1.6882	1.1264	1.1525	1.1934	1.2897	1.4817	1.4819
218	2.2783	1.6993	1.1369	1.1637	1.2044	1.3024	1.4944	1.4947
217	2.2910	1.7120	1.1486	1.1756	1.2164	1.3153	1.5081	1.5090
216	2.3034	1.7245	1.1605	1.1879	1.2287	1.3283	1.5224	1.5234

215	2.3181	1.7382	1.1736	1.2013	1.2422	1.3421	1.5377	1.5390
214	2.3330	1.7529	1.1868	1.2151	1.2561	1.3567	1.5543	1.5552
213	2.3487	1.7680	1.2018	1.2299	1.2721	1.3722	1.5730	1.5750
212	2.3646	1.7843	1.2165	1.2452	1.2883	1.3880	1.5906	1.5931
211	2.3833	1.8015	1.2327	1.2633	1.3046	1.4051	1.6095	1.6121
210	2.4001	1.8190	1.2509	1.2804	1.3220	1.4225	1.6286	1.6317
209	2.4186	1.8378	1.2691	1.2989	1.3399	1.4412	1.6490	1.6528
208	2.4382	1.8585	1.2875	1.3173	1.3585	1.4600	1.6704	1.6742
207	2.4574	1.8800	1.3072	1.3370	1.3782	1.4800	1.6926	1.6969
206	2.4785	1.9023	1.3279	1.3573	1.3985	1.5031	1.7160	1.7212
205	2.5001	1.9264	1.3505	1.3800	1.4211	1.5268	1.7419	1.7478
204	2.5246	1.9524	1.3746	1.4034	1.4443	1.5509	1.7689	1.7766
203	2.5496	1.9807	1.4010	1.4289	1.4717	1.5782	1.8007	1.8113
202	2.5772	2.0119	1.4312	1.4593	1.5003	1.6080	1.8348	1.8472
201	2.6080	2.0465	1.4649	1.4914	1.5327	1.6421	1.8725	1.8879
200	2.6444	2.0878	1.5032	1.5282	1.5692	1.6815	1.9154	1.9350
199	2.6845	2.1353	1.5469	1.5703	1.6120	1.7276	1.9653	1.9893
198	2.7319	2.1890	1.5975	1.6192	1.6605	1.7808	2.0239	2.0527
197	2.7877	2.2522	1.6598	1.6791	1.7218	1.8442	2.0929	2.1276
196	2.8593	2.3299	1.7332	1.7512	1.7950	1.9205	2.1752	2.2164
195	2.9295	2.4116	1.8127	1.8286	1.8725	2.0042	2.2616	2.3100
194	3.0247	2.5165	1.9167	1.9325	1.9776	2.1118	2.3744	2.4277
193	3.1428	2.6420	2.0388	2.0549	2.0995	2.2388	2.5062	2.5669
192	3.2896	2.7930	2.1886	2.2017	2.2491	2.3913	2.6589	2.7245
191	3.4978	2.9924	2.3896	2.4018	2.4496	2.5932	2.8621	2.9317
190	3.6235	3.1401	2.5410	2.5582	2.6067	2.7454	3.0035	3.0659

Magnaflow optimum dose determination high turbidity Rideau River water with Actiflo process chemicals								
In-line spectrophotometer (4mm path length)								
Wavelength (nm)	0.05 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	2.0 mg/L	4.0 mg/L	6.0 mg/L	8.0 mg/L
189.8	2.3344	1.7460	1.1214	1.3923	1.5328	1.7201	2.0077	2.1356
192.8	2.0537	1.5049	0.9393	1.1909	1.3167	1.4780	1.7164	1.8226
195.8	1.9408	1.4150	0.8622	1.1087	1.2294	1.3802	1.5989	1.6940
198.9	1.8524	1.3387	0.7986	1.0426	1.1589	1.3017	1.5066	1.5959
201.9	1.7922	1.2865	0.7621	0.9993	1.1135	1.2537	1.4475	1.5363
204.9	1.7430	1.2458	0.7238	0.9590	1.0728	1.2098	1.3951	1.4826
208	1.7055	1.2066	0.6954	0.9273	1.0393	1.1752	1.3521	1.4398
211	1.6703	1.1785	0.6695	0.8992	1.0118	1.1449	1.3159	1.4033
214	1.6455	1.1574	0.6511	0.8770	0.9884	1.1195	1.2866	1.3729
217	1.6242	1.1393	0.6334	0.8542	0.9648	1.0969	1.2570	1.3444
220	1.6058	1.1209	0.6179	0.8377	0.9480	1.0780	1.2343	1.3243
223.1	1.5856	1.1043	0.6014	0.8188	0.9279	1.0574	1.2097	1.2966
226.1	1.5678	1.0899	0.5910	0.8037	0.9124	1.0412	1.1907	1.2841
229.1	1.5556	1.0764	0.5787	0.7889	0.8972	1.0252	1.1721	1.2582
232.1	1.5453	1.0689	0.5674	0.7788	0.8846	1.0123	1.1579	1.2511
235.1	1.5363	1.0621	0.5582	0.7689	0.8764	1.0041	1.1481	1.2468
238.1	1.5333	1.0601	0.5532	0.7623	0.8691	0.9977	1.1397	1.2381
241.1	1.5349	1.0554	0.5479	0.7568	0.8645	0.9936	1.1341	1.2325
244.1	1.5387	1.0525	0.5451	0.7541	0.8615	0.9907	1.1315	1.2300
247.1	1.5379	1.0532	0.5442	0.7509	0.8583	0.9888	1.1287	1.2290
250.1	1.5429	1.0523	0.5387	0.7482	0.8576	0.9871	1.1268	1.2281

Hydrex 3661 optimum dose determination high turbidity Rideau River water (9000 NTU)								
Desktop spectrophotometer (1cm path length)								
Wavelength (nm)	3.0 mg/L	4.0 mg/L	5.0 mg/L	6.0 mg/L	7.0 mg/L	8.0 mg/L	10.0 mg/L	12.0 mg/L
250	0.5035	0.3738	0.3364	0.3109	0.3563	0.2968	0.3305	0.3856
249	0.5085	0.3787	0.3413	0.3157	0.3612	0.3013	0.3355	0.3909
248	0.5140	0.3839	0.3466	0.3209	0.3666	0.3062	0.3408	0.3963
247	0.5194	0.3892	0.3516	0.3255	0.3717	0.3112	0.3460	0.4017
246	0.5246	0.3941	0.3565	0.3301	0.3766	0.3158	0.3507	0.4069
245	0.5297	0.3990	0.3612	0.3349	0.3813	0.3206	0.3556	0.4119
244	0.5343	0.4036	0.3658	0.3393	0.3858	0.3249	0.3601	0.4167
243	0.5388	0.4076	0.3698	0.3432	0.3899	0.3290	0.3642	0.4211
242	0.5429	0.4116	0.3735	0.3469	0.3938	0.3325	0.3679	0.4251
241	0.5466	0.4150	0.3769	0.3502	0.3974	0.3357	0.3713	0.4289
240	0.5503	0.4182	0.3800	0.3532	0.4004	0.3388	0.3746	0.4325
239	0.5534	0.4211	0.3828	0.3560	0.4033	0.3415	0.3773	0.4357
238	0.5564	0.4238	0.3855	0.3586	0.4058	0.3439	0.3800	0.4386
237	0.5593	0.4262	0.3878	0.3608	0.4083	0.3460	0.3823	0.4413
236	0.5621	0.4285	0.3901	0.3628	0.4105	0.3481	0.3845	0.4440
235	0.5647	0.4309	0.3923	0.3651	0.4130	0.3501	0.3868	0.4469
234	0.5676	0.4333	0.3948	0.3674	0.4153	0.3525	0.3892	0.4497
233	0.5707	0.4362	0.3974	0.3698	0.4180	0.3548	0.3918	0.4528
232	0.5743	0.4392	0.4002	0.3726	0.4209	0.3575	0.3946	0.4562
231	0.5780	0.4425	0.4037	0.3759	0.4244	0.3604	0.3979	0.4599
230	0.5823	0.4464	0.4075	0.3794	0.4282	0.3639	0.4015	0.4642
229	0.5871	0.4509	0.4117	0.3838	0.4325	0.3682	0.4058	0.4689
228	0.5926	0.4559	0.4166	0.3887	0.4374	0.3726	0.4106	0.4742
227	0.5990	0.4615	0.4224	0.3942	0.4431	0.3780	0.4162	0.4804
226	0.6057	0.4680	0.4287	0.4002	0.4495	0.3841	0.4223	0.4873
225	0.6136	0.4753	0.4359	0.4074	0.4567	0.3913	0.4297	0.4951
224	0.6222	0.4834	0.4438	0.4154	0.4647	0.3991	0.4375	0.5036
223	0.6319	0.4925	0.4530	0.4241	0.4736	0.4077	0.4465	0.5131
222	0.6423	0.5026	0.4628	0.4338	0.4835	0.4172	0.4562	0.5235
221	0.6542	0.5137	0.4739	0.4446	0.4948	0.4282	0.4675	0.5352
220	0.6665	0.5258	0.4856	0.4563	0.5066	0.4398	0.4791	0.5479
219	0.6809	0.5391	0.4989	0.4693	0.5199	0.4525	0.4925	0.5618
218	0.6952	0.5529	0.5125	0.4830	0.5336	0.4658	0.5063	0.5764
217	0.7109	0.5681	0.5274	0.4975	0.5486	0.4804	0.5212	0.5921
216	0.7267	0.5835	0.5425	0.5125	0.5638	0.4952	0.5364	0.6086

215	0.7435	0.5996	0.5587	0.5283	0.5799	0.5108	0.5527	0.6260
214	0.7604	0.6162	0.5749	0.5445	0.5962	0.5268	0.5689	0.6438
213	0.7781	0.6336	0.5920	0.5611	0.6132	0.5433	0.5862	0.6627
212	0.7960	0.6509	0.6089	0.5778	0.6310	0.5599	0.6032	0.6811
211	0.8140	0.6684	0.6269	0.5951	0.6485	0.5770	0.6214	0.7004
210	0.8319	0.6857	0.6443	0.6126	0.6658	0.5940	0.6386	0.7191
209	0.8500	0.7033	0.6616	0.6299	0.6835	0.6112	0.6564	0.7381
208	0.8678	0.7206	0.6788	0.6466	0.7005	0.6277	0.6734	0.7568
207	0.8859	0.7377	0.6958	0.6632	0.7177	0.6443	0.6906	0.7756
206	0.9033	0.7545	0.7130	0.6798	0.7347	0.6608	0.7077	0.7942
205	0.9209	0.7714	0.7297	0.6964	0.7515	0.6770	0.7248	0.8129
204	0.9380	0.7881	0.7465	0.7128	0.7683	0.6933	0.7414	0.8319
203	0.9561	0.8057	0.7638	0.7297	0.7859	0.7099	0.7589	0.8516
202	0.9742	0.8239	0.7819	0.7475	0.8042	0.7272	0.7769	0.8718
201	0.9946	0.8434	0.8017	0.7663	0.8243	0.7459	0.7970	0.8942
200	1.0164	0.8646	0.8230	0.7876	0.8459	0.7667	0.8182	0.9184
199	1.0412	0.8896	0.8478	0.8114	0.8706	0.7905	0.8430	0.9455
198	1.0694	0.9159	0.8754	0.8384	0.8983	0.8172	0.8703	0.9765
197	1.1038	0.9496	0.9091	0.8715	0.9324	0.8501	0.9039	1.0137
196	1.1447	0.9896	0.9505	0.9116	0.9740	0.8902	0.9449	1.0583
195	1.1912	1.0369	0.9966	0.9573	1.0203	0.9355	0.9909	1.1070
194	1.2522	1.0971	1.0577	1.0171	1.0810	0.9952	1.0511	1.1701
193	1.3263	1.1714	1.1320	1.0900	1.1552	1.0681	1.1246	1.2468
192	1.4214	1.2675	1.2262	1.1833	1.2497	1.1616	1.2182	1.3425
191	1.5545	1.3939	1.3595	1.3150	1.3819	1.2932	1.3503	1.4767
190	1.6819	1.5252	1.4876	1.4420	1.5096	1.4208	1.4767	1.6043

Hydrex 3661 optimum dose determination high turbidity Rideau River water (9000 NTU)								
In-line spectrophotometer (4mm path length)								
Wavelength (nm)	3.0 mg/L	4.0 mg/L	5.0 mg/L	6.0 mg/L	7.0 mg/L	8.0 mg/L	10.0 mg/L	12.0 mg/L
189.8	0.7785	0.6798	0.6405	0.6365	0.6416	0.6306	0.6622	0.7692
192.8	0.6805	0.5814	0.5426	0.5395	0.5451	0.5328	0.5631	0.6575
195.8	0.6373	0.5388	0.5005	0.4970	0.5015	0.4907	0.5194	0.6082
198.9	0.5956	0.4978	0.4602	0.4575	0.4614	0.4533	0.4800	0.5628
201.9	0.5620	0.4665	0.4282	0.4256	0.4290	0.4193	0.4470	0.5258
204.9	0.5215	0.4260	0.3897	0.3889	0.3916	0.3820	0.4082	0.4841
208	0.4830	0.3879	0.3530	0.3500	0.3531	0.3442	0.3703	0.4426
211	0.4491	0.3549	0.3193	0.3170	0.3193	0.3115	0.3372	0.4064
214	0.4179	0.3232	0.2892	0.2870	0.2897	0.2821	0.3083	0.3750
217	0.3881	0.2959	0.2597	0.2589	0.2618	0.2543	0.2791	0.3459
220	0.3706	0.2749	0.2417	0.2399	0.2432	0.2358	0.2600	0.3254
223.1	0.3507	0.2569	0.2226	0.2216	0.2248	0.2169	0.2409	0.3057
226.1	0.3362	0.2438	0.2090	0.2091	0.2107	0.2037	0.2276	0.2910
229.1	0.3240	0.2316	0.1982	0.1974	0.1992	0.1927	0.2159	0.2784
232.1	0.3154	0.2223	0.1884	0.1876	0.1895	0.1847	0.2063	0.2678
235.1	0.3079	0.2159	0.1824	0.1807	0.1828	0.1760	0.1991	0.2597
238.1	0.3025	0.2089	0.1752	0.1740	0.1769	0.1698	0.1929	0.2527
241.1	0.2969	0.2034	0.1702	0.1690	0.1721	0.1646	0.1876	0.2474
244.1	0.2952	0.2008	0.1677	0.1663	0.1681	0.1615	0.1842	0.2445
247.1	0.2912	0.1968	0.1625	0.1624	0.1638	0.1571	0.1796	0.2396
250.1	0.2872	0.1928	0.1593	0.1583	0.1604	0.1538	0.1773	0.2348

Hydrex 3661 optimum dose determination low turbidity Rideau River water (546 NTU)										
Desktop spectrophotometer (1cm path length)										
Wavelength (nm)	0.025 mg/L	0.05 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	2.0 mg/L	4.0 mg/L	6.0 mg/L	8.0 mg/L	10.0 mg/L
250	0.7545	0.6536	0.6657	0.5377	0.3545	0.2676	0.2585	0.2692	0.2650	0.3145
249	0.7595	0.6585	0.6705	0.5425	0.3594	0.2723	0.2632	0.2737	0.2698	0.3193
248	0.7645	0.6634	0.6756	0.5475	0.3642	0.2772	0.2681	0.2785	0.2746	0.3241
247	0.7694	0.6681	0.6803	0.5522	0.3689	0.2818	0.2727	0.2830	0.2793	0.3289
246	0.7741	0.6728	0.6849	0.5566	0.3736	0.2862	0.2772	0.2876	0.2839	0.3334
245	0.7785	0.6772	0.6893	0.5611	0.3778	0.2904	0.2815	0.2917	0.2881	0.3378
244	0.7826	0.6813	0.6933	0.5652	0.3817	0.2943	0.2852	0.2958	0.2919	0.3418
243	0.7862	0.6850	0.6971	0.5688	0.3852	0.2976	0.2886	0.2992	0.2955	0.3454
242	0.7896	0.6883	0.7003	0.5718	0.3883	0.3007	0.2918	0.3024	0.2985	0.3487
241	0.7925	0.6941	0.7045	0.5748	0.3910	0.3033	0.2944	0.3049	0.3013	0.3514
240	0.7953	0.7025	0.7118	0.5767	0.3949	0.3056	0.2966	0.3071	0.3036	0.3538
239	0.7974	0.7048	0.7169	0.5752	0.4059	0.3066	0.3006	0.3083	0.3048	0.3560
238	0.7990	0.7065	0.7189	0.5770	0.4073	0.3179	0.3067	0.3196	0.3160	0.3568
237	0.7981	0.7081	0.7203	0.5785	0.4086	0.3189	0.3034	0.3208	0.3173	0.3692
236	0.7998	0.7094	0.7218	0.5797	0.4097	0.3201	0.2976	0.3218	0.3185	0.3705
235	0.8013	0.7107	0.7230	0.5811	0.4107	0.3209	0.2985	0.3227	0.3195	0.3716
234	0.8027	0.7120	0.7242	0.5822	0.4116	0.3218	0.2995	0.3235	0.3204	0.3729
233	0.8044	0.7134	0.7256	0.5837	0.4126	0.3228	0.3005	0.3246	0.3216	0.3741
232	0.8062	0.7148	0.7272	0.5849	0.4139	0.3239	0.3017	0.3256	0.3229	0.3755
231	0.8084	0.7165	0.7289	0.5867	0.4151	0.3228	0.3030	0.3272	0.3222	0.3773
230	0.8106	0.7188	0.7309	0.5886	0.4169	0.3245	0.3046	0.3287	0.3240	0.3796
229	0.8135	0.7213	0.7333	0.5911	0.4190	0.3288	0.3067	0.3308	0.3283	0.3818
228	0.8164	0.7240	0.7363	0.5938	0.4216	0.3313	0.3091	0.3332	0.3308	0.3846
227	0.8202	0.7276	0.7396	0.5971	0.4247	0.3340	0.3120	0.3362	0.3340	0.3880
226	0.8242	0.7316	0.7436	0.6008	0.4283	0.3374	0.3222	0.3398	0.3377	0.3920
225	0.8294	0.7362	0.7483	0.6052	0.4325	0.3417	0.3330	0.3439	0.3420	0.3967
224	0.8347	0.7415	0.7535	0.6102	0.4372	0.3465	0.3379	0.3490	0.3471	0.4020
223	0.8409	0.7474	0.7595	0.6200	0.4428	0.3521	0.3435	0.3546	0.3529	0.4080
222	0.8479	0.7541	0.7663	0.6348	0.4491	0.3584	0.3501	0.3611	0.3597	0.4149
221	0.8557	0.7617	0.7739	0.6425	0.4563	0.3656	0.3573	0.3684	0.3673	0.4227
220	0.8642	0.7701	0.7822	0.6511	0.4643	0.3738	0.3656	0.3766	0.3757	0.4316
219	0.8736	0.7792	0.7914	0.6604	0.4732	0.3826	0.3747	0.3859	0.3854	0.4411
218	0.8910	0.7893	0.8014	0.6705	0.4829	0.3926	0.3847	0.3961	0.3963	0.4521
217	0.9057	0.7997	0.8119	0.6812	0.4929	0.4029	0.3953	0.4070	0.4080	0.4639
216	0.9178	0.8106	0.8231	0.6927	0.5038	0.4143	0.4067	0.4188	0.4208	0.4767

215	0.9303	0.8221	0.8347	0.7045	0.5152	0.4259	0.4187	0.4312	0.4343	0.4903
214	0.9435	0.8340	0.8467	0.7170	0.5269	0.4381	0.4310	0.4441	0.4486	0.5048
213	0.9569	0.8463	0.8666	0.7299	0.5394	0.4509	0.4443	0.4578	0.4638	0.5200
212	0.9707	0.8710	0.8840	0.7432	0.5622	0.4638	0.4575	0.4715	0.4789	0.5394
211	0.9849	0.8845	0.8976	0.7566	0.5777	0.4767	0.4709	0.4853	0.4941	0.5637
210	0.9989	0.8984	0.9117	0.7699	0.5913	0.4899	0.4844	0.4991	0.5092	0.5800
209	1.0131	0.9122	0.9256	0.7834	0.6046	0.5029	0.4974	0.5127	0.5324	0.5964
208	1.0275	0.9262	0.9392	0.7967	0.6181	0.5243	0.5189	0.5393	0.5524	0.6125
207	1.0414	0.9399	0.9528	0.8213	0.6312	0.5422	0.5369	0.5534	0.5675	0.6288
206	1.0551	0.9534	0.9660	0.8349	0.6445	0.5559	0.5505	0.5674	0.5825	0.6447
205	1.0686	0.9667	0.9795	0.8485	0.6575	0.5693	0.5642	0.5809	0.5973	0.6606
204	1.0941	0.9801	0.9927	0.8620	0.6704	0.5828	0.5774	0.5949	0.6120	0.6768
203	1.1085	0.9933	1.0060	0.8758	0.6834	0.5962	0.5911	0.6087	0.6267	0.6934
202	1.1233	1.0069	1.0193	0.8896	0.6968	0.6100	0.6049	0.6227	0.6420	0.7106
201	1.1384	1.0207	1.0406	0.9040	0.7122	0.6242	0.6191	0.6375	0.6581	0.7386
200	1.1544	1.0478	1.0601	0.9189	0.7362	0.6392	0.6342	0.6533	0.6755	0.7616
199	1.1718	1.0645	1.0773	0.9350	0.7527	0.6552	0.6503	0.6703	0.7017	0.7852
198	1.1911	1.0811	1.0913	0.9533	0.7670	0.6774	0.6724	0.6972	0.7241	0.8072
197	1.2020	1.0946	1.1062	0.9708	0.7822	0.6914	0.6867	0.7137	0.7433	0.8312
196	1.2308	1.1157	1.1277	0.9969	0.8043	0.7182	0.7137	0.7377	0.7703	0.8622
195	1.2614	1.1402	1.1522	1.0234	0.8290	0.7439	0.7399	0.7651	0.8003	0.9040
194	1.2945	1.1804	1.1951	1.0548	0.8690	0.7750	0.7710	0.8047	0.8434	0.9509
193	1.3402	1.2202	1.2330	1.0984	0.9088	0.8230	0.8195	0.8482	0.8903	0.9983
192	1.3995	1.2755	1.2887	1.1558	0.9636	0.8757	0.8720	0.9027	0.9509	1.0684
191	1.4565	1.3336	1.3477	1.2143	1.0238	0.9365	0.9310	0.9673	1.0162	1.1421
190	1.5356	1.4114	1.4313	1.2978	1.1007	1.0154	1.0127	1.0454	1.0973	1.2264

Hydrex 3661 optimum dose determination low turbidity Rideau River water (546 NTU)										
In-line spectrophotometer (4mm path length)										
Wavelength (nm)	0.025 mg/L	0.05 mg/L	0.1 mg/L	0.5 mg/L	1.0 mg/L	2.0 mg/L	4.0 mg/L	6.0 mg/L	8.0 mg/L	10.0 mg/L
189.8	0.9751	0.9119	0.8888	0.6290	0.4532	0.3987	0.4370	0.4871	0.5378	0.5993
192.8	0.9010	0.8538	0.8243	0.5716	0.4017	0.3467	0.3827	0.4263	0.4679	0.5158
195.8	0.8671	0.8238	0.7930	0.5419	0.3740	0.3207	0.3590	0.3949	0.4320	0.4722
198.9	0.8329	0.7965	0.7600	0.5116	0.3413	0.2953	0.3277	0.3654	0.3982	0.4341
201.9	0.8021	0.7707	0.7336	0.4886	0.3180	0.2737	0.3104	0.3404	0.3701	0.4035
204.9	0.7726	0.7412	0.7042	0.4607	0.2941	0.2484	0.2777	0.3110	0.3362	0.3667
208	0.7481	0.7139	0.6754	0.4349	0.2705	0.2258	0.2571	0.2832	0.3033	0.3320
211	0.7231	0.6927	0.6519	0.4120	0.2461	0.2039	0.2310	0.2593	0.2770	0.3051
214	0.7037	0.6727	0.6320	0.3925	0.2256	0.1862	0.2129	0.2402	0.2562	0.2837
217	0.6843	0.6546	0.6118	0.3733	0.2097	0.1698	0.1963	0.2227	0.2377	0.2649
220	0.6687	0.6397	0.5986	0.3590	0.1985	0.1580	0.1840	0.2102	0.2247	0.2512
223.1	0.6557	0.6271	0.5826	0.3469	0.1836	0.1452	0.1717	0.1973	0.2113	0.2377
226.1	0.6464	0.6207	0.5730	0.3376	0.1765	0.1377	0.1691	0.1892	0.2027	0.2286
229.1	0.6390	0.6132	0.5657	0.3293	0.1716	0.1308	0.1602	0.1821	0.1952	0.2209
232.1	0.6331	0.6076	0.5582	0.3245	0.1665	0.1263	0.1525	0.1764	0.1895	0.2150
235.1	0.6287	0.6048	0.5554	0.3199	0.1651	0.1237	0.1495	0.1726	0.1858	0.2101
238.1	0.6263	0.6011	0.5526	0.3163	0.1651	0.1197	0.1465	0.1688	0.1819	0.2065
241.1	0.6246	0.5968	0.5486	0.3115	0.1597	0.1154	0.1421	0.1650	0.1782	0.2027
244.1	0.6208	0.5977	0.5462	0.3092	0.1529	0.1128	0.1400	0.1612	0.1752	0.1990
247.1	0.6198	0.5956	0.5426	0.3050	0.1525	0.1099	0.1352	0.1569	0.1707	0.1947
250.1	0.6197	0.5952	0.5409	0.3021	0.1511	0.1059	0.1320	0.1544	0.1686	0.1919

Appendix E: Particle count data for experimental phase 4

Magnaflow High Turbidity Particle Count Data									
Polymer Dose (mg/L)	Median Floc Size								Total Particle Concentration
	4	10	22	46	94	190	382	766	
0.1	397101.7	122586.1	12248.1	3407.4	3039.0	1749.7	92.1	0.0	540224.09
0.5	353370.0	113790.0	25791.5	2657.0	292.0	36.0	1.0	0.0	495937.50
1.0	276033.0	74516.0	14520.5	1327.5	65.0	6.5	0.0	0.0	366468.50
1.5	185249.5	44618.5	10273.0	1455.5	104.0	4.5	0.0	0.0	241705.00
2.0	181034.5	44594.0	8805.5	1159.0	195.5	8.0	0.0	0.0	235796.50
3.0	217685.0	57697.5	13436.5	2485.5	369.5	17.0	0.0	0.0	291691.00
4.0	247450.5	67325.0	15626.0	2384.5	257.0	24.0	0.0	0.0	333067.00
5.0	283130.5	73342.0	16718.0	2919.5	252.5	20.5	0.0	0.0	376383.00

Magnaflow Low Turbidity Particle Count Data									
Polymer Dose (mg/L)	Median Floc Size								Total Particle Concentration
	4	10	22	46	94	190	382	766	
0.05	190442.50	80653.50	17280	3187	1117	661.5	382	197.00	293920.50
0.1	129433.00	61007.5	17644	2708	295	9	0.5	0	211097.00
0.5	136396.00	73345.5	26933	5798	520	5	0	0.50	242998.00
1.0	152846.00	82272.5	25128.5	3357	208	8	0	0	263820.00
1.5	166951	89974.5	26481.5	3168.5	69.5	1	0.00	0.00	286646.00
2.0	172991.50	94733.5	31868.5	6737	712.5	11.5	0.5	0.00	307055.00
3.0	181549.00	101563	33523.5	4448	242	6	0.5	0.00	321332.00

Magnaflow High Turbidity with Actiflo Particle Count Data									
Polymer Dose (mg/L)	Median Floc Size								Total Particle Concentration
	4	10	22	46	94	190	382	766	
0.05	139506.00	67449.00	44358.5	30395	16159	4481	314.5	3.00	302666.00
0.1	93535.00	31409.5	13373.5	4224	676	463.5	123	29.5	143834.00
0.5	78695.00	22169	5246	602	42.5	28.5	52	42.50	106877.50
1.0	341928.00	88265.5	17377	2835.5	366	42.5	20	18.5	450853.00
2.0	339985	75025	20729.5	4138	516	50	8.00	3.50	440455.00
4.0	401289.00	85267.5	21185	4022	471	64	7.5	1.50	512307.50
6.0	407761.50	73518.5	16492	3313	376	77	28	6.50	501572.50
8.0	504940.50	106291.00	21671.00	3012.00	413.00	103.50	12.00	0.50	636443.50

Hydrex 3661 High Turbidity Particle Count Data									
Polymer Dose (mg/L)	Median Floc Size								Total Particle Concentration
	4	10	22	46	94	190	382	766	
3	66846.00	16329.50	4928	1082	188	46	8.5	0.00	89428.00
4	23698.00	7188.5	2653.5	612	80.5	9	1.5	0.5	34243.50
5	24883.50	9883	4573.5	1345.5	179.5	13.5	2.5	0.00	40881.00
6	18559.50	6455	2628	701.5	110.5	12.5	3.5	0.5	28471.00
7	14186	5129	2027.5	445.5	53.5	2.5	0.00	0.00	21844.00
8	13824.00	5145.5	2255	579.5	91.5	7.5	0.5	0.00	21903.50
10	22279.00	8301	3147	690.5	67.5	2	0.5	0.00	34487.50
12	76258.00	28974.50	10922.00	2399.00	172.50	6.50	1.00	0.00	118733.50

Hydrex 3661 Low Turbidity Particle Count Data									
Polymer Dose (mg/L)	Median Floc Size								Total Particle Concentration
	4	10	22	46	94	190	382	766	
0.025	386280.5	240004.0	126156.0	35303.0	1300.5	2.0	2.0	0.0	789048.00
0.050	363299.5	226738.5	123514.5	43011.0	4147.5	15.0	0.0	0.0	760726.00
0.10	257034.0	171155.0	105582.5	40089.0	3709.5	13.5	0.0	0.0	577583.50
0.50	42006.5	8562.5	2649.0	666.0	122.5	31.0	17.5	18.5	54073.50
1.0	12669.0	2963.0	786.0	199.0	37.0	3.0	6.5	21.0	16684.50
2.0	17807.5	3143.0	247.0	35.5	19.0	4.0	0.5	0.0	21256.50
4.0	26860.5	6865.0	1334.0	270.0	141.0	23.5	0.0	0.0	35494.00
6.0	55160.5	17473.5	5427.0	1722.5	337.0	6.0	0.5	0.0	80127.00
8.0	92292.5	29168.0	7111.0	1687.5	393.5	86.5	0.0	0.0	130739.00
10.0	105614.5	35863.5	10245.0	2304.5	451.0	32.5	0.5	0.0	154511.50

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