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ADAPTING NEAR-ULTRAVIOLET COLORIMETRY FOR LONG-TERM *IN SITU* MONITORING OF HEXAVALENT CHROMIUM IN GROUNDWATER AQUIFERS

By

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Adapting Near-Ultraviolet Colorimetry for Long-Term In Situ Monitoring of Hexavalent Chromium in Groundwater Aquifers

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Abstract

This paper briefly describes sources of hexavalent chromium [Cr(VI)] and the risk it poses to human health and the environment; current methods used to regulate, monitor, and measure Cr(VI); the basic design of a submersible, direct-reading sensor in development for long-term monitoring of Cr(VI) concentration in natural waters; and the means developed to correct sensor readings for two common analytical interferences, turbidity and pH, that could lead to an incorrect measurement of Cr(VI). The principal purposes of this study are to analyze the current methods used to compensate for sample turbidity, to develop methods to compensate for sample pH, and to investigate a method for estimation of pH by measuring sample absorbance at two wavelengths.

Cr(VI) in humans and some animals is carcinogenic, and in acute exposures, can result in respiratory strain, gastrointestinal, and neurological effects. Chronic exposure can increase the risk of respiratory cancer when inhaled and can cause liver, kidney, and blood cell damage when ingested.

Current methods for monitoring and measuring Cr(VI) in groundwater are labor intensive, therefore costly and infrequent. The sensor under development at Freestone Environmental Services, Inc. produces a near-continuous data flow and is fully submersible for long-term deployment in groundwater monitoring wells. The sensor is based on the principle of absorption spectrophotometry where an ultraviolet (UV) light beam, at a specific wavelength (371 nm), is passed through a water sample toward a photoelectric sensor and is partially absorbed by Cr(VI).

Turbidity interferes with the UV light beam by scattering the light in random directions, thus mimicking absorption. To compensate for turbidity, a second photoelectric sensor measures the intensity of the scattered light, and the result is used to calculate the corrected absorption.

The effect of pH on the Cr(VI) measurement is more complex than the turbidity effect because there are two different species, chromate and hydrogen chromate, that can exist in aqueous solutions above pH 3.5 and at lower concentrations than 1,000 µg/L. Both the sensor's UV light source and chromate's peak absorbance is at the UV wavelength of 371 nm. Absorption by hydrogen chromate is relatively weak at that wavelength. Chromate is dominant relative to hydrogen chromate in solutions with a pH equal to or higher than pH 7.8. If the aqueous environment has a pH between pH 3.5 and pH 7.8, the ratio of chromate to hydrogen chromate can be calculated from pH. The calculated ratio is used to temporarily correct the sensor calibration by adjusting net molar absorptivity.

Hydrogen chromate's peak absorbance is at 349 nm. Theoretically, if chromate and hydrogen chromate are independently measured, the results could be interpreted as pH. Solutions containing different concentrations of Cr(VI) at pH values ranging from pH 3 to pH 9.2 were measured in a spectrophotometer at both the 349 nm and 371 nm wavelength. Results show that if the relative strengths of both the 349 nm and the 371 nm peaks are measured, it is possible to calculate pH. The practicality of this method for estimating sample pH has yet to be established.

Acknowledgements

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1.0   Introduction

Hexavalent chromium, Cr(VI), is of increasing concern worldwide because of its environmental and human health effects, as well as its mobility in aquifers and surface water bodies. Sources of Cr(VI) include waste effluent originating from the electroplating, galvanizing, leather, and paint industries, as well as from U.S. Department of Energy (USDOE) energy and weapons production facilities (Darrie, 2001). Knowledge of Cr(VI) and its apparent degree of hazard to human health and the environment has been increasing (Eisler, 1986; USEPA, 2012). The scale and potential severity of the hazard has prompted various governmental agencies to mandate regular testing of water sources either currently exposed or potentially exposed to Cr(VI) (Safe Drinking Water Act, 1974).

Collecting and analyzing environmental water samples for Cr(VI) are labor intensive tasks. Therefore, costs are high and sampling is commonly performed with minimum required frequency. The most common analytical method used to measure Cr(VI) in water samples is visible range colorimetry based on the Beer-Lambert law (Rice et al, 2012). While sensitive and accurate, the visible range method uses chemical reagents and often requires filtered water samples. Freestone Environmental Services, Inc. (Freestone), of Richland, WA, has developed a direct-reading Cr(VI) sensor that requires neither chemical additives nor filtration. The new sensor provides real-time measurements and is submersible for use in groundwater monitoring wells. The comparatively accurate sensor is based on direct ultraviolet (UV) spectrophotometric measurement (absorbance) of Cr(VI) and a method to compensate for the effect of sample turbidity (Hall, 2014). Sample pH, however, is a ubiquitous interference that can affect species of Cr(VI) in a sample, which in turns affects the absorption of the UV light by Cr(VI). Therefore, pH must be addressed for successful interpretation of the sensor's analytical signals.

This paper describes the sources and significance of environmental contamination by Cr(VI), a submersible instrument designed for direct measurement of Cr(VI) in monitoring wells, and techniques devised to circumvent measurement interference caused by turbidity and pH.

2.0   Background

Chromium is the 21st most abundant metal in the earth's crust. Chromium metal is steel-gray, with a high melting point, and a strong resistance to oxidation (ATSDR, 2012). Chromium exists in the environment in a broad range of oxidation states, from -2 to +6, but only the +3 and +6 states are stable under most conditions of the surface environment (Fendorf et al., 2000; Losi et al., 1994). Trivalent chromium is the most stable valence state in anoxic environments, and may be present as a cationic species or a slightly soluble or insoluble compound such as chromite ore. The hexavalent state is more common in oxidized environments and is in the anionic form bound to oxygen. The solubility, mobility, and bioavailability of Cr(VI) is very high, causing the likelihood of natural environmental exposure to it to be significantly greater than that of trivalent chromium (Fendorf et al., 2000, Losi et al., 1994). The trivalent form of chromium adsorbs to sediments when introduced to a groundwater aquifer, and it is thus virtually immobile, whereas Cr(VI) is highly mobile in the aqueous environment unless it is reduced to the trivalent state (Jardine, et al. 1999; Puls, et al., 1994).

In aqueous solution, Cr(VI) can exist as seven different species, depending on pH and concentration. These include chromate CrO_4^{2-} , dichromate $Cr_2O_7^{2-}$, hydrogen chromate $HCrO_4^-$, dihydrogen chromate H_2CrO_4, hydrogen dichromate $HCr_2O_7^-$, tetrachromate $Cr_4O_{13}^{2-}$, and trichromate $Cr_3O_{10}^{2-}$. The last three ions do not exist in solutions having a pH higher than 0, or at total chromium concentrations lower than 1 mol /L (Fournier-Salaun and Salaun, 2007). The remaining four ions, dichromate, chromate, hydrogen chromate, and dihydrogen chromate, are the forms found in soils and surface waters (Eisler, 1986).

3.0   Health and Environmental Concerns

Environmental contamination from chromium waste is of concern because of its effects on human, animal, and environmental health. Chromium waste generated from industrial processes, subsequently disposed or inadvertently released on land or in designated landfills has increased the concentration of both trivalent and hexavalent chromium in soils, groundwater, and surface waters, thus damaging aquatic ecosystems and poisoning wildlife. The mass of chromium and chromium compounds

annually released to soil is tallied in the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI). Figure 3-1 represents the estimated annual totals of chromium and chromium compounds released and reported by facilities across the U.S since reporting began in 1988 (USEPA, 2014). In 2014 alone, 2,377 facilities released 11 million pounds of chromium, and 1,344 facilities released 49 million pounds of chromium compounds.
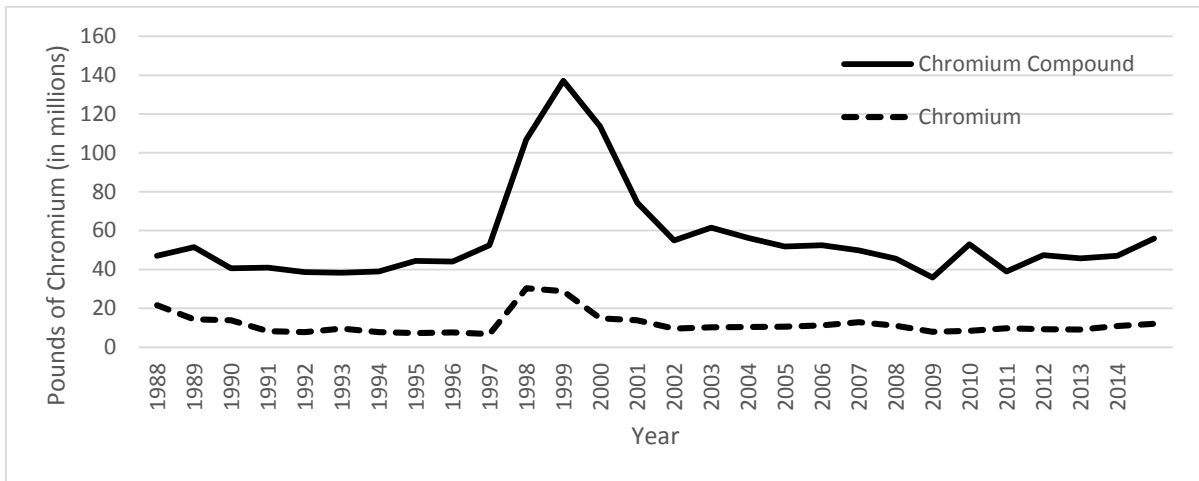
Figure 3-1. Estimated annual totals of chromium and chromium compounds

Trivalent chromium is much less toxic than Cr(VI), and has been considered an essential nutrient to human health for normal glucose, protein, and fat metabolism (ATSDR, 2012). However, trivalent chromium can accumulate in tissue at toxic levels (USEPA, 1998). Because of its high oxidizing potential, Cr(VI) can easily penetrate biological membranes, damaging tissue (Eisler, 1986). Anionic Cr(VI) compounds readily oxidize organic matter on contact, yielding reduced (trivalent) chromium. In living tissue, the oxidation damages cell membranes and other structures including cellular proteins, lipids, and DNA. When Cr(VI) is metabolized, free radicals are created which bind to other molecules causing further damage. While organisms can normally cope with some free radicals, and need them to function effectively, an overload of free radicals can accelerate certain diseases including cancer (Lobo et al., 2010).

Numerous investigations have addressed the effects of Cr(VI) in laboratory animals and humans. These include studies summarized by the National Toxicology Program (2014), the USEPA (2012), and the Integrated Risk Information System (IRIS) (2010). The findings of these studies are in agreement that in humans and some animals, Cr(VI) is carcinogenic, and in acute exposures, can result in respiratory strain, gastrointestinal, and neurological effects. Further, chronic exposure to Cr(VI) can increase the risk of respiratory cancer when inhaled and can cause liver, kidney, gastrointestinal, and blood cell damage when ingested (Cohen et al., 1993; Costa and Klein, 2006; Holmes et al., 2008).

Public exposure to Cr(VI) is most often through inhalation of ambient air, ingestion of water, or dermal contact with products that contain Cr(VI), such as pressure-treated wood. People living near industrial facilities that use or release Cr(VI) compounds or near chromium waste disposal sites have the greatest potential for exposure (ATSDR 2012).

The degree of Cr(VI) toxicity to the environment is significantly influenced by geochemical variables such as hardness, temperature, pH, and salinity of water, and by biological factors such as species, life stage, and potential differences in sensitivities of local populations (Eisler, 1986). A study performed by Eisler (1986), describes the ecological and toxicological aspects of chromium in the environment in detail; his conclusions were:

> *"…sensitive species of freshwater aquatic organisms showed reduced growth, inhibited reproduction, and increased bioaccumulation at 10.0 ug/L of Cr+6, and other adverse effects at 30.0 ug/L of Cr+3. Among marine organisms, measurable accumulations were recorded in oysters and worms at 5.0 ug/L of Cr+6, algal growth was reduced at 10.0 ug/L, and reproduction of polychaete annelid worms was inhibited at 12.5 ug/L; in all situations, Cr+3 was less damaging than Cr+6. For birds and mammals, dietary levels of 10.0 mg Cr+3/kg adversely affected young black ducks, and 5.1 mg Cr+6/kg in food and water of mice was associated with elevated tissue residues. The significance of Cr residues is unclear, but available evidence suggests that organs and tissues of fish and wildlife that contain 4.0 mg total Cr/kg dry weight should be viewed as presumptive evidence of Cr contamination. Aerosol concentrations in excess of 10.0 ug Cr+6/m3 are potentially harmful to human health; in the absence of supporting data, this value is recommended for protection of sensitive species of wildlife, especially migratory waterfowl."*

4.0   Federal Regulations

In an effort to reduce environmental exposure to Cr(VI) and other contaminants, wide-ranging Federal regulations have been enacted, including the Clean Air Act of 1970 (CAA), the Clean Water Act of 1972, amended 1977 (CWA), the Safe Drinking Water Act of 1974 (SDWA), the Resource Conservation and Recovery Act of 1976 (RCRA), the Toxic Substances Control Act of 1976 (TSCA), and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).

As a result of CAA (1970), the USEPA has listed chromium compounds as hazardous air pollutants and regulates chromium emissions using technology-based "maximum achievable control technology" (MACT) standards for industrial categories, rather than numerical emissions standards. Due to the CWA (1977) and SDWA (1974), chromium and chromium compounds are listed as toxic pollutants, and the USEPA regulates a maximum contaminant level (MCL) of 100 µg/L in drinking water. In an effort to control the manufacture, distribution, use, and disposal of nontoxic and toxic chemicals, including Cr(VI), TSCA (1976) was sanctioned.

RCRA (1976) was enacted to strengthen the regulations controlling the handling and disposal of both nonhazardous and hazardous waste, including waste containing chromium and chromium compounds. RCRA requires adequate groundwater monitoring for hazardous waste treatment, storage, and disposal facilities (TSDFs). Requirements include detection monitoring, compliance monitoring, and corrective action. Detection monitoring involves the installation of groundwater monitoring wells both up-gradient and down-gradient of TSDFs in an effort to detect and characterize release of hazardous substances. If a release is identified, the facility must begin compliance monitoring, which must meet USEPA's MCLs (Maximum Contaminant Levels). If the MCLs are not met, a corrective action, such as treatment of the contaminant, must begin.

CERCLA (1980), a.k.a. "Superfund", was enacted to address historical or current releases of hazardous substances by identifying responsible parties and imposing on them liability for the site

contamination. The CERCLA legislation also levies tax on industries that create or use hazardous substances. The tax funds remediation and restoration at abandoned waste sites. CERCLA mandates that releases of hazardous substances are reported; the reportable quantity (RQ) of chromium is 5,000 pounds and the RQ of chromium compounds vary from 10 to 1,000 pounds.

5.0 Cr(VI) Contaminated Sites

Contamination from Cr(VI) releases are of significant concern nationwide. Several known releases of Cr(VI) have become classified as CERCLA or "Superfund" sites and have made it onto CERCLA's National Priority List (NPL). Of the 751 currently classified active Superfund sites, 530 sites are on the NPL and 141 sites have been remediated sufficiently to be deleted from the NPL (USEPA, 2015). One site currently on the NPL is located at a retired lumber mill in Libby, Montana, where wood treating compounds such as copper-chromium-arsenate were used as a wood preservative.   Migration of Cr(VI) from the wood processing facilities and waste disposal pits has contaminated the soil and groundwater in the area (USEPA, 2015; U.S. Congress, OTA, 1995). At an electroplating facility located in Garfield, New Jersey, an underground storage tank leaked approximately 3,640 gallons of chromic acid directly into the groundwater resulting in reported adult exposure levels of 1700 µg/L per day, significantly exceeding the MCLs (USEPA, 2015; NJDHSS, 2010).   Due to the operation and maintenance of aircraft on the McClellan Air Force Base north of Sacramento, California, hazardous materials containing Cr(VI) have been disposed of at 326 difference waste areas, some of which are known to have released contaminants to groundwater (USEPA, 2015; Schettler, 1995).

Nuclear reservations such as the Savannah River Site located northeast of Augusta, Georgia and the Hanford Site located north of the Richland, Washington, contributed large amounts environmental contamination, including Cr(VI) that have resulted in extensive reclamation and remediation projects (USEPA, 2015; USEPA, 1997). At Hanford, the principal source Cr(VI) contamination is sodium dichromate used as a corrosion inhibitor in nuclear reactor cooling water systems (Dresel et al., 2008).

6.0 Study Site

The Department of Energy's 1,450-km^2 Hanford Site is located in south-central Washington State. The Hanford Site produced plutonium for the government's weapons programs between 1944 and 1989. Nine nuclear reactors operated in the "100 Areas" located along the Columbia River in the northern and eastern part of the site. The reactors used single-pass cooling water consisting of Columbia River water treated to remove particulate matter. Then the water, treated with sodium dichromate as a corrosion inhibitor, was passed through cooling tubes that surrounded the fuel rods. After cooling the fuel rods, the water was typically retained in retention basins for thermal cooling and to allow short-lived radionuclides to decay prior to discharge back to the Columbia River. Cooling water leaks from the piping and retention basins, as well as leaks and spills of the concentrated stock sodium dichromate solids and liquids, released Cr(VI) to the environment and ultimately to groundwater (USDOE, 2010; Dresel, et al. 2008).

In the 100-D Area, chromium occurs in the groundwater in two distinct plumes with concentrations up to 4,000 µg/L. The plumes are monitored and are under investigation to identify possible vadose zone sources of chromium. Understanding the nature of the vadose contamination in the area is important for evaluating remediation options (USDOE, 2010; Dresel, et al. 2008). The nearby Hanford Reach is of particular concern because it is the only remaining area on the Columbia River where significant mainstream spawning of fall chinook salmon occurs (Patton, et al., 2001; Woodward, et al., 1999).

At the Hanford Site, mandatory groundwater monitoring programs are the direct result of Federal environmental regulations. Many of the hundreds of Hanford monitoring wells are fitted with pressure transducers that continuously measure depth to water for the unconfined aquifer. Seasonal and even daily variations in hydraulic gradients and apparent directions of flow are important parameters for assessing the rate and direction of contaminant transport in the aquifer. The water level measurement network is made possible by the availability of affordable and reliable pressure transducers.

In contrast, monitoring wells at Hanford are most commonly sampled for chemical analysis only quarterly or annually. The result is that there is no way to adequately correlate hydraulic data with chemical data, and contaminant flux from the source to the biosphere cannot be quantitatively addressed.

7.0   Methods of Measuring Cr(VI)

There are several methods available for determining the concentration of Cr(VI) in a groundwater sample, including flow injection analysis (FIA) (Escobar et al., 1995), x-ray absorption near-edge structure (XANES) spectrometry (Bajt et al., 1993), separation and preconcentration of the Cr(VI)-diphenylcarbazide (DPC) complex on membrane embedded cation exchange material (Frenzel, 1998) or on surfactant coated alumina (Manzoori et al., 1996), cation exchange Zeeman-corrected graphite furnace atomic absorption spectrometry (GFAAS) (Ball and McKleskey, 2001), ion chromatography (IC) (USEPA Method 218.6) (Arar et al., 1991; Arar and Pfaff, 1991), and direct colorimetric measurement of the Cr(VI)-DPC complex (Method 8023) (Hach Company, 1992).

One of the most commonly used methods is USEPA method 218.6 (Arar et al., 1991; Arar and Pfaff, 1991). This method uses an ion chromatograph and eluent solution which are pumped, with the sample, through an anion-exchange column where the Cr(VI) is concentrated and separated from potential interferents. The Cr(VI) is then mixed with DPC color reagent and measured with an absorbance detector. The detection limit for this method is 1 µg/L. Another commonly used method is Method 8023 (Hach Company, 1992). In this method, the sample is filtered to remove fine particles and mixed with a DPC color reagent. This method is less sensitive than USEPA method 218.6, having a detection limit of 10 µg/L. The absorbance of the solution for both methods is proportional to its Cr(VI) concentration.

The methods noted above are adapted to neither *in* situ measurements nor continuous field measurement. Freestone has developed and field tested a new submersible Cr(VI) sensor that exhibits analytical sensitivity comparable to that of the Hach Method 8023, and that is designed for extended-term

service deployed in wells. The new sensor can serve as a means to provide spatial and temporal plume characterization data to complement Hanford's current program of hydraulic data collection.

8.0   Analytical Interferences

Much of the sensor development effort has been focused on mechanical, electronic, and optical design which together describe a rugged and stable submersible instrument. The instrument is a colorimeter that uses a light-emitting diode (LED) as the source of near-UV radiation that is beamed through a water sample. A silicon-based phototransistor is used to measure the intensity of light passed through the sample, where beam attenuation is a function of Cr(VI) concentration according to the Beer-Lambert Law which specifies that the absorbance of a light beam passing through a sample is proportional to the concentration of the substance being measured. A second phototransistor is used to measure the intensity of light scattered orthogonally from the path of the transmitted beam. The intensity of the scattered light is a function of turbidity (Sadar, 1998).

The sensor design and operation includes a novel method that corrects for sample turbidity, an important interference in colorimetric methods (Hall, 2014). However, correction for other interferences is not similarly inherent in the sensor design. Specifically, any substance in the water being tested that absorbs UV light at the analytical wavelength, or is excited to fluoresce at some longer wavelength that is within the range detectable by the instrument's phototransistors, will be an analytical interference if it is present in sufficient concentration.

Fortunately, the inorganic anions and cations that make up most natural waters are inert to the near-UV analytical wavelength (370 to 375) nm. Further, at the Hanford Site, WA, where the submersible instrument is being field-tested, the groundwater in the unconfined aquifer has been characterized extensively with respect to naturally occurring major and trace substances as well as to contaminants (Hartman et al, 2004). Direct laboratory comparison of the sensor's analytical method with conventional methods, as well as a search of a comprehensive UV/visible photochemistry database

(Noelle et al, 2013), have established that there are no direct chemical interferences at the Hanford test wells.

Sample pH, on the other hand, represents an indirect interference that must be addressed for every site where the hexavalent chromium sensor is used. This arises because the fundamental sensitivity of the method is significantly affected by the effect of pH on Cr(VI) speciation (Fournier-Salaun and Salaun, 2007).

The research described here is focused principally on correcting the effect of pH on the sensor's Cr(VI) measurements. The correction for turbidity is described briefly because the first field data validating the method have been recently obtained and because, like pH, it is always a concern for in situ measurements made using the submersible sensor. That is, correction for turbidity must be viewed as the first step to be taken before pH can be addressed.

9.0   Methods and Materials

The method for compensating for the effect of turbidity for *in situ* measurement of Cr(VI) has been described previously (Rod et al., 2015). The data used to initially develop the correction algorithm were gathered solely in the laboratory. New data presented herein demonstrating the turbidity correction method were collected during the extended-term deployment of a fully functional submersible hexavalent chromium sensor in Hanford Site, WA, (Hanford) monitoring well 199-D5-125. The well is completed in the water table aquifer in the vicinity of Hanford's 100-D Area reactor site. The local aquifer is the current subject of pump-and-treat remediation to remove hexavalent chromium contamination. The groundwater intercepted by the test well has a burden of 59 to 86 µg/L as Cr(VI) based on samples collected and analyzed in the laboratory.

The field test installation is solar powered, with real-time telemetry to an offsite server. Signals from the optoelectronic sensing circuit are digitized within the submersed sensing module before being transmitted to the surface control module that contains the telemetry instrumentation.

The analytical method used in the laboratory to measure Cr(VI) in water samples is USEPA accepted for wastewater reporting and is adapted from *Standard Methods for the Examination of Water and Wastewater* (Rice et al., 2012). The method is colorimetric, where 1,5-diphenylcarbohydrazide reacts in acid media with Cr(VI) to produce a purple-red color measured at 540 nm which is measured spectrophotometrically.

The spectrophotometer was also used for near-UV measurements of chemically untreated samples for development of the pH correction method. Buffer solutions were prepared according to Bower and Bates (1963) and verified with a pH meter. Buffer compositions are included in TABLE 1 of Appendix B.

Hexavalent chromium solutions of known concentration were prepared using a commercial 50 mg/L (as Cr(VI)) standard solution.

10.0   Turbidity Correction

Sample turbidity, caused by suspended particulate matter, mimics absorption by scattering light from the transmitted beam. Unless compensated, the reduced transmission (expressed as %T) is interpreted as increased analyte concentration. The submersible sensor compensates for the turbidity by sampling the intensity of the scattered light as discussed above and using the result to correct the %T. The basis for the correction is the empirical observation that for an analyte concentration *C1*, a plot of %T *versus* scattered light intensity as turbidity increases will be parallel to similar plots for concentrations *C2, C3,* and so on. Figure 10-1 illustrates this pattern for six Cr(VI) concentrations ranging from 83 to 800 µg/L.
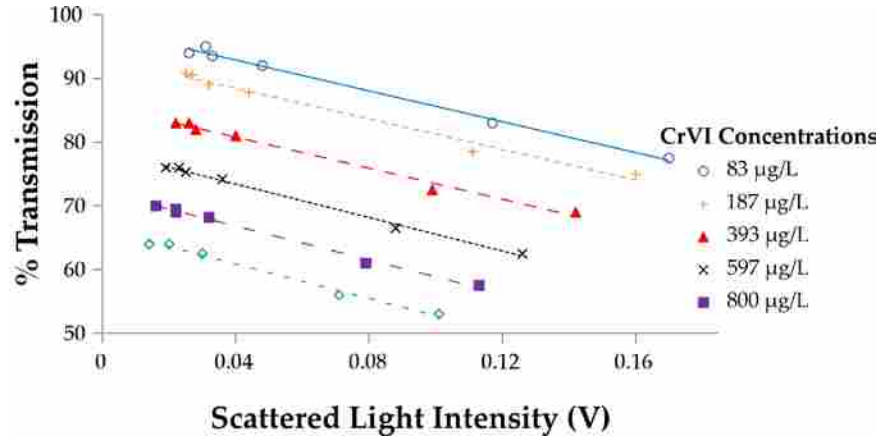
Figure 10-1. %Transmission versus scattered light intensity

Individual plots in Figure 2 were prepared by adding turbidity to a known volume of water. The source of the turbidity was the silt and clay from local surface soil. A small amount of soil was mixed with water, allowed to settle to remove the coarse particle fraction, and finally decanted, yielding very turbid water. Aliquots of the turbid water were used to establish various levels of turbidity.

Then, for each level of turbidity, aliquots of a standard solution of Cr(VI) were added stepwise to the sample to establish each of the six concentration levels. Despite some obvious data scatter, the plots in Figure 2 justify the expectation that such plots can be generally taken as parallel to one another.

Not more than about 20% of the transmitted light was lost due to turbidity in the plots shown in Figure 2. Within that range, the plots can be for practical purposes treated as linear. Each plot can be described using the formula for a straight line:

$$\%T_{meas.} = sV + \%T_{corr.} \qquad \text{(Eq. 1)}$$

Where *%T_{meas.}* is the measured main signal strength, *s* is the mean slope common to all of the plots, *V* is the scattered light signal in volts, and intercept *%T_{corr.}* is the corrected %T. That is, the plot defined by a measured transmitted light signal and a scattered light signal is extrapolated to zero turbidity by rearranging terms:

$$\%T_{corr.} = \%T_{meas.} - sV \qquad \text{(Eq. 2)}$$

Because the slope, *s*, is negative, the corrected %T will be greater than the measured %T.

One additional correction is needed. The zero-chromium plot extrapolates to an intercept slightly greater than 100%T because there is always a small amount of scattering as light passes through a medium and there is also likely to be some reflected "stray" light. Let Δ be the difference between the intercept of the zero-chromium plot and 100%T. The equation for the corrected %T is then:

$$\%T_{corr.} = \%T_{meas.} - sV - \Delta \qquad \text{(Eq. 3)}$$

Figure 3 illustrates the signals in millivolts (mV) from the phototransistors monitoring the transmitted light intensity (plot A) and scattered light intensity (plot B) from the prototype sensor deployed in a Hanford well, during which time four samples were collected, one by pumping and others using a manual bailer.

The instrument, programmed for hourly measurements, used a built-in miniature pump to flush the sample chamber before each measurement.

Inspection of plots A and B in Figure 10-2 show sharp reductions in transmitted light intensity that correspond to similarly sharp increases in scattered light intensity. The spikes in scattered light intensity are a direct result of turbidity caused by fine sediments stirred up during sampling events.

Plot C in Figure 10-2 represents the transmitted light intensity corrected for turbidity as described above. Note that the transmitted light signal appears to not have been fully corrected for the turbidity caused by a Hanford scheduled pumped-sample event on October 14. The likely explanation for this is that the Cr(VI) is not evenly distributed vertically within the aquifer, and the procedure of pumping three bore volumes to purge the well before sample collection caused a temporary increase in Cr(VI) concentration in the upper part of the aquifer where the sensor was located. Manual sampling caused similar but much smaller mixing effects.

Figure 10-3 shows the transmitted light signal *versus* the scattered light signal for the 12-hour period immediately following the pumped-sample event. The linear relationship between transmitted and scattered light permit a simplified correction for sample turbidity. The figure corroborates the assumption of linearity as represented by Figure 10-1. The data represented in Figure 10-2 and Figure 10-3 can be found in Table 1 and Table 2 of Appendix A.

Figure 10-2 Transmitted, scattered, and turbidity corrected transmitted light signals
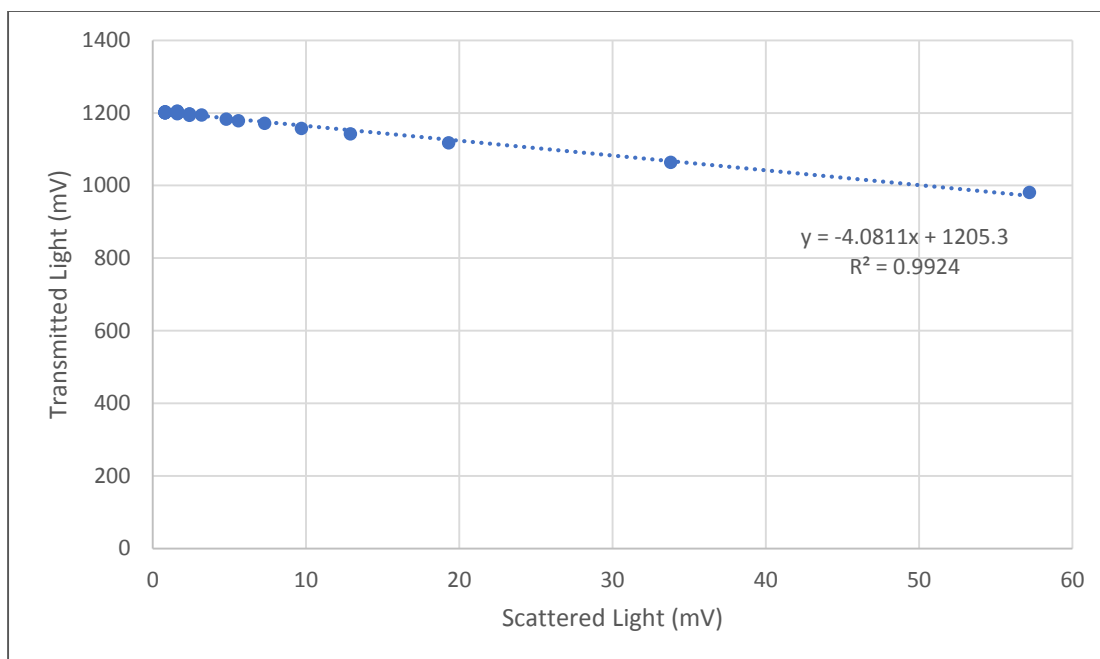
Figure 10-3. Turbidity correction equation

11.0   Chromium Speciation Relative to pH

When sample pH is less than approximately 7.8 to 8, the ability of hexavalent chromium to absorb light at 370 to 375 nm is significantly reduced. (Note: LED UV light sources are available nominally rated at 5 nm increments for near-UV applications. Peak absorbance for chromate is 371 nm (Fournier-Salaun and Salaun, 2007). Both 370 nm and 375 nm LEDs have performed well in the Freestone sensor.) As noted earlier, four species of Cr(VI) can coexist in aqueous solutions, and their relative abundance in a given solution is a function of pH and of the total hexavalent chromium concentration.

Each of these hexavalent chromium species exhibits a unique coefficient of absorptivity at the analytical wavelength currently used in the submersible sensor. Each species contributes to the total measured sample absorbance according to its concentration and coefficient of absorptivity. Therefore, the relative abundance of the species must be known in order to interpret measured total absorbance in terms of the individual contribution of each species to the total.

Fournier-Salaun and Salaun (2007) provide a mathematical approach to estimate the

concentration of each species based on total Cr(VI) and solution pH. Their analysis is based upon the

following equilibrium equations and equilibrium constants, expressed at 25°C and molar concentrations.

$$K_1 = \frac{[H^+][HCrO_4{}^{-1}]}{[H_2CrO_4]} = 0.20 \qquad\qquad \text{(Eq. 4)}$$

$$K_2 = \frac{[H^+][CrO_4{}^{-2}]}{[HCrO_4{}^{-1}]} = 1.87 \times 10^{-6} \qquad\qquad \text{(Eq. 5)}$$

$$K_3 = \frac{[HCrO_4{}^{-1}]^2}{[Cr_2O_7{}^{-2}]} = 0.031 \qquad\qquad \text{(Eq. 6)}$$

It is clear that Eq. 4 through Eq. 6 can be rearranged to express chromate, dihydrogen chromate,

and dichromate in terms of hydrogen chromate, and that the total molar concentration of hexavalent

chromium is equal to the sum of the molar concentrations of chromate, hydrogen chromate, and

dihydrogen chromate plus twice the molar concentration of dichromate. Substituting and rearranging

yields the following second order equation:

$$[CrVI]_{Total} = \frac{[H^+][HCrO_4{}^{-1}]}{K_1} + [HCrO_4{}^{-1}] + \frac{K_2[HCrO_4{}^{-1}]}{[H^+]} + \frac{2[HCrO_4{}^{-1}]^2}{K_3} \qquad \text{(Eq. 7)}$$

A Microsoft Excel®[1] spreadsheet was prepared to calculate total hexavalent chromium using Eq.

7 for a wide range of pH and for three Cr(VI) concentrations representing the likely range of

concentrations that the Freestone sensor has been designed to address (10 to 1000 µg/L as Cr(VI)). Table

11-1 shows the resulting data.

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[1] *Microsoft Excel® is a registered trademark of the Microsoft Corporation in the United States and other countries.*

Inspection of Table 11-1 shows that for Cr(VI) concentrations up to 1000 µg/L (1.92×10^{-5}M) there is no significant concentration expected for dichromate or dihydrogen chromate for sample solutions within the range of pH 3.5 to pH 11.5.

Table 11-1. Relative mole percent of Cr(VI) species

pH	% H_2CrO_4	% $HCrO_4^{-1}$	% CrO_4^{-2}	% $Cr_2O_7^{-2}$
3.5	0.16	99.20	0.59	0.03
4	0.05	98.06	1.83	0.03
4.5	0.01	94.35	5.58	0.03
5	0.00	84.21	15.75	0.02
5.5	0.00	62.82	37.15	0.01
6	0.00	34.84	65.15	0.00
6.5	0.00	14.46	85.53	0.00
7	0.00	5.08	94.92	0.00
7.5	0.00	1.66	98.34	0.00
8	0.00	0.53	99.47	0.00
8.5	0.00	0.17	99.83	0.00
9	0.00	0.05	99.95	0.00
9.5	0.00	0.02	99.98	0.00
10	0.00	0.01	100.00	0.00
10.5	0.00	0.00	100.01	0.00
11	0.00	0.00	100.01	0.00
11.5	0.00	0.00	99.87	0.00

Other investigators have reported equilibrium coefficients that differ from those shown for Eq. 4 to Eq. 6. Tong and Li (1986) reported results calculated per Eq. 7 for total ionic strengths from ~0 to 3.0, $[Cr(VI)]_{Total}$ ranging from 10^{-6} to 10^{-2} mol/L, and various reported equilibrium constants. For the lower concentrations, the calculated results are in general agreement with the conclusion based on Table 11-1 that chromate and hydrogen chromate predominate.

Figure 11-1 illustrates the ratio of chromate to hydrogen chromate as a function of pH. Figure 11-1 is based on the definition of pH and rearranging Eq. 5:

$$\frac{[CrO_4^{-2}]}{[HCrO_4^{-1}]} = \frac{K_2}{[H^+]} = K_2 \times 10^{pH} \qquad \text{(Eq. 8)}$$

The ratio of chromate to hydrogen chromate as a function of pH is shown, with axis labels "Ratio of chromate to hydrogen chromate" and "pH", and the fitted equation $y = 1.87 x 10^{-6} 10^{pH}$.
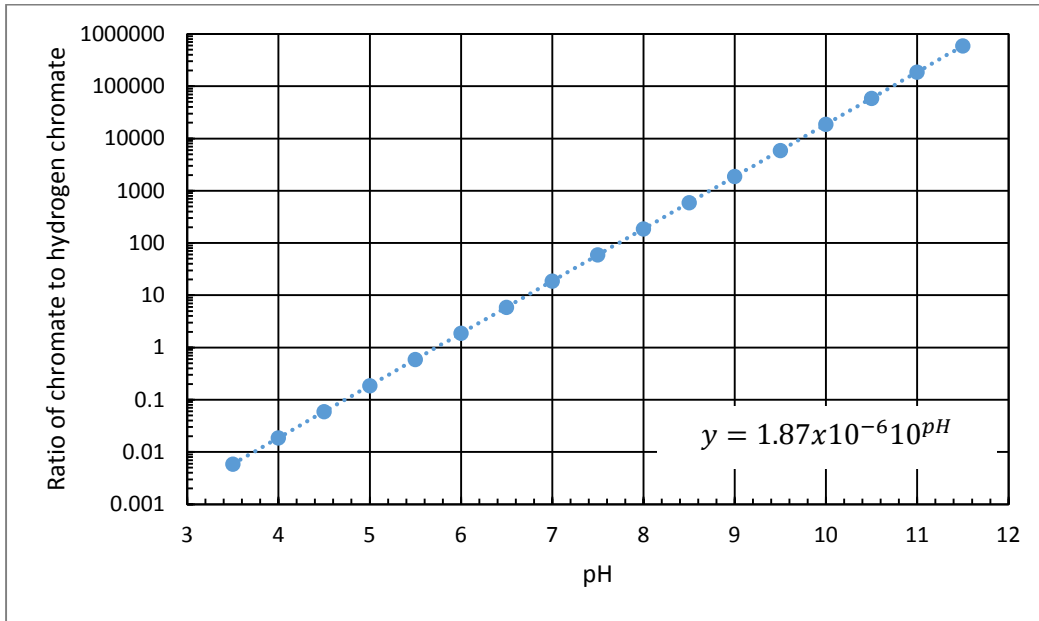
Figure 11-1. The ratio of chromate to hydrogen chromate as a function of pH

From Eq. 8, the molar ratio of chromate to hydrogen chromate (*y* in Figure 11-1) can be calculated directly from solution pH. Means to address the accuracy of Figure 11-1 is discussed below. Fournier-Salaun and Salaun (2007) noted that each species will absorb light at 371 nm according to its concentration and effective coefficient of absorptivity at that wavelength. Therefore, if the coefficients of absorptivity are known, and the molar ratio is determined from sample pH, then the measured sample absorbance can be interpreted as total Cr(VI) concentration as follows.

11.1   Instrument Correction for pH

The following experiments were conducted using the spectrophotometer adjusted to the ideal 371 nm chromate absorption peak, and (where noted) at the 349 nm which is the Cr(VI) absorption peak for acidic solutions (Fournier-Salaun and Salaun, 2007).

From Figure 5, Cr(VI) solutions at pH = 9.2 and at pH = 3 represent virtually 100% chromate and 100% hydrogen chromate, respectively. The Beer-Lambert law is then used to calculate molar absorptivity for each of the species.

Recall the Beer-Lambert Law:

$$log_{10}\left(\frac{100}{\%T}\right) = Abs = \alpha l \mathcal{C} \qquad \text{(Eq. 9)}$$

Where: α= coefficient of absorptivity, l= path length, which is 2.54 cm for the sample vials used, and $\mathcal{C}$= concentration. Absorbance measurements were made using solutions containing 500 µg/L $(9.619\times10^{-6}$ mol/L) and 1000 µg/L $(1.923\times10^{-5}$ mol/L) to determine coefficients of absorptivity for chromate and hydrogen chromate at both wavelengths. Table 11-2 lists the results. The values reported by Fournier-Salaun and Salaun (2007) were derived from data gathered using a Unicam Helios Alpha©[2] spectrophotometer which has a 2 nm spectral bandwidth, while the Hach DR2800[3] used by Freestone has a bandwidth ≤8 nm. Bandwidth and other instrument characteristics will affect measured absorptivity coefficients.

Table 11-2. Molar absorptivity coefficients

Wavelength (λ)	pH	L/mol-cm (500 ppb)	L/mol-cm (1000 ppb)	L/mol-cm (mean)	L/mol-cm Reported
371 nm	9.2 (CrO_4^{-2})	3930	4238	4084	4730
371 nm	3 ($HCrO_4^{-1}$)	819	839	829	590
349 nm	9.2 (CrO_4^{-2})	2046	2375	2210	
349 nm	3 ($HCrO_4^{-1}$)	1228	1290	1259	

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[2] *Unicam Helios Alpha Spectrophotometer© is a copyright of Unicam Limited, Thermos Spectronic in the United States and other countries.*
[3] *Hach Company DR2800 Spectrophotometer© is a copyright of Hach Company in the United States and other countries.*

To calculate total Cr(VI) from sample absorbance at 371 nm, let:

$\alpha_{CrO_4^{-2}}$ = chromate absorptivity

$\alpha_{HCrO_4^{-1}}$ = hydrogen chromate absorptivity

And:

$$Abs_{Total} = \alpha_{CrO_4^{-2}}\left(CrO_4^{-2}\right)l + \alpha_{HCrO_4^{-1}}\left(HCrO_4^{-1}\right)l \qquad \text{(Eq. 10)}$$

Also, from Figure 3, let:

$$\frac{\left(CrO_4^{-2}\right)}{\left(HCrO_4^{-1}\right)} = y \qquad \text{(Eq. 11)}$$

So:

$$\left(HCrO_4^{-1}\right) = \frac{\left(CrO_4^{-2}\right)}{y} \qquad \text{(Eq. 12)}$$

Substituting and rearranging:

$$Abs_{Total} = \alpha_{CrO_4^{-2}}\left(CrO_4^{-2}\right)l + \alpha_{HCrO_4^{-1}}\left[\frac{\left(CrO_4^{-2}\right)}{y}\right]l \qquad \text{(Eq. 13)}$$

$$Abs_{Total} = \left(CrO_4^{-2}\right)\left(\alpha_{CrO_4^{-2}} + \frac{\alpha_{HCrO_4^{-1}}}{y}\right)l \qquad \text{(Eq. 14)}$$

We get:

$$\left(CrO_4^{-2}\right) = \frac{Abs_{Total}}{\left(\alpha_{CrO_4^{-2}} + \frac{\alpha_{HCrO_4^{-1}}}{y}\right)l} \qquad \text{(Eq. 15)}$$

Similarly:

$$(CrO_4^{-2}) = y(HCrO_4^{-1}) \tag{Eq. 16}$$

Substituting and rearranging:

$$Abs_{Total} = \alpha_{CrO_4^{-2}} y(HCrO_4^{-1})l + \alpha_{HCrO_4^{-1}}(HCrO_4^{-1})l \tag{Eq. 17}$$

$$Abs_{Total} = (HCrO_4^{-1})(\alpha_{CrO_4^{-2}} y + \alpha_{HCrO_4^{-1}})l \tag{Eq. 18}$$

We get:

$$(HCrO_4^{-1}) = \frac{Abs_{Total}}{(y\alpha_{CrO_4^{-2}} + \alpha_{HCrO_4^{-1}})l} \tag{Eq. 19}$$

Substituting $1.87 \times 10^{pH-6}$ for y and 2.54 cm for path length l permits direct calculation of chromate and hydrogen chromate concentration

Combine results from equations 15 and 19 and we get total molar concentration of Cr(VI):

$$(Cr^{6+})_{Total} = (CrO_4^{-2}) + (HCrO_4^{-1}) \tag{Eq. 20}$$

Figure 5 was derived ultimately from Eq. 4 through Eq. 6 and the accuracy of ratio y depends on the accuracy of equilibrium coefficient K2. The accuracy of K2 can be tested by using Eq. 10 to calculate total absorbance using the experimentally derived coefficients of absorptivity, the value for y from Figure 5 for the known pH, and the known concentration, where:

$$(CrO_4^{-2}) = \frac{(Cr^{6+})_{Total}}{1 + \frac{1}{y}} \tag{Eq. 21}$$

Eq. 12 then yields $(HCrO_4^{-1})$ and Eq. 10 is applied. If there is a poor match between the calculated and observed absorbance, y can be varied. A plot of y against calculated absorbance will quickly reveal the best value. Eq. 8 will then yield a corrected K_2.

11.2   Freestone Laboratory Practice

Cr(VI) concentration expressed in terms of µg/L or mg/L are directly proportional to molar concentrations of chromate and hydrogen chromate (expressed as mol/L). The foregoing derivations have used molar units to be easily compared to the work of Fournier-Salaun and Salaun (2007) However, in Freestone's practice, the path length is, in most cases, identical for all of the prototype instruments. Therefore, the coefficient of absorptivity, α, and path length, l, are combined as a single factor, a. Using this convention, for a plot of concentration (in µg/L) *versus* measured absorbance (on the abscissa), concentration is calculated directly as the product of absorbance and the slope of the plot.

12.0   Estimating pH by Dual Wavelength Measurements

Recent laboratory work has suggested an approach for estimating pH that, if suitably precise, may eliminate the need for a conventional pH sensor.

As described above, knowing pH allows us to easily calculate the ratio of chromate to hydrogen chromate. Therefore, if chromate and hydrogen chromate were to be independently measured, the results would logically be interpretable as pH. This was tested in the laboratory as follows.

The chromate and hydrogen chromate species have absorption peaks at 371 nm and 349 nm, respectively. In the laboratory, the 100, 500, and 1000 µg/L Cr(VI) solutions measured at 371 nm for pH values ranging from pH 3 to pH 9.2 were also measured at 349 nm using the DR2800 spectrophotometer. Buffer solutions were prepared based on Bates and Bowes (1963) and verified using a pH electrode meter. The difference in measured absorbance for the two peaks, *Abs(371 nm)-Abs(349 nm)*, was plotted as a function of pH for the three concentration levels. Figure 12-1 illustrates absorbance at 371 nm minus absorbance at 349 nm as a function of pH for three levels of Cr(VI) concentration, 100, 500, and 1000 µg/L. From Figure 12-1 it is clear that if the measured absorbances are equal, the pH is very near to 5.6. The more general approach for estimating pH from absorbance measured at both 371 nm and 349 nm is based on simultaneous equations.
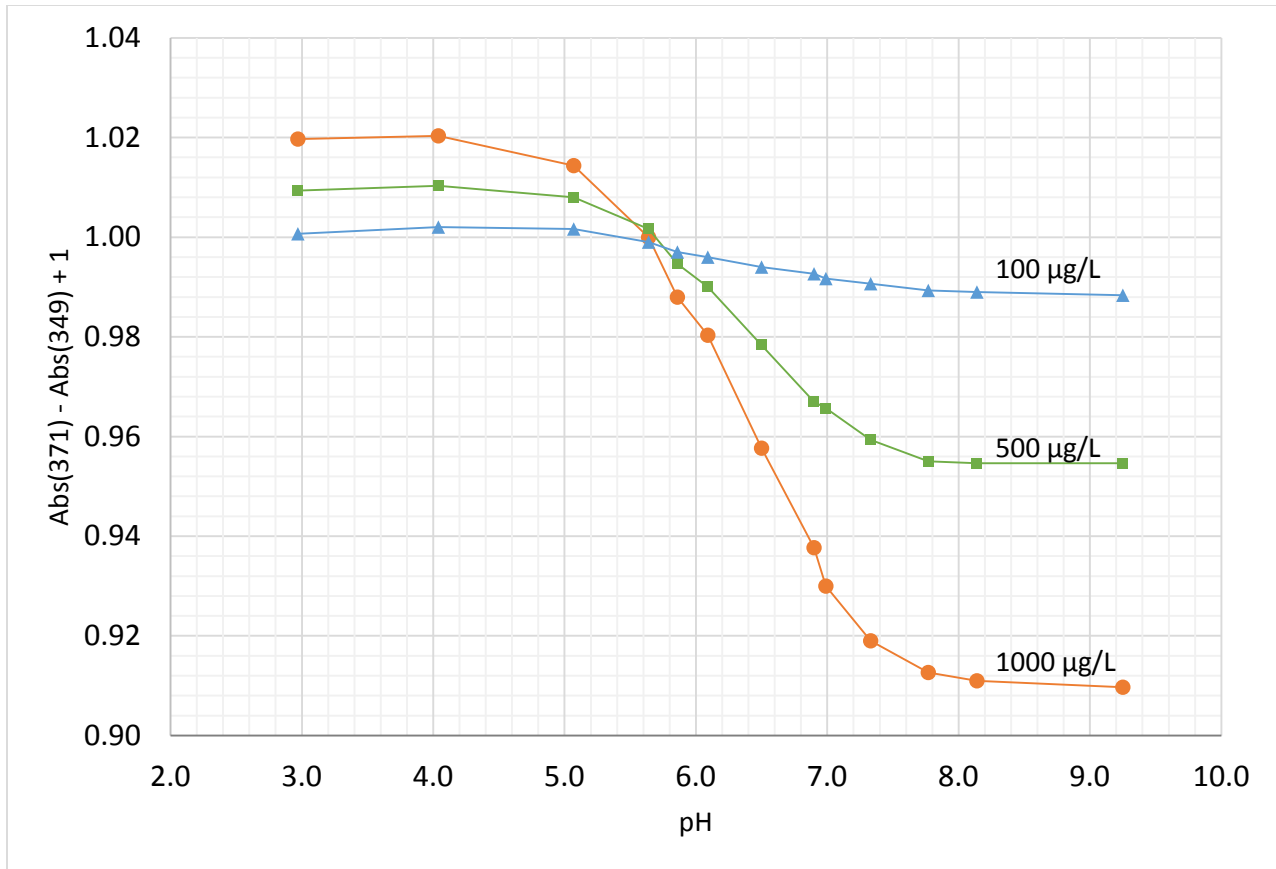
Figure 12-1. Absorbance at 371 nm minus absorbance at 349 nm as a function of pH

By rearranging Eq. 5 and substituting into Eq. 10, the result is:

$$Abs_{371\,nm} = \alpha_{CrO_4^{-2}} \frac{K_2}{[H^+]}\left(HCrO_4^{-1}\right)l + \alpha_{HCrO_4^{-1}}\left(HCrO_4^{-1}\right)l \qquad \text{(Eq. 22)}$$

Letting the symbol β represent absorptivities derived for the 349 nm wavelength, Eq. 23 is the result:

$$Abs_{349\,nm} = \beta_{CrO_4^{-2}} \frac{K_2}{[H^+]}\left(HCrO_4^{-1}\right)l + \beta_{HCrO_4^{-1}}\left(HCrO_4^{-1}\right)l \qquad \text{(Eq. 23)}$$

Eq. 22 and Eq. 23 are simultaneous equations that can be solved to directly yield [H⁺] from the ratio, *R*, of the measured absorbances, *Abs₃₇₁/Abs₃₄₉*, and application of Eq. 24:

$$[H^+] = K_2(\alpha_{CrO_4^{-2}} - R\beta_{CrO_4^{-2}})/(R\beta_{HCrO_4^{-1}} - \alpha_{HCrO_4^{-1}}) \qquad \text{(Eq. 24)}$$

And pH is of course defined as $-\log_{10}[H^+]$. Initial tests using the data represented by Figure 12-1 were favorable. Basic mechanical and optical design for incorporating the second wavelength into the submersible sensor has been completed. Composition of prepared buffer solutions and the results of testing at the dual wavelengths are listed in TABLES 1-4 of Appendix B.

13.0 Conclusions

The submersible hexavalent chromium sensor was conceived as an economical alternative to conventional sampling and analysis at sites such as the Hanford Site, WA, where Cr(VI) contamination in the ground water is widespread, and many of the monitoring wells are in remote locations. Budgets limit conventional sampling and laboratory analysis, both of which are labor intensive. Infrequent sampling (quarterly) necessarily limits the ability to assess the fate and transport of Cr(VI) contaminant plumes.

To be an economical alternative, simplicity of design and construction of the sensor continues to be of foremost concern. For example, if it ultimately proves practical to estimate pH using the above dual-wavelength method, the expense and complexity of separate instrumentation to monitor pH is obviated.

At Hanford, remediation of hexavalent chromium plumes is currently conducted using pump-and-treat plants. At each plant, contaminated water from several extraction wells serves as plant feedstock, with the treated effluent returned to the aquifer via injection wells. Sensors to monitor the Cr(VI) content of the several influent streams could be effective in maximizing plant efficiency.

14.0   References

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Appendix A – Field Sensor Data

Table A-1. Data collected between September 30 and November 15, 2015

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
9/30/15	12:19	1211.2	4	1227.5	10/2/15	10:48	1220.1	0.8	1223.4
9/30/15	13:21	1214.4	4.8	1234.0	10/2/15	11:50	1220.9	0.8	1224.2
9/30/15	14:23	1216.8	3.2	1229.9	10/2/15	12:51	1219.3	0.8	1222.6
9/30/15	15:25	1220.9	2.4	1230.7	10/2/15	13:53	1219.3	0.8	1222.6
9/30/15	16:26	1221.7	1.6	1228.2	10/2/15	14:55	1219.3	0.8	1222.6
9/30/15	17:28	1221.7	1.6	1228.2	10/2/15	15:57	1219.3	0.8	1222.6
9/30/15	18:30	1222.5	1.6	1229.0	10/2/15	16:59	1219.3	0.8	1222.6
9/30/15	19:32	1223.3	1.6	1229.8	10/2/15	18:01	1219.3	0.8	1222.6
9/30/15	20:34	1223.3	1.6	1229.8	10/2/15	19:03	1219.3	0.8	1222.6
9/30/15	21:36	1225.7	1.6	1232.2	10/2/15	20:05	1216.8	0.8	1220.1
9/30/15	22:38	1224.1	1.6	1230.6	10/2/15	21:07	1218.5	0.8	1221.8
9/30/15	23:40	1224.1	0.8	1227.4	10/2/15	22:09	1217.7	0.8	1221.0
10/1/15	0:42	1224.1	1.6	1230.6	10/2/15	23:11	1219.3	1.6	1225.8
10/1/15	1:44	1224.9	0.8	1228.2	10/3/15	0:13	1216.8	1.6	1223.3
10/1/15	2:46	1224.9	1.6	1231.4	10/3/15	1:15	1219.3	0.8	1222.6
10/1/15	3:48	1224.1	1.6	1230.6	10/3/15	2:17	1218.5	0.8	1221.8
10/1/15	4:50	1223.3	0.8	1226.6	10/3/15	3:19	1219.3	0.8	1222.6
10/1/15	5:52	1224.1	0.8	1227.4	10/3/15	4:21	1218.5	0.8	1221.8
10/1/15	6:54	1223.3	0.8	1226.6	10/3/15	5:23	1217.7	0.8	1221.0
10/1/15	7:56	1223.3	0.8	1226.6	10/3/15	6:25	1218.5	1.6	1225.0
10/1/15	8:58	1222.5	0.8	1225.8	10/3/15	7:27	1218.5	0.8	1221.8
10/1/15	10:00	1222.5	0.8	1225.8	10/3/15	8:29	1218.5	0.8	1221.8
10/1/15	11:02	1222.5	0.8	1225.8	10/3/15	9:31	1220.9	0.8	1224.2
10/1/15	12:04	1220.9	0.8	1224.2	10/3/15	10:33	1218.5	1.6	1225.0
10/1/15	13:06	1222.5	0.8	1225.8	10/3/15	11:35	1218.5	0.8	1221.8
10/1/15	14:08	1221.7	0.8	1225.0	10/3/15	12:37	1217.7	1.6	1224.2
10/1/15	15:10	1220.9	0.8	1224.2	10/3/15	13:39	1216.8	0.8	1220.1
10/1/15	16:12	1221.7	0.8	1225.0	10/3/15	14:41	1217.7	0.8	1221.0
10/1/15	17:14	1221.7	0.8	1225.0	10/3/15	15:43	1216.8	0.8	1220.1
10/1/15	18:16	1221.7	0.8	1225.0	10/3/15	16:45	1217.7	0.8	1221.0
10/1/15	19:18	1220.9	1.6	1227.4	10/3/15	17:47	1216.8	0.8	1220.1
10/1/15	20:20	1221.7	0.8	1225.0	10/3/15	18:49	1217.7	0.8	1221.0
10/1/15	21:22	1221.7	0.8	1225.0	10/3/15	19:51	1216.8	0.8	1220.1
10/1/15	22:24	1221.7	1.6	1228.2	10/3/15	20:53	1217.7	0.8	1221.0
10/1/15	23:26	1220.9	0.8	1224.2	10/3/15	21:55	1216.8	0.8	1220.1
10/2/15	0:28	1220.9	0.8	1224.2	10/3/15	22:57	1216.8	0.8	1220.1
10/2/15	1:29	1223.3	0.8	1226.6	10/3/15	23:59	1217.7	0.8	1221.0
10/2/15	2:31	1220.9	0.8	1224.2	10/4/15	1:01	1216.8	0.8	1220.1
10/2/15	3:34	1222.5	0.8	1225.8	10/4/15	2:03	1217.7	0.8	1221.0
10/2/15	4:36	1220.1	0.8	1223.4	10/4/15	3:05	1216	0.8	1219.3
10/2/15	5:38	1219.3	0.8	1222.6	10/4/15	4:07	1216.8	0.8	1220.1
10/2/15	6:40	1220.9	1.6	1227.4	10/4/15	5:09	1217.7	0.8	1221.0
10/2/15	7:42	1220.9	0.8	1224.2	10/4/15	6:10	1217.7	0.8	1221.0
10/2/15	8:44	1221.7	0.8	1225.0	10/4/15	7:12	1216.8	0.8	1220.1
10/2/15	9:46	1220.1	0.8	1223.4	10/4/15	8:14	1216.8	0.8	1220.1

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/4/15	9:16	1218.5	0.8	1221.8	10/6/15	7:45	1215.2	0.8	1218.5
10/4/15	10:18	1216.8	0.8	1220.1	10/6/15	8:48	1187.8	7.3	1217.6
10/4/15	11:20	1216.8	0.8	1220.1	10/6/15	9:50	1174.9	9.7	1214.5
10/4/15	12:22	1216.8	0.8	1220.1	10/6/15	10:51	1197.5	5.6	1220.4
10/4/15	13:24	1217.7	0.8	1221.0	10/6/15	11:53	1203.2	4	1219.5
10/4/15	14:26	1217.7	0.8	1221.0	10/6/15	12:55	1207.2	2.4	1217.0
10/4/15	15:28	1216	0.8	1219.3	10/6/15	13:57	1210.4	2.4	1220.2
10/4/15	16:30	1217.7	0.8	1221.0	10/6/15	14:59	1212	1.6	1218.5
10/4/15	17:32	1217.7	0.8	1221.0	10/6/15	16:01	1212.8	1.6	1219.3
10/4/15	18:34	1216.8	0.8	1220.1	10/6/15	17:03	1211.2	1.6	1217.7
10/4/15	19:36	1215.2	0.8	1218.5	10/6/15	18:05	1212	1.6	1218.5
10/4/15	20:38	1216.8	0.8	1220.1	10/6/15	19:07	1212.8	1.6	1219.3
10/4/15	21:40	1216.8	0.8	1220.1	10/6/15	20:09	1214.4	1.6	1220.9
10/4/15	22:42	1216	0.8	1219.3	10/6/15	21:11	1211.2	1.6	1217.7
10/4/15	23:44	1215.2	0.8	1218.5	10/6/15	22:13	1212.8	0.8	1216.1
10/5/15	0:46	1218.5	0.8	1221.8	10/6/15	23:15	1215.2	0.8	1218.5
10/5/15	1:48	1218.5	0.8	1221.8	10/7/15	0:17	1212.8	0.8	1216.1
10/5/15	2:50	1219.3	0.8	1222.6	10/7/15	1:19	1212.8	0.8	1216.1
10/5/15	3:52	1217.7	0.8	1221.0	10/7/15	2:21	1212.8	0.8	1216.1
10/5/15	4:54	1216	0.8	1219.3	10/7/15	3:23	1213.6	0.8	1216.9
10/5/15	5:56	1216.8	0.8	1220.1	10/7/15	4:25	1213.6	0.8	1216.9
10/5/15	6:58	1216.8	1.6	1223.3	10/7/15	5:27	1215.2	0.8	1218.5
10/5/15	8:00	1215.2	0.8	1218.5	10/7/15	6:29	1214.4	0.8	1217.7
10/5/15	9:02	1216.8	1.6	1223.3	10/7/15	7:31	1213.6	0.8	1216.9
10/5/15	10:04	1216.8	0.8	1220.1	10/7/15	8:33	1214.4	0.8	1217.7
10/5/15	11:06	1216	0.8	1219.3	10/7/15	9:35	1212.8	0.8	1216.1
10/5/15	12:08	1216.8	1.6	1223.3	10/7/15	10:37	1213.6	0.8	1216.9
10/5/15	13:10	1216.8	0.8	1220.1	10/7/15	11:39	1213.6	0.8	1216.9
10/5/15	14:12	1216	0.8	1219.3	10/7/15	12:41	1213.6	0.8	1216.9
10/5/15	15:14	1216.8	0.8	1220.1	10/7/15	13:43	1213.6	0.8	1216.9
10/5/15	16:16	1216	0.8	1219.3	10/7/15	14:45	1212.8	0.8	1216.1
10/5/15	17:17	1217.7	0.8	1221.0	10/7/15	15:47	1212.8	0.8	1216.1
10/5/15	18:19	1217.7	0.8	1221.0	10/7/15	16:49	1212	0.8	1215.3
10/5/15	19:21	1216	0.8	1219.3	10/7/15	17:51	1216.8	1.6	1223.3
10/5/15	20:23	1216.8	0.8	1220.1	10/7/15	18:53	1213.6	0.8	1216.9
10/5/15	21:25	1216.8	0.8	1220.1	10/7/15	19:55	1216	0.8	1219.3
10/5/15	22:27	1216	0.8	1219.3	10/7/15	20:57	1213.6	1.6	1220.1
10/5/15	23:29	1216	0.8	1219.3	10/7/15	21:59	1214.4	0.8	1217.7
10/6/15	0:31	1217.7	0.8	1221.0	10/7/15	23:01	1211.2	0.8	1214.5
10/6/15	1:33	1214.4	0.8	1217.7	10/8/15	0:03	1211.2	0.8	1214.5
10/6/15	2:35	1215.2	0.8	1218.5	10/8/15	1:05	1212	0.8	1215.3
10/6/15	3:37	1216.8	0.8	1220.1	10/8/15	2:07	1212.8	0.8	1216.1
10/6/15	4:39	1216.8	0.8	1220.1	10/8/15	3:09	1211.2	0.8	1214.5
10/6/15	5:41	1215.2	0.8	1218.5	10/8/15	4:11	1211.2	0.8	1214.5
10/6/15	6:43	1216.8	0.8	1220.1	10/8/15	5:13	1211.2	0.8	1214.5

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/8/15	6:15	1213.6	0.8	1216.9	10/10/15	4:44	1210.4	0.8	1213.7
10/8/15	7:17	1213.6	1.6	1220.1	10/10/15	5:46	1212	0.8	1215.3
10/8/15	8:19	1215.2	0.8	1218.5	10/10/15	6:48	1212	0.8	1215.3
10/8/15	9:21	1212.8	0.8	1216.1	10/10/15	7:50	1212	0.8	1215.3
10/8/15	10:22	1212.8	0.8	1216.1	10/10/15	8:52	1213.6	0.8	1216.9
10/8/15	11:24	1211.2	0.8	1214.5	10/10/15	9:54	1211.2	1.6	1217.7
10/8/15	12:26	1210.4	1.6	1216.9	10/10/15	10:56	1213.6	1.6	1220.1
10/8/15	13:28	1213.6	0.8	1216.9	10/10/15	11:57	1208.8	0.8	1212.1
10/8/15	14:30	1211.2	0.8	1214.5	10/10/15	12:59	1211.2	0.8	1214.5
10/8/15	15:32	1211.2	0.8	1214.5	10/10/15	14:01	1211.2	0.8	1214.5
10/8/15	16:34	1215.2	0.8	1218.5	10/10/15	15:03	1211.2	0.8	1214.5
10/8/15	17:36	1212	0.8	1215.3	10/10/15	16:05	1211.2	0.8	1214.5
10/8/15	18:38	1212	0.8	1215.3	10/10/15	17:07	1212	0.8	1215.3
10/8/15	19:40	1212	1.6	1218.5	10/10/15	18:09	1211.2	1.6	1217.7
10/8/15	20:42	1212.8	0.8	1216.1	10/10/15	19:11	1211.2	0.8	1214.5
10/8/15	21:44	1212	0.8	1215.3	10/10/15	20:13	1211.2	0.8	1214.5
10/8/15	22:46	1211.2	0.8	1214.5	10/10/15	21:15	1212	0.8	1215.3
10/8/15	23:48	1211.2	0.8	1214.5	10/10/15	22:17	1212	0.8	1215.3
10/9/15	0:50	1212.8	0.8	1216.1	10/10/15	23:19	1212.8	0.8	1216.1
10/9/15	1:52	1212.8	0.8	1216.1	10/11/15	0:21	1212	0.8	1215.3
10/9/15	2:54	1212	0.8	1215.3	10/11/15	1:23	1212	0.8	1215.3
10/9/15	3:56	1212.8	0.8	1216.1	10/11/15	2:25	1216.8	0.8	1220.1
10/9/15	4:58	1211.2	1.6	1217.7	10/11/15	3:27	1212	0.8	1215.3
10/9/15	6:00	1211.2	0.8	1214.5	10/11/15	4:29	1211.2	0.8	1214.5
10/9/15	7:02	1212	0.8	1215.3	10/11/15	5:31	1213.6	0.8	1216.9
10/9/15	8:04	1211.2	0.8	1214.5	10/11/15	6:33	1212	0.8	1215.3
10/9/15	9:06	1215.2	0.8	1218.5	10/11/15	7:35	1210.4	0.8	1213.7
10/9/15	10:08	1212	1.6	1218.5	10/11/15	8:37	1211.2	0.8	1214.5
10/9/15	11:10	1215.2	1.6	1221.7	10/11/15	9:39	1210.4	0.8	1213.7
10/9/15	12:12	1212	0.8	1215.3	10/11/15	10:41	1210.4	0.8	1213.7
10/9/15	13:14	1212	0.8	1215.3	10/11/15	11:43	1211.2	0.8	1214.5
10/9/15	14:16	1212.8	0.8	1216.1	10/11/15	12:45	1212	0.8	1215.3
10/9/15	15:18	1212.8	0.8	1216.1	10/11/15	13:47	1212.8	0.8	1216.1
10/9/15	16:20	1212.8	0.8	1216.1	10/11/15	14:49	1212.8	1.6	1219.3
10/9/15	17:22	1212	0.8	1215.3	10/11/15	15:50	1211.2	0.8	1214.5
10/9/15	18:23	1212	0.8	1215.3	10/11/15	16:52	1211.2	0.8	1214.5
10/9/15	19:25	1212	0.8	1215.3	10/11/15	17:54	1209.6	0.8	1212.9
10/9/15	20:27	1212	0.8	1215.3	10/11/15	18:56	1210.4	0.8	1213.7
10/9/15	21:29	1212.8	0.8	1216.1	10/11/15	19:58	1210.4	0.8	1213.7
10/9/15	22:32	1211.2	0.8	1214.5	10/11/15	21:00	1210.4	0.8	1213.7
10/9/15	23:34	1212	0.8	1215.3	10/11/15	22:02	1210.4	0.8	1213.7
10/10/15	0:36	1211.2	0.8	1214.5	10/11/15	23:04	1211.2	0.8	1214.5
10/10/15	1:38	1211.2	0.8	1214.5	10/12/15	0:06	1209.6	0.8	1212.9
10/10/15	2:40	1210.4	0.8	1213.7	10/12/15	1:08	1214.4	0.8	1217.7
10/10/15	3:42	1212.8	0.8	1216.1	10/12/15	2:10	1210.4	1.6	1216.9

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/12/15	3:12	1212	0.8	1215.3	10/14/15	1:41	1199.9	1.6	1206.4
10/12/15	4:14	1209.6	0.8	1212.9	10/14/15	2:43	1199.9	1.6	1206.4
10/12/15	5:16	1211.2	0.8	1214.5	10/14/15	3:45	1204	1.6	1210.5
10/12/15	6:18	1209.6	0.8	1212.9	10/14/15	4:47	1202.3	1.6	1208.8
10/12/15	7:20	1208.8	0.8	1212.1	10/14/15	5:49	1203.2	1.6	1209.7
10/12/15	8:22	1210.4	0.8	1213.7	10/14/15	6:51	1202.3	0.8	1205.6
10/12/15	9:24	1212	0.8	1215.3	10/14/15	7:53	1200.7	0.8	1204.0
10/12/15	10:26	1213.6	0.8	1216.9	10/14/15	8:55	1202.3	1.6	1208.8
10/12/15	11:28	1214.4	0.8	1217.7	10/14/15	9:57	1200.7	1.6	1207.2
10/12/15	12:30	1212	0.8	1215.3	10/14/15	10:59	1200.7	0.8	1204.0
10/12/15	13:32	1208.8	0.8	1212.1	10/14/15	12:01	1202.3	0.8	1205.6
10/12/15	14:34	1211.2	0.8	1214.5	10/14/15	13:03	1204.8	1.6	1211.3
10/12/15	15:36	1210.4	0.8	1213.7	10/14/15	14:05	1203.2	0.8	1206.5
10/12/15	16:38	1209.6	0.8	1212.9	10/14/15	15:07	1201.5	0.8	1204.8
10/12/15	17:40	1210.4	0.8	1213.7	10/14/15	16:09	1200.7	0.8	1204.0
10/12/15	18:42	1209.6	0.8	1212.9	10/14/15	17:11	1201.5	0.8	1204.8
10/12/15	19:44	1209.6	0.8	1212.9	10/14/15	18:13	1202.3	1.6	1208.8
10/12/15	20:46	1211.2	0.8	1214.5	10/14/15	19:15	1197.5	1.6	1204.0
10/12/15	21:48	1209.6	0.8	1212.9	10/14/15	20:17	1201.5	1.6	1208.0
10/12/15	22:50	1209.6	0.8	1212.9	10/14/15	21:19	1202.3	0.8	1205.6
10/12/15	23:52	1209.6	0.8	1212.9	10/14/15	22:21	1202.3	0.8	1205.6
10/13/15	0:54	1208.8	0.8	1212.1	10/14/15	23:23	1201.5	0.8	1204.8
10/13/15	1:56	1212	0.8	1215.3	10/15/15	0:25	1200.7	1.6	1207.2
10/13/15	2:58	1209.6	0.8	1212.9	10/15/15	1:27	1200.7	0.8	1204.0
10/13/15	4:00	1209.6	0.8	1212.9	10/15/15	2:29	1203.2	0.8	1206.5
10/13/15	5:02	1209.6	1.6	1216.1	10/15/15	3:31	1202.3	0.8	1205.6
10/13/15	6:04	1210.4	0.8	1213.7	10/15/15	4:33	1201.5	1.6	1208.0
10/13/15	7:06	1204.8	1.6	1211.3	10/15/15	5:35	1200.7	0.8	1204.0
10/13/15	8:08	980.7	57.2	1214.1	10/15/15	6:37	1201.5	0.8	1204.8
10/13/15	9:10	1063.7	33.8	1201.6	10/15/15	7:39	1202.3	0.8	1205.6
10/13/15	10:12	1117.7	19.3	1196.5	10/15/15	8:41	1202.3	0.8	1205.6
10/13/15	11:14	1142.7	12.9	1195.3	10/15/15	9:43	1202.3	0.8	1205.6
10/13/15	12:16	1157.2	9.7	1196.8	10/15/15	10:45	1201.5	0.8	1204.8
10/13/15	13:18	1171.7	7.3	1201.5	10/15/15	11:47	1204	0.8	1207.3
10/13/15	14:20	1178.2	5.6	1201.1	10/15/15	12:49	1201.5	1.6	1208.0
10/13/15	15:22	1183	4.8	1202.6	10/15/15	13:50	1201.5	0.8	1204.8
10/13/15	16:24	1194.3	3.2	1207.4	10/15/15	14:52	1201.5	0.8	1204.8
10/13/15	17:25	1193.5	2.4	1203.3	10/15/15	15:54	1202.3	0.8	1205.6
10/13/15	18:27	1196.7	2.4	1206.5	10/15/15	16:56	1204	1.6	1210.5
10/13/15	19:29	1196.7	2.4	1206.5	10/15/15	17:58	1202.3	1.6	1208.8
10/13/15	20:31	1197.5	1.6	1204.0	10/15/15	19:00	1202.3	0.8	1205.6
10/13/15	21:33	1199.9	1.6	1206.4	10/15/15	20:02	1202.3	1.6	1208.8
10/13/15	22:35	1199.9	1.6	1206.4	10/15/15	21:04	1201.5	0.8	1204.8
10/13/15	23:37	1200.7	1.6	1207.2	10/15/15	22:06	1201.5	0.8	1204.8
10/14/15	0:39	1201.5	1.6	1208.0	10/15/15	23:08	1202.3	0.8	1205.6

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/16/15	0:10	1203.2	0.8	1206.5	10/17/15	22:39	1201.5	0.8	1204.8
10/16/15	1:12	1200.7	0.8	1204.0	10/17/15	23:41	1203.2	0.8	1206.5
10/16/15	2:14	1200.7	1.6	1207.2	10/18/15	0:43	1201.5	0.8	1204.8
10/16/15	3:16	1202.3	0.8	1205.6	10/18/15	1:45	1201.5	0.8	1204.8
10/16/15	4:18	1202.3	1.6	1208.8	10/18/15	2:47	1201.5	0.8	1204.8
10/16/15	5:20	1203.2	0.8	1206.5	10/18/15	3:49	1201.5	1.6	1208.0
10/16/15	6:22	1203.2	0.8	1206.5	10/18/15	4:51	1204.8	1.6	1211.3
10/16/15	7:24	1201.5	0.8	1204.8	10/18/15	5:53	1200.7	0.8	1204.0
10/16/15	8:26	1201.5	0.8	1204.8	10/18/15	6:55	1203.2	1.6	1209.7
10/16/15	9:28	1204	0.8	1207.3	10/18/15	7:57	1203.2	1.6	1209.7
10/16/15	10:30	1201.5	1.6	1208.0	10/18/15	8:59	1202.3	0.8	1205.6
10/16/15	11:32	1201.5	0.8	1204.8	10/18/15	10:01	1203.2	0.8	1206.5
10/16/15	12:34	1203.2	0.8	1206.5	10/18/15	11:03	1202.3	0.8	1205.6
10/16/15	13:36	1201.5	1.6	1208.0	10/18/15	12:05	1201.5	1.6	1208.0
10/16/15	14:38	1202.3	0.8	1205.6	10/18/15	13:07	1201.5	1.6	1208.0
10/16/15	15:40	1204	0.8	1207.3	10/18/15	14:09	1201.5	0.8	1204.8
10/16/15	16:42	1200.7	0.8	1204.0	10/18/15	15:10	1199.9	1.6	1206.4
10/16/15	17:44	1202.3	0.8	1205.6	10/18/15	16:12	1201.5	1.6	1208.0
10/16/15	18:45	1203.2	0.8	1206.5	10/18/15	17:14	1202.3	0.8	1205.6
10/16/15	19:47	1201.5	0.8	1204.8	10/18/15	18:16	1202.3	0.8	1205.6
10/16/15	20:49	1201.5	0.8	1204.8	10/18/15	19:18	1201.5	0.8	1204.8
10/16/15	21:51	1203.2	0.8	1206.5	10/18/15	20:20	1202.3	0.8	1205.6
10/16/15	22:53	1201.5	1.6	1208.0	10/18/15	21:22	1203.2	1.6	1209.7
10/16/15	23:55	1201.5	0.8	1204.8	10/18/15	22:24	1201.5	0.8	1204.8
10/17/15	0:57	1202.3	1.6	1208.8	10/18/15	23:26	1200.7	1.6	1207.2
10/17/15	1:59	1201.5	1.6	1208.0	10/19/15	0:28	1200.7	0.8	1204.0
10/17/15	3:01	1201.5	1.6	1208.0	10/19/15	1:30	1202.3	0.8	1205.6
10/17/15	4:03	1201.5	1.6	1208.0	10/19/15	2:32	1201.5	0.8	1204.8
10/17/15	5:05	1201.5	1.6	1208.0	10/19/15	3:34	1200.7	0.8	1204.0
10/17/15	6:07	1200.7	0.8	1204.0	10/19/15	4:36	1202.3	0.8	1205.6
10/17/15	7:09	1200.7	0.8	1204.0	10/19/15	5:38	1201.5	0.8	1204.8
10/17/15	8:11	1201.5	1.6	1208.0	10/19/15	6:40	1201.5	0.8	1204.8
10/17/15	9:13	1200.7	0.8	1204.0	10/19/15	7:42	1202.3	0.8	1205.6
10/17/15	10:15	1201.5	0.8	1204.8	10/19/15	8:44	1202.3	0.8	1205.6
10/17/15	11:17	1203.2	0.8	1206.5	10/19/15	9:46	1201.5	0.8	1204.8
10/17/15	12:19	1200.7	0.8	1204.0	10/19/15	10:48	1200.7	1.6	1207.2
10/17/15	13:21	1201.5	1.6	1208.0	10/19/15	11:50	1200.7	1.6	1207.2
10/17/15	14:23	1200.7	0.8	1204.0	10/19/15	12:52	1201.5	0.8	1204.8
10/17/15	15:25	1202.3	1.6	1208.8	10/19/15	13:54	1200.7	1.6	1207.2
10/17/15	16:27	1201.5	0.8	1204.8	10/19/15	14:56	1204	1.6	1210.5
10/17/15	17:29	1201.5	0.8	1204.8	10/19/15	15:58	1202.3	0.8	1205.6
10/17/15	18:31	1203.2	0.8	1206.5	10/19/15	17:00	1202.3	1.6	1208.8
10/17/15	19:33	1200.7	0.8	1204.0	10/19/15	18:02	1201.5	0.8	1204.8
10/17/15	20:35	1201.5	0.8	1204.8	10/19/15	19:04	1200.7	1.6	1207.2
10/17/15	21:37	1204	1.6	1210.5	10/19/15	20:06	1201.5	0.8	1204.8

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/19/15	21:08	1201.5	0.8	1204.8
10/19/15	22:10	1201.5	1.6	1208.0
10/19/15	23:12	1201.5	0.8	1204.8
10/20/15	0:14	1201.5	0.8	1204.8
10/20/15	1:16	1201.5	0.8	1204.8
10/20/15	2:18	1202.3	0.8	1205.6
10/20/15	3:20	1202.3	0.8	1205.6
10/20/15	4:22	1202.3	0.8	1205.6
10/20/15	5:24	1201.5	0.8	1204.8
10/20/15	6:26	1201.5	1.6	1208.0
10/20/15	7:28	1201.5	0.8	1204.8
10/20/15	8:30	1201.5	1.6	1208.0
10/20/15	9:32	1199.9	0.8	1203.2
10/20/15	10:34	1201.5	0.8	1204.8
10/20/15	11:36	1202.3	0.8	1205.6
10/20/15	12:37	1200.7	1.6	1207.2
10/20/15	13:39	1200.7	0.8	1204.0
10/20/15	14:41	1201.5	0.8	1204.8
10/20/15	15:43	1200.7	0.8	1204.0
10/20/15	16:45	1201.5	0.8	1204.8
10/20/15	17:47	1200.7	1.6	1207.2
10/20/15	18:49	1201.5	0.8	1204.8
10/20/15	19:51	1203.2	0.8	1206.5
10/20/15	20:53	1201.5	0.8	1204.8
10/20/15	21:55	1203.2	1.6	1209.7
10/20/15	22:57	1201.5	0.8	1204.8
10/20/15	23:59	1201.5	0.8	1204.8
10/21/15	1:01	1202.3	1.6	1208.8
10/21/15	2:03	1202.3	0.8	1205.6
10/21/15	3:05	1200.7	1.6	1207.2
10/21/15	4:07	1200.7	0.8	1204.0
10/21/15	5:09	1201.5	0.8	1204.8
10/21/15	6:11	1200.7	0.8	1204.0
10/21/15	7:13	1202.3	0.8	1205.6
10/21/15	8:15	1201.5	0.8	1204.8
10/21/15	9:17	1202.3	0.8	1205.6
10/21/15	10:19	1201.5	1.6	1208.0
10/21/15	11:21	1202.3	1.6	1208.8
10/21/15	12:23	1201.5	0.8	1204.8
10/21/15	13:25	1203.2	0.8	1206.5
10/21/15	14:27	1202.3	0.8	1205.6
10/21/15	15:29	1198.3	0.8	1201.6
10/21/15	16:31	1201.5	1.6	1208.0
10/21/15	17:33	1200.7	1.6	1207.2
10/21/15	18:35	1200.7	0.8	1204.0
10/21/15	19:37	1201.5	0.8	1204.8
10/21/15	20:39	1201.5	0.8	1204.8
10/21/15	21:41	1201.5	0.8	1204.8
10/21/15	22:43	1202.3	0.8	1205.6
10/21/15	23:45	1202.3	0.8	1205.6
10/22/15	0:47	1200.7	0.8	1204.0
10/22/15	1:49	1201.5	0.8	1204.8
10/22/15	2:51	1204	1.6	1210.5
10/22/15	3:53	1201.5	0.8	1204.8
10/22/15	4:55	1201.5	0.8	1204.8
10/22/15	5:57	1200.7	1.6	1207.2
10/22/15	6:59	1200.7	0.8	1204.0
10/22/15	8:01	1202.3	0.8	1205.6
10/22/15	9:03	1201.5	1.6	1208.0
10/22/15	10:05	1202.3	0.8	1205.6
10/22/15	11:07	1200.7	1.6	1207.2
10/22/15	12:09	1200.7	1.6	1207.2
10/22/15	13:11	1201.5	0.8	1204.8
10/22/15	14:13	1200.7	0.8	1204.0
10/22/15	15:15	1200.7	1.6	1207.2
10/22/15	16:17	1200.7	0.8	1204.0
10/22/15	17:19	1200.7	0.8	1204.0
10/22/15	18:21	1201.5	0.8	1204.8
10/22/15	19:23	1200.7	0.8	1204.0
10/22/15	20:25	1201.5	0.8	1204.8
10/22/15	21:27	1202.3	0.8	1205.6
10/22/15	22:29	1203.2	0.8	1206.5
10/22/15	23:31	1201.5	0.8	1204.8
10/23/15	0:33	1199.9	0.8	1203.2
10/23/15	1:35	1201.5	0.8	1204.8
10/23/15	2:37	1201.5	1.6	1208.0
10/23/15	3:39	1200.7	1.6	1207.2
10/23/15	4:41	1200.7	0.8	1204.0
10/23/15	5:43	1200.7	1.6	1207.2
10/23/15	6:45	1202.3	0.8	1205.6
10/23/15	7:47	1202.3	0.8	1205.6
10/23/15	8:49	1201.5	0.8	1204.8
10/23/15	9:51	1201.5	0.8	1204.8
10/23/15	10:53	1203.2	0.8	1206.5
10/23/15	11:55	1202.3	1.6	1208.8
10/23/15	12:57	1201.5	1.6	1208.0
10/23/15	13:59	1201.5	1.6	1208.0
10/23/15	15:01	1202.3	0.8	1205.6
10/23/15	16:03	1201.5	0.8	1204.8
10/23/15	17:05	1202.3	1.6	1208.8

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/23/15	18:07	1200.7	0.8	1204.0	10/25/15	16:37	1199.1	0.8	1202.4
10/23/15	19:09	1201.5	0.8	1204.8	10/25/15	17:39	1199.9	0.8	1203.2
10/23/15	20:11	1201.5	1.6	1208.0	10/25/15	18:41	1199.9	1.6	1206.4
10/23/15	21:13	1201.5	0.8	1204.8	10/25/15	19:43	1199.9	0.8	1203.2
10/23/15	22:15	1201.5	0.8	1204.8	10/25/15	20:45	1202.3	1.6	1208.8
10/23/15	23:17	1200.7	0.8	1204.0	10/25/15	21:47	1199.1	0.8	1202.4
10/24/15	0:19	1202.3	1.6	1208.8	10/25/15	22:49	1199.9	0.8	1203.2
10/24/15	1:21	1201.5	0.8	1204.8	10/25/15	23:51	1200.7	1.6	1207.2
10/24/15	2:23	1201.5	0.8	1204.8	10/26/15	0:53	1201.5	0.8	1204.8
10/24/15	3:25	1201.5	0.8	1204.8	10/26/15	1:55	1200.7	1.6	1207.2
10/24/15	4:27	1201.5	1.6	1208.0	10/26/15	2:57	1202.3	0.8	1205.6
10/24/15	5:29	1202.3	0.8	1205.6	10/26/15	3:59	1201.5	0.8	1204.8
10/24/15	6:31	1203.2	1.6	1209.7	10/26/15	5:02	1201.5	0.8	1204.8
10/24/15	7:33	1203.2	1.6	1209.7	10/26/15	6:04	1201.5	0.8	1204.8
10/24/15	8:35	1201.5	0.8	1204.8	10/26/15	7:06	1200.7	0.8	1204.0
10/24/15	9:37	1201.5	0.8	1204.8	10/26/15	8:08	1202.3	0.8	1205.6
10/24/15	10:39	1202.3	1.6	1208.8	10/26/15	9:10	1200.7	0.8	1204.0
10/24/15	11:41	1202.3	0.8	1205.6	10/26/15	10:12	1201.5	0.8	1204.8
10/24/15	12:43	1202.3	0.8	1205.6	10/26/15	11:14	1200.7	1.6	1207.2
10/24/15	13:45	1201.5	0.8	1204.8	10/26/15	12:16	1201.5	0.8	1204.8
10/24/15	14:47	1201.5	0.8	1204.8	10/26/15	13:18	1201.5	0.8	1204.8
10/24/15	15:49	1202.3	1.6	1208.8	10/26/15	14:20	1201.5	0.8	1204.8
10/24/15	16:51	1202.3	0.8	1205.6	10/26/15	15:22	1202.3	1.6	1208.8
10/24/15	17:53	1201.5	0.8	1204.8	10/26/15	16:24	1201.5	0.8	1204.8
10/24/15	18:55	1199.9	1.6	1206.4	10/26/15	17:26	1201.5	0.8	1204.8
10/24/15	19:57	1200.7	0.8	1204.0	10/26/15	18:28	1202.3	0.8	1205.6
10/24/15	20:59	1201.5	1.6	1208.0	10/26/15	19:30	1201.5	0.8	1204.8
10/24/15	22:01	1201.5	0.8	1204.8	10/26/15	20:31	1201.5	1.6	1208.0
10/24/15	23:03	1201.5	1.6	1208.0	10/26/15	21:33	1201.5	0.8	1204.8
10/25/15	0:05	1202.3	0.8	1205.6	10/26/15	22:36	1200.7	0.8	1204.0
10/25/15	1:07	1201.5	1.6	1208.0	10/26/15	23:38	1201.5	0.8	1204.8
10/25/15	2:09	1202.3	1.6	1208.8	10/27/15	0:40	1202.3	1.6	1208.8
10/25/15	3:11	1201.5	0.8	1204.8	10/27/15	1:42	1201.5	1.6	1208.0
10/25/15	4:13	1202.3	0.8	1205.6	10/27/15	2:44	1201.5	1.6	1208.0
10/25/15	5:15	1201.5	0.8	1204.8	10/27/15	3:46	1201.5	1.6	1208.0
10/25/15	6:17	1201.5	0.8	1204.8	10/27/15	4:48	1202.3	0.8	1205.6
10/25/15	7:19	1201.5	0.8	1204.8	10/27/15	5:50	1200.7	1.6	1207.2
10/25/15	8:21	1201.5	0.8	1204.8	10/27/15	6:52	1201.5	0.8	1204.8
10/25/15	9:23	1200.7	0.8	1204.0	10/27/15	7:54	1201.5	0.8	1204.8
10/25/15	10:25	1202.3	0.8	1205.6	10/27/15	8:56	1202.3	1.6	1208.8
10/25/15	11:28	1201.5	0.8	1204.8	10/27/15	9:58	1201.5	0.8	1204.8
10/25/15	12:30	1199.9	1.6	1206.4	10/27/15	11:00	1202.3	1.6	1208.8
10/25/15	13:31	1194.3	2.4	1204.1	10/27/15	12:02	1201.5	0.8	1204.8
10/25/15	14:33	1197.5	1.6	1204.0	10/27/15	13:04	1202.3	0.8	1205.6
10/25/15	15:35	1197.5	1.6	1204.0	10/27/15	14:06	1202.3	0.8	1205.6

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/27/15	15:08	1202.3	0.8	1205.6	10/29/15	13:38	1200.7	0.8	1204.0
10/27/15	16:10	1201.5	0.8	1204.8	10/29/15	14:40	1201.5	0.8	1204.8
10/27/15	17:12	1201.5	1.6	1208.0	10/29/15	15:42	1201.5	0.8	1204.8
10/27/15	18:14	1202.3	1.6	1208.8	10/29/15	16:44	1201.5	0.8	1204.8
10/27/15	19:15	1201.5	1.6	1208.0	10/29/15	17:46	1202.3	0.8	1205.6
10/27/15	20:18	1202.3	0.8	1205.6	10/29/15	18:48	1202.3	0.8	1205.6
10/27/15	21:19	1202.3	0.8	1205.6	10/29/15	19:50	1202.3	0.8	1205.6
10/27/15	22:22	1200.7	0.8	1204.0	10/29/15	20:52	1201.5	0.8	1204.8
10/27/15	23:24	1201.5	0.8	1204.8	10/29/15	21:53	1201.5	0.8	1204.8
10/28/15	0:26	1202.3	0.8	1205.6	10/29/15	22:55	1201.5	0.8	1204.8
10/28/15	1:28	1202.3	0.8	1205.6	10/29/15	23:57	1201.5	0.8	1204.8
10/28/15	2:30	1201.5	0.8	1204.8	10/30/15	0:59	1200.7	0.8	1204.0
10/28/15	3:32	1203.2	0.8	1206.5	10/30/15	2:01	1202.3	0.8	1205.6
10/28/15	4:34	1202.3	0.8	1205.6	10/30/15	3:03	1201.5	1.6	1208.0
10/28/15	5:36	1202.3	1.6	1208.8	10/30/15	4:05	1201.5	1.6	1208.0
10/28/15	6:38	1202.3	0.8	1205.6	10/30/15	5:07	1202.3	0.8	1205.6
10/28/15	7:40	1202.3	0.8	1205.6	10/30/15	6:09	1202.3	0.8	1205.6
10/28/15	8:42	1201.5	1.6	1208.0	10/30/15	7:11	1202.3	0.8	1205.6
10/28/15	9:44	1201.5	0.8	1204.8	10/30/15	8:13	1202.3	1.6	1208.8
10/28/15	10:46	1202.3	1.6	1208.8	10/30/15	9:15	1202.3	0.8	1205.6
10/28/15	11:48	1202.3	0.8	1205.6	10/30/15	10:17	1202.3	0.8	1205.6
10/28/15	12:50	1201.5	0.8	1204.8	10/30/15	11:19	1203.2	0.8	1206.5
10/28/15	13:52	1202.3	0.8	1205.6	10/30/15	12:21	1201.5	0.8	1204.8
10/28/15	14:54	1202.3	0.8	1205.6	10/30/15	13:23	1201.5	0.8	1204.8
10/28/15	15:56	1202.3	1.6	1208.8	10/30/15	14:25	1201.5	0.8	1204.8
10/28/15	16:58	1203.2	0.8	1206.5	10/30/15	15:27	1202.3	0.8	1205.6
10/28/15	18:00	1201.5	0.8	1204.8	10/30/15	16:29	1201.5	0.8	1204.8
10/28/15	19:02	1203.2	1.6	1209.7	10/30/15	17:31	1201.5	1.6	1208.0
10/28/15	20:04	1201.5	0.8	1204.8	10/30/15	18:33	1203.2	0.8	1206.5
10/28/15	21:06	1201.5	0.8	1204.8	10/30/15	19:35	1202.3	0.8	1205.6
10/28/15	22:08	1202.3	0.8	1205.6	10/30/15	20:37	1202.3	0.8	1205.6
10/28/15	23:10	1200.7	1.6	1207.2	10/30/15	21:39	1202.3	0.8	1205.6
10/29/15	0:12	1201.5	1.6	1208.0	10/30/15	22:41	1202.3	0.8	1205.6
10/29/15	1:14	1201.5	1.6	1208.0	10/30/15	23:43	1202.3	0.8	1205.6
10/29/15	2:16	1201.5	0.8	1204.8	10/31/15	0:45	1201.5	1.6	1208.0
10/29/15	3:18	1201.5	1.6	1208.0	10/31/15	1:47	1202.3	0.8	1205.6
10/29/15	4:20	1202.3	0.8	1205.6	10/31/15	2:49	1200.7	0.8	1204.0
10/29/15	5:22	1202.3	0.8	1205.6	10/31/15	3:50	1203.2	0.8	1206.5
10/29/15	6:24	1201.5	1.6	1208.0	10/31/15	4:52	1202.3	0.8	1205.6
10/29/15	7:26	1202.3	0.8	1205.6	10/31/15	5:54	1201.5	0.8	1204.8
10/29/15	8:28	1201.5	0.8	1204.8	10/31/15	6:56	1202.3	0.8	1205.6
10/29/15	9:30	1203.2	0.8	1206.5	10/31/15	7:58	1201.5	1.6	1208.0
10/29/15	10:32	1202.3	0.8	1205.6	10/31/15	9:00	1202.3	0.8	1205.6
10/29/15	11:34	1202.3	0.8	1205.6	10/31/15	10:02	1202.3	0.8	1205.6
10/29/15	12:36	1202.3	0.8	1205.6	10/31/15	11:04	1202.3	0.8	1205.6

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
10/31/15	12:06	1201.5	0.8	1204.8	11/2/15	9:36	1201.5	0.8	1204.8
10/31/15	13:08	1204	1.6	1210.5	11/2/15	10:38	1200.7	0.8	1204.0
10/31/15	14:10	1201.5	1.6	1208.0	11/2/15	11:40	1201.5	0.8	1204.8
10/31/15	15:12	1203.2	0.8	1206.5	11/2/15	12:42	1202.3	0.8	1205.6
10/31/15	16:14	1203.2	0.8	1206.5	11/2/15	13:44	1203.2	0.8	1206.5
10/31/15	17:16	1202.3	0.8	1205.6	11/2/15	14:46	1201.5	1.6	1208.0
10/31/15	18:18	1201.5	0.8	1204.8	11/2/15	15:48	1200.7	0.8	1204.0
10/31/15	19:20	1200.7	0.8	1204.0	11/2/15	16:50	1200.7	0.8	1204.0
10/31/15	20:22	1201.5	0.8	1204.8	11/2/15	17:52	1200.7	0.8	1204.0
10/31/15	21:24	1201.5	0.8	1204.8	11/2/15	18:54	1200.7	0.8	1204.0
10/31/15	22:26	1201.5	0.8	1204.8	11/2/15	19:56	1201.5	0.8	1204.8
10/31/15	23:28	1202.3	0.8	1205.6	11/2/15	20:58	1200.7	0.8	1204.0
11/1/15	0:30	1202.3	0.8	1205.6	11/2/15	22:00	1201.5	0.8	1204.8
11/1/15	1:32	1202.3	0.8	1205.6	11/2/15	23:02	1201.5	1.6	1208.0
11/1/15	1:34	1200.7	0.8	1204.0	11/3/15	0:04	1201.5	0.8	1204.8
11/1/15	2:36	1202.3	0.8	1205.6	11/3/15	1:06	1200.7	0.8	1204.0
11/1/15	3:38	1202.3	1.6	1208.8	11/3/15	2:08	1200.7	0.8	1204.0
11/1/15	4:40	1201.5	0.8	1204.8	11/3/15	3:10	1201.5	0.8	1204.8
11/1/15	5:42	1202.3	0.8	1205.6	11/3/15	4:12	1201.5	0.8	1204.8
11/1/15	6:44	1202.3	0.8	1205.6	11/3/15	5:14	1201.5	0.8	1204.8
11/1/15	7:46	1201.5	0.8	1204.8	11/3/15	6:16	1201.5	0.8	1204.8
11/1/15	8:48	1202.3	0.8	1205.6	11/3/15	7:18	1200.7	1.6	1207.2
11/1/15	9:50	1201.5	0.8	1204.8	11/3/15	8:20	1200.7	0.8	1204.0
11/1/15	10:52	1201.5	0.8	1204.8	11/3/15	9:22	1201.5	1.6	1208.0
11/1/15	11:54	1201.5	1.6	1208.0	11/3/15	10:24	1201.5	0.8	1204.8
11/1/15	12:56	1201.5	1.6	1208.0	11/3/15	11:26	1201.5	0.8	1204.8
11/1/15	13:58	1202.3	1.6	1208.8	11/3/15	12:28	1201.5	0.8	1204.8
11/1/15	15:00	1201.5	0.8	1204.8	11/3/15	13:30	1201.5	0.8	1204.8
11/1/15	16:02	1201.5	1.6	1208.0	11/3/15	14:32	1200.7	0.8	1204.0
11/1/15	17:04	1202.3	0.8	1205.6	11/3/15	15:33	1200.7	1.6	1207.2
11/1/15	18:06	1201.5	0.8	1204.8	11/3/15	16:35	1200.7	0.8	1204.0
11/1/15	19:08	1200.7	1.6	1207.2	11/3/15	17:37	1201.5	0.8	1204.8
11/1/15	20:10	1201.5	0.8	1204.8	11/3/15	18:39	1201.5	0.8	1204.8
11/1/15	21:12	1201.5	0.8	1204.8	11/3/15	19:41	1201.5	0.8	1204.8
11/1/15	22:14	1201.5	0.8	1204.8	11/3/15	20:43	1200.7	0.8	1204.0
11/1/15	23:16	1201.5	0.8	1204.8	11/3/15	21:45	1200.7	0.8	1204.0
11/2/15	0:18	1201.5	0.8	1204.8	11/3/15	22:47	1200.7	0.8	1204.0
11/2/15	1:20	1202.3	0.8	1205.6	11/3/15	23:49	1201.5	0.8	1204.8
11/2/15	2:22	1201.5	0.8	1204.8	11/4/15	0:51	1201.5	0.8	1204.8
11/2/15	3:24	1202.3	1.6	1208.8	11/4/15	1:53	1202.3	0.8	1205.6
11/2/15	4:26	1200.7	0.8	1204.0	11/4/15	2:55	1200.7	1.6	1207.2
11/2/15	5:28	1200.7	0.8	1204.0	11/4/15	3:57	1202.3	0.8	1205.6
11/2/15	6:30	1199.9	0.8	1203.2	11/4/15	4:59	1199.9	0.8	1203.2
11/2/15	7:32	1202.3	0.8	1205.6	11/4/15	6:02	1200.7	0.8	1204.0
11/2/15	8:34	1201.5	1.6	1208.0	11/4/15	7:04	1200.7	0.8	1204.0

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
11/4/15	8:06	1199.9	0.8	1203.2	11/6/15	6:36	1201.5	0.8	1204.8
11/4/15	9:08	1199.9	0.8	1203.2	11/6/15	7:38	1201.5	0.8	1204.8
11/4/15	10:10	1199.1	0.8	1202.4	11/6/15	8:40	1200.7	0.8	1204.0
11/4/15	11:12	1199.9	1.6	1206.4	11/6/15	9:42	1201.5	0.8	1204.8
11/4/15	12:14	1199.1	1.6	1205.6	11/6/15	10:44	1202.3	0.8	1205.6
11/4/15	13:16	1199.9	0.8	1203.2	11/6/15	11:46	1201.5	0.8	1204.8
11/4/15	14:17	1199.9	0.8	1203.2	11/6/15	12:48	1201.5	0.8	1204.8
11/4/15	15:19	1199.9	1.6	1206.4	11/6/15	13:50	1201.5	0.8	1204.8
11/4/15	16:21	1200.7	0.8	1204.0	11/6/15	14:52	1200.7	0.8	1204.0
11/4/15	17:23	1200.7	0.8	1204.0	11/6/15	15:54	1200.7	0.8	1204.0
11/4/15	18:25	1200.7	0.8	1204.0	11/6/15	16:56	1200.7	0.8	1204.0
11/4/15	19:27	1200.7	0.8	1204.0	11/6/15	17:58	1201.5	0.8	1204.8
11/4/15	20:29	1199.9	0.8	1203.2	11/6/15	19:00	1202.3	0.8	1205.6
11/4/15	21:31	1200.7	0.8	1204.0	11/6/15	20:02	1200.7	0.8	1204.0
11/4/15	22:33	1201.5	0.8	1204.8	11/6/15	21:04	1201.5	0.8	1204.8
11/4/15	23:35	1200.7	0.8	1204.0	11/6/15	22:06	1201.5	0.8	1204.8
11/5/15	0:37	1199.9	0.8	1203.2	11/6/15	23:08	1201.5	0.8	1204.8
11/5/15	1:39	1200.7	0.8	1204.0	11/7/15	0:10	1200.7	1.6	1207.2
11/5/15	2:41	1199.9	0.8	1203.2	11/7/15	1:12	1201.5	0.8	1204.8
11/5/15	3:44	1200.7	0.8	1204.0	11/7/15	2:14	1200.7	0.8	1204.0
11/5/15	4:46	1199.9	1.6	1206.4	11/7/15	3:16	1199.1	0.8	1202.4
11/5/15	5:48	1199.9	0.8	1203.2	11/7/15	4:18	1200.7	1.6	1207.2
11/5/15	6:50	1199.9	0.8	1203.2	11/7/15	5:20	1200.7	0.8	1204.0
11/5/15	7:52	1199.1	0.8	1202.4	11/7/15	6:22	1200.7	0.8	1204.0
11/5/15	8:54	1199.1	0.8	1202.4	11/7/15	7:24	1199.9	0.8	1203.2
11/5/15	9:56	1199.9	0.8	1203.2	11/7/15	8:26	1199.9	0.8	1203.2
11/5/15	10:58	1200.7	0.8	1204.0	11/7/15	9:28	1200.7	0.8	1204.0
11/5/15	12:00	1200.7	0.8	1204.0	11/7/15	10:30	1200.7	0.8	1204.0
11/5/15	13:02	1199.9	0.8	1203.2	11/7/15	11:32	1201.5	0.8	1204.8
11/5/15	14:04	1199.9	0.8	1203.2	11/7/15	12:34	1200.7	0.8	1204.0
11/5/15	15:06	1199.1	0.8	1202.4	11/7/15	13:36	1201.5	0.8	1204.8
11/5/15	16:08	1200.7	0.8	1204.0	11/7/15	14:38	1201.5	0.8	1204.8
11/5/15	17:10	1200.7	0.8	1204.0	11/7/15	15:40	1199.9	0.8	1203.2
11/5/15	18:12	1200.7	1.6	1207.2	11/7/15	16:42	1200.7	0.8	1204.0
11/5/15	19:14	1199.9	0.8	1203.2	11/7/15	17:44	1200.7	0.8	1204.0
11/5/15	20:16	1199.9	0.8	1203.2	11/7/15	18:46	1201.5	0.8	1204.8
11/5/15	21:18	1200.7	0.8	1204.0	11/7/15	19:48	1200.7	0.8	1204.0
11/5/15	22:20	1201.5	0.8	1204.8	11/7/15	20:50	1200.7	0.8	1204.0
11/5/15	23:22	1199.9	0.8	1203.2	11/7/15	21:52	1202.3	0.8	1205.6
11/6/15	0:24	1201.5	0.8	1204.8	11/7/15	22:54	1200.7	0.8	1204.0
11/6/15	1:26	1201.5	1.6	1208.0	11/7/15	23:56	1200.7	0.8	1204.0
11/6/15	2:28	1200.7	0.8	1204.0	11/8/15	0:58	1199.9	0.8	1203.2
11/6/15	3:30	1200.7	1.6	1207.2	11/8/15	2:00	1200.7	0.8	1204.0
11/6/15	4:32	1201.5	0.8	1204.8	11/8/15	3:02	1200.7	0.8	1204.0
11/6/15	5:34	1199.9	0.8	1203.2	11/8/15	4:04	1201.5	0.8	1204.8

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
11/8/15	5:06	1200.7	1.6	1207.2	11/10/15	3:36	1199.9	0.8	1203.2
11/8/15	6:08	1200.7	0.8	1204.0	11/10/15	4:38	1200.7	0.8	1204.0
11/8/15	7:10	1200.7	0.8	1204.0	11/10/15	5:40	1200.7	0.8	1204.0
11/8/15	8:12	1201.5	0.8	1204.8	11/10/15	6:42	1200.7	0.8	1204.0
11/8/15	9:14	1201.5	0.8	1204.8	11/10/15	7:44	1201.5	0.8	1204.8
11/8/15	10:16	1200.7	0.8	1204.0	11/10/15	8:46	1199.9	0.8	1203.2
11/8/15	11:18	1199.9	0.8	1203.2	11/10/15	9:48	1200.7	0.8	1204.0
11/8/15	12:20	1200.7	0.8	1204.0	11/10/15	10:50	1200.7	0.8	1204.0
11/8/15	13:22	1200.7	0.8	1204.0	11/10/15	11:52	1200.7	0.8	1204.0
11/8/15	14:24	1200.7	0.8	1204.0	11/10/15	12:54	1200.7	0.8	1204.0
11/8/15	15:26	1200.7	0.8	1204.0	11/10/15	13:56	1200.7	0.8	1204.0
11/8/15	16:28	1200.7	0.8	1204.0	11/10/15	14:58	1200.7	0.8	1204.0
11/8/15	17:30	1200.7	0.8	1204.0	11/10/15	16:00	1200.7	0.8	1204.0
11/8/15	18:32	1201.5	0.8	1204.8	11/10/15	17:02	1201.5	0.8	1204.8
11/8/15	19:34	1200.7	0.8	1204.0	11/10/15	18:04	1200.7	0.8	1204.0
11/8/15	20:36	1200.7	0.8	1204.0	11/10/15	19:06	1201.5	0.8	1204.8
11/8/15	21:38	1199.9	0.8	1203.2	11/10/15	20:08	1201.5	0.8	1204.8
11/8/15	22:40	1200.7	0.8	1204.0	11/10/15	21:10	1200.7	0.8	1204.0
11/8/15	23:42	1199.1	0.8	1202.4	11/10/15	22:12	1201.5	0.8	1204.8
11/9/15	0:44	1200.7	0.8	1204.0	11/10/15	23:14	1200.7	0.8	1204.0
11/9/15	1:46	1200.7	0.8	1204.0	11/11/15	0:16	1200.7	0.8	1204.0
11/9/15	2:48	1200.7	0.8	1204.0	11/11/15	1:18	1200.7	0.8	1204.0
11/9/15	3:50	1200.7	0.8	1204.0	11/11/15	2:20	1199.9	0.8	1203.2
11/9/15	4:52	1201.5	0.8	1204.8	11/11/15	3:22	1199.9	0.8	1203.2
11/9/15	5:54	1201.5	0.8	1204.8	11/11/15	4:24	1200.7	0.8	1204.0
11/9/15	6:56	1201.5	0.8	1204.8	11/11/15	5:26	1201.5	0.8	1204.8
11/9/15	7:58	1200.7	0.8	1204.0	11/11/15	6:28	1200.7	0.8	1204.0
11/9/15	9:00	1200.7	0.8	1204.0	11/11/15	7:30	1200.7	0.8	1204.0
11/9/15	10:02	1200.7	0.8	1204.0	11/11/15	8:32	1200.7	0.8	1204.0
11/9/15	11:04	1200.7	0.8	1204.0	11/11/15	9:34	1201.5	0.8	1204.8
11/9/15	12:06	1194.3	0.8	1197.6	11/11/15	10:36	1200.7	0.8	1204.0
11/9/15	13:08	1200.7	0.8	1204.0	11/11/15	11:38	1200.7	0.8	1204.0
11/9/15	14:10	1201.5	0.8	1204.8	11/11/15	12:40	1200.7	0.8	1204.0
11/9/15	15:12	1200.7	0.8	1204.0	11/11/15	13:42	1199.9	0.8	1203.2
11/9/15	16:14	1200.7	0.8	1204.0	11/11/15	14:44	1199.9	0.8	1203.2
11/9/15	17:16	1199.9	0.8	1203.2	11/11/15	15:46	1199.9	0.8	1203.2
11/9/15	18:18	1200.7	0.8	1204.0	11/11/15	16:48	1200.7	0.8	1204.0
11/9/15	19:20	1200.7	0.8	1204.0	11/11/15	17:50	1199.9	0.8	1203.2
11/9/15	20:22	1199.9	0.8	1203.2	11/11/15	18:52	1200.7	0.8	1204.0
11/9/15	21:24	1200.7	0.8	1204.0	11/11/15	19:53	1199.9	0.8	1203.2
11/9/15	22:26	1200.7	0.8	1204.0	11/11/15	20:55	1202.3	0.8	1205.6
11/9/15	23:28	1200.7	0.8	1204.0	11/11/15	21:57	1200.7	0.8	1204.0
11/10/15	0:30	1199.9	0.8	1203.2	11/11/15	22:59	1200.7	0.8	1204.0
11/10/15	1:32	1200.7	0.8	1204.0	11/12/15	0:01	1199.9	0.8	1203.2
11/10/15	2:34	1200.7	0.8	1204.0	11/12/15	1:03	1200.7	0.8	1204.0

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)	Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)	Turbidity Corrected Transmitted Light Signal (mV)
11/12/15	2:05	1200.7	0.8	1204.0	11/14/15	0:35	1198.3	0.8	1201.6
11/12/15	3:08	1200.7	0.8	1204.0	11/14/15	1:37	1198.3	0.8	1201.6
11/12/15	4:10	1199.9	0.8	1203.2	11/14/15	2:39	1198.3	0.8	1201.6
11/12/15	5:12	1200.7	0.8	1204.0	11/14/15	3:41	1198.3	0.8	1201.6
11/12/15	6:14	1200.7	0.8	1204.0	11/14/15	4:43	1198.3	0.8	1201.6
11/12/15	7:16	1096.8	23.4	1192.3	11/14/15	5:45	1197.5	0.8	1200.8
11/12/15	8:18	1129.8	16.1	1195.5	11/14/15	6:47	1197.5	0.8	1200.8
11/12/15	9:20	1150	10.5	1192.9	11/14/15	7:49	1197.5	0.8	1200.8
11/12/15	10:22	1163.7	8.1	1196.8	11/14/15	8:51	1198.3	0.8	1201.6
11/12/15	11:24	1175.8	5.6	1198.7	11/14/15	9:52	1198.3	0.8	1201.6
11/12/15	12:26	1180.6	4.8	1200.2	11/14/15	10:54	1198.3	0.8	1201.6
11/12/15	13:28	1184.6	3.2	1197.7	11/14/15	11:56	1198.3	0.8	1201.6
11/12/15	14:30	1187	2.4	1196.8	11/14/15	12:58	1198.3	0.8	1201.6
11/12/15	15:32	1190.3	2.4	1200.1	11/14/15	14:00	1197.5	0.8	1200.8
11/12/15	16:34	1192.7	1.6	1199.2	11/14/15	15:02	1197.5	0.8	1200.8
11/12/15	17:36	1193.5	1.6	1200.0	11/14/15	16:04	1199.1	0.8	1202.4
11/12/15	18:38	1195.1	1.6	1201.6	11/14/15	17:06	1197.5	0.8	1200.8
11/12/15	19:40	1194.3	1.6	1200.8	11/14/15	18:08	1198.3	0.8	1201.6
11/12/15	20:42	1196.7	1.6	1203.2	11/14/15	19:10	1197.5	0.8	1200.8
11/12/15	21:44	1195.9	0.8	1199.2	11/14/15	20:12	1199.1	0.8	1202.4
11/12/15	22:46	1195.9	0.8	1199.2	11/14/15	21:14	1197.5	0.8	1200.8
11/12/15	23:48	1196.7	1.6	1203.2	11/14/15	22:16	1197.5	0.8	1200.8
11/13/15	0:50	1197.5	0.8	1200.8	11/14/15	23:18	1198.3	0.8	1201.6
11/13/15	1:52	1197.5	1.6	1204.0	11/15/15	0:20	1197.5	0.8	1200.8
11/13/15	2:54	1196.7	1.6	1203.2	11/15/15	1:22	1198.3	0.8	1201.6
11/13/15	3:56	1197.5	0.8	1200.8	11/15/15	2:24	1197.5	0.8	1200.8
11/13/15	4:58	1197.5	0.8	1200.8	11/15/15	3:26	1198.3	0.8	1201.6
11/13/15	6:00	1198.3	1.6	1204.8	11/15/15	4:28	1198.3	0.8	1201.6
11/13/15	7:02	1198.3	0.8	1201.6	11/15/15	5:30	1197.5	0.8	1200.8
11/13/15	8:04	1197.5	0.8	1200.8	11/15/15	6:32	1197.5	0.8	1200.8
11/13/15	9:06	1198.3	0.8	1201.6	11/15/15	7:34	1197.5	0.8	1200.8
11/13/15	10:07	1197.5	0.8	1200.8	11/15/15	8:36	1196.7	0.8	1200.0
11/13/15	11:09	1197.5	0.8	1200.8	11/15/15	9:38	1197.5	0.8	1200.8
11/13/15	12:11	1196.7	1.6	1203.2	11/15/15	10:40	1197.5	0.8	1200.8
11/13/15	13:13	1198.3	0.8	1201.6	11/15/15	11:42	1198.3	0.8	1201.6
11/13/15	14:15	1197.5	0.8	1200.8	11/15/15	12:44	1197.5	0.8	1200.8
11/13/15	15:17	1198.3	0.8	1201.6	11/15/15	13:46	1197.5	0.8	1200.8
11/13/15	16:19	1197.5	0.8	1200.8	11/15/15	14:48	1197.5	0.8	1200.8
11/13/15	17:21	1197.5	0.8	1200.8	11/15/15	15:50	1197.5	0.8	1200.8
11/13/15	18:23	1198.3	0.8	1201.6	11/15/15	16:52	1197.5	0.8	1200.8
11/13/15	19:25	1198.3	0.8	1201.6	11/15/15	17:54	1197.5	0.8	1200.8
11/13/15	20:27	1197.5	0.8	1200.8	11/15/15	18:56	1197.5	0.8	1200.8
11/13/15	21:29	1199.1	0.8	1202.4	11/15/15	19:58	1197.5	0.8	1200.8
11/13/15	22:31	1198.3	0.8	1201.6	11/15/15	21:00	1197.5	0.8	1200.8
11/13/15	23:33	1197.5	0.8	1200.8	11/15/15	22:02	1197.5	0.8	1200.8

Table A-2. Transmitted and scattered light signals

Date	Time	Transmitted Light Signal (mV)	Scattered Light Signal (mV)
10/13/2015	8:08:26	980.7	57.2
10/13/2015	9:10:25	1063.7	33.8
10/13/2015	10:12:23	1117.7	19.3
10/13/2015	11:14:20	1142.7	12.9
10/13/2015	12:16:17	1157.2	9.7
10/13/2015	13:18:14	1171.7	7.3
10/13/2015	14:20:10	1178.2	5.6
10/13/2015	15:22:05	1183	4.8
10/13/2015	16:24:00	1194.3	3.2
10/13/2015	17:25:57	1193.5	2.4
10/13/2015	18:27:54	1196.7	2.4
10/13/2015	19:29:52	1196.7	2.4
10/13/2015	20:31:49	1197.5	1.6
10/13/2015	21:33:46	1199.9	1.6
10/13/2015	22:35:45	1199.9	1.6
10/13/2015	23:37:44	1200.7	1.6
10/14/2015	0:39:45	1201.5	1.6
10/14/2015	1:41:44	1199.9	1.6
10/14/2015	2:43:43	1199.9	1.6
10/14/2015	3:45:43	1204	1.6
10/14/2015	4:47:44	1202.3	1.6
10/14/2015	5:49:45	1203.2	1.6
10/14/2015	6:51:46	1202.3	0.8
10/14/2015	7:53:47	1200.7	0.8
10/14/2015	8:55:47	1202.3	1.6
10/14/2015	9:57:46	1200.7	1.6
10/14/2015	10:59:44	1200.7	0.8
10/14/2015	12:01:41	1202.3	0.8
10/14/2015	13:03:38	1204.8	1.6
10/14/2015	14:05:33	1203.2	0.8
10/14/2015	15:07:30	1201.5	0.8
10/14/2015	16:09:27	1200.7	0.8
10/14/2015	17:11:23	1201.5	0.8

Appendix B – Laboratory Data

Table B-1. pH buffer solutions and corresponding pH values

Solution	pH (20.5°C)
50 ml 0.1 M KH phthalate + 22.3 ml 0.1 M HCl, diluted to 100 ml	2.97
0.05 M KH phtalate	4.04
50 ml 0.1 M KH phthalate + 22.6 ml 0.1 M NaOH, diluted to 100 ml	5.07
50 ml 0.1 M KH phthalate + 36.6 ml 0.1 M NaOH, diluted to 100 ml	5.64
50 ml 0.1 M KH phthalate + 42.3 ml 0.1 M NaOH, diluted to 100 ml	5.86
50 ml 0.1 M KH2PO4 + 5.6 ml 0.1 M NaOH, diluted to 100 ml	6.09
50 ml 0.1 M KH2PO4 + 11.6 ml 0.1 M NaOH, diluted to 100 ml	6.5
50 ml 0.1 M KH2PO4 + 22.4 ml 0.1 M NaOH, diluted to 100 ml	6.9
0.025 M KH2PO4 + 0.025 M Na2HPO4	6.99
50 ml 0.1 M KH2PO4 + 34.7 ml 0.1 M NaOH, diluted to 100 ml	7.33
50 ml 0.1 M KH2PO4 + 42.4 ml 0.1 M NaOH, diluted to 100 ml	7.77
50 ml 0.1 M KH2PO4 + 46.1 ml 0.1 M NaOH, diluted to 100 ml	8.14
0.01 M borax	9.25

Table B-2. Absorbance measurements at a Cr(VI) concentration of 100 μg/L.

pH (20.5°C)	Test 1 Abs at 349 nm	Test 2 Abs at 349 nm	Test 3 Abs at 349 nm	Test 1 Abs at 371 nm	Test 2 Abs at 371 nm	Test 3 Abs at 371 nm	Avg Abs at 349 nm	Avg Abs at 371 nm	(Avg Abs at 371 nm - Avg Abs at 349 nm) +1
2.97	-0.005	-0.005	-0.005	-0.005	-0.006	-0.006	-0.005	-0.006	1.001
4.04	-0.003	-0.003	-0.004	-0.005	-0.005	-0.006	-0.003	-0.005	1.002
5.07	-0.003	-0.003	-0.003	-0.004	-0.005	-0.005	-0.003	-0.005	1.002
5.64	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001	-0.002	-0.001	0.999
5.86	0.001	0.001	0.001	0.004	0.004	0.004	0.001	0.004	0.997
6.09	0.001	0.001	0.001	0.005	0.005	0.005	0.001	0.005	0.996
6.5	-0.001	0.001	0.001	0.005	0.007	0.007	0.000	0.006	0.994
6.9	0.001	0.001	0.001	0.009	0.008	0.008	0.001	0.008	0.993
6.99	0.003	0.001	0.002	0.011	0.010	0.010	0.002	0.010	0.992
7.33	0.002	0.002	0.001	0.011	0.011	0.011	0.002	0.011	0.991
7.77	0.000	0.000	0.000	0.011	0.011	0.010	0.000	0.011	0.989
8.14	0.002	0.002	0.002	0.013	0.013	0.013	0.002	0.013	0.989
9.25	0.013	0.009	0.008	0.024	0.021	0.020	0.010	0.022	0.988

Table B-3. Absorbance measurements at a Cr(VI) concentration of 500 μg/L

pH (20.5°C)	Test 1 Abs at 349 nm	Test 2 Abs at 349 nm	Test 3 Abs at 349 nm	Test 1 Abs at 371 nm	Test 2 Abs at 371 nm	Test 3 Abs at 371 nm	Avg Abs at 349 nm	Avg Abs at 371 nm	(Avg Abs at 371 nm - Avg Abs at 349 nm) +1
					500 μg/L Cr(VI)				
2.970	0.025	0.020	0.020	0.015	0.011	0.011	0.022	0.012	1.009
4.040	0.034	0.029	0.028	0.023	0.019	0.018	0.030	0.020	1.010
5.070	0.038	0.030	0.028	0.030	0.022	0.020	0.032	0.024	1.008
5.640	0.041	0.035	0.033	0.039	0.033	0.032	0.036	0.035	1.002
5.860	0.030	0.030	0.028	0.035	0.035	0.034	0.029	0.035	0.995
6.090	0.035	0.033	0.033	0.045	0.043	0.043	0.034	0.044	0.990
6.500	0.041	0.040	0.037	0.063	0.061	0.059	0.039	0.061	0.978
6.900	0.047	0.046	0.045	0.080	0.079	0.078	0.046	0.079	0.967
6.990	0.054	0.053	0.047	0.088	0.088	0.081	0.051	0.086	0.966
7.330	0.047	0.044	0.042	0.087	0.085	0.083	0.044	0.085	0.959
7.770	0.049	0.047	0.047	0.094	0.092	0.092	0.048	0.093	0.955
8.140	0.050	0.047	0.047	0.096	0.092	0.092	0.048	0.093	0.955
9.250	0.052	0.049	0.050	0.098	0.094	0.095	0.050	0.096	0.955

Table B-4. Absorbance measurements at a Cr(VI) concentration of 1,000 μg/L

pH (20.5°C)	Test 1 Abs at 349 nm	Test 2 Abs at 349 nm	Test 3 Abs at 349 nm	Test 1 Abs at 371 nm	Test 2 Abs at 371 nm	Test 3 Abs at 371 nm	Avg Abs at 349 nm	Avg Abs at 371 nm	(Avg Abs at 371 nm - Avg Abs at 349 nm) +1
				1000 μg/L Cr(VI)					
2.970	0.061	0.061	0.061	0.042	0.041	0.041	0.061	0.041	1.020
4.040	0.064	0.063	0.062	0.043	0.043	0.042	0.063	0.043	1.020
5.070	0.062	0.061	0.062	0.048	0.047	0.047	0.062	0.047	1.014
5.640	0.069	0.069	0.068	0.069	0.069	0.068	0.069	0.069	1.000
5.860	0.077	0.076	0.076	0.089	0.088	0.088	0.076	0.088	0.988
6.090	0.078	0.078	0.077	0.098	0.097	0.097	0.078	0.097	0.980
6.500	0.091	0.092	0.091	0.134	0.134	0.133	0.091	0.134	0.958
6.900	0.108	0.107	0.108	0.170	0.170	0.170	0.108	0.170	0.938
6.990	0.103	0.103	0.103	0.173	0.173	0.173	0.103	0.173	0.930
7.330	0.110	0.109	0.109	0.191	0.190	0.190	0.109	0.190	0.919
7.770	0.111	0.111	0.111	0.198	0.198	0.199	0.111	0.198	0.913
8.140	0.112	0.112	0.112	0.201	0.201	0.201	0.112	0.201	0.911
9.250	0.117	0.117	0.115	0.207	0.207	0.206	0.116	0.207	0.910