

ANALYSIS OF A PILOT-SCALE CONSTRUCTED WETLAND TREATMENT SYSTEM
FOR FLUE GAS DESULFURIZATION WASTEWATER

by

MARY KATHERINE TALLEY

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Biological and Agricultural Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:

Major Professor
Stacy L. Hutchinson

Abstract

Coal-fired generation accounts for 45% of the United States electricity and generates harmful emissions, such as sulfur dioxide. With the implementation of Flue Gas Desulfurization (FGD) systems, sulfur dioxide is removed as an air pollutant and becomes a water pollutant. Basic physical/chemical wastewater treatment can be used to treat FGD wastewater, but increased regulations of effluent water quality have created a need for better, more economical wastewater treatment systems, such as constructed wetlands.

At Jeffrey Energy Center, north of St. Mary's, KS, a pilot-scale constructed wetland treatment system (CWTS) was implemented to treat FGD wastewater before releasing the effluent into the Kansas River. The objectives of this study were to 1.) determine if a portable water quality meter could be used to assess water quality and track pollutant concentrations, 2.) develop a water balance of the CTWS, 3.) generate a water use coefficient for the CWTS, and 4.) create a mass balance on the pollutants of concern. Water quality measurements were taken with a HORIBA U-50 Series Multi Water Quality Checker and compared to analytical water tests provided by Continental Analytic Services, Inc. (CAS) (Salina, KS). The water balance was created by comparing inflows and outflows of data determined through flow meters and a Vantage Pro2™ weather station. Information from the on-site weather station was also used to compute the system water use coefficient. Water sampling was conducted from date to date at 10 locations within the CWTS.

In general, there was little to no relationship between the HORIBA water quality measurements and the analytical water tests. Therefore, it was recommended that JEC continue to send water samples on a regular basis to an analytical testing laboratory to assess the CWTS function and track pollutants of concern. Because the water balance was conducted during system initiation, there was a great deal of fluctuation due to problems with the pumping system, issues with the upstream FGD treatment system, extreme weather events, and immature vegetation. This fluctuation resulted in the system having a non-steady state operation, which weakened the ability to calculate a system water use coefficient. However, during periods of strong system function, the water use coefficient was similar to previous studies with maximum water use being approximately equal to the reference evapotranspiration. The results of the mass balance indicated high removals mercury, selenium, and fluoride, but low removals of boron, manganese, chloride, and sulfate were exported from the CWTS.

Table of Contents

List of Figures	vi
List of Tables	x
List of Abbreviations	xi
Chapter 1 - Coal-Fired Generation	1
Chapter 2 - FGD Wastewater Treatment Systems.....	8
Physical/Chemical Processes.....	8
Biological Treatment	10
Zero-Liquid Discharge.....	12
Deep-Well Injection.....	14
Constructed Wetlands	15
Hydrology	18
Evapotranspiration	19
Treatment Performace.....	21
FGD Wastewater.....	22
Research Objectives.....	27
Chapter 3 - Methods and Materials.....	29
Site Description.....	29
Water Quality Measurements.....	46
Weather Data	46
Water Use Coefficient.....	47
System Evapotranspiration	48
Reference Evapotranspiration.....	49
Water Use Coefficient Curve Development	49
Effluent Flow Meter Data	50
Water Sampling	50
Mass Balance of the CWTS.....	51
Chapter 4 - Results and Discussion	52
Water Quality Measurement Results	52

Weather Data and Effluent Flow Meter Results	54
Water Use Coefficient Curve	56
Water Sampling Results.....	62
Mass Balances for Seven Pollutants	62
Boron.....	63
Manganese	66
Mercury.....	70
Selenium	71
Chloride.....	74
Fluoride	77
Sulfate	78
Chapter 5 - Conclusions and Recommendations	84
Recommendations.....	88
References.....	89
Appendix A - Horiba Meter Instruction Manual	95
pH Calibration.....	95
HORIBA Site Selection	97
Data Collection Download for HORIBA.....	97
Appendix B - Weather Data Download Instructions	98
Appendix C - Reference Evapotranspiration	98
ASCE Penman-Montheith Method.....	98
Hargreaves	104
Appendix D - Instructions to Download Effluent Flow Meter Data	104
Appendix E - Water Sampling Instructions	106
Appendix F - Water Quality Measurements	109
Water Quality Measurement Data	109
Water Quality Measurement Results	118
Temperature	118
pH.....	126
ORP.....	134
Conductivity.....	140

Turbidity	147
DO	154
TDS	161
Salinity	168
Appendix G - The Water Balance.....	176
Appendix H - Water Use Coefficient Curve Data	190
Appendix I - The Mass Balance.....	239
Boron	262
Manganese	264
Mercury.....	266
Selenium	270
Chloride	272
Fluoride.....	274
Sulfate	278

List of Figures

Figure 1.1. National nitrogen oxides annual emissions by source sector in 2008. Chart taken from US EPA 2012	2
Figure 1.2. Kansas annual nitrogen oxides annual emissions by source sector in 2008. Chart taken from US EPA 2012	3
Figure 1.3. National sulfur dioxide annual emissions by source sector in 2008. Chart taken from US EPA 2012	3
Figure 1.4. Kansas sulfur dioxide annual emissions by source sector. Chart taken from US EPA 2012.....	4
Figure 1.5. Process flow diagram for a Limestone Forced Oxidation FGD System. Figure derived from US EPA 2009	5
Figure 2.1. Individual components for a wetland water budget. Figure derived from Kadlec and Knight 1996	19
Figure 2.2. Crop coefficient curve. Figure derived from Allen <i>et al.</i> 1998	20
Figure 2.3. Example of a wetland water use coefficient curve for two wetland sites in Utah and Florida. Figure derived from Kadlec 1989.....	21
Figure 3.1. Climograph for Jeffrey Energy Center with monthly averages of precipitation, maximum temperature and minimum temperature from 1981 to 2010, and pan evaporation from 1971-2000. Information taken from PRISM Climate Group and National Weather Service (Oregon State University, 2012; NOAA/National Weather Service, 2005)	30
Figure 3.2. Blueprint of the CWTS at JEC including all 8 wetland cells (Burns & McDonnell, 2012).	32
Figure 3.3. Vantage Pro2™ weather station located at the CWTS at JEC to collect hourly weather data.	47
Figure 3.4. Basic schematic of a water balance for the CWTS at JEC.....	49
Figure 4.1. 2011 weekly influent (RAW, FGDWW, and Precipitation) and effluent (LS) water amounts entering and leaving the CWTS at JEC.....	55
Figure 4.2. 2012 weekly influent (RAW, FGDWW, and Precipitation) and effluent (LS) water amounts from the CWTS at JEC.....	56

Figure 4.3. Three week running average of system ET (ET_{sys}), reference ET (ET_o), and water use coefficient (K_c), with ET values plotted against the primary y-axis and water use coefficient values plotted against the secondary y-axis for each DOY starting on 3/10/2011 (steady-state) to 5/12/2012. ET_o was determined using the ASCE-Penman Monteith method.....	57
Figure 4.4. Three week running average of system ET (ET_{sys}), reference ET (ET_o), and water use coefficient (K_c), with ET values plotted against the primary y-axis and water use coefficient values plotted against the secondary y-axis for each DOY starting on 3/10/2011 (steady-state) to 5/12/2012. ET_o was determined using the Hargreaves method.	58
Figure 4.5. Water use coefficients from Utah, Florida, and Jeffrey Energy Center are compared from 3/10/2011 (steady-state) to 5/12/2012. Estimated water use coefficients are shown in the dotted line. ET_o determined using the ASCE Penman-Monteith method.....	59
Figure 4.6. Water use coefficients from Utah, Florida, and Jeffrey Energy Center are compared from 3/10/2011 (steady-state) to 5/12/2012. Estimated water use coefficients are shown in the dotted line. ET_o was determined using the Hargreaves method.....	60
Figure 4.7. Proposed water use coefficient for JEC from 0.45 to 1.10 mm/mm using a ASCE Penman-Monteith ET_o	62
Figure 4.8. Weekly total boron mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	63
Figure 4.9. Weekly total boron mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.....	64
Figure 4.10. The running total of input and output for the mass of boron for all weeks the CWTS was being researched.	65
Figure 4.11. Weekly total manganese mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	67

Figure 4.12. Weekly total manganese mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	68
Figure 4.13. The running total of input and output for the mass of manganese for all weeks the CWTS was being researched.	69
Figure 4.14. The running total of input and output for the mass of mercury for all weeks the CWTS was being researched.	70
Figure 4.15. Weekly total selenium mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	71
Figure 4.16. Weekly total selenium mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	72
Figure 4.17. The running total of input and output for the mass of selenium for all weeks the CWTS was being researched.	73
Figure 4.18. Weekly total chloride mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	74
Figure 4.19. Weekly total chloride mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.	75
Figure 4.20. The running total of input and output for the mass of chloride for all weeks the CWTS was being researched.	76
Figure 4.21. The running total of input and output for the mass of fluoride for all weeks the CWTS was being researched.	77

Figure 4.22. Weekly total sulfate mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is beyond a one-hundred value, either positive or negative, unless stated otherwise.	79
Figure 4.23. Weekly total sulfate mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is beyond a one-hundred value, either positive or negative, unless stated otherwise.	80
Figure 4.24. The running total of input and output for the mass of sulfate for all weeks the CWTS was being researched.	81

List of Tables

Table 1.1. Historical NAAQS for nitrogen oxides from 1971 to 2010. Table taken from US EPA 2012.....	4
Table 1.2 Historical NAAQS for sulfur dioxide from 1971 to 2012. Table taken from US EPA 2012.....	4
Table 3.1. Each wetland cell based on cell type and number, vegetation, soil structure, and storage capacity. Information collected from Burns & McDonnell et al. 2011 and Morrison et al. 2011.....	31
Table 4.1. The R^2 values for each water quality measurement (dependent variable) compared to each pollutant (independent variable) provide a goodness of fit of the model, in which values of 1 would indicate the regression line produced from the graphs in Appendix F would perfectly fit the data provided. Below, R^2 values shown in red indicate the best R^2 values, or the best goodness of fit for that model.	53
Table 5.1. KDHE water quality standards compared to each of the seven pollutants average concentration exiting the pilot-scale CWTS at JEC in $\mu\text{g/L}$. Table taken from KDHE 2004	86
Table 5.2. Estimated full-scale CWTS concentrations of each pollutant entering the Kansas River based on the lowest, highest, and average flow rates over the past 75 years for the Kansas River. The Kansas River had a low, high, and average flow over the past 75 years of 1.24×10^7 L/d, 1.44×10^9 L/d, and 3.84×10^8 L/d, which were used to determine change in concentration of pollutant affecting the Kansas River in Topeka (USGS, 2012).....	87

List of Abbreviations

Δ WS	Change in Water Storage
ABMet	GE Water & Technology ABMET Biological Treatment
AD-1	Agri-Drain 1
AD-2	Agri-Drain 2
AD-3	Agri-Drain 3
AD-4	Agri-Drain 4
AD-5	Agri-Drain 5
AD-6	Agri-Drain 6
AD-7	Agri-Drain 7
AD-8	Agri-Drain 8
ASCE	American Society of Civil Engineers
B	Boron
BOD	Biological Oxygen Demand
CAS	Continental Analytical Services, Inc.
Cl^-	Chloride
COC	Chain of Custody
COD	Chemical Oxygen Demand
CTBD	Cooling Tower Blow Down
CWTS	Constructed Wetland Treatment System
DO	Dissolved Oxygen
DOY	Day of Year
EPA	Environmental Protection Agency
ET	Evapotranspiration
ET_0	Reference Evapotranspiration
ET_{sys}	System Evapotranspiration
F^-	Fluoride
FGD	Flue Gas Desulfurization
FGDWW	Flue Gas Desulfurization Wastewater
FWS	Free Water Surface

GAC	Granular Activated Carbon
GPD.....	Gallons per Day
Hg.....	Mercury
HSSF	Horizontal Subsurface Flow
I	Infiltration
JEC.....	Jeffrey Energy Center
K _c	Crop Coefficient/Water Use Coefficient
KDHE	Kansas Department of Health and Environment
LS	Lift Station
Mn.....	Manganese
MPD.....	Million Gallons per Day
NAAQS.....	National Ambient Air Quality Standards
NPDES	National Pollutant Discharge Elimination System
ORP	Oxidation/Reduction Potential
P	Precipitation
ppb.....	Parts per Billion
ppm	Parts per Million
ppt	Parts per Trillion
Q _{in}	Volumetric Inflow
Q _{out}	Volumetric Outflow
RAW	Makeup Lake Water
S	Seepage
SB.....	Splitter Box
Se.....	Selenium
SBR	Sequencing Batch Reactors
SO ₄ ⁻²	Sulfate
TDS	Total Dissolved Solids
TSS.....	Total Suspended Solids
VF	Vertical Flow
WS _i	Initial Water Storage
WS _{i+1}	Water Storage at Time (i+1)

WW_{in} Wastewater Inflow
 WW_{out} Wastewater Outflow
ZLD..... Zero Liquid Discharge

Chapter 1 - Coal-Fired Generation

According to the U.S. Energy Information Administration, coal-fired generation accounts for 45% of the electricity generated in the United States. Coal is a relatively low cost fossil fuel and is quite abundant throughout the United States. Based on current consumption levels, there is enough coal to last more than 200 years (U.S. Energy Information Administration, 2011). Because of this, the United States has more than 600 operating coal-fired generation power plants across the country, resulting in the consumption of “one billion short tons of coal per year” (U.S. Energy Information Administration, 2011). While coal is abundant and low cost, there are many environmental disadvantages including harmful emissions into the atmosphere (e.g. sulfur dioxide, nitrogen oxides, and mercury) that can result in acid rain, smog, and health issues.

In order to reduce harmful emissions, the Clean Air Act was established in 1970 as a “comprehensive federal law that regulates air emissions from stationary and mobile sources”, authorizing the EPA to establish National Ambient Air Quality Standards (NAAQS) “to protect public health and welfare and to regulate emissions of hazardous air pollutants” (US EPA, 2012). The Clean Air Act recognizes two types of national ambient air quality standards, including: (1) primary standards, which “provide public health protection, including protecting the health of ‘sensitive’ populations such as asthmatics, children, and the elderly, and (2) secondary standards, which “provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings” (US EPA, 2012). National ambient air quality standards were set by the EPA for six pollutants, including carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide, in which coal-fired generation emits both nitrogen oxides and sulfur dioxides (US EPA, 2012).

The first major source for nitrogen oxides is mobile sources (automobiles) and the second major source is fuel combustion (i.e. power plants) (Figure 1.1) Within Kansas, about half of nitrogen oxides comes from mobile sources, while the remaining half comes from fuel combustion (Figure 1.2). For sulfur dioxides, the major source, for both the nation and Kansas, is fuel combustion (Figure 1.3; Figure 1.4). Both of these emissions have been connected to increased respiratory effects in humans, including airway inflammation, increased respiratory

symptoms in asthmatics, and bronchoconstriction (US EPA 2012); therefore, primary and secondary standards were set for both criteria pollutants (Table 1.1; Table 1.2).

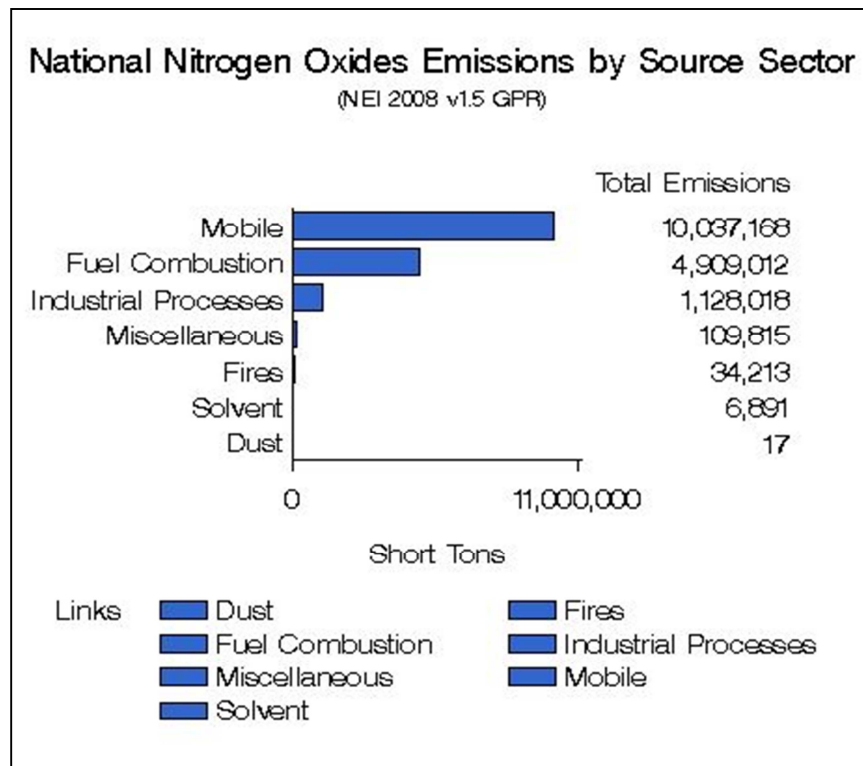


Figure 1.1. National nitrogen oxides annual emissions by source sector in 2008. Chart taken from US EPA 2012

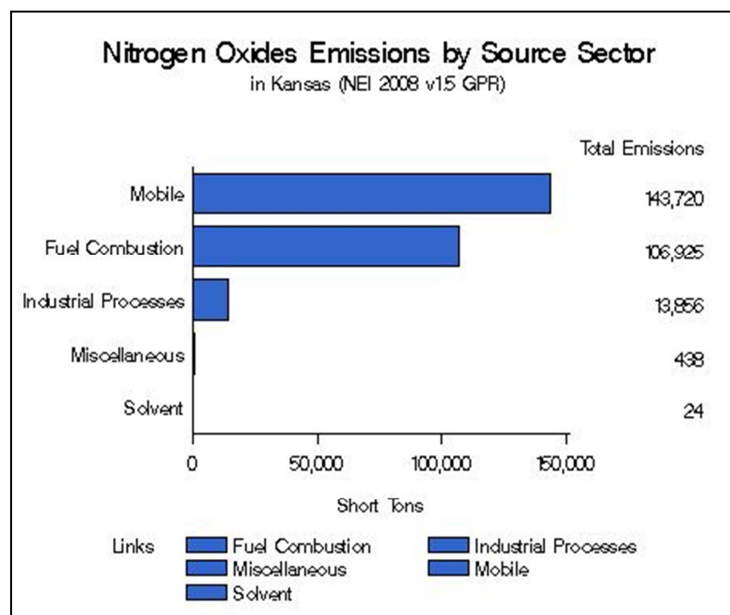


Figure 1.2. Kansas annual nitrogen oxides annual emissions by source sector in 2008. Chart taken from US EPA 2012

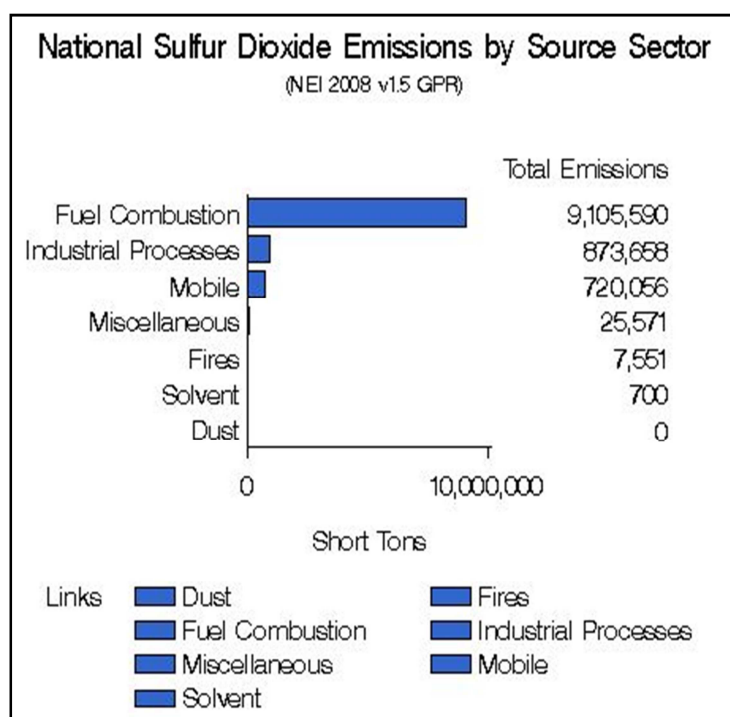


Figure 1.3. National sulfur dioxide annual emissions by source sector in 2008. Chart taken from US EPA 2012

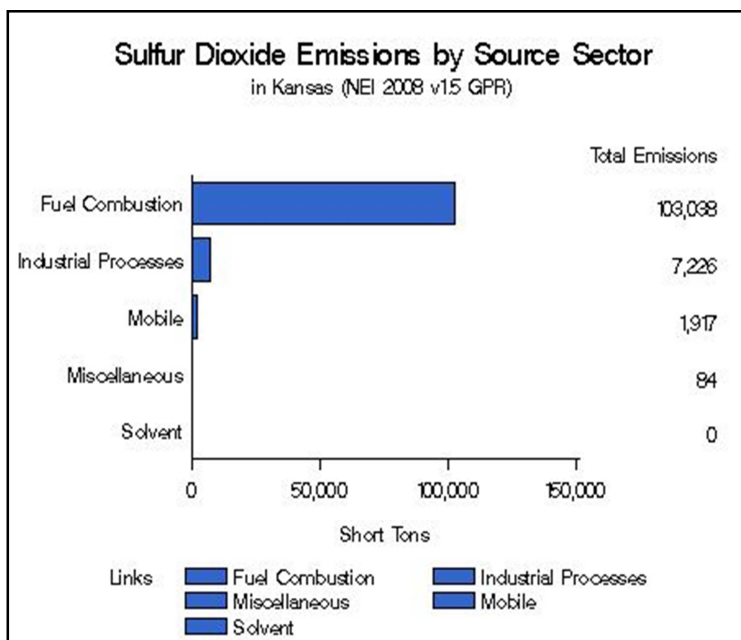


Figure 1.4. Kansas sulfur dioxide annual emissions by source sector. Chart taken from US EPA 2012

Table 1.1. Historical NAAQS for nitrogen oxides from 1971 to 2010. Table taken from US EPA 2012

Year	Primary/Secondary	Averaging Time	Level	Form
1971	Primary/Secondary	Annual	53 ppb	Annual arithmetic average
2010	Primary	1-Hour	100 ppb	98 th percentile, average over 3 years
	Primary	Annual	53 ppb	Annual arithmetic average

Table 1.2 Historical NAAQS for sulfur dioxide from 1971 to 2012. Table taken from US EPA 2012

Year	Primary/Secondary	Averaging Time	Level	Form
1971	Primary	24-Hour Annual	0.14 ppm 0.03 ppm	Not to be exceeded more than once per year Annual arithmetic average
	Secondary	3-Hour Annual	0.50 ppm 0.02 ppm	Not to be exceeded more than once per year Annual arithmetic average
1973	Secondary	3-Hour Annual	0.50 ppm Revoked	Not to be exceeded more than once per year N/A
2010	Primary	1-Hour	75 ppb	99 th percentile, averaged over 3 years
		24-Hour	Revoked	N/A
		Annual	Revoked	N/A

The new emissions' standards have resulted in huge reductions in criteria pollutants across the nation. Starting in 1980, the national nitrogen oxide emissions have been reduced by 52%, while sulfur dioxide emissions have been reduced nationally by 83%. These criteria pollutants were greatly reduced as a result of increased process and regulation equipment specifically designed to target these pollutants. For example, in coal-fired generation, the implementation of flue gas desulfurization systems, or FGD systems have decreased the amount of sulfur dioxides tremendously. Flue gas desulfurization systems release a liquid stream through scrubbers containing a sorbent, typically lime ($\text{Ca}(\text{OH})_2$) or limestone (CaCO_3) (Figure 1.5) (US EPA, 2009). When the flue gas comes in contact with the sorbent, the sorbents react with the sulfur found in the flue gas to form calcium sulfite (CaSO_3), which is further oxidized to calcium sulfate (CaSO_4) within the reaction tank (US EPA, 2009; Srivastava *et al.*, 2001). By applying the sorbent to the flue gas, clean flue gas is released through smoke stacks, while the scrubber blowdown is transferred to a solids separation tank, where finer and heavier solids are separated. The heavy solids are dewatered and landfilled, while the finer solids go into a purge tank, which is later sent to wastewater treatment. By using FGD systems, sulfur dioxide, along with other pollutants found in flue gas, is removed from the air at the expense of water.

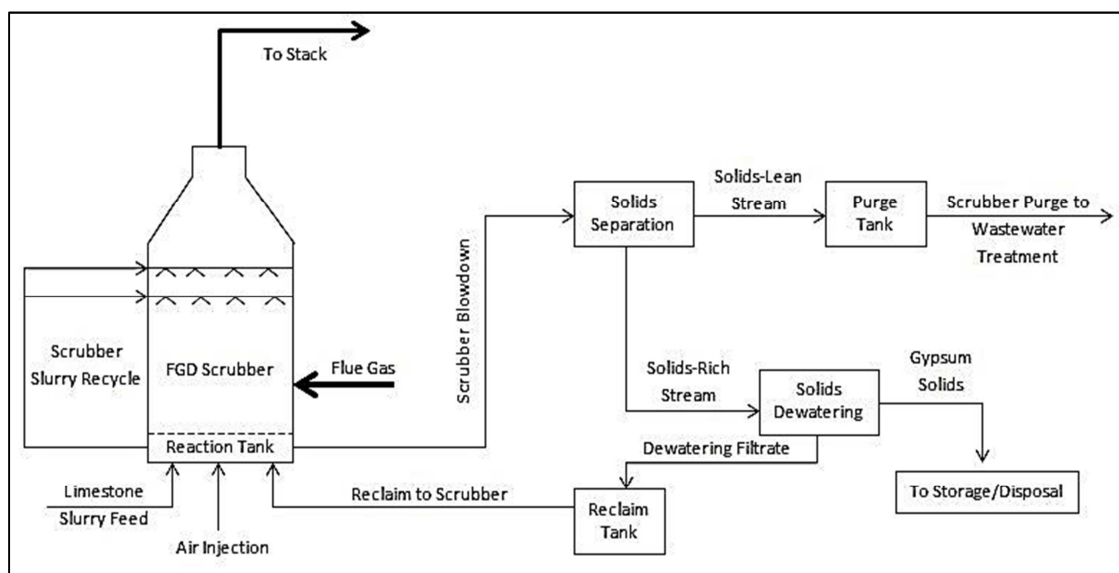


Figure 1.5. Process flow diagram for a Limestone Forced Oxidation FGD System. Figure derived from US EPA 2009

With an increased number of FGD systems, the amount of air pollutants emitted into the atmosphere have been greatly decreased, especially sulfur dioxide; however, a decrease in air pollution results in an increase in water pollution. Recently, the news has made an impact on the reality of FGD systems. For example, in 2009, New York Times journalist, Charles Duhigg, wrote *Cleansing the Air at the Expense of Waters*, which discussed a coal-fired power plant in southwest Pennsylvania that was dumping wastewater from the FGD process into the Monongahela River (Duhigg, 2009). Duhigg states, “even as a growing number of coal-burning power plants around the nation have moved to reduce their air emissions, many of them are creating another problem: water pollution” (Duhigg, 2009).

In 2008, Hatfield’s Ferry, a coal-fired power plant located in southwest Pennsylvania, asked the state of Pennsylvania permission to “dump scrubber wastewater into the Monongahela River, which the Pennsylvania Department of Environmental Protection approved, but with limits on certain chemicals” (Duhigg, 2009). However, no limits were set on chemicals like arsenic, aluminum, boron, chromium, manganese, nickel and other chemicals, which have all been detected in Hatfield’s Ferry scrubber wastewater (Duhigg, 2009). Officials from Hatfield’s Ferry say residents using the water from Monongahela River should not be concerned because the plant has “installed a \$25 million water treatment plant that removes many of the toxic particles and solids from scrubber wastewater” and the solids are placed into a landfill with a synthetic line to prevent leaking (Duhigg, 2009). With the controversy occurring at Hatfield’s Ferry, the US EPA planned to revise the current standards for water discharges from coal-fired generation power plants similar Hatfield’s Ferry.

Along with Hatfield’s Ferry, many other coal-fired generation plants have been targeted as health and environmental dangers by converting their waste from air pollution to water pollution. In Indiana, one of the world’s largest coal-fired power plants uses a manmade lake (Gibson Lake) to hold its wastewater (Coefield, 2009). This wastewater lake contains high levels of selenium that are threatening the local bird and fish populations; therefore, the US EPA plans to reevaluate the current industry wastewater regulations, because according to the US EPA, “current regulations have not kept pace with changes that have occurred in the electric power industry over the last three decades” (Coefield, 2009).

With an increasing interest from the media and public as well as increasing environmental regulations, more research is needed to assist with the development and implementation of new technologies to minimize the effects of environmental issues resulting from clean air at the expense of water.

Chapter 2 - FGD Wastewater Treatment Systems

Currently, the US EPA is working to set new regulations on coal-fired generation wastewater, which will require more than 600 coal-fired generation power plants in the United States to install new FGD wastewater treatment technologies. To help coal-fired generation power plants treat FGD wastewater more efficiently, a report presented by the US EPA (2009), *Steam Electric Power Generating Point Source Category: Final Detailed Study Report*, discussed many different FGD wastewater treatment approaches, including: physical/chemical processes, biological treatment, zero-liquid discharge, deep-well injection, and constructed wetlands.

Physical/Chemical Processes

Physical/chemical processes are the most commonly used methods for treating FGD wastewater, with 15 systems currently in use since 2004, and another 25 to be installed in the United States (Chapman *et al.*, 2007; Riffe *et al.*, 2008). Physical/chemical processes are treatment methods used to reduce the amount of total suspended solids, adjust pH, desupersaturate the purge stream, and reduce heavy metals (Riffe *et al.*, 2008). Physical/chemical processes can differ in the equipment that is used in the treatment system based on differing FGD wastewater composition and flowrate, which depends on many factors including the coal burn rate, coal composition, and plant design (Riffe *et al.*, 2008).

The first step of the physical/chemical treatment system is the equalization tank, which is used to reduce the flowrate and alter the chemistry of the wastewater (Wylie *et al.*, 2008). Next, the wastewater is pumped to reaction tank #1 (RX1) where alkali (hydrated lime) is added to adjust pH to values ranging between 8.5—9.2 and force gypsum desupersaturation (Wylie *et al.*, 2008). The pH adjustment is used to enhance the efficiency of the other chemicals added to the physical/chemical process for precipitating heavy metals (Riffe *et al.*, 2008). The alkali added in RX1 also allows for the precipitation of heavy metals, such as aluminum, iron and manganese as metal hydroxides (Riffe *et al.*, 2008). Recycled sludge from the clarifier is added to RX1 to promote crystal growth of gypsum reducing scale formation on downstream equipment (Wylie *et al.*, 2008).

From RX1, wastewater is moved to reaction tank #2, or RX2, where organosulfide is added to the tank to precipitate excess heavy metals from RX1 (Riffe *et al.*, 2008). The wastewater is then moved from RX2 to reaction tank #3, or RX3, where enhanced coagulation occurs through the addition of an iron salt, such as ferric chloride (Wylie *et al.*, 2008). By adding the iron salt, denser flocs will form, improving the clarifier performance. Also, iron salt co-precipitates other metals, non-metals, and organic matter (Riffe *et al.*, 2008). Reaction tank #3 is the last reaction tank that the wastewater goes through before entering the clarifier.

A polymer is added to the wastewater before the clarifier to help coagulation and solid settling within the clarifier (Riffe *et al.*, 2008). After clarification, the treated wastewater continues to a gravity filter if a low suspended solids level is required, in which the filter further removes and reduces any total suspended solids (TSS) and metals before discharge (Wylie *et al.*, 2008; Riffe *et al.*, 2008). Depending on discharge requirements of the plant, the treated effluent may discharge into another treatment process from the gravity filter, or be discharged to the nearest receiving body of water (Wylie *et al.*, 2008).

The backwash from the gravity filter is recycled back to the equalization tank for reprocessing (Wylie *et al.*, 2008). The sludge from the clarifier contains gypsum and stable and precipitated metals with about 15 to 20% solids by weight; therefore, the sludge is pumped into a sludge holding tank before being dewatered in a filter press (Wylie *et al.*, 2008). Once through the filter press, a “filter cake” is disposed of in non-hazardous lined landfills, either onsite or offsite (Riffe *et al.*, 2008).

With this typical physical/chemical treatment system, adjustments can be applied to the system as necessary for the coal-fired generation plant. Depending on the discharge requirements of the plant, additional treatment may be required after the physical/chemical treatment system (Riffe *et al.*, 2008). Discharge requirements may include state and regional requirements that limit certain pollutants within the discharge. For example, the Chesapeake Bay Initiative limits total nitrogen in the treated effluent (Riffe *et al.*, 2008). In North Carolina, selenium is limited on certain water bodies, while organic load, such as chemical oxygen demand and biological oxygen demand (COD/BOD), is limited in other states. Currently, no information was found about the average FGD water quality output; therefore, more research needs to be

conducted on the performance of physical/chemical treatment systems and their average water quality output.

Biological Treatment

Biological treatment processes can be broken down into aerobic and anaerobic processes that are used to reduce biological oxygen demand (BOD) and heavy metals present in FGD wastewater (Chapman *et al.*, 2007). According to the US EPA (2009), aerobic biological treatment processes remove BOD, while anoxic/anaerobic biological systems remove metals and nutrients. With both biological treatment processes, either fixed film or suspended growth bioreactors can be used and operated as either conventional flow-through or as sequencing batch reactors (SBRs) (US EPA, 2009).

GE Water & Process Technologies' ABMet biological treatment is a popular biological treatment system that reduces selenium concentrations by more than 99%, reducing concentrations to less than 0.010 ppm (Pickett *et al.*, 2006). Besides selenium, ABMet has been shown to reduce other toxic metals, including mercury removal to concentrations of 150 ppt, arsenic to concentrations of 10 ppb, and total nitrogen to concentrations of 10 ppm (Pickett *et al.*, 2006). Pickett *et al.* (2006) states that four ABMet projects were being designed and installed into coal-fired generation plants in the southeastern United States as of 2007, with flow rates ranging from 190,000 gallons per day (GPD) to 2 million gallons per day (MGD); however, despite the range of flow rates, ABMet is capable of being scaled to treat any FGD wastewater discharge rate. Compared to other FGD wastewater treatment processes, ABMet is less complex, has minimal sludge production, negligible chemical addition, low power requirement, small plant foot print, and scalability to meet site demands (Pickett *et al.*, 2006).

Before implementation into a coal-fired generation plant, ABMet is designed, based on the target metals and inorganic compounds that need to be removed and best retention time to remove these pollutants (Pickett *et al.*, 2006). The GE ABMet biological treatment process consists of “a series of bioreactors, each containing a bed of granular activated carbon (GAC) inoculated with site-specific bacteria to handle the waste stream” (Pickett *et al.*, 2006). The GAC is an ideal growing medium for bacteria, because it has a large, irregular surface that

allows biomass to accommodate (Pickett *et al.*, 2006). Likewise, GAC creates a biological film by “fixing” microorganisms, allowing biomass to retain and precipitate contaminants to maintain a stable operation (Pickett *et al.*, 2006). The wastewater is introduced into the bioreactors, moving over the GAC and microorganisms with minimal axial mixing that approaches plug flow, (Pickett *et al.*, 2006). Plug flow ensures constant wastewater velocity, eliminates any mixing within the bioreactor, and allows operators to control the biological process easily (Pickett *et al.*, 2006).

The microorganisms must stay on the GAC in order to decrease redox potential within the carbon beds, creating multiple zones within the bioreactor capable of reducing several contaminants, such as nutrients including nitrate and selenium (Pickett *et al.*, 2006). Typically, nitrate is reduced to nitrogen gas, which is released into the atmosphere, at the entrance of the bioreactor (Pickett *et al.*, 2006). Because selenium is reduced from an oxidized state, it is sorbed to the growth media and later removed. Besides nitrate and selenium removal, other metals, such as zinc, copper, nickel, lead, and other primary metals, form metal complexes with sulfide and precipitate out of the wastewater and stay inside the bioreactor (Pickett *et al.*, 2006). After the first bioreactor, the treated wastewater is fed into another bioreactor and depending on the site, the treated wastewater might go through several bioreactors in order to achieve contaminant removal levels (Pickett *et al.*, 2006). The carbon beds inside all the bioreactors must be flushed occasionally to remove total suspended solids, biomass, and inorganic contaminants that were converted to solid forms within the bioreactors (Pickett *et al.*, 2006).

A full scale GE ABMet biological treatment system was implemented to remove selenium from FGD wastewaters at Progress Energy’s Roxboro Station outside of Roxboro, NC approximately 75 miles away from Raleigh, NC (Sonstegard *et al.*, 2008). Before entering the full scale GE ABMet biological treatment system, the FGD wastewater is placed in a settling pond to settle out suspended solids (Sonstegard *et al.*, 2008). Roxboro Station’s ABMet biological treatment system consists of four parallel bioreactor trains each with two identical bioreactors. After the water is sent to the first bioreactor, it continues to the second bioreactor, and ends at an ash pond discharge canal (Sonstegard *et al.*, 2008). FGD wastewater was fed into the ABMet biological treatment system, and by week 5 of operation, the effluent selenium concentration was below design requirements (Sonstegard *et al.*, 2008). By June 2008, the

average removal of selenium was 99.3%, with an average incoming selenium concentration of 1,500 µg/L and a final selenium concentration less than 10 µg/L (Sonstegard *et al.*, 2008).

In 2002, Duke Energy-Carolinas installed biological treatment systems for Belews Creek and Allen Station FGD wastewater (McCarthy *et al.*, 2006). Belews Creek Station is located near Walnut Cove, NC and is currently the largest coal-fired generation plant operated by Duke Energy-Carolinas (McCarthy *et al.*, 2006). Selenium and mercury were the key contaminants that needed to be reduced before discharging into the Dan River. A biological treatment system consisting of an anoxic/anaerobic, fixed-film, biological filter system (similar to ABMet), was used for selenium removal (Wylie *et al.*, 2008; McCarthy *et al.*, 2006). The goal of the Belews Creek Station FGD wastewater treatment system was to reduce selenium concentrations to an average of 26 µg/L and mercury to 63 µg/L (McCarthy, 2006). According to Wylie *et al.* (2008), the average FGD wastewater contained 5,300 µg/L of selenium, which was reduced to 13 µg/L after the biological treatment system. This was an overall selenium removal of 99.8% (Wylie *et al.*, 2008). Mercury concentrations reduced from 85 µg/L to detect ion limits of 1 µg/L after biological treatment system, an overall removal of 98.8% (Wylie *et al.*, 2008).

Zero-Liquid Discharge

Zero-liquid discharge (ZLD) systems are another possible treatment method for FGD wastewaters. In ZLD systems there is no liquid waste because dissolved species are completely separated from the water, producing a solid that is disposed of in a land fill (Shaw, 2008). ZLD systems are primarily used for treating cooling tower blow down (CTBD), which have a different water chemistry compared to FGD systems (Table 2.1) (Mittal and Hoskin, 2006). Because of the significant differences between these two wastewaters, like high levels of hardness as a result of chlorides and total dissolved solids (TDS), the design of a basic ZLD system changes into two separate processes that are capable of evaporating FGD wastewater, both with advantages and disadvantages (Mittal and Hoskin, 2006; Nicholson, 2007).

Table 2.1. Comparison of wastewater from CTBD vs. FGD. Table taken from Mittal and Hoskin 2006

Constituent in mg/L	Typical CTBD Waste	Typical FGD Waste
Calcium, Ca	300	6,000
Magnesium, Mg	80	2,000
Sodium, Na	900	2,000
Chloride, Cl	1,100	20,000
Sulfate, SO ₄	1,500	2,500
Silica, SiO ₂	150	50
Total Dissolved Solids	4,000	35,000

The first ZLD system used for FGD wastewater evaporation is a Direct Feed Configuration. In the Direct Feed configuration, wastewater is directly taken from the FGD system and sent to a brine concentrator where it is pre-concentrated (Mandigo, 2007). The purpose of the brine concentrator is to reduce the wastewater volume through evaporation and remove calcium in units operating in a seeded slurry mode (Mittal and Hoskin, 2006). The brine concentrator separates the brine from the wastewater and continues to the spray dryer (Mandigo, 2007). The spray dryer evaporates the water from the wastewater and the moist air is discharged into the atmosphere (Mandigo, 2007). By evaporating the water, dry solids form and are recovered using a bag filter, then taken off-site for disposal (Mittal and Hoskin, 2006; Mandigo, 2007).

The second ZLD system used for FGD wastewater evaporation is a Softened Feed Configuration (Mandigo, 2007). Instead of directly taking the FGD wastewater to a brine concentrator, a Softened Feed Configuration takes the FGD wastewater through a physical/chemical pretreatment step, which might include the following steps: limesoda softening, sulfide precipitation, aerobic and anaerobic biological treatment (Mandigo, 2007). This pretreatment step can be designed to remove different impurities like heavy metals and dibasic acid; however, the most important step of the overall ZLD system, is to reduce hard calcium and magnesium cations for soft sodium cations, similar to the sodium cations found in CTBD wastewater (Mandigo, 2007). After the physical/chemical pretreatment step, the softened feedwater is pre-concentrated in the brine concentrator and the water is recovered with a forced-circulation type crystallizer (Mandigo, 2007). The crystallizer reduces the wastewater volume

through evaporation and removes salts through precipitation and crystallization. The salts are later removed through a de-watering unit and trucked offsite for proper disposal (Mittal and Hoskin, 2006).

ZLD systems have shown great success for industrial wastes, specifically cooling tower blow down wastewater; however, FGD wastewater is a new and different waste stream that ZLD systems could be used for. Currently, minimal data was found for FGD wastewater treatment using ZLD systems, which could be due to the lack of information over how the ZLD system will work with FGD wastewater, as well as the initial expensive cost of ZLD systems.

Deep-Well Injection

Deep-well injection has also been considered as a treatment option for FGD wastewaters. However, it is not a treatment system, but rather a long-term storage or disposal mechanism (Tofflemire and Brezner, 1970). Tofflemire and Brezner (1970) state that deep-well injection is a disposal method for only certain wastes, in which the waste is pumped into a permeable disposal zone bounded above and below by impermeable rocks. There are three types of wastes that can use deep-well injection as a treatment system including: salt disposal, industrial waste disposal, and radioactive waste disposal (Tofflemire and Brezner, 1970); however, little research is currently being conducted on the use of deep-well injection as a possible way to dispose of FGD wastewaters. The most researched deep-well injection waste is salt water from oil field or salt-mining operations, which could be used as a reference for the disposal of FGD wastewater due to similarities in high salt content. Oil field waste occurs when the oil from an oil-salt mixture is removed from a production well, and the salt water is returned to a disposal well (Tofflemire and Brezner, 1970). Salt water has low toxicity and is typically injected into areas of low pressure, such as permeable or cavernous formations, where fewer precautions are taken compared to industrial wastes (Tofflemire and Brezner, 1970).

There are advantages and disadvantages to deep-well injection. Some advantages of deep-well injection include: (i) waste is removed from surface waters, (ii) can be economical and require minimal land, (iii) has been used successfully for over 40,000 salt brine disposal wells throughout the United States, and (iv) “solves” the surface treatment problem (Tofflemire and

Brezner, 1970). Despite these advantages, deep-well injection also poses serious disadvantages including: (i) increased risk for fresh water pollution through well failure and geological faults,, (ii) limited knowledge over the long-term geological effects of the injection and location of waste, (iii) any adverse effects may be difficult to determine and correct, and (iv) limited by type and volume of waste (Tofflemire and Brezner, 1970). Other factors, including geology, wastewater characteristics and pretreatment, well construction, and well operation and monitoring, must be considered as well to ensure deep-well injection is the best removal for the waste (Tofflemire and Brezner, 1970).

Despite the fact that deep-well injection has been limited to only three types of wastewater, currently, some research is being conducted to approve deep-well injection as a possible disposal of FGD wastewater. At the International Water Conference in 2007, Rick Cleveland and Jim Mezo from Duke Energy presented the paper, *FGD Wastewater Disposed of via Deep-Well Injection at Duke Energy's Gibson Generating Station*, which discusses the FGD wastewater removal at one of Duke Energy's sites located in Owensville, Indiana. Duke Energy's Gibson Generating Station uses deep-well injection to dispose of FGD wastewater generated from three separate FGD systems.

The biggest concern for Duke Energy and the Gibson Generation Station was the ability of the wells to continuously accept flow over time where the rock strata must not become clogged by suspended solids or mineral scale deposits. Tests and computer modeling were conducted to determine the tendency of scale formation under current conditions of the deep-well injection site; however, there are no other deep-well injection sites used for removing FGD wastewater to compare results to and make changes as necessary. Currently, no new information has been found stating the success or failure of FGD wastewater deep-well injection sites located at Gibson Generation Station.

Constructed Wetlands

Since the 1950's, both natural and constructed wetlands have been used for water purification and wastewater treatment (Verhoeven and Meuleman, 1998). These wetlands often use large helophytes, which are herbaceous plants where only the buds survive during extreme

conditions, including *Phragmites australis* (Common Reed), *Typha spp.* (Cattail), and *Scirpus spp.* (Bull Rush) (Verhoeven and Meuleman, 1998). There are several characteristics that make wetland ecosystems suitable for wastewater purification, (1) wetland ecosystems are semi-aquatic systems that contain large quantities of water, (2) wetland ecosystems have oxic and anoxic soils where organic matter is broken down, (3) wetland ecosystems support vegetation that is highly productive and capable of taking up large amounts of nutrients (Verhoeven and Meuleman, 1999).

According to Verhoeven and Meuleman (1999), constructed wetlands are better at treating wastewater compared to natural wetlands, because they are designed for maximum performance of the BOD, COD and nutrient removal processes and for overall control of hydraulic and vegetation management. There are three primary constructed wetlands overall using either surface or subsurface flow as a treatment technology, including: (i) free water surface (FWS) wetlands, where there are areas of open water similar to natural wetlands; (ii) horizontal subsurface flow (HSSF) wetlands, which use a planted wetland vegetation in a gravel bed and the water flows horizontally across the bed; (iii) vertical flow (VF) wetlands, where water is distributed across wetland vegetation planted in a sand or gravel bed, in which the water is treated as it percolates through the plant root zone (Kadlec and Wallace, 2009). These three types of constructed wetland have been used throughout history to remediate multiple waste streams including domestic and municipal wastewater, animal and industrial wastes, urban and agricultural stormwaters, mine waters, groundwater remediation, and other application, all over the world from North America, Europe, and in developing countries (Kadlec and Wallace, 2009; NCASI 2004; Knight *et al.*, 2000; Knight *et al.*, 1997; Kleinman and Hedin, 1989; Wieder, 1989).

Regardless of which wetland type is used, wetlands perform well for COD, BOD, and bacterial pollution removal; however, nutrient removal is limited. COD and BOD have high removal rates due to sedimentation of suspended solids and rapid decomposition processes in the water and the upper soil layers (Verhoeven and Meuleman, 1999). There are several different soil redox and soil acidity conditions that allow nutrient removal processes to perform optimally. Nitrogen removal occurs through bacterial transformations. Nitrification is when ammonium is oxidized to nitrate by nitrifying bacteria, which occurs under aerobic conditions (Verhoeven and

Meuleman, 1999). In an anaerobic environment, denitrification would occur, where organic matter is broken down by bacteria using nitrate as the electron acceptor instead of oxygen (Verhoeven and Meuleman, 1999). Denitrification occurs in two steps, in which nitrate is reduced to nitrous oxide, then further reduced to atmospheric nitrogen, which is emitted into the atmosphere. The pH of the wastewater should remain above 6.0 to ensure the nitrogen is leaving as atmospheric nitrogen, because at low pH levels, the second step of denitrification does not occur, releasing nitrogen as nitrous oxide, which is a greenhouse gas that contributes to climate change (Verhoeven and Meuleman, 1999). To achieve both aerobic and anaerobic conditions for both processes, large emergent plants should be planted to help aerate the soil, as well as alternating flooded and dry conditions with the water regime (Brix, 1989, 1994; Reddy *et al.*, 1989).

Phosphorus is another nutrient that has difficulty being removed through wetland systems; however, phosphorus can be removed through the adsorption of phosphates to soil particles (Verhoeven and Meuleman, 1999). The amount of phosphorus that is adsorbed depends on the presence of iron, aluminum, or calcium within the clay minerals or bound to the soil organic matter (Verhoeven and Meuleman, 1999). In aerobic conditions, phosphates are bound to Fe(III); however, in anaerobic conditions, Fe(III) is reduced to Fe(II), in which phosphates are released, because less adsorption occurs (Faulkner and Richardson, 1989). Verhoeven and Meuleman (1999) state that phosphates bind to calcium within aerobic conditions. Despite what compounds are found within the clay minerals and soil organic matter, each soil has an adsorption capacity, in which all adsorption sites will be occupied and no more adsorption will occur (Kadlec, 1985). Besides adsorption, phosphates can precipitate with iron, aluminum, and soil compounds, in which phosphates fixate on the matrix of clay minerals and allow the availability of adsorption sites to occur (Nichols, 1983).

Nutrients can temporarily be stored within the wetland vegetation, primarily at the beginning of the growing season, when large quantities of nutrients can be taken up through the root system (Verhoeven and Meuleman, 1999). The nutrients can end up as litter if the vegetation is not harvested at the end of the growing season (Verhoeven and Meuleman, 1999). Also, nutrients can be lost, especially in the fall and winter seasons, through leaching and organic matter mineralization (Verhoeven and Meuleman, 1999). Only a small percentage of nutrients

are removed through the vegetation if it is harvested or collected within aggrading wood or rhizome (Verhoeven and Meuleman, 1999).

Hydrology

Hydrology is an important factor in determining the success or failure of constructed wetlands because these systems are highly dependent on creating and maintaining appropriate water depths and flow (Kadlec and Wallace, 2009). A basic water budget for a constructed wetland, similar to Figure 2.1, can help determine how much water is entering and leaving the system and where (Kadlec and Knight, 1996). Water enters a constructed wetland through streamflow, runoff, groundwater discharge, and precipitation, while water leaves through streamflow, groundwater infiltration, and evapotranspiration (ET). According to Kadlec and Wallace (2009), ET occurs with strong daily and seasonal cycles and is an important water loss in constructed wetlands. These sources of water inflow and outflow affect the change in wetland water storage, in which large variations in storage can occur with high variability in inflows and outflows of water; therefore, most constructed wetlands use some form of outlet water level control structure allowing little to no variation in water level (Kadlec and Wallace, 2009).

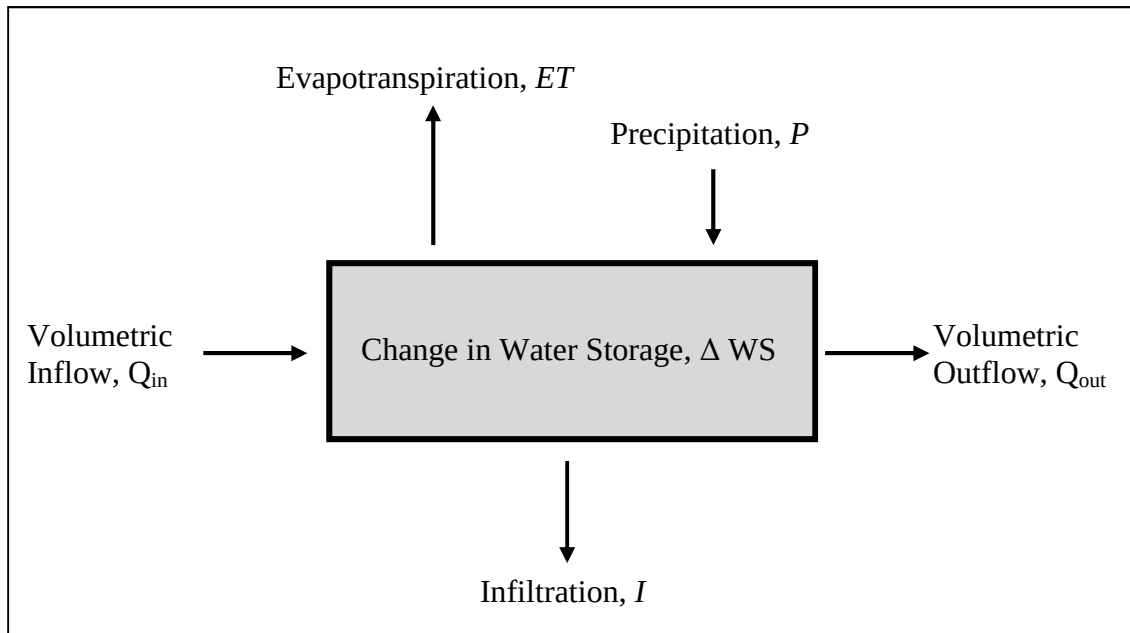


Figure 2.1. Individual components for a wetland water budget. Figure derived from Kadlec and Knight 1996

Evapotranspiration

Evapotranspiration is the combination of water loss to the atmosphere within the wetland system from water, soil, and plants solely driven by solar radiation. According to Kadlec and Wallace (2009), evapotranspiration is the primary energy loss mechanism for a wetland, and dissipates the majority of energy. There are several methods for estimating ET, but for large constructed wetlands, there is a common assumption that system ET (ET_{sys}) can be estimated by a reference ET (ET_o), which can be computed from weather data for a reference crop under standing water or saturated soil surface conditions (Kadlec and Wallace, 2009). A reference crop is a hypothetical grass or alfalfa reference surface at an assumed height (grass=0.12 m (0.39 ft); alfalfa=0.5 m (1.64 ft)) and resembles a continuous green surface of an actively growing crop (Allen *et al.*, 1998). The reference ET can be computed using several different equations such as the Penman-Monteith equation presented in the United Nations FAO Irrigation and Drainage Paper 56 (Allen *et al.*, 1998), the ASCE Penman-Monteith equation (ASCE, 2005), Hargreaves (Hargreaves, 1994), and others where weather data is used to calculate specific reference ET.

For large FWS wetlands, the reference ET determined for the wetland can be used to approximate the overall ET of the wetland system; however, in smaller wetland systems, a crop coefficient is used along with a reference ET to determine the overall ET for the constructed wetland (Kadlec and Wallace, 2009). According to Lafleur (1990), the reference ET estimate should be used as an “independent variable in a linear regression for specific vegetation types”. For example, in an agricultural setting, crop coefficients of a specific crop influence the overall ET at a specific site, modifying the reference ET for site-specific circumstances (Kadlec and Wallace 2009). Crop coefficients vary depending on the crop or vegetation as well as what part of the year it is. A crop coefficient curve is developed to determine how the crop coefficient changes throughout the growing season based on more water loss through ET. From Allen *et al.* (1998), an example of a crop coefficient curve can be seen in which the crop coefficient increases throughout the growing season, correlating to more water being lost through ET (Figure 2.2).

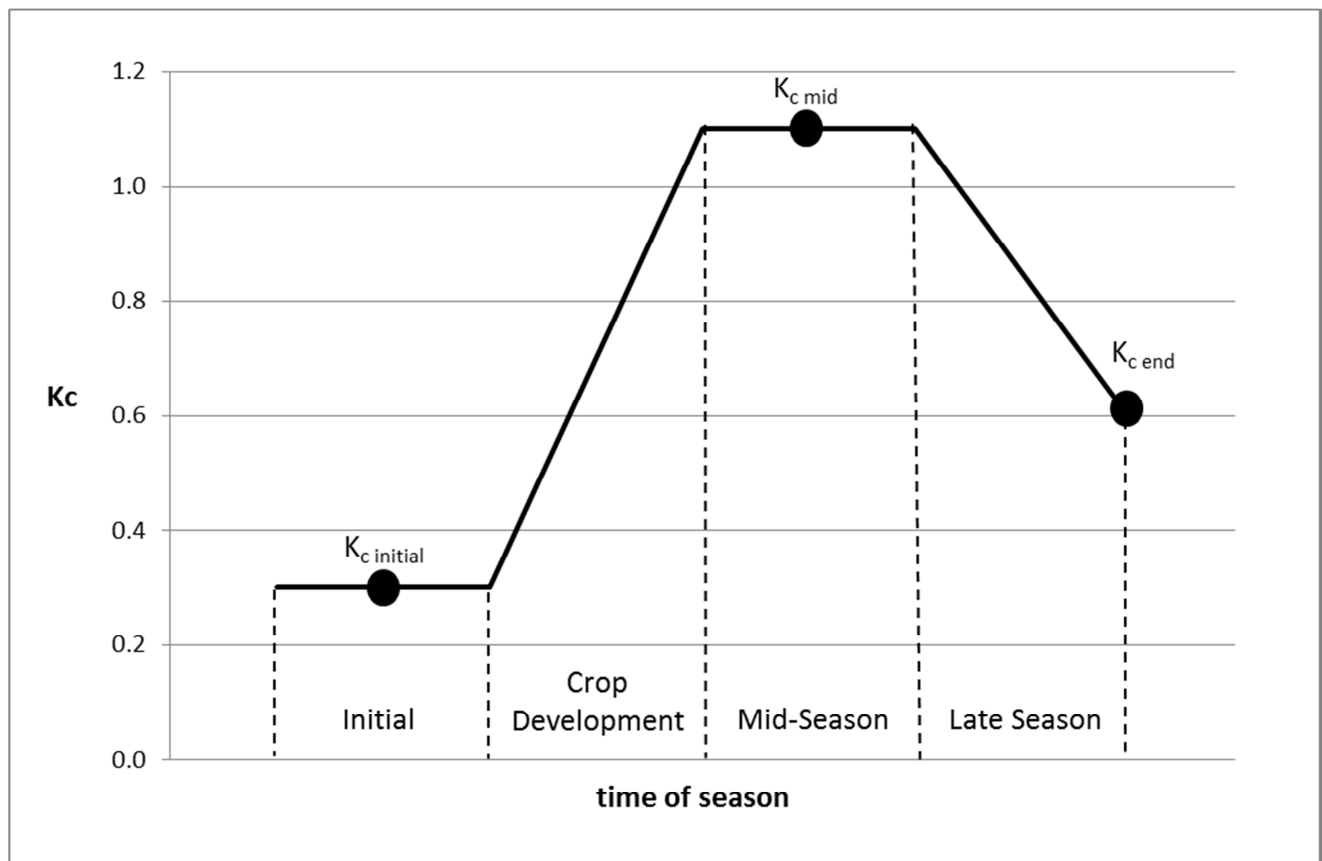


Figure 2.2. Crop coefficient curve. Figure derived from Allen *et al.* 1998

For a constructed wetland, a water use coefficient (i.e. crop coefficient) can be determined based on the whole wetland instead of being based on each individual plant, (Figure 2.3) (Kadlec 1989). By determining the water use coefficient, the amount of water lost through ET can be determined more accurately than the reference ET, because the water use coefficient “represents the ratio of ET for a given wetland to potential ET_o ” (reference ET) (Kadlec and Wallace 2009). By establishing a water use coefficient for a constructed wetland, the long-term ET rates can be determined and used to as a way to size constructed wetlands based on how much water is lost through ET, along with inflow and outflow amounts and precipitation (Kadlec and Wallace 2009).

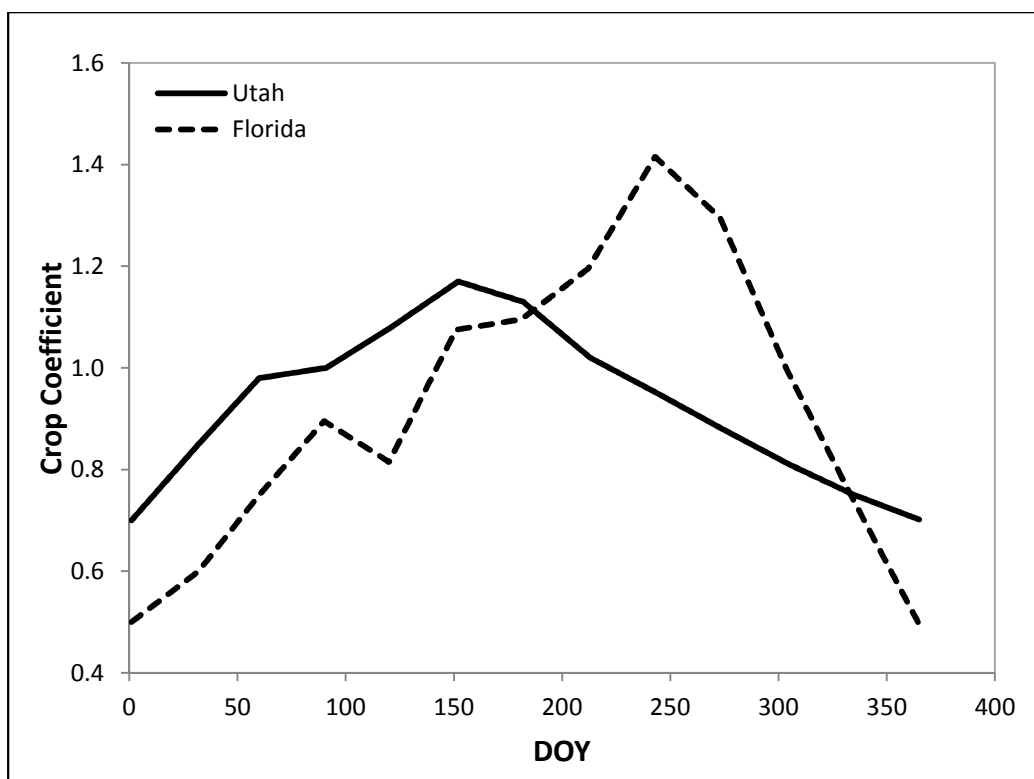


Figure 2.3. Example of a wetland water use coefficient curve for two wetland sites in Utah and Florida. Figure derived from Kadlec 1989

Treatment Performance

Two factors influence the performance of constructed wetlands, including: (1) “the central treatment tendency for a wetland”, and (2) “the anticipated variability away from that central tendency” (Kadlec and Wallace, 2009). Central tendencies are induced through flows and concentrations of pollutants as well as environmental factors, while random events within the

constructed wetland can influence variations in performance; therefore, both of these factors are used to determine and describe the performance of constructed wetlands (Kadlec and Wallace, 2009). Constructed wetlands can change year to year based on environmental factors, vegetation, and hydraulic or organic loadings, which allows for changes in performance; therefore, mass balances can be created in order to determine the performance of a constructed wetland based on its ability to reduce pollutant concentrations (Kadlec and Wallace, 2009).

FGD Wastewater

While constructed wetlands have been used for numerous waste streams, there has been very limited work on the use of constructed wetlands for FGD wastewater. One major study was conducted at Clemson University to determine the performance of a pilot-scale constructed wetland remediating FGD wastewater to decrease mercury and selenium concentrations, specifically. Pilot-scale constructed wetland treatment systems (CWTs) were designed to treat constituents of concern in FGD wastewater. To evaluate the ability of the CWTs, three different types of FGD wastewater were put through the CWTs including formulated FGD water, actual FGD waters, and pilot-scale scrubber FGD waters (Eggert *et al.*, 2008). The studies main objectives were to (1) define FGD wastewater based on chemical composition and constituents of concern, (2) design CWTs to remediate constituents of concern, and (3) measure the performance of CWTs for formulated and actual FGD waters based on the effluent criteria established by the USEPA and regulated by NPDES permits (Eggeret *et al.*, 2008).

The FGD wastewaters were collected from scrubber systems and measured for chemical composition by total elemental and water chemistry analysis (Eggert *et al.*, 2008). The pilot-scale CWTs were designed to remediate constituents of concern by evaluating their biogeochemical cycling within aquatic systems (Eggert *et al.*, 2008). From this information, the constructed wetland treatment systems were assembled on a sequential ordering of desired reactions and potential for effective removal of constituents (Eggert *et al.*, 2008). Two different pilot-scale constructed wetland treatment systems (A&B) were assembled to determine the performance of the wetland system on formulated FGD water, actual FGD waters, and pilot-scale scrubber FGD waters (Figure 2.4) (Eggert *et al.*, 2008).

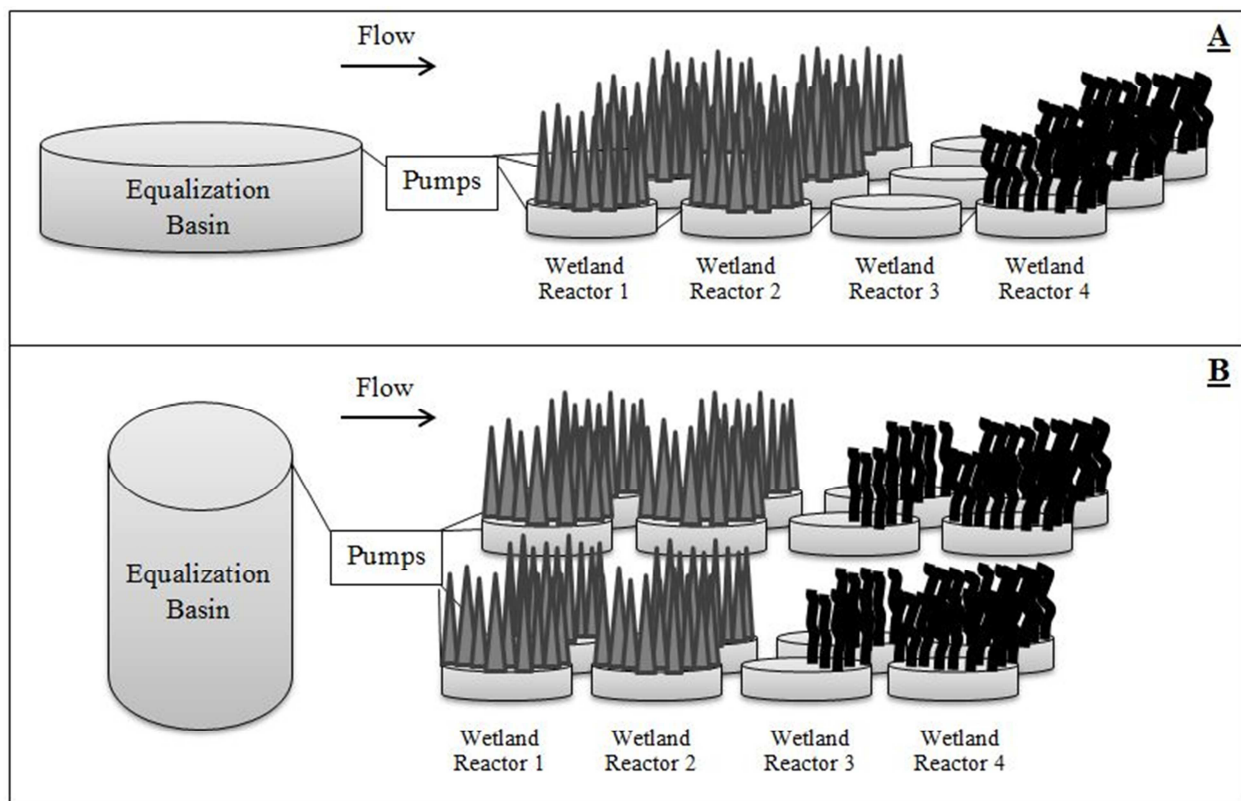


Figure 2.4. Schematic diagram of the pilot-scale CWTs used at Clemson University to determine the performance criteria for (A) formulated and actual FGD waters and (B) pilot-scale scrubber FGD waters. Figure derived from Eggert *et al.* 2008

For both A and B pilot-scale constructed wetland treatment systems, an equalization basin was the first component designed to remove suspended solids and regulate the concentrations of other contaminants before entering the treatment system (Eggert *et al.*, 2008). Systems A and B were assembled differently and information from Eggert *et al.* (2008) were used to explain the following designs of each system.

System A was used to evaluate the performance of pilot-scale CWTs with both formulated and actual FGD waters, consisting of three treatment lines each with four treatment reactors in series. The first two treatment reactors were reducing reactors designed to have a redox condition used to reduce Se(VI) to Se(IV) and further reduce any selenite to insoluble Se^0 , making the selenium species less mobile. The next treatment reactor was a rock basin followed by an oxidizing reactor designed to maintain redox potentials and deoxygenate the FGD

wastewater, decreasing the nutrient concentration and preventing further environmental effects downstream.

System B was used to also evaluate the performance of pilot-scale CWTSs with pilot-scale scrubber FGD wastewater through the use of an Ash CWTS and No-Ash CWTS treatment systems. Both treatment lines consisted of four reactors, similar to System A, where the first two reactors were reducing reactors, followed by a modified rock basin, and finishing with an oxidizing reactor. The function of each reactor was similar to System A, while the components between the reactors differed. The reducing reactors were the same as the reducing reactors in system A. The main differences between the Ash CWTS from the No-Ash CWTS was in the modified rock basins and oxidizing reactors, in which the Ash CWTS contained bottom ash instead of river sand hydrosol.

According to Eggert *et al.* (2008), both treatment systems being tested received analytical procedures and toxicity evaluations to determine the remediation of constituents and the toxicity of effluents and their effect on receiving waters, respectively. For analytical procedures, water samples were taken from the equalization basin, inflows to the pilot-scale CWTS, and the outflows from each treatment line and the amount of constituents removed was determined along with selenium and mercury removal rates. Toxicity evaluations were also conducted on the water samples collected from the equalization basin and the ending reactors on the treatment lines.

The average removal amounts for mercury from the equalization basin to the last reactor was 93.2% for formulated FGD waters, 96.1% for amended FGD waters, and 99.0%, 68.7%, no removal, and 98.7% for the first thru fourth pilot-scale scrubber FGD waters (Eggert *et al.*, 2008). More mercury was removed in FGD water containing more mercury at the beginning of treatment compared to less mercury, where 98% of mercury was removed at an incoming concentration of 36 $\mu\text{g/L}$ compared to 0 to 69% mercury removal at incoming concentrations of less than 0.9 $\mu\text{g/L}$ (Eggert *et al.*, 2008).

Selenium average removal amounts and rates for formulated FGD waters were 84.6%, 80.1% for amended FGD waters, and 89.7%, 63.6%, 51.2%, and 29.5% for the first through fourth pilot-scale scrubber FGD waters (Eggert *et al.*, 2008). There were no NPDES permits that required a maximum daily limit for selenium; therefore, performance criteria or maximum daily

limit could not be established for selenium for the CWTSS (Eggert *et al.*, 2008). The pilot-scale scrubber FGD waters did have a sequential decline in selenium removal with each scrubber FGD water, which could have resulted from “removal mechanisms possibly inhibited by constituents in these FGD waters, subject to decreasing binding sites or reactants, or were less efficient because of differences in forms of selenium” (Eggert *et al.*, 2008).

Arsenic was the last constituent of concern, in which arsenic’s average removal amounts were 64.4% for formulated FGD waters, but no removal was measured for amended FGD waters (Eggert *et al.*, 2008). It was found that after 4 weeks of loading, the equalization basin contained 0.074 mg/L, with a mean outflow concentration of 0.028 ± 0.383 mg/L 61.6% removal; however, total arsenic concentrations in the outflow samples (0.173 ± 0.06 mg/L) were approximately 2.5 times greater than the equalization basin (0.073 mg/L) during the first sampling period (Eggert *et al.*, 2008). During these sampling times, total selenium removal was the greatest in the outflow samples of the rock basins instead of the final reactor; therefore, insoluble forms of arsenic and selenium leached throughout these sampling periods (Eggert *et al.*, 2008). The pilot-scale scrubber FGD waters also showed no sign of arsenic removal (Eggert *et al.*, 2008).

Toxicity evaluations were conducted using *C. dubia* (*Ceriodaphnia dubia*). By contrasting the toxicity results from pre- and post-treatment samples, the performance of the CWTSS based on toxicity can be determined (Eggert *et al.*, 2008). For the amended FGD waters, *C. dubia* increased in survival and reproductive rates from pre- to post-treatment sampling, decreasing toxicity (Eggert *et al.*, 2008). The pilot-scale scrubber FGD water was also tested for toxicity, in which the first and fourth pilot-scale scrubber FGD waters endured significant *C. dubia* mortality when exposed to the pre-treatment samples and did not change with the post-treatment samples (Eggert *et al.*, 2008). Reproduction of *C. dubia* was inhibited in both pre- and post-treatment samples of either treatment (Eggert *et al.*, 2008). The second pilot-scale scrubber FGD water resulted in low *C. dubia* reproduction for pre-treatment samples, but slightly increased for the post-treatment samples (Eggert *et al.*, 2008). The third pilot-scale scrubber FGD water had no significant mortality effects on the *C. dubia* for the pre- and post-treatment systems (Eggert *et al.*, 2008). Overall, reproduction was not affected in pre-treatment samples for no-ash or ash systems (pilot-scale scrubber FGD water only), but a significant decrease was measured for post-treatment sample exposure from the no-ash system (Eggert *et al.*, 2008).

With these results, it was determined the pilot-scale CWTSs can decrease environmental risks by FGD waters to receiving systems, enabling the discharge of post-treatment water within NPDES permit limits (Eggert *et al.*, 2008). Based on these pilot-scale CWTSs studies, full-scale CWTS were designed, constructed and are currently in operation to treat FGD wastewater (Murray-Gulde and Mooney, 2007). In Murray-Gulde and Mooney's International Water Conference Paper, *Designing Constructed Wetlands for Mitigating Risks from Flue Gas Desulfurization Wastewater*, which was presented in 2007 and discusses the first six months of operation for a full-scale CWTS designed for FGD wastewater treatment, is further discussed below.

Information from the pilot-scale study conducted by Clemson University was used to design full-scale CWTS for the removal of selenium and mercury at three locations. The CWTS consisted of two to three treatment lines with gravity flows from an equalization basin, through the wetland cells, a monitoring station, and a NPDES discharge point. Before the equalization basin, primary wastewater treatment was conducted to stabilize constituent concentrations, settle solids, and cool the FGD wastewater. After primary treatment, the FGD wastewater entered the equalization basin, and then discharged into a constructed wetland treatment train with four treatment stages in series including: two sequential bulrush (*Schoenoplectus californicus*) constructed wetland cells, a rock aeration cascade, and a cattail (*Typha latifolia*) constructed wetland cell. The bulrush cells purpose was to remove selenium and mercury from the FGD wastewater, which would continue to the rock aeration cascade, where the FGD wastewater was aerated. The final, polishing cells (cattail cells), are used to further precipitate iron-mercury and iron-selenium complexes.

The full-scale CWTS had an overall hydraulic retention time of 7 days and was designed to remove mercury and selenium. The performance evaluation began in December 2006 and continued until June 2007. Grab samples were taken from six locations in the CWTS including: influent to the equalization basin, effluent from the equalization basin, effluent from the first bulrush cell, effluent from the second bulrush cell, effluent from the cattail cell, and from the monitoring station. Along with these 6 grab samples, water samples were also taken from before the CWTS, post scrubber, and post clarifier. In addition to mercury and selenium, the samples

were analyzed for chlorides, biological oxygen demand, chemical oxygen demand, total suspended solids, and boron (Murray-Gulde and Mooney, 2007).

The overall performance of the CWTS from December 2006 to June 2007 showed varying concentrations of measured constituents from one sampling event to the next. Mercury and selenium removal was 88% and 25%, respectively. The TSS removal averaged 58%, which seems relatively low; however, the concentrations of TSS entering the equalization basin were already lower than expected, averaging a concentration of about 9.3 mg/L. Biological oxygen demand (BOD) and chemical oxygen demand (COD) showed removal efficiencies of 21% and 47%, respectively. Chlorides and boron were not removed, with average removal of 2% and 5%, respectively. Overall, Murray-Gulde and Mooney (2007) state that the performance of the full-scale CWTS achieved mercury and selenium levels that are reasonable for discharge based on NPDES compliance.

Research Objectives

Constructed wetlands have shown some promise as an effective way to remove contaminants from FGD wastewater such as BOD, bacteria pollutants, metals, and some nutrients (Eggert *et al.*, 2008; Murray-Gulde and Mooney, 2007). Based on the potential positives of CWTS and the many negatives and large costs associated with other treatment technologies (e.g. deep well injection and ZLD) constructed wetlands were chosen to treat FGD wastewater from Westar Energy's Jeffrey Energy Center (JEC) near St. Mary's, KS.

JEC uses a limestone forced oxidation wet FGD process, similar to Figure 1.5, to remove sulfur dioxide from the flue gas before releasing the gas into the atmosphere. The scrubber purge from the limestone forced oxidation wet FGD process is sent to a wastewater treatment system. At the time of this study, no other FGD wastewater treatment system was used to remove pollutants and the basic physical/chemical treated wastewater was released into the Kansas River. However, the Kansas Department of Health and Environment (KDHE) will begin enforcing stricter limitations of pollutant concentrations entering the Kansas River. Because of these limitations, a pilot-scale constructed wetland treatment system (CWTS) was designed and installed by Burns & McDonnell to treat FGD wastewater after the basic physical/chemical treatment. In order to develop a better understanding of the CWTS function and scale up

potential, Kansas State University was contracted to assist with system monitoring and other aspects of the research. This thesis represents a portion of that work with the specific objectives to: (i) evaluate the use of a portable, water quality meter for assessing wastewater in the field; (ii) develop a water balance for the CWTS; (iii) generate a water use coefficient for the CWTS; and (iv) create a mass balance of the pollutants of concern.

Chapter 3 - Methods and Materials

Westar Energy is the largest electric company in Kansas, serving over 687,000 industrial, commercial, and residential customers through natural gas, nuclear, wind, and coal-fired generation power plants (Westar, 2012). Jeffrey Energy Center (JEC) consists of three 720 MW units, which is the largest coal-fired generation power plant located in KS (Westar, 2012). JEC burns over 9 million tons of coal per year, which requires a water use of 24,000 gallons per minute, 29 million gallons per day, and over 10 billion gallons per year (Westar, 2012). In 2007, JEC updated their existing scrubber system, which was removing 60% of the sulfur dioxide, to a Flue Gas Desulfurization (FGD) system capable of removing 95% of sulfur dioxide, as well as reducing mercury emissions by 25% and particulate matter by 20% (Westar, 2012).

Site Description

Jeffrey Energy Center (JEC) is located about 11 km (7 miles) north of St. Mary's, KS in Pottawatomie County (39.2861° N, 96.1169° W). Jeffrey Energy Center is located in the Flint Hills ecoregion (US EPA Level III ecoregions), which consists of rolling hills, narrow steep valleys, and area that is typically grazed by beef cattle. This ecoregion marks “the western edge of the tallgrass prairie, and contains the largest remaining intact tallgrass prairie in the Great Plains” (US EPA, 2012).

Jeffrey Energy Center experiences a typical Mid-continental climate, with extreme hot temperatures during the summer months and extreme cold temperatures during the winter, with moderate to high wind speeds. Average annual minimum and maximum temperatures for Pottawatomie County are 5-6°C (41-43°F) and 17-19°C (64-66°F), while annual precipitation averages from 762-889 mm (30-35 in) (Goodin et al., 1995). Average monthly values for precipitation and temperature, both maximum and minimum, are shown in Figure 3.1.

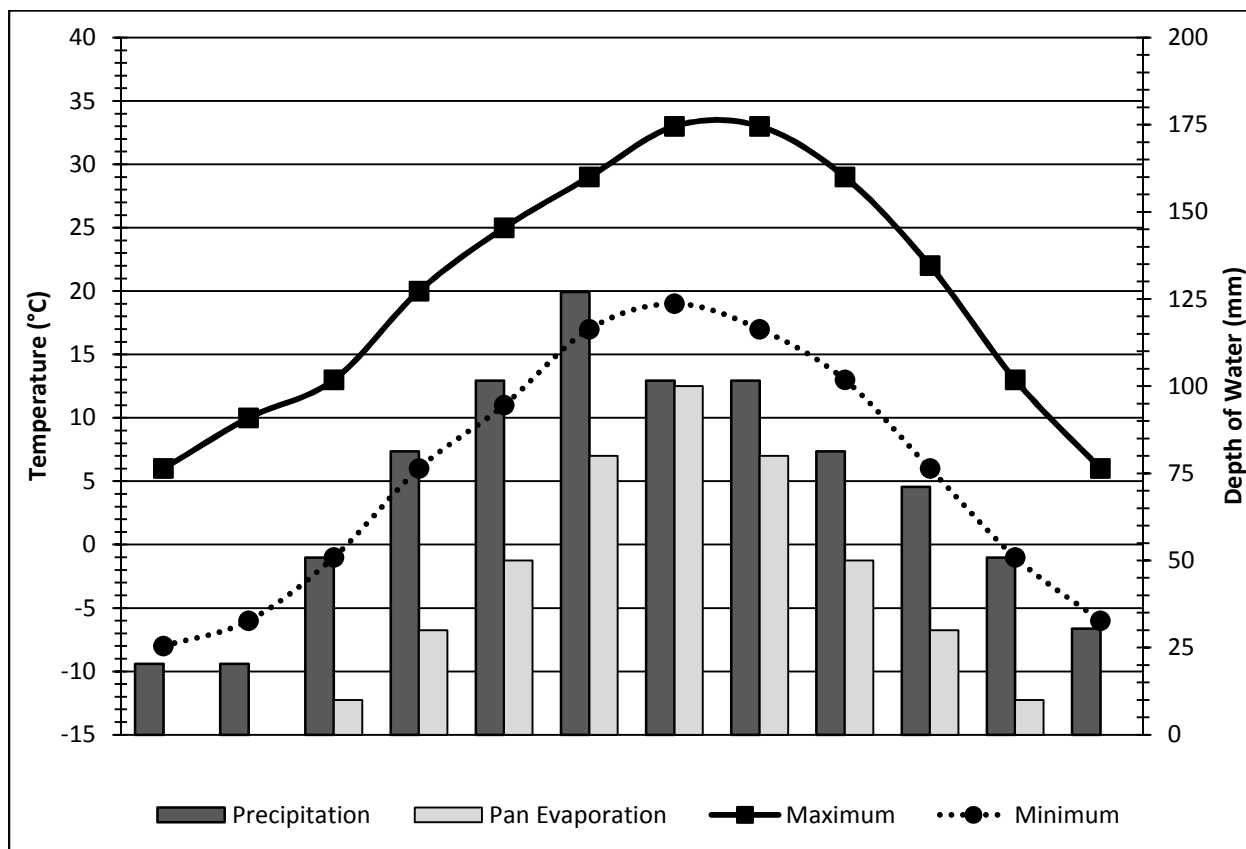


Figure 3.1. Climograph for Jeffrey Energy Center with monthly averages of precipitation, maximum temperature and minimum temperature from 1981 to 2010, and pan evaporation from 1971-2000. Information taken from PRISM Climate Group and National Weather Service (Oregon State University, 2012; NOAA/National Weather Service, 2005)

The Flint Hills ecoregion has a rocky soil composed of cherty limestone and shale (US EPA, 2012). The constructed wetland treatment system (CWTS) at JEC was built in an area containing two main types of soil where over 90% of the soil was a Clime-Sogn complex and the remaining 10% was gravel pits and quarries (USDA NRCS, 2012). The Clime-Sogn complex has an overall soil texture of a silty clay loam and contains 1.41% organic matter, 6.6% sand, 52.8% silt, and 38.1% clay. Clime-Sogn is classified as Hydrologic Soil Group C. Group C soils are characterized by a layer that impedes the downward movement of water and/or soils of moderately fine texture or fine texture resulting in a slow infiltration rate of about 1.27-3.81 mm/hr (0.05-0.15 in/hr) when thoroughly wet (USDA, 2009). Due to low infiltration rates, it is expected to see high runoff potential from these soils (USDA, 2009).

The CWTS consisted of two parallel lines of four wetland cells for a total of eight wetland cells, including: (1) two free water surface cells, (2) two vegetated submerged bed cells, (3) two vertical flow bed cells, and (4) two more vegetated submerged bed cells (Table 3.1 and Figure 3.2). Each cell is approximately 32 m by 32 m by 0.5 m (105 ft by 105 ft by 1.75 ft) and lined with a high density, flexible membrane liner (HDPE 60 mil FML) to prevent seepage into the soil and groundwater (Burns & McDonnell et al., 2011). The cells are hydraulically connected such that the lines can function as replicates or flow can serpentine through all 8 cells. Flow is controlled through various valves into the CWTS and between the cells (Burns & McDonnell et al., 2011).

Table 3.1. Each wetland cell based on cell type and number, vegetation, soil structure, and storage capacity. Information collected from Burns & McDonnell et al. 2011 and Morrison et al. 2011

Cell Type	Cell Number	Vegetation	Soil Structure	Storage
Free Water Surface	A1, B1	Arrow Head Bulrush Cattail Water Lily	15 cm (6 in) Top Soil 30 cm (12 in) Soil 15 cm (6 in) Subgrade	613,267 L (162,000 gal)
Vertical Submerged Bed	A2, A4 B2, B4	Bulrush Cattail Switch Grass Inland Salt Grass Sedges	15 cm (6 in) Top Soil 15 cm (6 in) Engineered Soil 8 cm (3 in) Sand Filter 23 cm (9 in) Crushed Limestone Non-Woven Geotextile Fabric 30 cm (12 in) Soil 15 cm (6 in) Subgrade	370,970 L (98,000 gal)
Vertical Flow Bed	A3, B3	Inland Saltgrass Western Wheat Grass Sedges Cattail Bulrush	15 cm (6 in) Top Soil 60 cm (24 in) Engineered Soil 8 cm (3in) Sand Filter 23 cm (9 in) Crushed Limestone Non-Woven Geotextile Fabric 30 cm (12 in) Soil 15 cm (6 in) Subgrade	492,104 L (130,000 gal)

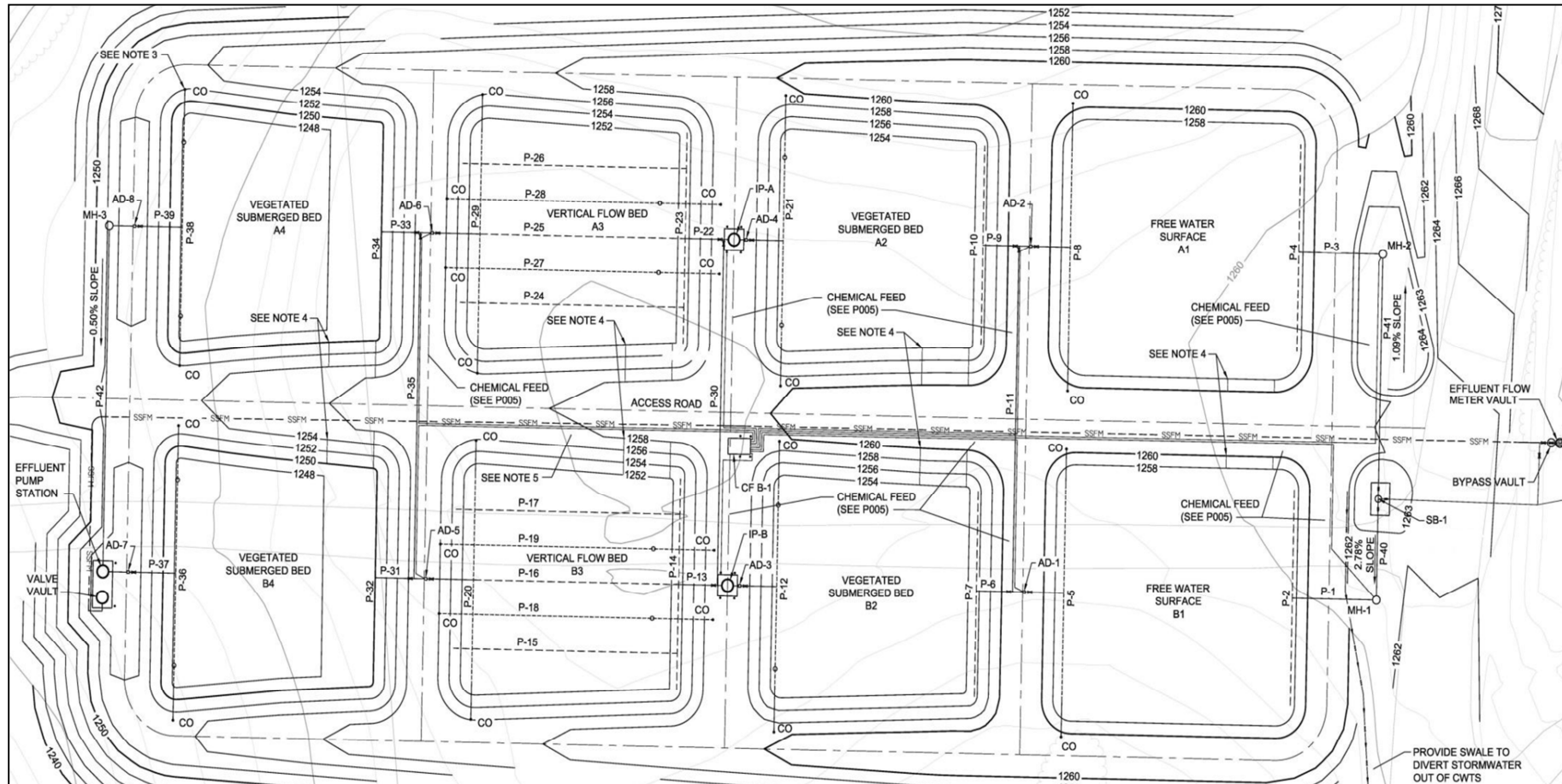


Figure 3.2. Blueprint of the CWTs at JEC including all 8 wetland cells (Burns & McDonnell, 2012).

A splitter box (SB), located at the entrance of the CWTS, received water from the FGD blowdown treatment system transfer station, where FGD wastewater is mixed with RAW water from the makeup lake to dilute the high concentrations of constituents (Burns & McDonnell et al. 2011). The SB was used to control the amount of water entering both treatment lines (Burns & McDonnell et al., 2011). A lift station (LS) located at the outlet of the CWTS was used to release water to Lost Creek (Burns & McDonnell et al., 2011). An effluent flow meter vault, located upstream of SB, recorded how much water was released into Lost Creek. Agri-drains were placed at the outlet of each cell and used to move water from one wetland cell to the next. There were eight agri-drains (AD-1, AD-2, AD-3, AD-4, AD-5, AD-6, AD-7, and AD-8) that ranged in depths from 6 to 8 ft.

Water Quality Measurements

Water quality measurements were taken at 10 sites in sequence from the least to most contaminated water starting at the outlet (LS) then AD-7, AD-8, AD-5, AD-6, AD-3, AD-4, AD-1, AD-2, and ending with SB. A HORIBA U-50 Series Multi Water Quality Checker (Horiba, Ltd., Kyoto, Japan) was used for water quality measurements. The HORIBA meter was used to measure: (a) temperature (°C), (b) pH (0-14 scale), (c) ORP (mV), (d) conductivity (mS/cm), (e) turbidity (NTU), (f) DO (mg/L), TDS (g/L), and salinity (ppt). Water quality measurements were only taken from January 2011 to January 2012. Data is located in Appendix F.

Weather Data

A Vantage Pro2™ weather station (Figure 3.1, Davis Instruments, Hayward, California) was located on site, between the second and third cells on the south line. The Vantage Pro2™ console was located inside the chemical feed building. A WeatherLink® data logger, was attached to the Vantage Pro2™ console to record hourly weather values, including: temperature, relative humidity, dew point, wind speed, wind direction, heat index, precipitation, and solar radiation. Every two weeks for the beginning 3 months (March to May), weather data was downloaded using WeatherLink® 5.9.2 software from the weather station console on to a laptop;

however, after the first 3 months, weather data was downloaded weekly. The weather data was saved onto a USB drive and later downloaded and analyzed at Kansas State University.



Figure 3.3. Vantage Pro2™ weather station located at the CWTS at JEC to collect hourly weather data.

Water Use Coefficient

In order to understand long-term evapotranspiration potential of the CWTS, a system water use coefficient was developed. The water use coefficient, similar to a crop coefficient, was calculated using the following equation:

$$ET_C = K_C ET_O \quad (3.1)$$

where ET_C is the system or crop evapotranspiration, ET_O is the grass reference evapotranspiration, and K_C is the water use or crop coefficient (Allen, 1998; Allen, 2000).

The water use coefficient is affected by four main factors, including vegetation, climate, soil evaporation, and vegetation growth stages (Allen, 1998). Many different crops and plants

have a specific crop coefficient, which helps determine evapotranspiration of that crop or plant; however, for the CWTS at JEC, no crop coefficient has been developed, making it difficult to predict the long-term evapotranspiration potential of this system. The crop coefficient or the water use coefficient of this wetland was determined by rearranging equation 3.1:

$$K_C = \frac{ET_{sys}}{ET_O} \quad (3.2)$$

where the original crop evapotranspiration, ET_C , is now denoted as the system evapotranspiration, ET_{sys} . The system evapotranspiration, ET_{sys} , and the reference evapotranspiration, ET_O , need to be determined in order to solve for the water use coefficient, K_C .

System Evapotranspiration

The system evapotranspiration was determined using a simple water balance (Figure 3.4):

$$P + WW_{in} - S - WW_{out} - ET_{sys} = WS_{i+1} - WS_i \quad (3.3)$$

where P is the precipitation, WW_{in} is the wastewater flow in, S is seepage, WW_{out} is the wastewater flow out, ET_{sys} is the actual evapotranspiration of the wetland system, WS_{i+1} is the wetland water storage at time measurement (i+1), and WS_i is the wetland water storage at time (i). Because the CWTS was lined, seepage was assumed to be negligible, and the actual evapotranspiration, ET_{sys} was calculated with the following equation:

$$ET_{sys} = P + WW_{in} - WW_{out} - \Delta WS \quad (3.4)$$

where ΔWS is the difference between water stored in the wetland cells at time measurement (i+1) and (i). The water storage in the wetland cells, ΔWS , was assumed to be maintained at a constant level such that changes in the system storage were minimal; thus this value was negligible.

Precipitation, P , was determined from the on-site weather station. Wastewater flows, both WW_{in} and WW_{out} , were measured using flow meters located at the inlet and outlet of the wetland system. Flow data was collected by JEC and received from Andy Rietcheck, a professional engineer at Westar Energy. WW_{in} was a combination of RAW and FGD. RAW water inflow

came from the make-up lake, while FGD water came from the FGD blowdown treatment system transfer station; WW_{out} values were retrieved from an onsite effluent flow meter (see Effluent Flow Meter section below).

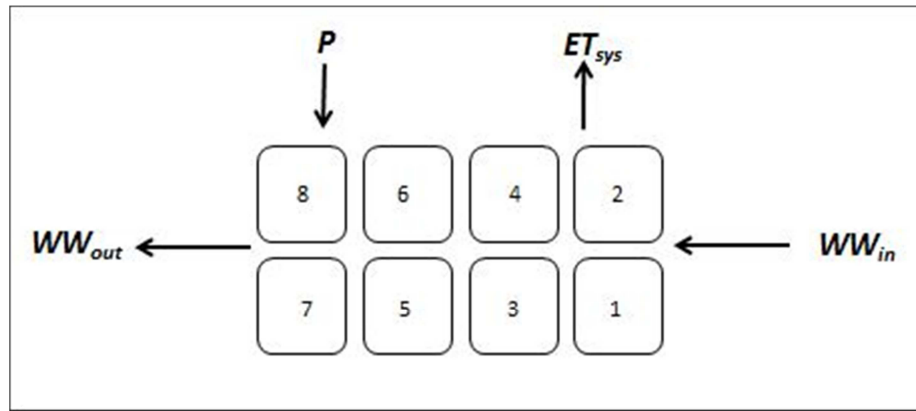


Figure 3.4. Basic schematic of a water balance for the CWTS at JEC.

Reference Evapotranspiration

The reference evapotranspiration (ET_o) was calculated on a daily basis for JEC using the ASCE Penman-Monteith method (ASCE-EWRI, 2005) and the Hargreaves method (Hargreaves 1985). A more detailed description of the calculations is located in Appendix C. The ASCE Penman-Monteith ET method is considered to be the most accurate ET calculation (ASCE-EWRI, 2005) and requires comprehensive weather data to complete an energy and mass balance. Because detailed weather data is not always available, the simpler Hargreaves method (Jensen, 1997) that depends on air temperature and location was used. The Hargreaves method tends to overestimate evapotranspiration, especially in humid regions (Trajkovic, 2007), and should only be used for time steps of five days or longer, because of sudden changes in weather that could cause changes in wind and cloud cover (Hargreaves, 2003). For this study, both the ASCE Penman-Monteith and Hargreaves methods were compared and discussed in the results section.

Water Use Coefficient Curve Development

After the system evapotranspiration, ET_{sys} , was calculated from the water balance and the reference evapotranspiration was calculated from the ASCE Penman-Monteith equation, a daily

water use coefficient was developed. A water use curve, similar to a crop coefficient curve (Figure 2.2) and the wetland water use curve (figure 2.3), were developed.

Effluent Flow Meter Data

An effluent flow meter and vault were located on the east side of the CWTS and recorded the effluent water flow leaving the CWTS at LS. The meter recorded two effluent water flow values every hour including grand volume and volume total, which represents the accurate CWTS total effluent flow. The daily total volume was used in the water balance calculations. Information about how the effluent flow meter data was downloaded can be located in Appendix D.

Water Sampling

Water samples were collected beginning on April 12, 2011 at the same locations as described above for the HORIBA measurements. Five different water sampling bottles, with labels according to each location, were used to take water samples. After sampling was completed, a Chain of Custody (COC) form was filled out and placed inside the cooler along with the water samples. The water samples were iced down and sent to Continental Analytical Services, Inc. (CAS) in Salina, KS, where all laboratory testing was conducted on each of the water samples.

Water samples were analyzed for seven constituents included: boron (B), manganese (Mn), mercury (Hg), selenium (Se), chloride (Cl^-), fluoride (F^-), and sulfate (SO_4^{2-}). These seven constituents were tested for using specific laboratory methods from CAS from the US EPA including: 200.7 for boron; 200.8 for manganese; SM 3112B/7470A for mercury; 200.8(IC-ICP-DRC-MS) for selenium; 300.0 for chloride; 300.0 for fluoride; 300.0 for sulfate. Laboratory results were used to complete a mass balance on each constituent. Further information about water sampling and changes throughout the water sampling can be found in Appendix E.

Mass Balance of the CWTS

A mass balance was created for the CWTS. The purpose of the mass balance was to determine the performance of the CWTS at removing seven main pollutants including boron, manganese, mercury, selenium, chloride, fluoride, and sulfate. The water samples sent to CAS were used to determine the incoming and outgoing concentrations of the main pollutants of concern; therefore, incoming concentrations were multiplied with respect to the incoming flow of both FGDWW and RAW water, while outgoing flow was multiplied with the outgoing concentrations. As a result, the masses of all the compounds entering and leaving the CWTS were determined and used to evaluate the performance of the CWTS. Additional information about how the mass balance was created and used to determine the performance of the CWTS can be viewed in Appendix F.

Chapter 4 - Results and Discussion

Research and data collection occurred for the CWTS at JEC from January 17, 2011 until May 22, 2012. From all of the results, each objective for the CWTS at JEC was completed. There was little to no relationship between the HORIBA water quality measurements and the analytical water tests conducted by CAS. A water balance was created for the CWTS, where times of unsteady flow in and out of the CWTS were determined and justified. With the use of the water balance and weather data, a water use coefficient was created and compared to other constructed wetland water use coefficients, where it was determined further research over multiple growing seasons would create a more accurate and consistent water use coefficient for the CWTS at JEC. Lastly, the mass balance for the CWTS was created and determined a high removal of mercury, selenium, and fluoride from the FGD wastewater, but low removals of boron, manganese, chloride, and sulfate. A more detailed discussion about the results of each objective can be viewed below.

Water Quality Measurement Results

In general, there was little to no relationship between the HORIBA water quality measurements and the analytical water tests conducted by CAS (Table 4.1 and Appendix G). While some water quality measurements were not expected to be affected by pollutant concentration (e.g. temperature, turbidity, and DO), the remaining five water quality measurements (pH, ORP, conductivity, TDS, and salinity) were expected to exhibit a stronger relationship with some of the pollutant concentrations, especially manganese, chloride, and sulfate.

The pH of a wetland system affects various biological processes as well as solubility and several important chemical reactions, such as the hydroxide and oxyhydroxide precipitates of manganese and sulfide phase equilibrium in submerged soils can affect the sorption and desorption of ions (Kadlec and Wallace, 2009). Oxidation-reduction potential (ORP) can affect both chemical and microbial processes as well as have a huge impact on “biological availability of major and trace nutrients in soils in general” (Patrick et al., 1985; Gambrell et al., 1987). For example, sulfate is reduced to sulfide within negative ORP environments, allowing

an increase in sulfide to be released into the environment (Wake et al., 1977). According to Younger (2000), wetlands built to remove metals with insoluble sulfides promote sulfate reduction; therefore, in positive ORP values, higher sulfate conditions would have been seen. Conductivity and total dissolved solids (TDS) are nearly proportional to each other and measurements can be conducted in wetlands to determine salt content. An increase in the chloride concentration should yield an increase in both conductivity and TDS (Kadlec and Wallace, 2009). Salinity measures the dissolved salt content within the water or soil, in which sodium chloride and calcium sulfates are common salts (Kadlec and Wallace, 2009). Depending on each form of chloride and sulfate located within the CWTS at JEC, there should have been a correlation between high salinity measurements and an increase in either chloride or sulfate concentration.

Table 4.1. The R^2 values for each water quality measurement (dependent variable) compared to each pollutant (independent variable) provide a goodness of fit of the model, in which values of 1 would indicate the regression line produced from the graphs in Appendix F would perfectly fit the data provided. Below, R^2 values shown in red indicate the best R^2 values, or the best goodness of fit for that model.

	Temp.	pH	ORP	Conductivity	Turbidity	DO	TDS	Salinity
Boron	0.407	0.076	0.082	0.412	0.104	0.218	0.416	0.395
Manganese	0.460	0.021	0.250	0.406	0.051	0.267	0.411	0.380
Mercury	0.008	0.001	0.013	0.002	0.017	0.005	0.002	0.001
Selenium	0.004	0.004	0.001	0.001	0.001	0.004	0.001	0.002
Chloride	0.320	0.030	0.223	0.408	0.109	0.209	0.414	0.393
Fluoride	0.056	0.026	0.000	0.047	0.146	0.022	0.047	0.037
Sulfate	0.404	0.027	0.193	0.452	0.101	0.252	0.458	0.438

The R^2 value determines the linear correlation between the water quality measurement (dependent variable) and each pollutant (independent variable), providing information about the goodness of fit of the model. The closer the R^2 value is to 1, the more accurate and/or less variance between the independent and dependent data; therefore, the regression line of a R^2 value of 1 would perfectly fit the data. From the table, the values in red bold font represent R^2 values above 0.400 or 40%. Only eleven R^2 values were above 40% out of all fifty-six R^2 values; however, despite these large R^2 values compared to the other values on the table, the values are

not high enough to show a positive relationship between any water quality measurement and any pollutant. With this analysis, it was determined that water quality measurements could not be used to determine an increase or decrease in pollutant concentration at any given time due to low R^2 values showing a lower goodness of fit of the model. Therefore, it was recommended to continue analytical water tests to determine changes in pollutant concentration.

Weather Data and Effluent Flow Meter Results

Weather and flow meter data were used in the development of the water balance for the CWTS (Equation 3.3). Figures 4.1 and 4.2 show the weekly water inputs (RAW, FGDWW, and precipitation) and outputs (LS) for 2011 and 2012, respectively. All data used in this analysis is located in Appendix G.

At the beginning of 2011, RAW and some FGDWW water were introduced into the CWTS to establish water within the new wetland cells. Starting in the middle of February, larger amounts of FGDWW were added to the system and steady state of the CWTS began on March 10, 2011, when an outflow began to leave the CWTS. Within the water balance, water storage in the wetland cells was assumed to be zero, stating the cells would be maintained at a constant level; therefore, by assuming water storage to be zero, the evapotranspiration of the system could be determined. Due to unexpected unsteady flow (Table 4.2), there were times throughout the course of the research where no inflow, no outflow, and/or increased outflow occurred within the CWTS causing a change in storage to occur. Some of these unsteady flows were a result of maintenance on broken pumps and pipes at the CWTS and within the wastewater treatment building at JEC; large precipitation events throughout the year impacted flows, also.

These large precipitation events resulted in an increase in outflow such that outflows were greater than the inflow of both RAW and FGDWW in order to maintain a constant depth of water within the CWTS. According to the climograph (Figure 3.1), large precipitation events between 100-150 mm (3.94-5.91 in) should be expected each month starting in May and continuing to August every year; however, with increasing periods of drought throughout Kansas over the past two years, these numbers vary from year to year. For design purposes, the wetland

should be able to accommodate extra inflows of water, such as precipitation, for a given area based on the climate conditions.

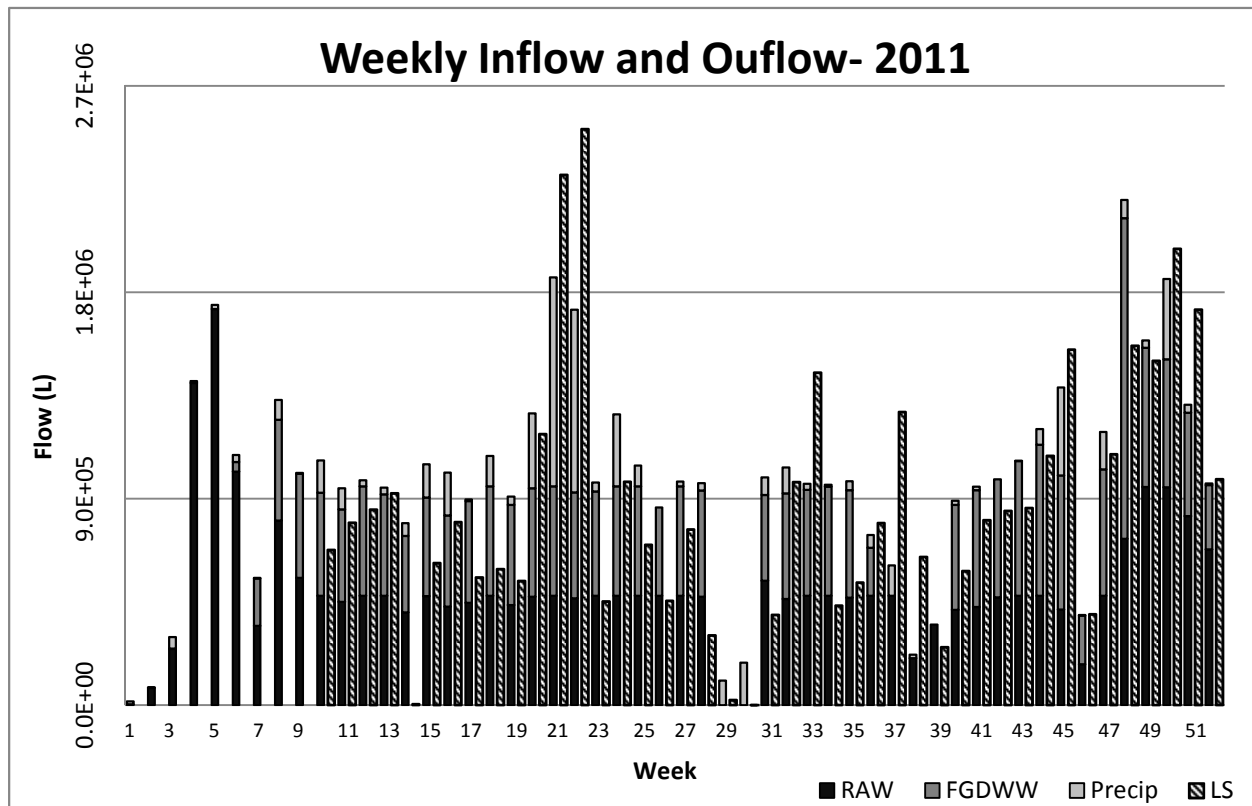


Figure 4.1. 2011 weekly influent (RAW, FGDWW, and Precipitation) and effluent (LS) water amounts entering and leaving the CWTs at JEC

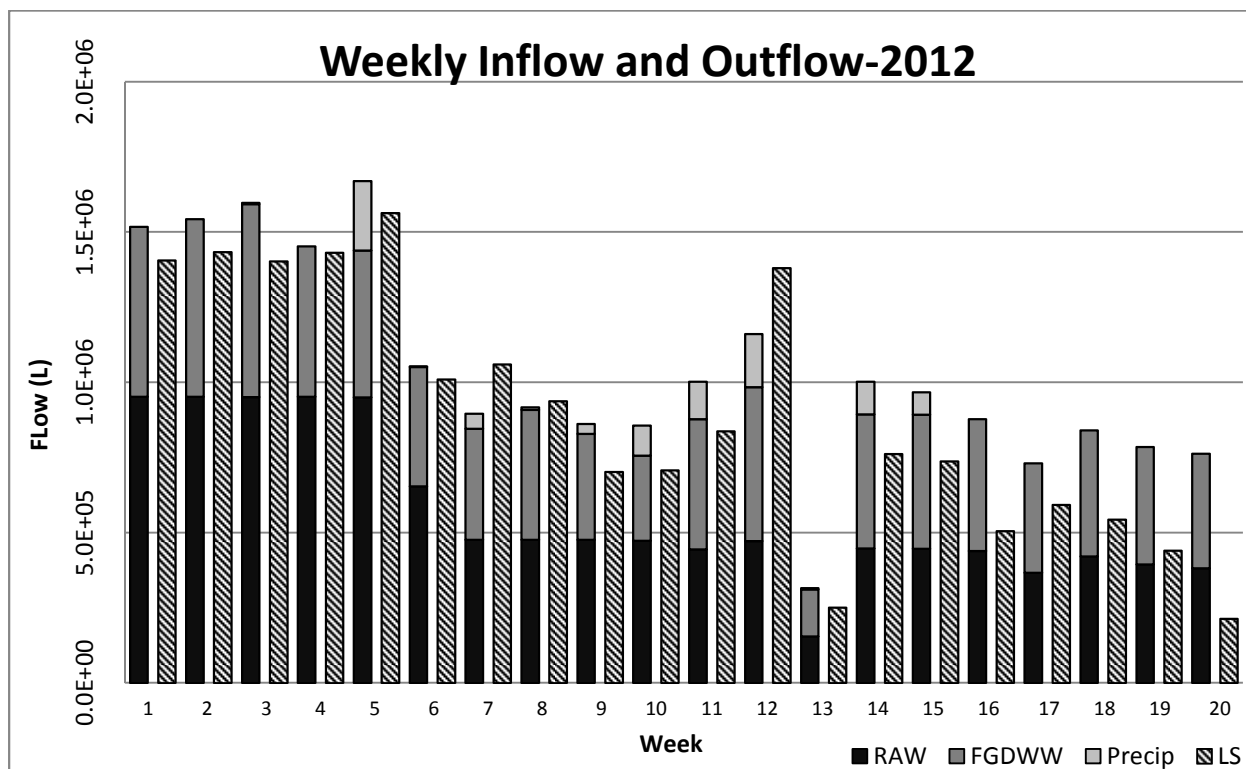


Figure 4.2. 2012 weekly influent (RAW, FGDWW, and Precipitation) and effluent (LS) water amounts from the CWTS at JEC

Water Use Coefficient Curve

From the weekly influent and effluent data discussed above, the system evapotranspiration was determined, which can be observed in the Appendix H in two separate tables to represent the system evapotranspiration for 2011 and 2012. Also located in Appendix H are the results from both the ASCE Penman-Monteith and Hargreaves methods to determine the reference evapotranspiration for the CWTS. The reference evapotranspiration values for both methods are represented in separate tables based on year and method used. A water use coefficient was determined by both of these values, in which several water use coefficient curves were created and can be viewed in Figures 4.3 through 4.6.

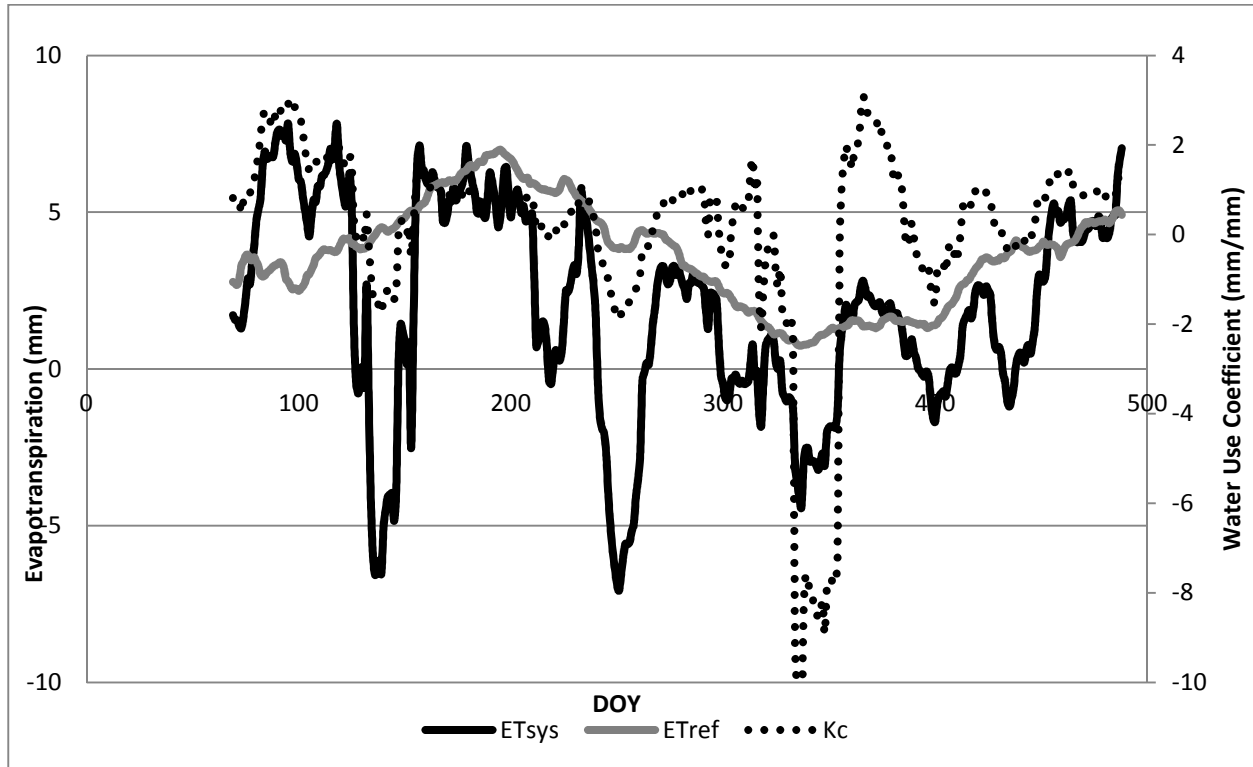


Figure 4.3. Three week running average of system ET (ET_{sys}), reference ET (ET_o), and water use coefficient (K_c), with ET values plotted against the primary y-axis and water use coefficient values plotted against the secondary y-axis for each DOY starting on 3/10/2011 (steady-state) to 5/12/2012. ET_o was determined using the ASCE-Penman Monteith method.

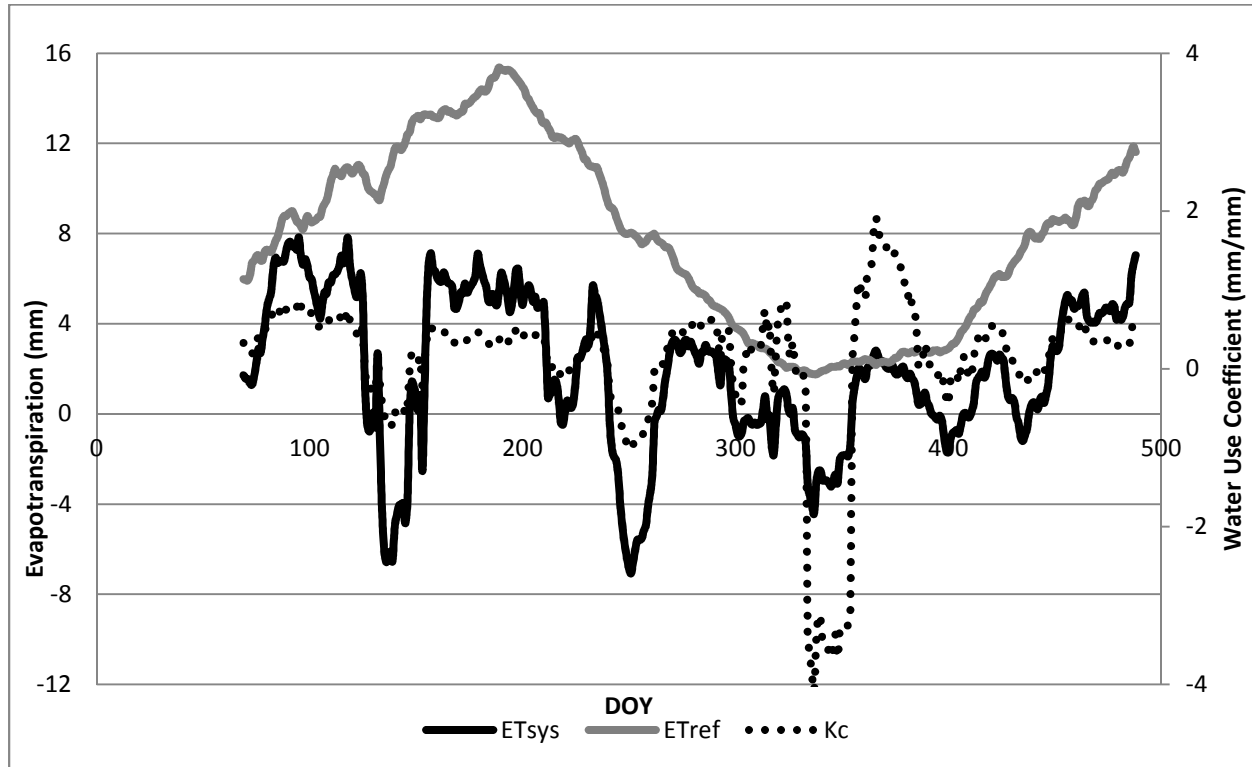


Figure 4.4. Three week running average of system ET (ET_{sys}), reference ET (ET_o), and water use coefficient (K_c), with ET values plotted against the primary y-axis and water use coefficient values plotted against the secondary y-axis for each DOY starting on 3/10/2011 (steady-state) to 5/12/2012. ET_o was determined using the Hargreaves method.

A three week running average was conducted to smooth out the short-term fluctuations for all variables (ET_{sys} , ET_o , and K_c) (Figure 4.3; Figure 4.4). By smoothing out each of the variables, short-term fluctuations were evened out to emphasize the long-term trends that were unable to be determined within the short amount of time data was collected at JEC. ET_{sys} was determined using a water balance and is denoted by the bold, black line. For the water balance, the change in storage was assumed zero in order to determine the system ET; therefore, when unsteady state occurred throughout the research period, this effected the change in system ET throughout the year. The dramatic spikes within Figures 4.3 and 4.4 are the result of the unsteady state. The ASCE-Penman Monteith (Figure 4.3) and Hargreaves methods (Figure 4.4) were both used to calculate ET_o , where both methods increase and decrease with correlating increasing and decreasing temperatures, showing less water is lost through evapotranspiration during the winter months and more during the summer. It should be noted that the Hargreaves

method over estimates ET values, due to less weather data applied, which can result in a higher ET_o . As a result of both ET_{sys} and ET_o , the water use coefficient, K_c , was determined and changes as both these variables change throughout the year.

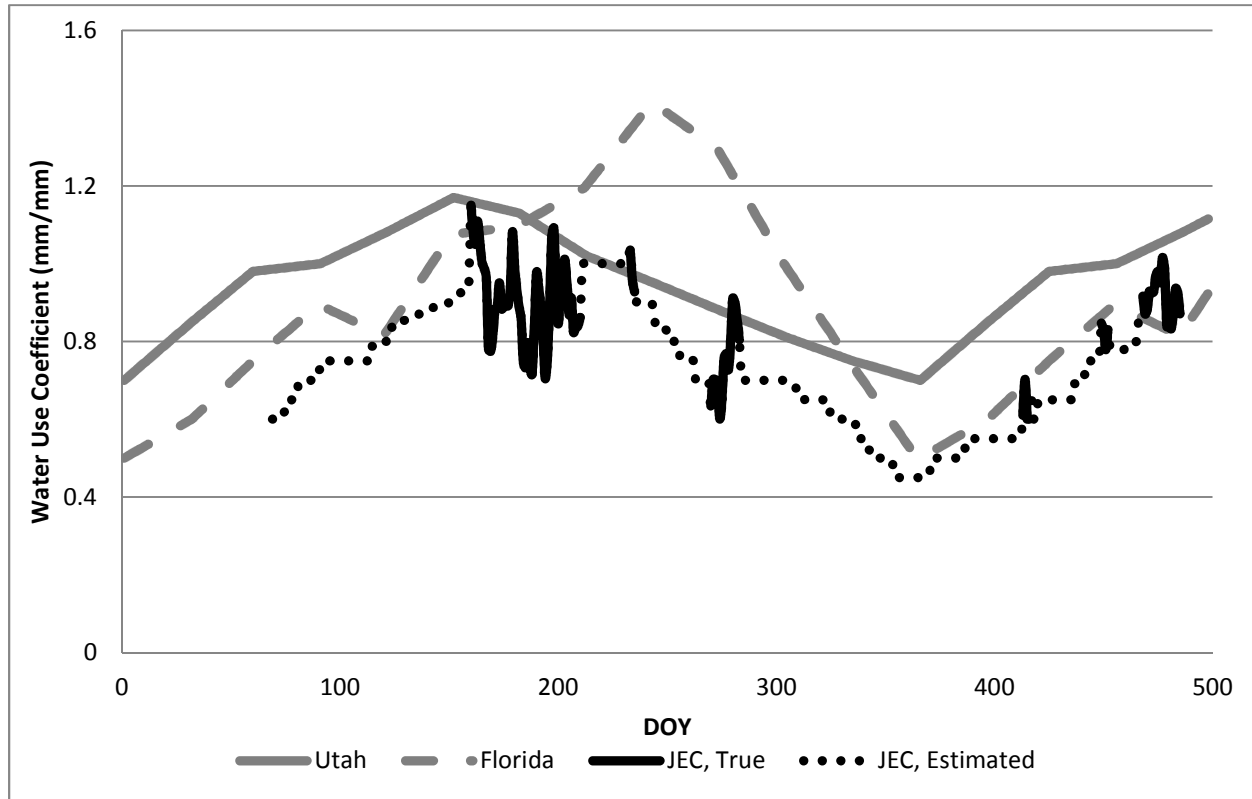


Figure 4.5. Water use coefficients from Utah, Florida, and Jeffrey Energy Center are compared from 3/10/2011 (steady-state) to 5/12/2012. Estimated water use coefficients are shown in the dotted line. ET_o determined using the ASCE Penman-Monteith method.

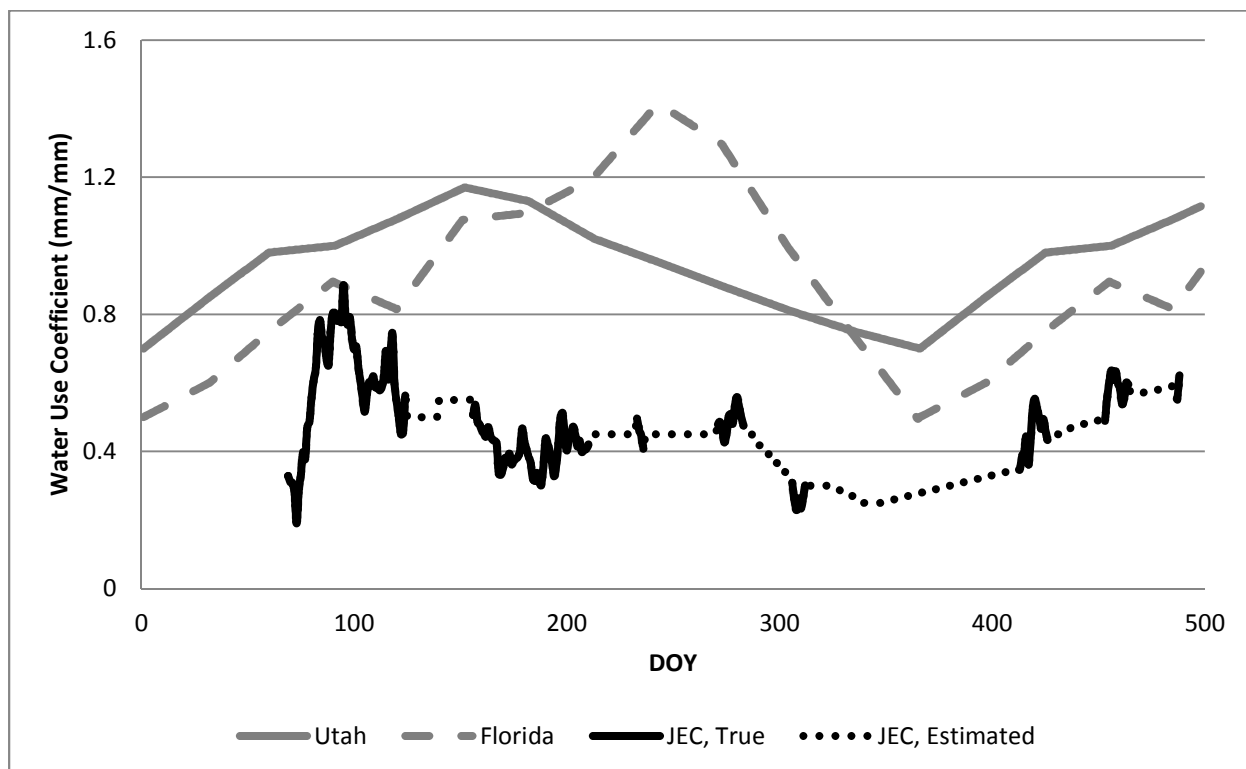


Figure 4.6. Water use coefficients from Utah, Florida, and Jeffrey Energy Center are compared from 3/10/2011 (steady-state) to 5/12/2012. Estimated water use coefficients are shown in the dotted line. ET_0 was determined using the Hargreaves method.

Figures 4.5 and 4.6 represent three separate water use coefficients developed for constructed wetlands located in Utah, Florida, and Jeffrey Energy Center (Kansas) (Kadlec, 1989), where Figure 4.5 uses the ASCE Penman-Monteith method for calculating ET_0 and Figure 4.6 uses Hargreaves. From both figures, the grey lines represent the Utah and Florida water use coefficients, while the black, bold line represents the three-week running average water use coefficient starting on 3/10/2011, while the dotted line shows the estimated water use coefficients determined for the CWTS at JEC. The Utah and Florida K_c values were used as a reference to compare the K_c developed at JEC. Because of a lack of repeatability over many growing seasons, the true K_c values for JEC are inconsistent over the time of research compared to the water use coefficients for Utah and Florida; therefore, during times where JEC K_c values were extreme due to unsteady state, an estimated K_c value was calculated in order to determine an overall water use coefficient for JEC. Unsteady state over the short research period is one of the main factors for extreme variability throughout the years. Other factors, including

immaturity of plants, small root zone, climate, and size of system, also could have affected the JEC K_c values to be more or less than Utah and Florida's K_c .

During times of steady-state when everything was working properly, such as DOY 150 to 200, the true K_c values are below both Utah and Florida's K_c values, but still within a reasonable range for water use coefficients. Figure 4.5 has water use coefficients closer in resemblance to Utah and Florida, because it is using a ET_0 determined by the ASCE Penman-Monteith method, which uses more weather data and in theory, can be more accurate compared to other ET_0 methods. In Figure 4.6, the true K_c values are not as equivalent to both Utah and Florida's K_c values, because the Hargreaves method was used to determine the ET_0 . The Hargreaves method uses less weather data compared to the ASCE and tends to overestimate the ET_0 . As a result, during times of extreme ET_{sys} , the K_c values with a Hargreaves ET_0 are much lower compared to Utah and Florida's K_c . Depending on how the ET_0 is computed, either with the ASCE Penman-Monteith or Hargreaves, this determines which water use coefficient to use. For example, at JEC, there is an on-site weather station that records the necessary data needed to compute both ASCE Penman-Monteith and Hargreaves method, but the weather station automatically records a reference ET using the ASCE Penman-Monteith method; therefore, the water use coefficient used at JEC should be dependent on the ASCE Penman-Monteith ET_0 .

At Jeffrey Energy Center, the main use of determining a water use coefficient was to assist in the scale-up of the pilot scale wetland to a full scale wetland; therefore, a water use coefficient ranging from 0.45 to 1.10 mm/mm, with a reference ET determined using the ASCE Penman-Monteith method, is proposed (Figure 4.7). During colder temperatures, the lower water use coefficients will be used as compared to warmer temperatures when the larger water use coefficient are used, due to more water being lost through evapotranspiration. As discussed in Chapter 2, for large constructed wetlands, the reference ET can be used as an equivalent to the system ET; however, for Jeffrey Energy Center, it is not recommended to use a reference ET as the system ET, especially with Hargreaves reference ET, because the amount of water lost through evapotranspiration would be extremely over estimated.

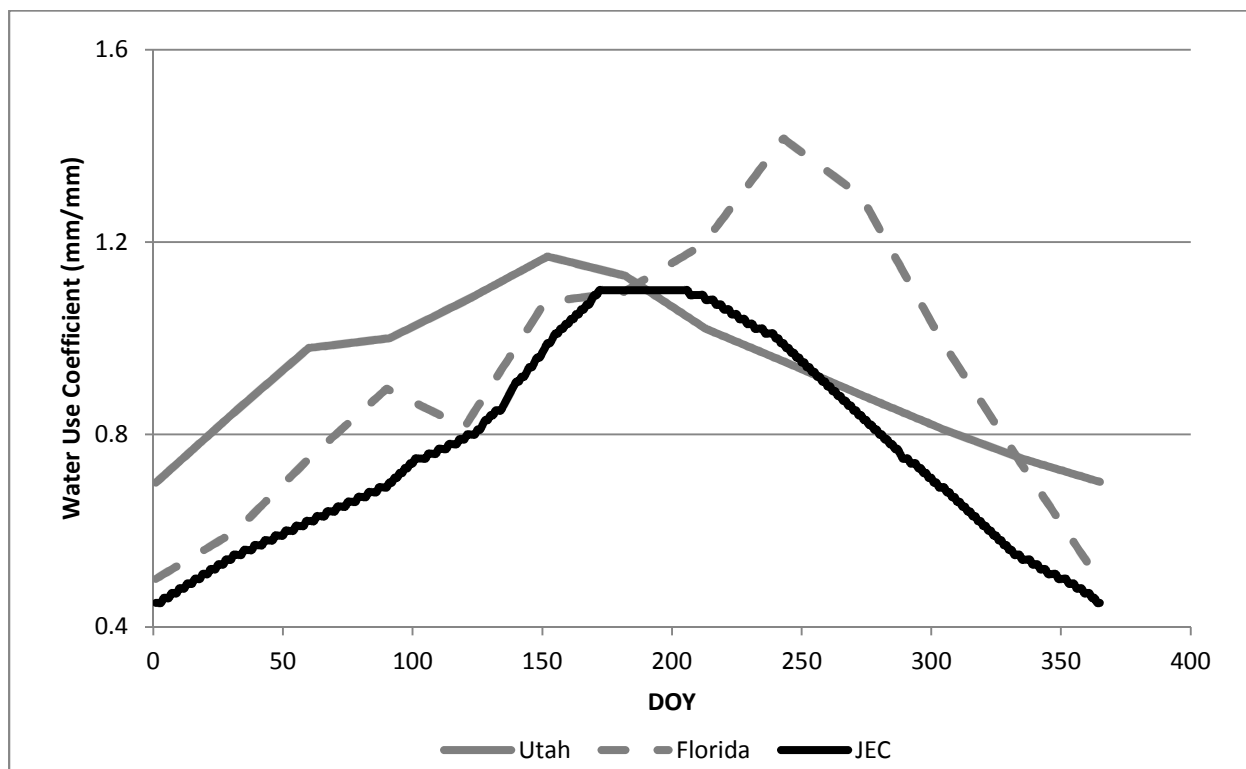


Figure 4.7. Proposed water use coefficient for JEC from 0.45 to 1.10 mm/mm using a ASCE Penman-Monteith ET_0 .

Water Sampling Results

As discussed earlier, several water samples were taken from different locations located on the CWTS at JEC and shipped to CAS for laboratory testing. All the water sampling data collected from CAS can be found in Appendix I. Pollutant concentration information was used to create mass balances for the CWTS to determine how well the CWTS was functioning based on removal of pollutants.

Mass Balances for Seven Pollutants

The seven main pollutants of concern for the CWTS at JEC include the following: boron (B), manganese (Mn), mercury (Hg), selenium (Se), chloride (Cl^-), fluoride (F^-), and sulfate (SO_4^{2-}). The incoming and outgoing mass concentrations, total mass concentration removed, weekly percentage of constituent removal, and running totals for incoming and outgoing mass

concentration amounts were determined for each pollutant and plotted to show the ability of the CWTS to remove each pollutant.

Boron

Boron was one of the main pollutants tested for in the water samples, in which Figures 4.8 to 4.10 represent the necessary data to determine the ability of the CWTS to remove this non-metal. Extra figures for boron can be found in Appendix I.

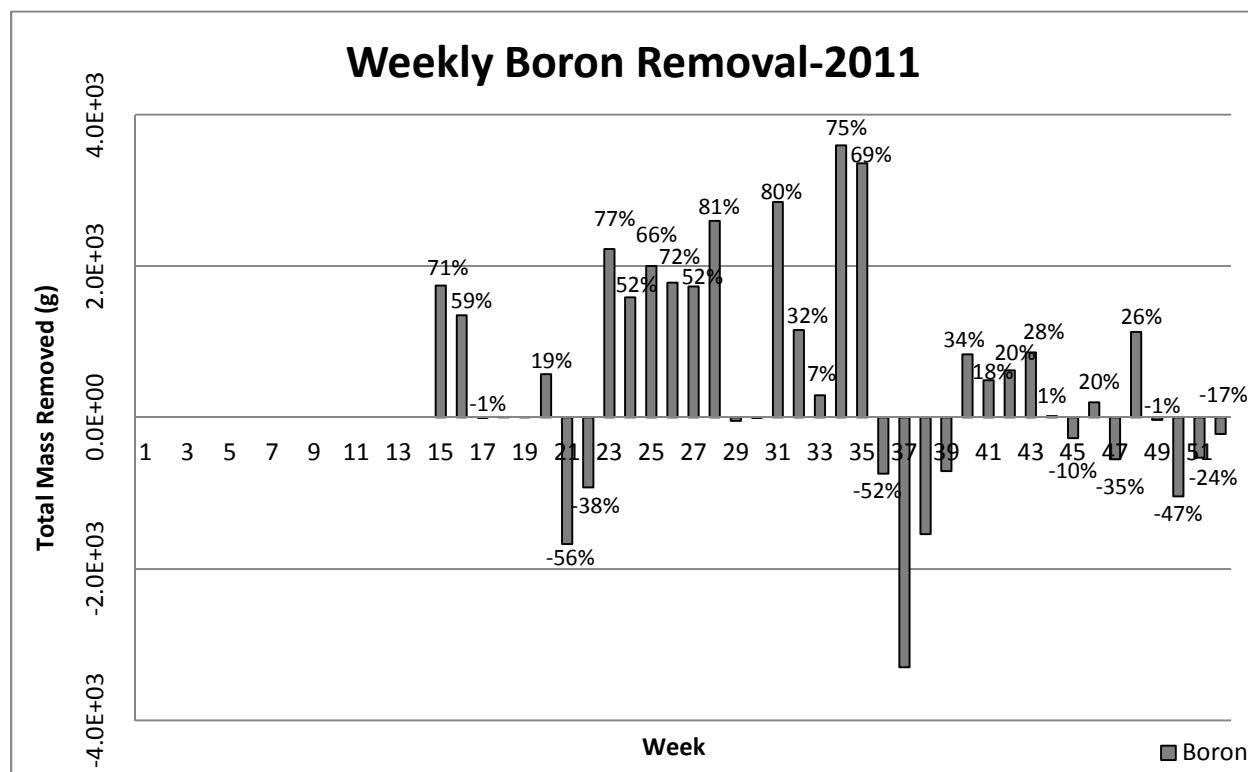


Figure 4.8. Weekly total boron mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

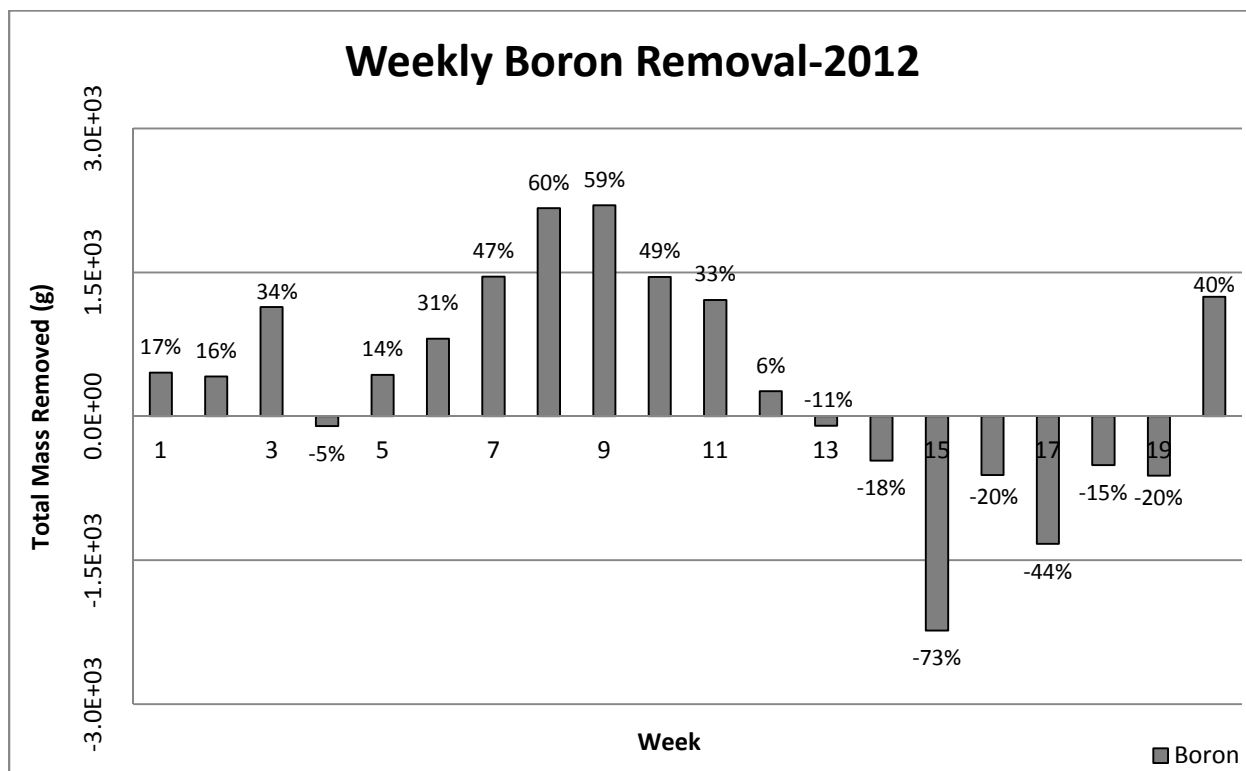


Figure 4.9. Weekly total boron mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Overall, boron removal from week to week varied throughout the research period. In 2011, during times of steady state, such as weeks 23 thru 28, the CWTS was consistently removing about 50% or above of boron; however, when there were times of unsteady flow, boron removal decreased greatly, even allowing some boron to be released. In 2012, boron removal also varied throughout the year; however, these values were not as strongly correlated to steady state flow as well as it was for 2011.

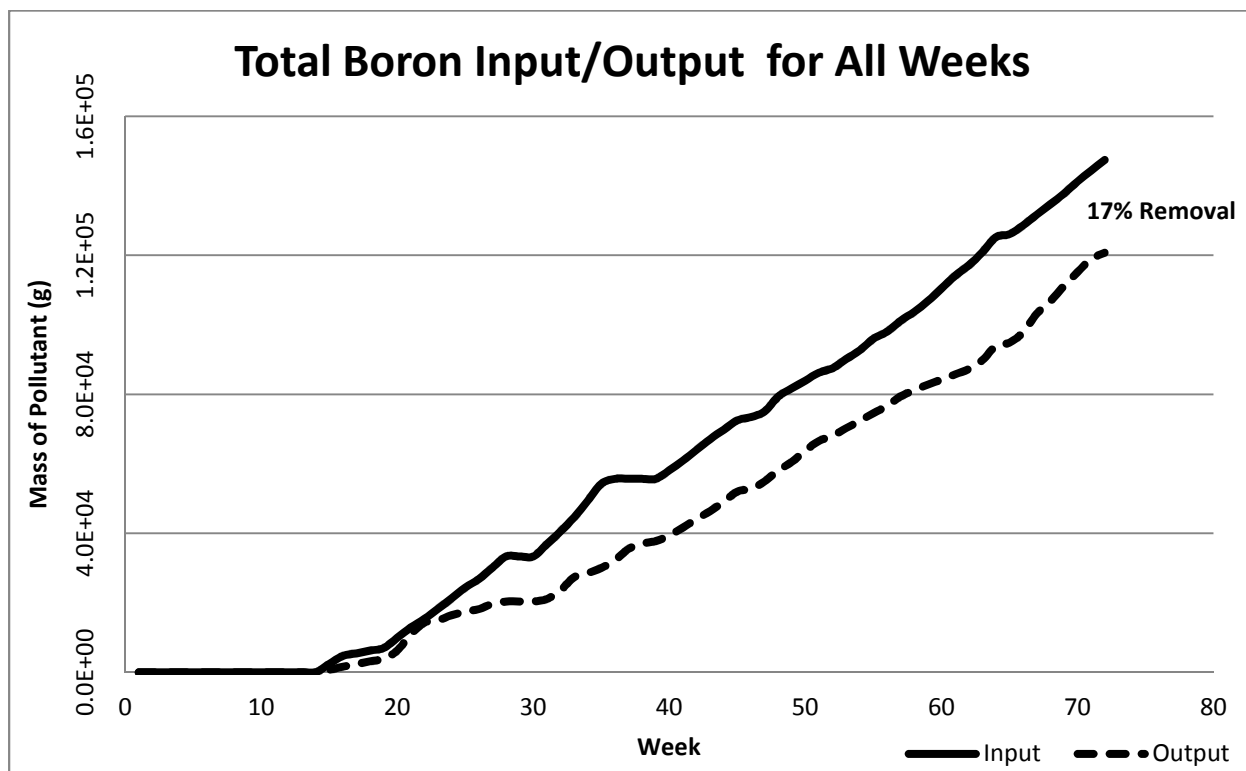


Figure 4.10. The running total of input and output for the mass of boron for all weeks the CWTS was being researched.

Figure 4.10 represents the total input and output of boron over the course of the research time. Roughly 147,500 g (325 lb) of boron entered the CWTS, while about 120,600 g (266 lb) of boron was released by the CWTS. Overall, over the course of the research time for the CWTS at JEC, the amount of boron removed averaged about 17%. Less than a quarter of the boron entering the CWTS was removed from the wastewater and retained within the wetland system by either the plants and/or soil. Over time, boron can become toxic to plants, which will allow less boron to be taken up by the plants and stored for a long period of time. In 2012, less boron was removed, which could be a result of plant toxicity increasing due to larger amounts of boron entering the CWTS; therefore, in order to allow more boron to be retained, the plants in the wetland system would have to be taken out and new plants would need to be planted.

According to Kansas Department of Health and Environment (KDHE), there is no criterion available for boron concentrations for acute and chronic aquatic life. Because of this, no regulations are put on the amount of boron leaving the CWTS to Lost Creek which eventually discharges into the Kansas River and possibly cause downstream issues. One main downstream

issue is many farmers and towns use the Kansas River as a source of irrigation and drinking water, in which KDHE does have a criterion for irrigation water. If water is used for livestock and irrigation agricultural purposes, the criteria for boron are 5,000 $\mu\text{g/L}$ (4.2×10^{-5} lb/gal) and 750 $\mu\text{g/L}$ (6.3×10^{-6} lb/gal), respectively. The average weekly effluent boron concentration leaving the CWTS was about 2,662 $\mu\text{g/L}$ (2.22×10^{-5} lb/gal); therefore, the average weekly effluent boron concentrations meets KDHE's water criteria for livestock water use, but not for irrigation water use.

Manganese

Manganese is another one of the seven pollutants tested for with the water samples. Figures 4.11-4.13 represent the data collected from the water samples and graphical representation to determine the capability of manganese removal by the CWTS. Extra graphs can be viewed in Appendix I.

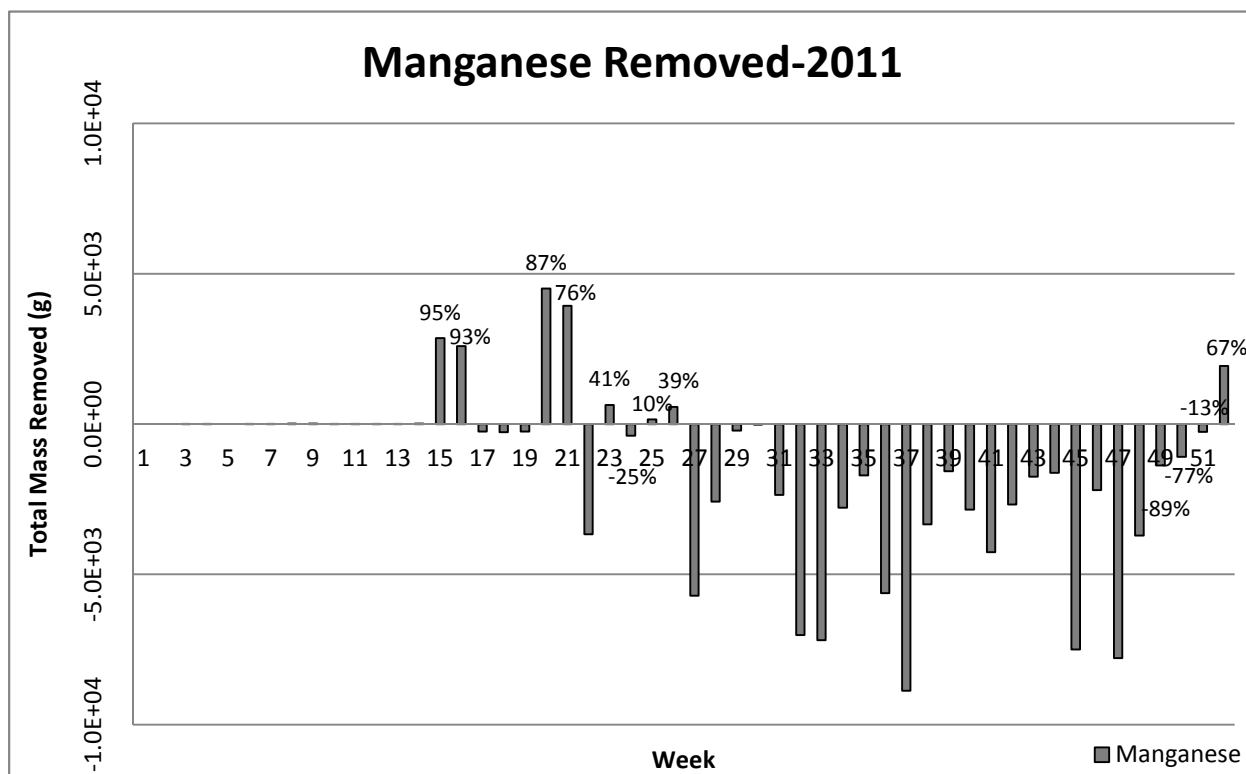


Figure 4.11. Weekly total manganese mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Figure 4.11 represents the weekly total manganese mass removal, in grams, for 2011, in which each bar has a percentage removal value above itself representing the percentage of manganese removed for a specific week; however, with manganese, most of the bars in the figure do not have a percentage above each bar, because the manganese removal in 2011 resulted in a weekly percentage removal over -100%. The first 14 weeks of 2011 resulted in positive total manganese removal, but the values are extremely small, ranging from 0-20 g (0-0.044 lb) removed weekly, which is the reason the bars for these weeks barely appear on the figure. Manganese removal at the beginning of the research period, between weeks 15-21, were high; however, despite these high manganese removals, overall manganese was not removed week to week in 2011.

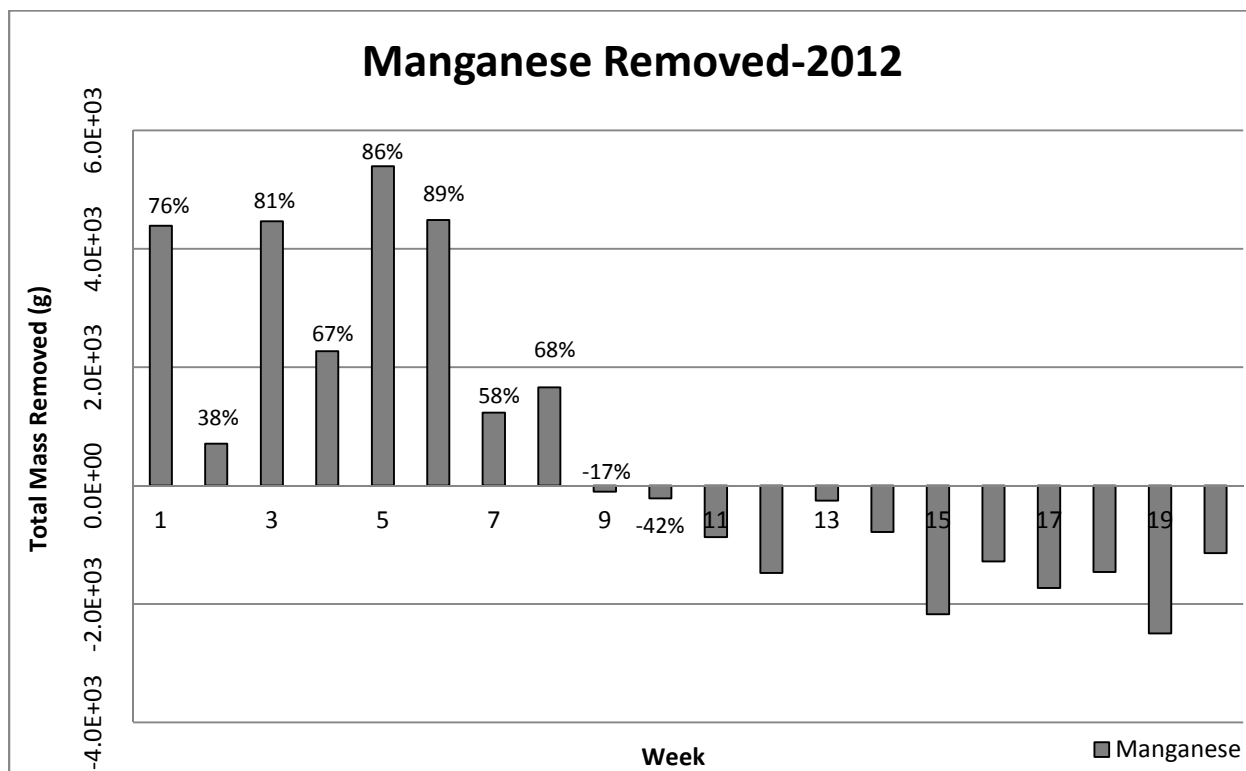


Figure 4.12. Weekly total manganese mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Figure 4.12 represents the weekly manganese removal in 2012. Despite no removal of manganese occurring in the winter months of 2011, the beginning of 2012, from weeks 1 thru 8, manganese was actually being removed at an average weekly removal of about 70%. Even with removal of manganese that occurred at the beginning of 2012, manganese was not being removed by the end of the research in 2012.

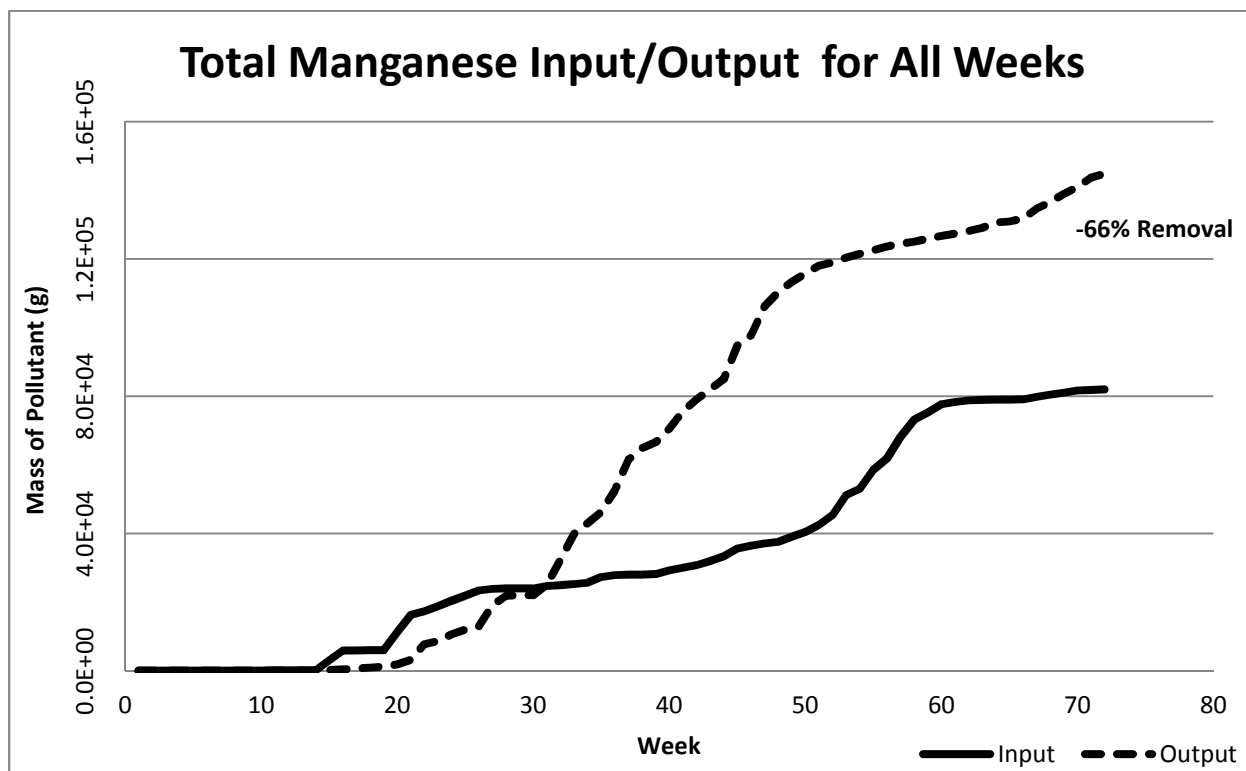


Figure 4.13. The running total of input and output for the mass of manganese for all weeks the CWTS was being researched.

Figure 4.13 shows the overall amount of manganese input and output for the CWTS. Clearly, manganese was not removed overall and more manganese was released than was actually input into the CWTS. About 82,000 g (181 lb) of manganese was input, while 144,900 g (319 lb) was released by the CWTS; therefore, the overall removal of manganese by the CWTS was about -66%. The negative removal of manganese occurs from the manganese located on the exchange sites of soil particles that are released during anaerobic conditions. Under anaerobic conditions, selenium bind to the exchange sites located on soil particles, releasing the already present manganese into the effluent; therefore, more manganese was released with the effluent than the amount that entered the CWTS, due to the presence of manganese within the wetland before the addition of the wastewater. Through KDHE, manganese does not have a criteria concentration for aquatic life, agricultural, and/or public health parameters, and typically only has an effect on the taste of water.

Mercury

Along with boron and manganese, mercury was another main pollutant tested for in the CWTS at JEC. Mercury was removed 100% each week in 2011 and 2012, minus a couple of weeks (Appendix I).

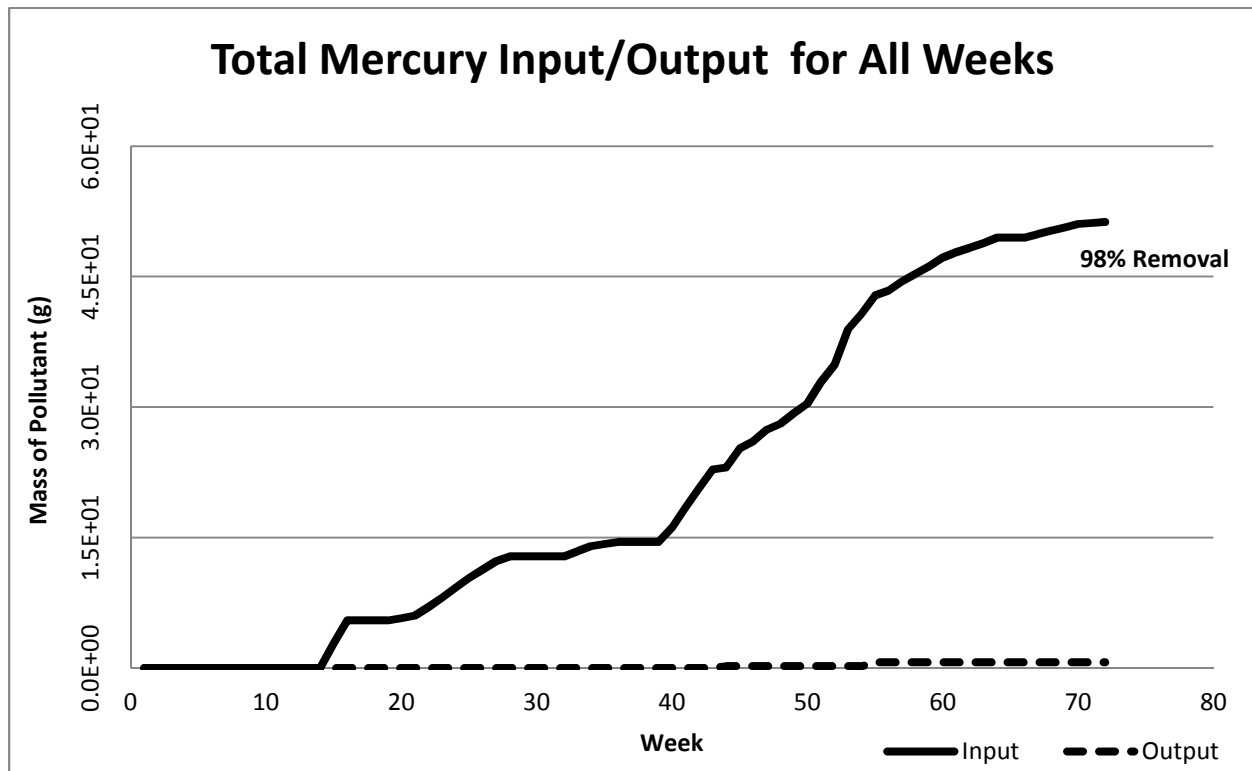


Figure 4.14. The running total of input and output for the mass of mercury for all weeks the CWTS was being researched.

Figure 4.14 shows the total input and output of mercury for all the weeks of research. About 51 g (0.11 lb) of mercury entered the CWTS, while less than 1 g (0.002 lb) of mercury was released; therefore, overall 98% of mercury was removed by the CWTS.

Mercury is a dangerous pollutant monitored by KDHE and has several criteria for different purposes. In this case, the remaining 2% of mercury which was released from the CWTS must meet the KDHE aquatic life criterion for acute and chronic parameters of 1.4 $\mu\text{g/L}$ (1.17×10^{-8} lb/gal) and 0.77 $\mu\text{g/L}$ (6.43×10^{-9} lb/gal), respectively. The average weekly effluent

mercury concentration was about 0.001 µg/L (8.35×10^{-12} lb/gal); therefore, there was no violation with effluent mercury concentrations from the CWTS at JEC.

Selenium

Selenium was another main pollutant tested for in the CWTS located at JEC. Selenium was the main pollutant, along with mercury, the CWTS was designed to remove in order to prevent environmental hazards downstream once the water was released from the CWTS; therefore, the ability of the CWTS to remove selenium was justified in Figure 4.15-17, with extra figures located in Appendix I.

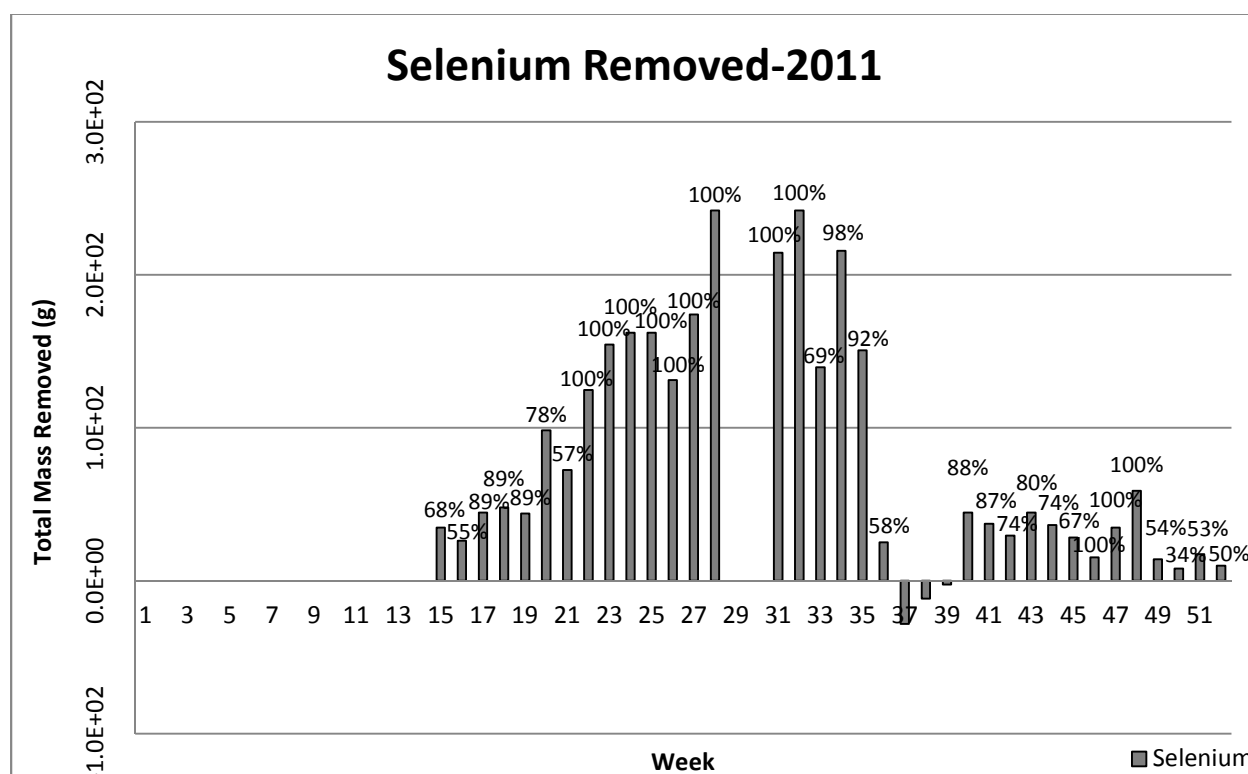


Figure 4.15. Weekly total selenium mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

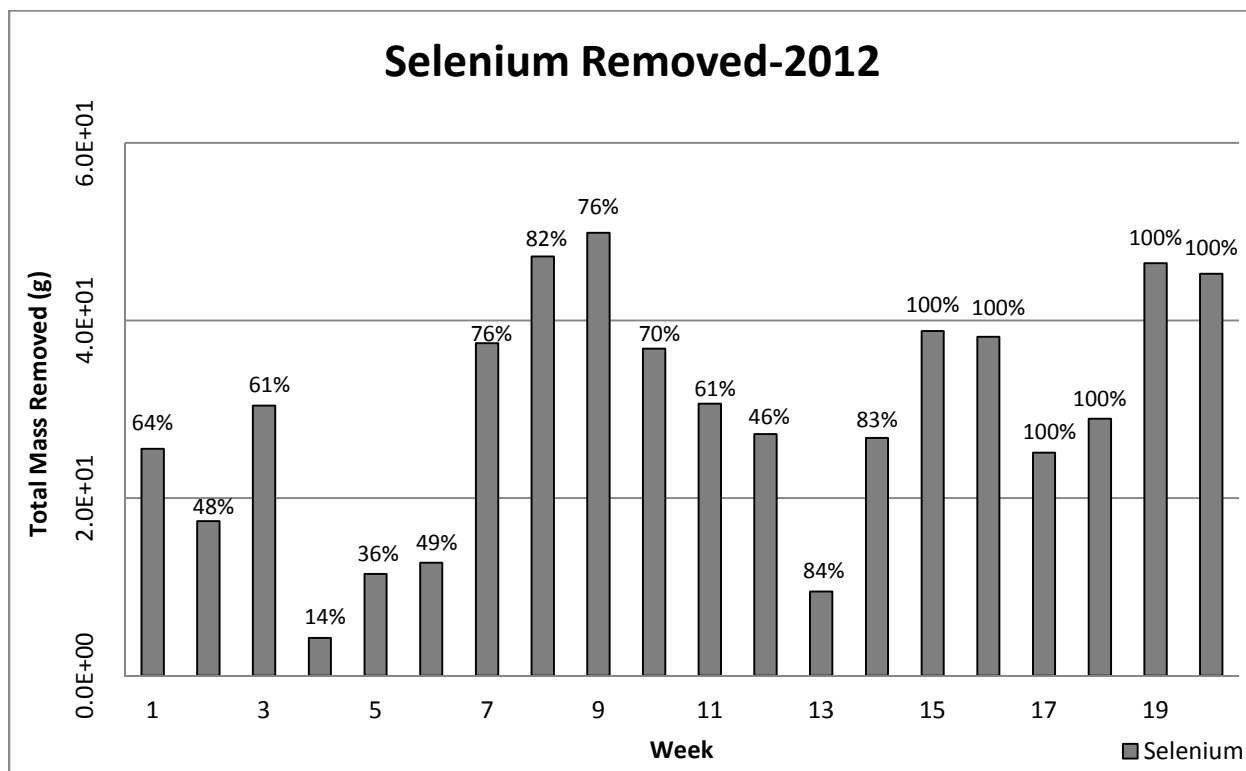


Figure 4.16. Weekly total selenium mass removal, in grams, for 2012 until May 22nd.
Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Overall, selenium was removed each week during 2011 and 2012, with some weeks of release or no removal of selenium occurred. From both figures, it appears more selenium is removed during periods within the year where there are warmer temperatures.

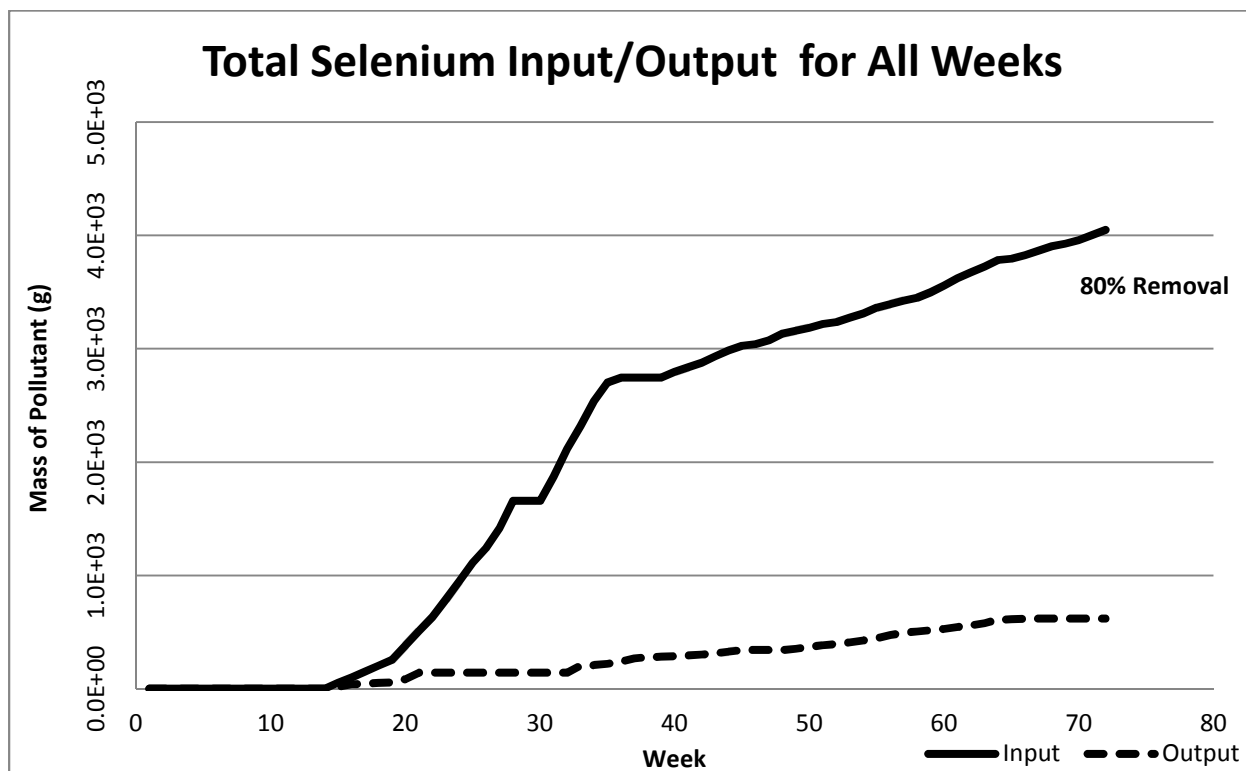


Figure 4.17. The running total of input and output for the mass of selenium for all weeks the CWTS was being researched.

In Figure 4.17, the total selenium input and output from the CWTS over all the weeks of research can be viewed. The total input of selenium was 4065 g (9 lb), while 620 g (1.4 lb) of selenium was released by the CWTS. Overall, the CWTS at JEC was able to remove on average about 80% of the selenium input, allowing only 20% to leave the wetland system. In order to remove more selenium within the wetland cells, some changes were made on the wetland system to ensure as much selenium removal as possible. Selenium was in the form of selenite as it entered the wetland system, but in order to retain selenium within the wetland system, the cells were converted from aerobic cells to anaerobic cells, which allowed selenite to reduce to elemental selenium. By doing this, the elemental selenium was held better within the soil particles and less was released by the CWTS; however, the absolute level of selenium must meet KDHE water quality criteria. For aquatic life, the amount of selenium allowed is 20 $\mu\text{g/L}$ (1.67×10^{-7} lb/gal) for acute and 5 $\mu\text{g/L}$ (4.17×10^{-8} lb/gal) for chronic exposure. For the CWTS at JEC, the average weekly output of selenium was about 8.85 $\mu\text{g/L}$ (7.39×10^{-8} lb/gal). Therefore, the CWTS meets KDHE's criterion for acute aquatic life, but not for chronic aquatic life.

Chloride

Chloride was another main pollutant tested for in the CWTS at JEC. At high concentrations, chloride can be extremely harmful to plants; therefore, chloride was one of the main reasons the FGD wastewater was diluted with RAW water from the lake on-site. Figure 4.18 thru 4.20 depict graphically the ability of the CWTS to remove chloride, with extra figures found in Appendix I.

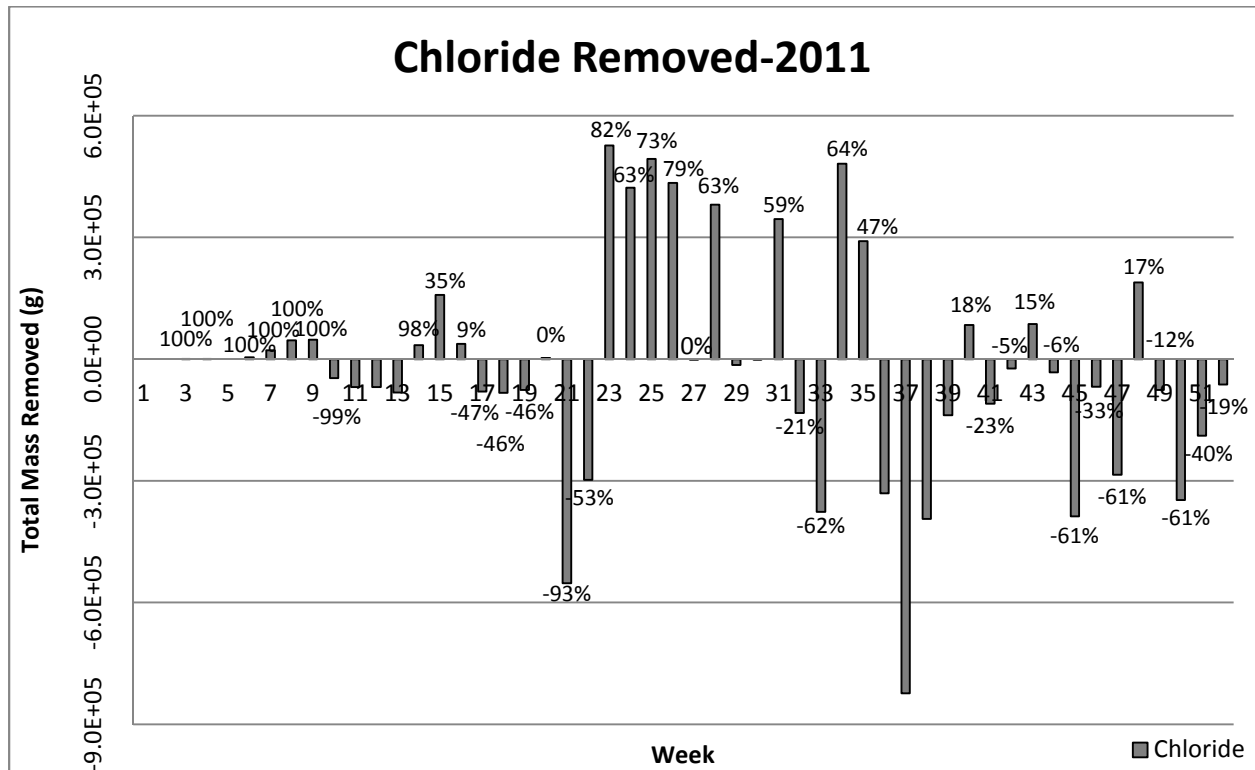


Figure 4.18. Weekly total chloride mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

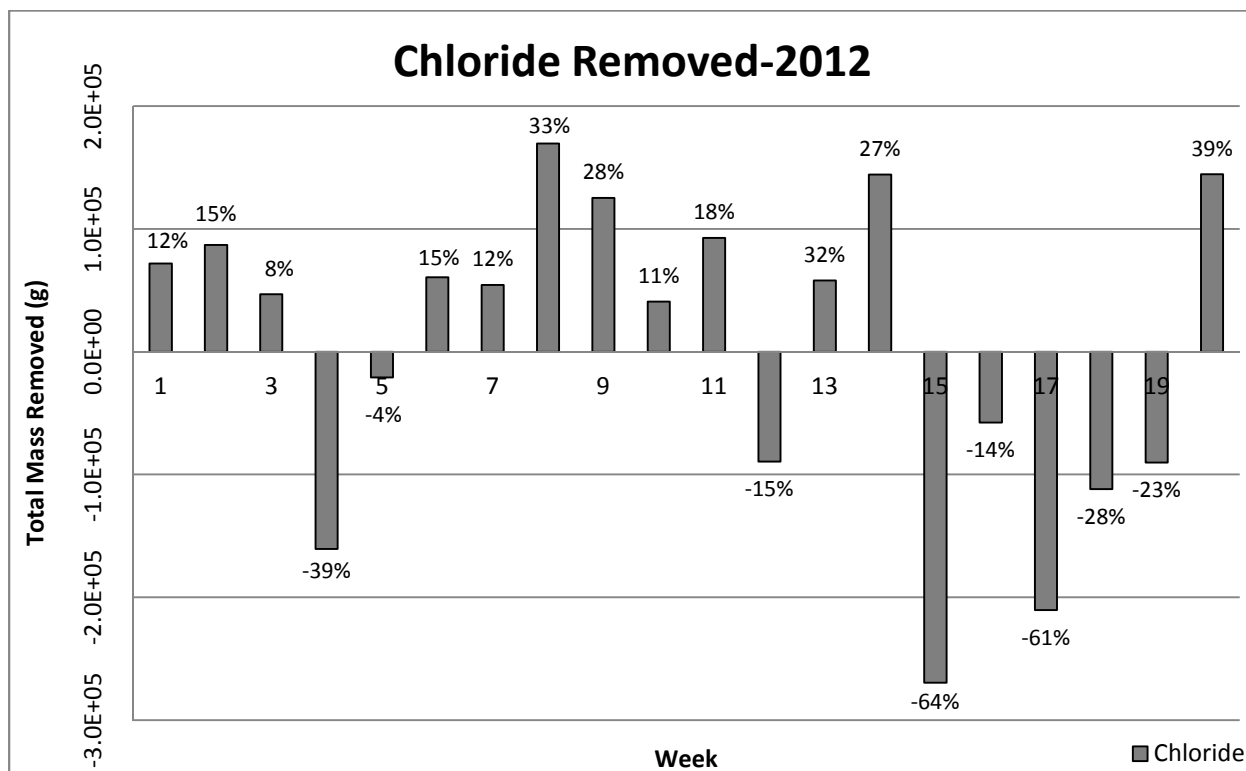


Figure 4.19. Weekly total chloride mass removal, in grams, for 2012 until May 22nd.

Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Throughout 2011 and 2012, chloride weekly removals varied week to week, showing no consistent removal or accumulation of chloride overall.

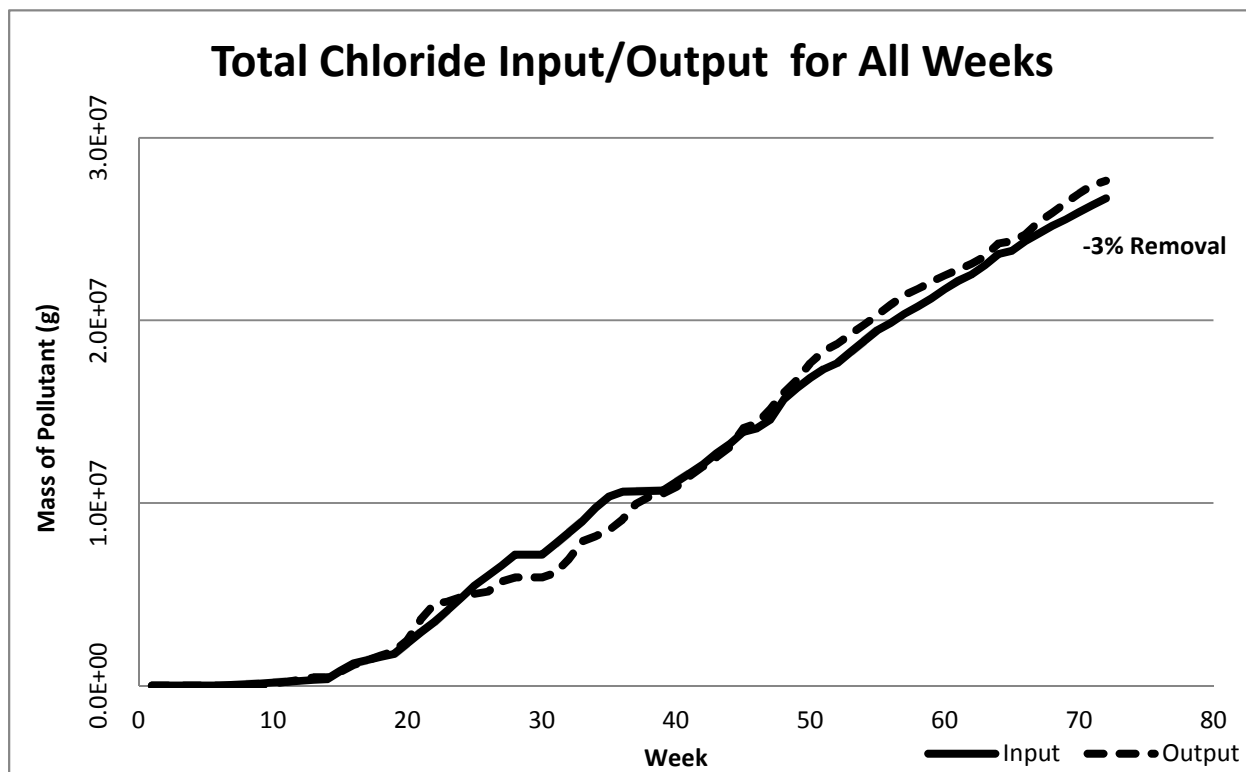


Figure 4.20. The running total of input and output for the mass of chloride for all weeks the CWTS was being researched.

Figure 4.20 presents the cumulative chloride input and output for all weeks of research. Throughout these weeks, an overall input of chloride was about 26,730,000 g (58,930 lb), while 27,650,000 g (60,958 lb) of chloride was released by the CWTS; therefore, the amount of chloride leaving the CWTS was 3% greater than the amount entering over the course of the project. Chloride has criteria for both acute exposure of aquatic life $860,000 \mu\text{g/L}$ (7.18×10^{-3} lb/gal) and domestic water supply $250,000 \mu\text{g/L}$ (2.09×10^{-3} lb/gal) through KDHE. The average weekly chloride concentration leaving the CWTS was about $514,000 \mu\text{g/L}$ (4.29×10^{-3} lb/gal). Despite the large amounts of chloride not retained within the CWTS at all, the amount of chloride leaving the CWTS was still under KDHE's criterion for acute exposure of aquatic life, but not for domestic water supply.

Fluoride

Fluoride, a simple anion of fluorine, was one of the last pollutants tested for in the CWTS at JEC. Fluoride can cause health problems if too much or too little is present within drinking water (Tölgyessy, 1993). Figure 4.21 can be viewed to determine the ability of the CWTS to remove fluoride. Additional graphs can be viewed in Appendix I. Fluoride removal from a week to week basis throughout the course of this project showed constantly high, positive values.

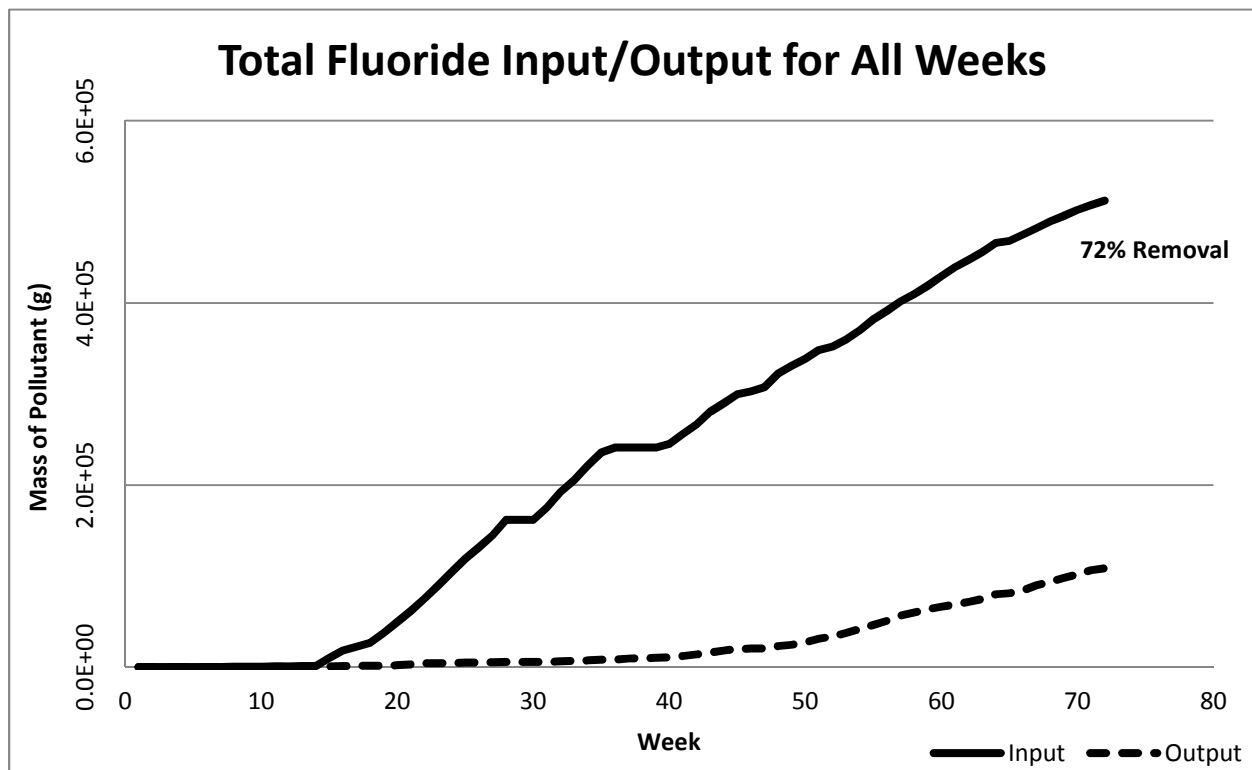


Figure 4.21. The running total of input and output for the mass of fluoride for all weeks the CWTS was being researched.

Figure 4.21 shows the total input and output of fluoride for all weeks. About 512,300 g (1,129 lb) of fluoride entered the CWTS, while 108,500 g (239 lb) of fluoride was in the effluent. Overall, fluoride removal over the course of time by the CWTS was on average about 72%. Fluoride does not have water quality criteria with acute and chronic exposure parameters for aquatic life through KDHE; however, agricultural uses, such as livestock and irrigation, as well as domestic water supply do have fluoride water quality criteria. Fluoride water quality criteria

are set for these three purposes by KDHE probably to ensure the correct amount of fluoride that could be obtained by humans without causing health issues as discussed above. For agricultural purposes, water criteria of fluoride for livestock $2,000 \mu\text{g/L}$ ($1.67 \times 10^{-5} \text{ lb/gal}$) and irrigation are $1,000 \mu\text{g/L}$ ($8.35 \times 10^{-6} \text{ lb/gal}$). Similar to livestock water criteria of fluoride, domestic water supply also has water criteria of $2,000 \mu\text{g/L}$ ($1.67 \times 10^{-5} \text{ lb/gal}$) for fluoride. With the CWTS releasing only 28% of fluoride, the average weekly effluent fluoride concentrations were about $2,797 \mu\text{g/L}$ ($2.33 \times 10^{-5} \text{ lb/gal}$). Despite high removal of fluoride, the average weekly effluent fluoride concentrations were in violation of KDHE water quality criteria for both agricultural purposes and domestic water supply.

Sulfate

Sulfate, a form of sulfur found in aerobic waters, was the last of seven pollutants tested for in the CWTS at JEC. The remaining figures, Figure 4.22 to Figure 4.24, show graphically the ability of the CWTS to remove sulfate from the wastewater before releasing it into Lost Creek and eventually reaching the Kansas River. Extra graphical representation can be viewed in Appendix I.

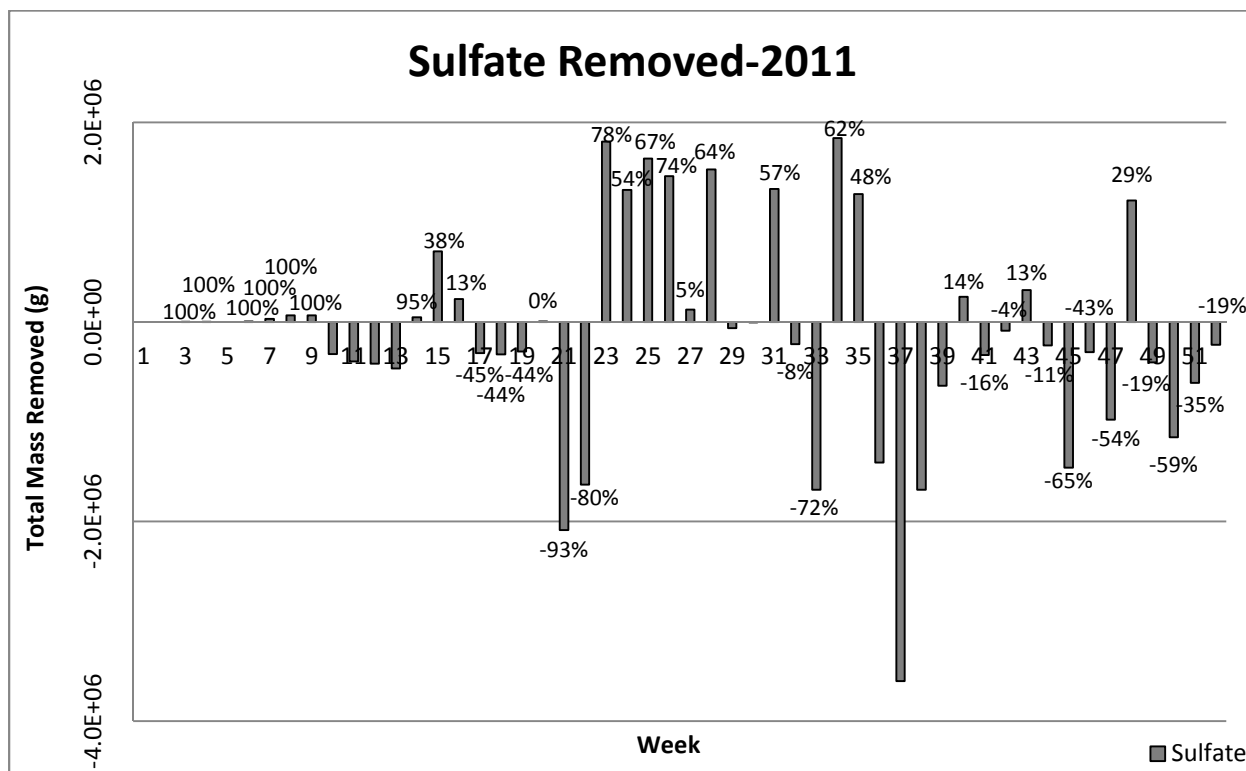


Figure 4.22. Weekly total sulfate mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is beyond a one-hundred value, either positive or negative, unless stated otherwise.

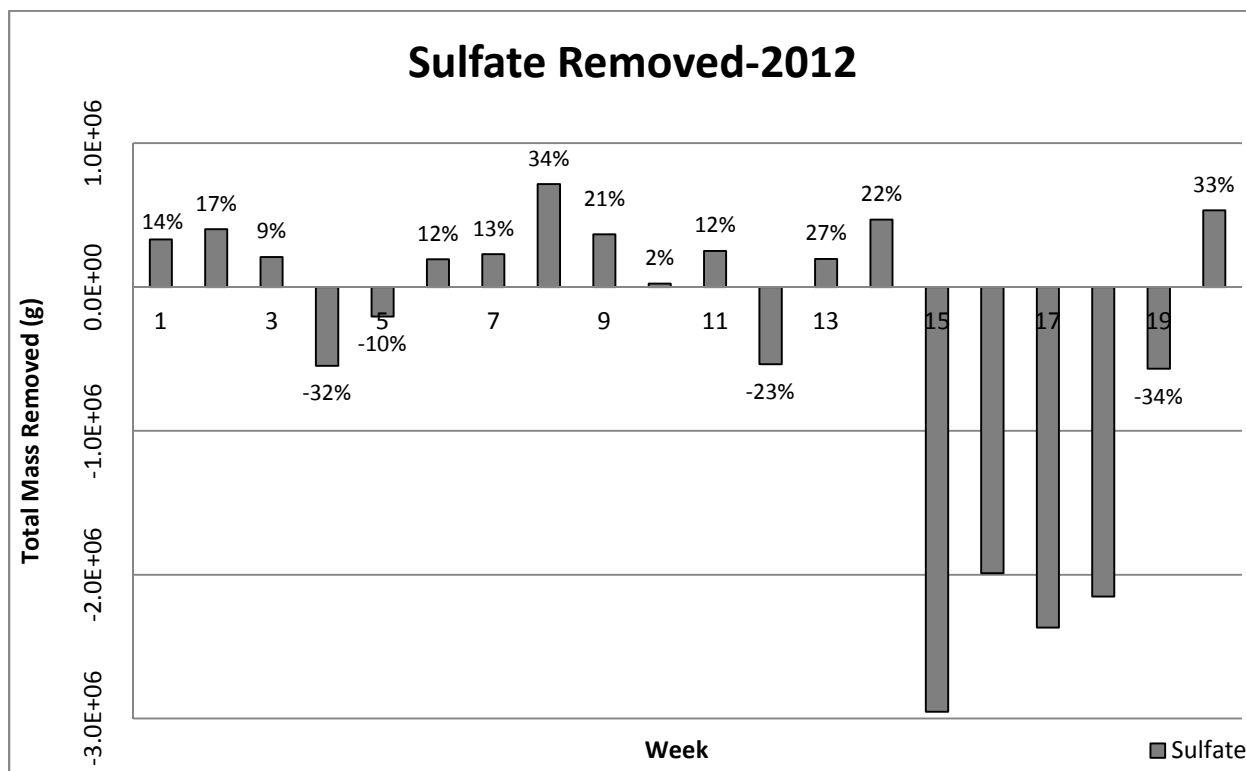


Figure 4.23. Weekly total sulfate mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is beyond a one-hundred value, either positive or negative, unless stated otherwise.

Between Figure 4.22 and Figure 4.23, weekly sulfate removal varies from week to week, where there are some periods of high removal followed by periods of extreme output of sulfate. After week 40 in 2011 and continuing into 2012, there was a constant low weekly removal of sulfate.

Figure 4.24 shows the running total of weekly sulfate input and output for 2011 for the overall mass of sulfate removed by the CWTS. The amount of sulfate entering and leaving the CWTS overall are about the same from the beginning of 2011 until week 20. Starting on week 21, the overall amount of sulfate leaving the CWTS was greater than the overall amount entering and lasted for about four weeks until week 25. From week 26 to week 37, the overall amount of sulfate entering the CWTS was greater than the overall amount of sulfate leaving; however, by week 38 until the end of the year, the overall amount of sulfate leaving exceeded the overall

amount of sulfate entering the CWTS. The overall amount of sulfate that entered the CWTS for 2011 was about 67,400,000 g (148,592 lb), while the overall amount of sulfate that left was about 73,435,000 g (161,896 lb); therefore, the overall amount of sulfate that was removed by the CWTS was about -9%.

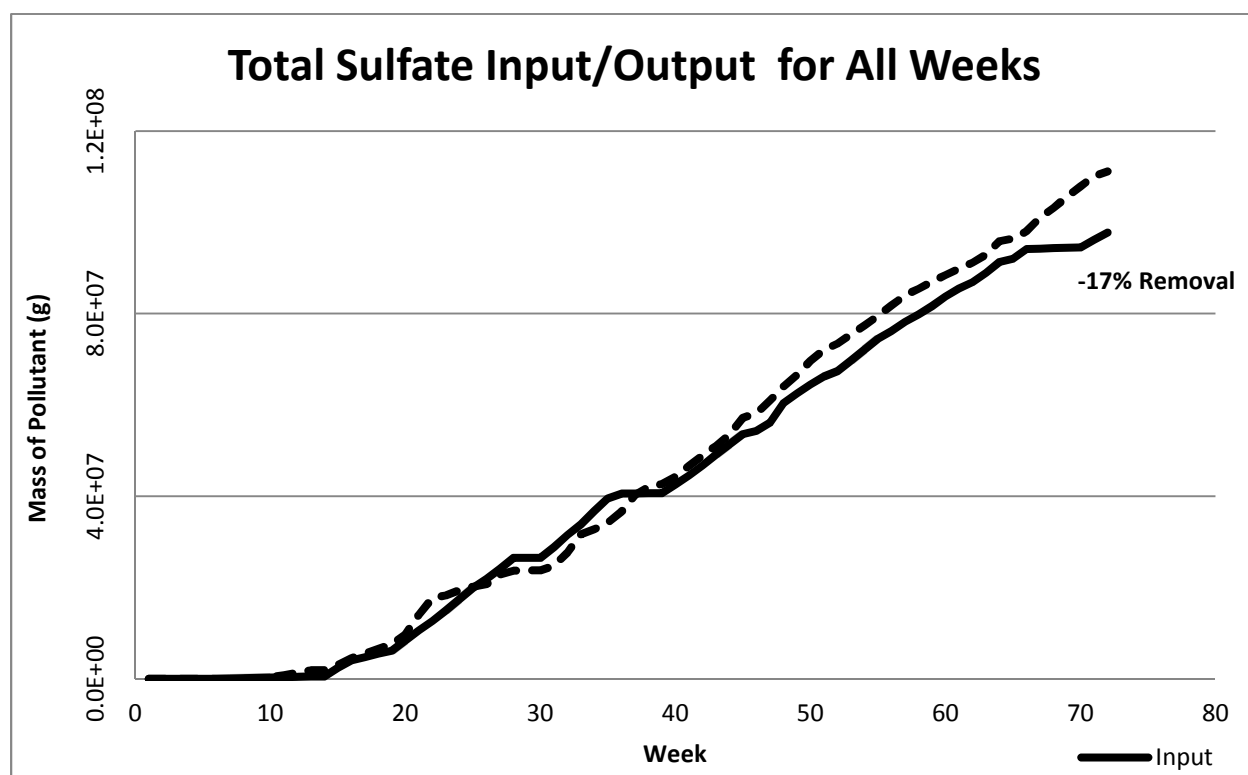


Figure 4.24. The running total of input and output for the mass of sulfate for all weeks the CWTS was being researched.

Figure 4.23 shows the overall input and output of sulfate for all weeks. The total sulfate input into the CWTS was about 97,745,000 g (215,491 lb), while over 110 million grams (24,500 lb) of sulfate was released by the CWTS between 2011 and 2012. Overall, the amount of sulfate removed by the CWTS over the course of time was about -17%, in which more sulfates were generated within the wetland system. According to Kadlec and Knight (1996), sulfur occurs as sulfate in aerobic systems and sulfide in anaerobic systems; however, in order to reduce selenite to elemental selenium, the wetland cells were kept anaerobic, allowing some sulfur to become sulfide. When tested for, sulfide concentrations were always zero for both incoming and outgoing concentrations. Rainwater does contain some amount of sulfate, about 1 to 2 mg/L

(8.345×10^{-6} to 1.67×10^{-5} lb/gal), which could be a source of the excess sulfate (Kadlec and Knight, 1996). KDHE requires two main water criteria for sulfate of 1,000,000 $\mu\text{g/L}$ (8.35×10^{-3} lb/gal) for livestock water use and 250,000 $\mu\text{g/L}$ (2.1×10^{-3} lb/gal) for domestic water supply. The average weekly effluent sulfate concentration was about 2,149,000 $\mu\text{g/L}$ (1.79×10^{-2} lb/gal); therefore, over the entire course of the time, sulfate concentrations were in violation of KDHE's water quality criteria for both livestock water use and domestic water supply.

Overall, the CWTS at JEC had removals of 98% mercury, 80% selenium, and 72% fluoride for the year and a half; however, the remaining four pollutants had much lower removals, including 17% boron, -66% manganese, -3% chloride, and -17% sulfate. The negative removals indicate more pollutants were exported from the CWTS than were imported. As discussed in Chapter 2, constructed wetlands with FGD wastewater have been designed and tested based on the removal of mercury and selenium, in which high removals of both pollutants occurred; however, little to no research has been conducted for CWTS treating FGD wastewater based on the removal of boron, manganese, chloride, and sulfate. Kadlec and Wallace (2009) give multiple examples of wetlands treating other forms of wastewater and the ability of these systems to remove, manganese, chloride, and sulfate, but no data was found on boron removals.

Manganese removal in constructed wetlands shown by Kadlec and Wallace (2009) to vary depending on how large the constructed wetland is and what type of waste it was removing. Constructed wetlands treating coal mine water had manganese removals ranging from 15% to 92% in respect to increasing size of the CWTS, which could be a reason for low removal of manganese at JEC since it was a pilot-scale (Younger, 2000; Hoover *et al.*, 1998). Manganese release from the CWTS at JEC could also be due to the dissolution of manganese oxyhydroxides precipitates in low redox potential, especially in constructed wetlands with sulfate present, manganous ions may precipitate with hydrogen sulfide during sulfate reduction (Kadlec and Wallace, 2009).

Chloride removal is relatively low in constructed wetlands due to a low biological demand for chloride; therefore, the total chloride mass is generally similar between the inflows and outflows in the constructed wetland (Kadlec and Wallace, 2009). Unpublished data from Kadlec and Wallace (2009) give multiple examples of constructed wetlands ranging from a

year's worth of data up to ten years of data both show little to no change in incoming and outgoing chloride concentrations. Sulfate removal is also relatively low in constructed wetlands, because the incoming concentration of sulfate typically exceeds the biological requirements of wetland species; therefore, wetlands are generally not an effective form to remove sulfate (Wieder, 1989). Data from 32 wetlands in Kadlec and Wallace (2009) have a median sulfate reduction of around 14%, with only a few wetlands having more than a 50% reduction that may be associated with anaerobic conditions.

With evidence from other constructed wetlands, it is not uncommon to see such low removals of chloride and sulfate; however, manganese removal through constructed wetlands is typically higher than seen in the CWTS at JEC. Overall, JEC CWTS had high removals of mercury, selenium, and fluoride, with low removals of boron, manganese, chloride, and sulfate; however, low chloride and sulfate removals are typical of most constructed wetlands.

Chapter 5 - Conclusions and Recommendations

With a large amount of electricity being generated by coal-fired generation power plants in the United States, more air pollution is being reduced with the use of flue gas desulfurization (FGD) systems or scrubbers. In FGD systems, limestone slurry is sprayed simultaneously as flue gas is being released through smoke stacks in order to adsorb sulfur dioxides and nitrous oxides to water particles in the limestone slurry. Thus, instead of releasing these harmful pollutants into the air, these pollutants are transferred to water pollution problems. Increasing interest from the media and public, as well as increased environmental regulations, have increased the need for more research to assist in the development and implementation of new technologies to minimize environmental issues from FGD wastewater. Currently, several wastewater treatments are used to reduce pollutant concentrations found within the wastewater before releasing the water back into the natural watershed. However, there is limited research of the use and performance of these treatments. Some of the wastewater treatments used over a broad spectrum of coal-fired power plants include physical/chemical process, biological treatment systems, zero-liquid discharge, deep-well injection, and constructed wetlands.

Jeffrey Energy Center, located north of St. Mary's, KS, is currently the largest coal-fired generation plant in the state. A pilot-scale constructed wetland treatment system (CWTS) was implemented to remediate FGD wastewater after it was pretreated with a basic physical/chemical wastewater treatment system. The objectives of this study included: (i) evaluate the use of a portable, water quality meter for assessing wastewater in the field; (ii) develop a water balance for the CWTS; (iii) generate a water use coefficient for the CWTS; and (iv) create a mass balance of the pollutants of concern.

Water quality measurements were taken using a HORIBA U-50 Series Multi Water Quality Checker (Horiba, Ltd., Kyoto, Japan) and included temperature, pH, ORP, conductivity, turbidity, DO, TDS, and salinity. Along with water quality measurements, data was downloaded from an onsite flow meter to determine the effluent flowrate of the wetland. The effluent flowrate assisted in determining the overall water balance of the CWTS as well as the system ET. A Vantage Pro2™ weather station (Davis Instruments, Hayward, California) was located onsite and collected hourly weather data. Data from the weather station was downloaded and

further analyzed to determine the reference ET of the CWTS. Water sampling was conducted throughout the CWTS and wastewater treatment building at JEC to determine influent and effluent pollutant concentration.

In general, there was little to no relationship between the HORIBA water quality measurements and the analytical water tests conducted by CAS; therefore, it was recommended to continue analytical water tests to determine changes in pollutant concentrations. The R^2 values for each water quality measurement compared to each pollutant were determined to provide a goodness of fit of the model, in which a value of one indicates a regression line perfectly fit to the data provided. The data provided from the HORIBA meter and water sampling results from CAS showed relatively low R^2 values. All the R^2 values computed were below 0.500, by which it was determined that these values were not high enough to show a positive relationship between any water quality measurement and any pollutant.

Water use coefficients were created for two separate reference ET values, the ASCE Penman-Monteith method and the Hargreaves method. It was evident that the lack of data, due to a short research period and inconsistent flow rates, caused variable water use coefficients. In order to provide a complete annual coefficient, estimated water use coefficients were developed for periods of questionable data using literature values. Because the Hargreaves method produced very high ETo values, the ASCE Penman-Monteith method was recommended. This method produced a water use coefficient between 0.45-1.10 mm/mm and most closely matches the values from literature. This information can be used to determine future water lost through evapotranspiration and assist in the scale-up of the current CWTS.

Water samples taken throughout the research period were used to create a mass balance of the seven priority pollutants in order to evaluate the performance of the wetland system. The CWTS resulted in high removal rates of mercury (98%), selenium (80%), and fluoride (72%); however, the remaining four pollutants (boron, manganese, chloride, and sulfate) were not removed by the CWTS. Seventeen percent of boron was removed, but manganese, chloride, and sulfate were exported from the system. Their removals were -66%, -3%, and -17%, respectively.

Despite the lack of removal for all pollutants, the discharge water passed the Kansas Department of Health and Environment (KDHE) water quality criteria set for different water

uses for each of these pollutants (Table 5.1). The effluent concentrations from the pilot-scale CWTS at JEC do not meet KDHE water quality standards for boron, selenium, chloride, fluoride, and sulfate for at least one designated use. With effluent concentrations from the pilot-scale CWTS not meeting KDHE water quality standards, major downstream effects could occur in Topeka and Lawrence, which use the Kansas River as a water supply source. Also, climate change and increased period of drought will impact the Kansas River flow rate and increase concentrations in the river.

Table 5.1. KDHE water quality standards compared to each of the seven pollutants average concentration exiting the pilot-scale CWTS at JEC in µg/L. Table taken from KDHE 2004

		KDHE WATER QUALITY STANDARDS				
		<i>Aquatic</i>		<i>Agriculture</i>		<i>Public</i>
Pollutant	Pilot-Scale CWTS	Acute	Chronic	Livestock	Irrigation	Water Supply
B	2,662			5,000	750	
Mn	2.60×10^{-3}					
Hg	1.00×10^{-3}	1.4	0.77			
Se	8.85	20	5			
Cl ⁻	514,000	860,000				250,000
F ⁻	2,797			2,000	1,000	2,000
SO ₄ ⁻²	2,149,000			1,000,000		250,000

The average flow rate of the Kansas River over the past 75 years is about 4.45 m³/sec (157 ft³/sec). If there is an increase in flowrate while the treated FGD wastewater stream is being discharged, more dilution of these pollutants will occur within the Kansas River; however, dilution is not a good solution because the pollutant mass is still an issue. With the increasing periods of drought, the Kansas River's flow rate will more than likely begin to decrease, which would increase the concentration of the pollutants in the river. If the flowrate of the Kansas River decreases while a large amount of treated FGD wastewater is being discharged into it, the pollutant concentrations within the treated FGD wastewater could begin to affect areas downstream due to less dilution in the river.

The average discharge from the pilot-scale CWTS at JEC into the Kansas River, about 129,310 L/d, is about 7% of the total effluent released from JEC. If the CWTS was at full-scale, the average discharge would be about 1,892,500 L/d. Using the average concentrations of each of the pollutants from the pilot scale wetland, the downstream concentration at Topeka was calculated for three different Kansas River flowrates. It was assumed that the current Kansas

River had no concentration of each pollutant. Table 5.2 shows the differences in the pollutant concentration in the Kansas River based on previous record lows, highs, and average flowrate of the river.

Table 5.2. Estimated full-scale CWTs concentrations of each pollutant entering the Kansas River based on the lowest, highest, and average flow rates over the past 75 years for the Kansas River. The Kansas River had a low, high, and average flow over the past 75 years of 1.24×10^7 L/d, 1.44×10^9 L/d, and 3.84×10^8 L/d, which were used to determine change in concentration of pollutant affecting the Kansas River in Topeka (USGS, 2012)

Pollutant	CWTs Effluent Concentration (mg/L)	Lowest	Highest	Average
		Concentration of Pollutant (mg/L)	Concentration of Pollutant (mg/L)	Concentration of Pollutant (mg/L)
B	39	5.95	0.0513	0.192
Mn	3.81×10^{-5}	5.81×10^{-6}	5.01×10^{-8}	1.88×10^{-7}
Hg	1.46×10^{-5}	2.23×10^{-6}	1.92×10^{-8}	7.20×10^{-8}
Se	0.130	1.98×10^{-2}	1.71×10^{-4}	6.41×10^{-4}
Cl ⁻	7,523	1,148	9.89	37.1
F ⁻	41	6.26	5.39×10^{-2}	0.202
SO ₂ ⁻⁴	31,451	4,800	41.3	155

From Table 5.2, the lowest, highest, and average concentration of each pollutant was theoretically determined based on 75 years' worth of data for the annual lowest, highest, and average discharge rates of the Kansas River downstream of JEC at Topeka, KS (USGS, 2012). Topeka, KS was chosen as a reference site to show how the effects of the effluent from the pilot-scale CWTs at JEC will affect residents and towns downstream. From the table, it is evident that when the Kansas River decreases in flowrate, the resulting concentration of each pollutant increases, because less water from the Kansas River is used to dilute these harmful pollutants. These activities occurring upstream of Topeka, KS at Jeffrey Energy Center affect downstream residents in Topeka, KS who use the Kansas River water throughout the city; therefore, increased water treatment would have to be completed in order to remove these pollutants and deliver safe drinking water.

Recommendations

Due to the poor performance of the CWTS for boron, manganese, chloride, and sulfate removal, it is not recommended to implement a full-scale CWTS. Despite the high removals of mercury, selenium, and fluoride, a full-scale CWTS be able to hold more water, allowing more boron, manganese, chloride, and sulfate to not be removed by the system if the same percent removal occurred. With the full-scale CWTS, these pollutants would continue to be transferred downstream by the Kansas River, moving the problem from one location to the next. Prior to scale-up, a CWTS effluent treatment system should be investigated to help remove the excess boron, manganese, chloride, and sulfate not removed by the CWTS. An open evaporation system could be a possible FGD wastewater treatment system to follow the full-scale wetland, where the water would evaporate into the air and the remaining contaminants would be removed and landfilled in a hazardous waste landfill. Despite its expense, this type of ZLD system would be the safest and most efficient way to remove the remaining contaminants contained within the wastewater after it is remediated using the full-scale CWTS.

References

- Abtew, W. 1996. Evapotranspiration Measurements and Modeling for Three Wetland Systems in South Florida. *Journal of American Water Resources Association* 32(3): 465-473.
- Allen, R. G. 2000. Using the FAO-56 dual Crop Coefficient Method Over an Irrigated Region as Part of an Evapotranspiration Intercomparison Study. *Journal of hydrology* 229(1-2): 27.
- Allen, R. G., Pereira L. S., Raes, D., and Smith, M. (1998). "Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements." Irrigation and Drainage Paper 56, United Nations Food and Agriculture Organization, Rome.
- Allen, R.G., Walkter, I.A., Ellito, R., Mecham, B., Jense, M.E., Itenfisu, D., Howell, T.A., Snyder, R., Brown, P., Eching, S., Spofford, T., Hattendorf, M., Cuenca, R.H., Wright, J.L., and Martin, D. (2000). Issues, Requirements, and Challenges in Selecting and Specifying a Standardized ET Equation. Proceedings of the 4th National Irrigation Symposium; American Society of Agricultural Engineers: Phoenix, Arizona.
- ASCE-EWRI. 2005. The ASCE Standardized Reference Evapotranspiration Equation.
- Brix, H., 1989. Gas Exchanges Through Dead Culms of Reed, *Phragmites australis* (Cav.) Trin. Ex Steudel. *Aquat. Bot.* 35, 81-98.
- Brix, H., 1994. Constructed Wetlands for Municipal Wastewater Treatment in Europe. In: Mitsch, W.J. (Ed.), *Global Wetlands; Old World and New*. Elsevier, Amsterdam pp. 325-334.
- Burns&McDonnell and Kansas State University. 2011. **2011 Annual Report: Constructed Wetland Treatment System Jeffrey Energy Center.**
- Chapman, C. A. and C. M. Layman. 2007. Considerations Impacting the Technology Selection Process for FGD Purge Stream Wastewater Treatment Systems. 38.
- Coefield, S. 2009. EPA Set to Regulate Wastewater from Coal-Fired Power Plants: High selenium levels in power plant wastewater may pose a risk to people and wildlife. *Scientific American*. Available at: <http://www.scientificamerican.com/article.cfm?id=selenium-wastewater-coal-power-plant-gibson-lake>. Accessed on 1 June 2012.
- Douglas Mooney, F. and C. Murray-Gulde. 2008. Constructed Treatment Wetlands for Flue Gas Desulfurization Waters: Full-Scale Design, Construction Issues, and Performance. *Environmental Geosciences* 15(3): 131-141.
- Duhigg, C. 2009. Cleansing the Air at the Expense of Waterways: 12 October 2009. *The New York Times*. Available at:

http://www.nytimes.com/2009/10/13/us/13water.html?pagewanted=all&_r=0. Accessed on 2 June 2012.

- Eastoe, C. and J. Artiola. 2003. *Journal of the Air & Waste Management Association*. 53(4): 417.
- Eggert, D. A., J. H. Rodgers Jr., G. M. Huddleston and C. E. Hensman. 2008. Performance of Pilot-Scale Constructed Wetland Treatment Systems for Flue Gas Desulfurization Waters. *Environmental Geosciences* 15(3): 115-129.
- Faulkner, S.P., Richardson, C.J., 1989. Physical and Chemical Characteristics of Freshwater Wetland Soils. In: Hammer, D.A., Freeman, R.J. (Eds.), *Constructed Wetlands for Wastewater Treatment*. Lewis Publishers, Chelsea, Michigan, pp. 41-72.
- Goodin, D. G., J. E. Mitchell, M. C. Knapp and R. E. Bivens. 1995. *Climate and Weather Atlas of Kansas*.
- Hargreaves, G. H. 2003. History and evaluation of Hargreaves evapotranspiration equation. *Journal of Irrigation and Drainage Engineering* 129(1): 53.
- Hargreaves, G. H. 1994. Defining and using reference evapotranspiration. *Journal of Irrigation and Drainage Engineering* 120(6): 1132.
- Hargreaves, G. H. 1989. Accuracy of estimated reference crop evapotranspiration. *Journal of Irrigation and Drainage Engineering* 115(6): 1000.
- Hargreaves, G. H. 1985. Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture* 1(2): 96.
- Hoover, K.L, Rightnour, T.A., Collins, R., and Herd, R. 1998. *Applications of Passive Treatment to Trace Metals Removal*. Proceedings of the American Power Conference in Chicago, Illinois; Pennwell Publishing: Tulsa, Oklahoma.
- Jensen, D. T. 1997. Computation of ETo under nonideal conditions. *Journal of Irrigation and Drainage Engineering* 123(5): 394.
- Kadlec, R.H. 1985. Aging Phenomena in Wastewater Wetlands. In: Godfrey, P.J., Kaynor, E.R., Pelczarski, S., Benforado, J. (Eds.), *Ecological Considerations in Wetlands Treatment of Municipal Wastewaters*. Van Nostrand Reinhold, New York, pp. 338-347.
- Kadlec, R. H. 1989. Hydrologic Factors in Wetland Water Treatment. In *Constructed wetlands for wastewater treatment : municipal, industrial, and agricultural*, ed. D. A. Hammer, Lewis Publishers. Pages 21-40.
- Kadlec, R.H. 2003. Integrated Natural Systems for Landfill Leachate Treatment. In: *Wetland – Nutrients, Metals, and Mass Cycling*, Vymazal, J. (Ed.) Backhuys Publishers: Leiden, The Netherlands, pp. 1-33.
- Kadlec, R.H., Knight, R.L. 1996. *Treatment Wetlands*. Lewis Publishers, CRC, New York.

- Kadlec, R.H., and Wallace, S.D. 2009. Treatment Wetlands, Second Edition. CRC Press, Taylor & Francis Group, LLC, United States of America.
- KDHE. 2004. Kansas Water Quality Standards and Supporting Documents.
- Kleinman, R.L.P., and Hedin, R. 1989. Biological Treatment of Mine Water: An Update. In: *Tailings and Effluent Management: Proceedings of the International Symposium on Tailings and Effluent Management 20-24 1989*, Chalkley, M.E., Conrad, B.R., Lakshmanan, V.I., Wheeland, K.G. (Eds.) Pergamon Press: Halifax, Nova Scotia, Canada, pp. 173-179.
- Knight, R.L., Kadlec, R.H., and Ohlendorf, H.M. 1997. The Use of Treatment Wetlands for Petroleum Industry Effluents, Prepared for the American Petroleum Institute (API), Publication Number 4672, API Publishing Services: Washington, D.C.
- Knight, R.L., Payne, V.W.E., Borer, R.E., Clarke, R.A., and Pries, J.H. 2000. Constructed Wetlands for Livestock Wastewater Management. *Ecological Engineering* 15(1-2): 41-55.
- Lafleur, P.M. 1990. Evapotranspiration from Sedge-Dominated Wetland Surfaces. *Aquatic Botany* 37:341-353.
- Laws, R. E., E. Byers, J. Dopatka and J. McCarthy. 2008. Duke Energy Carolinas' WFGD Retrofit Program: Operation at Marshall and Belews Creek Stations. In *7th Power Plant Air Pollutant Control "Mega" Symposium 2008*, 615.
- Lenntech B.V. 2011. Turbidity. Available at: <http://www.lenntech.com/turbidity.htm>. Accessed August 2012.
- Mandigo, G. 2007. ZLD Solutions for the Treatment of FGD Wastewater. In *International Water Conference 2007, Orlando, Florida, Paper 07-40*.
- McCarthy, J. 2006. *Duke energy-carolinas' WFGD retrofit program: Site-specific innovations and their implementation*. In *International Water Conference 2008, San Antonio, Texas, Paper IWC 08-32*.
- McCarthy, J., J. Dopatka, K. Barger, P. Rader and C. Bissell. 2006. Duke energy-carolinas' WFGD retrofit program: Site-specific innovations and their implementation. In *EPA-DOE-EPRI-A and WMA Power Plant Air Pollutant Control Mega Symposium 2006, August 28, 2006 - August 31, 1267-1285*. Baltimore, MD, United states: Air and Waste Management Association.
- Meuleman, A. F. M. 2003. Water and mass budgets of a vertical-flow constructed wetland used for wastewater treatment. *Ecological Engineering* 20(1): 31. complete pages
- Meuleman, A.F.M., 1994. Waterzuivering Door Moeras-Systemen: Onderzoek Naar De Water-En Stofbalansen Van Het Rietin Ltratieveld Lauwersoog. RIZA Nota 94.001, 1-134.

- Monteith, J.L. 1965. *Evaporation and the Environment*. Proceedings of the 19th Symposium of the Society of Experimental Biologists; Cambridge University: Swansea, United Kingdom, pp. 205-234
- Mooney, F. D. 2008. Constructed treatment wetlands for flue gas desulfurization waters: Full-scale design, construction issues, and performance. *Environmental geosciences* 15(3): 131.
- Murray-Gulde, C. and F. D. Mooney. 2007. Designing Constructed Wetlands for Mitigating Risks from Flue Gas Desulfurization Wastewater. In *International Water Conference*, 1
- NCASI. 2004. *Use of Constructed Wetland Effluent Treatment Systems in the Pulp and Paper Industry*, Technical Bulletin 876, National Council for Air and Stream Improvement (NCASI): Research Triangle Park, North Carolina.
- Nichols, D.S., 1983. Capacity of Natural Wetlands to Remove Nutrients from Wastewater. *J. Water Pollut. Control Fed.* 55, 495-505.
- Nicholson, M. C. 2007. Evaporation of Purge Water from Wet FGD Scrubbers. In *International Water Conference 2007, Orlando, Florida, Paper 07-39*.
- NOAA/National Weather Service. 2005. Evapotranspiration. Available at: <http://www.cpc.ncep.noaa.gov/soilmst/e.shtml>. Accessed 9/20 2012.
- Pickett, T., J. Sonstegard and B. Bonkoski. 2006. Using Biology to Treat Selenium: Biologically Treating Scrubber Wastewater can be an Alternative to Physical-Chemical Treatment. *Power Engineering* 110(11): 140.
- Platzer, C. and Netter, R. 1992. *Factors Affecting Nitrogen Removal in Horizontal Flow Reed Beds*. Proceedings of the 3rd International Conference on Wetland Systems for Water Pollution Control, 30 November to 3 December 1992; Australian Water and Wastewater Association: Sydney, Australia, pp. 4.1-4.6.
- Reddy, K.R., Patrick, W.H., Lindau, C.W., 1989. Nitrification Denitrification at the Plant Root Sediment Interface. *Limnol. Oceanogr.* 34, 1004-1013.
- Riffe, M. 2008. *Wastewater treatment for FGD purge streams*. In *7th Power Plant Air Pollutant Control "Mega" Symposium 2008*, 33.
- Schierup, H.H., Brix, H., Lorenzen, J., 1990. Wastewater Treatment in Constructed Reed Beds in Denmark; State of the Art. In: Cooper, P.F., Findlater, B.C. (Eds.), *Constructed Wetlands in Water Pollution Control*. Pergamon Press, Oxford, pp. 495-504.
- Shaw, W. 2008. Benefits of evaporating FGD purge water. *Power* 152(3): 59-62.
- Shaw, W. and J. Brosdal. 2008. Cover Story Strategies to Minimize Wastewater Discharge As industries evaluate the viability of zero-liquid discharge, the advantages of low-temperature evaporation should be considered. *Chemical engineering* 115(10): 60.

- Srivastava, R.K. & Jozewicz, W. 2001. Flue Gas Desulfurization: The State of the Art. *Journal of the Air & Waste Management Association* 51(12): 1676-1688.
- Sonstegard, J., T. Pickett, J. Harwood and D. Johnson. 2008. Full Scale Operation of GE ABMet Biological Technology for the Removal of Selenium from FGD Wastewaters. In *International Water Conference*, 1-11.
- Sundberg Jones, S. and S. Hassan. 2007. Macrophyte sorption and bioconcentration of elements in a pilot constructed wetland for flue gas desulfurization wastewater treatment. *Water, air and soil pollution* 183(1-4): 187-200.
- Tanaka, N. and R. Wicks. 2010. Power Generation from Coal: Measuring and Reporting Efficiency Performance and CO₂ Emissions.
- Tofflemire, T. J. and F. E. VanAlstyne. 1973. Deep-Well Injection. *Journal (Water Pollution Control Federation)* 45(6, Annual Literature Review): pp. 1103-1108.
- Tofflemire, T. J. and G. P. Brezner. 1971. Deep-Well Injection of Wastewater. *Journal (Water Pollution Control Federation)* 43(7): pp. 1468-1479.
- Trajkovic, S. 2007. Hargreaves versus Penman-Monteith under humid conditions. *Journal of Irrigation and Drainage Engineering* 133(1): 38-42.
- U.S. Department of the Interior and U.S. Geological Survey. 2012. Surface Water data for Kansas: USGS Surface-Water Annual Statistics. Available at: <http://waterdata.usgs.gov/ks/nwis/annual?>. Accessed 9/26 2012.
- USDA NRCS. 2009. National Soil Survey Handbook, Title 430-VI, Part 618-Soil Properties and Qualities. Available online at <http://soils.usda.gov/technical/handbook/>. Accessed 09/21/2012.
- USDA NRCS. 2012. Web Soil Survey. Available at: <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>. Accessed 8/6 2012.
- US EIA. 2011. What is the role of coal in the United States? Available at: http://www.eia.gov/energy_in_brief/role_coal_us.cfm. Accessed 5/22 2012.
- US EPA. 2012. Summary of the Clean Air Act. Available at: <http://www.epa.gov/lawsregs/laws/caa.html>. Accessed 5/22 2012.
- US EPA. 2012. National Ambient Air Quality Standards (NAAQS). Available at: <http://www.epa.gov/air/criteria.html>. Accessed 5/22 2012.
- US EPA. 2012. What are the Six Common Air Pollutants? Available at: <http://www.epa.gov/air/urbanair/>. Accessed 5/22 2012.
- US EPA. 2012. Level III and IV Ecoregions of the Continental United States. Available at: http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm. Accessed July 2012.

- US EPA. 2009. Steam Electric Power Generating Point Source Category: Final Detailed Study Report. EPA-821-R-09-008. Available at:
http://water.epa.gov/lawsregs/guidance/cwa/304m/archive/upload/2009_10_26_guide_steam_finalreport-2.pdf. Accessed July 2012.
- USGS. 2012. USGS Surface-Water Annual Statistics for Kansas: USGS 06889500 Soldier C NR Topeka, KS. Available at: http://waterdata.usgs.gov/ks/nwis/annual/?referred_module=sw&site_no=06889500&por_06889500_4=92445,00060,4,1929,2012&year_type=W&format=html_table&date_format=YYYY-MM-DD&rdb_compression=file&submitted_form=parameter_selection_list. Accessed 9/28 2012.
- Verhoeven, J. T. A. and A. F. M. Meuleman. 1999. Wetlands for wastewater treatment: Opportunities and limitations. *Ecological Engineering* 12: 5-12.
- Westar Energy. 2012. Jeffrey Energy Center - 1857 MW - Coal. Available at: <http://www.westarenergy.com/wcm.nsf/content/jeffrey>. Accessed July 2012.
- Wieder, R.K. 1989. A Survey of Constructed Wetlands for Acid Coal Mine Drainage Treatment in the Eastern United States. *Wetlands* 9: 299-315.
- Younger, P.L. 2000. The Adoption of and Adaptation of Passive Treatment Technologies for Mine Waters in the United Kingdom. *Mine Water and the Environment* 19: 84-97.
- Zarzo Martinez, D. and E. Campos Pozuelo. 2011. Project for the development of innovative solutions for brines from desalination plants. *Desalination and water treatment* 31(1-3): 206-217.

Appendix A - Horiba Meter Instruction Manual

pH Calibration

The HORIBA meter has two options on how to calibrate pH, either an auto or a manual calibration. To calibrate pH using the auto calibration, a pH 4 standard solution was used. First, the transparent calibration cup, which comes with the HORIBA meter, was cleaned out 2 or 3 times using deionized water, then the pH 4 standard solution was added until it reached the reference line. The sensor guard is removed from the HORIBA meter, so the sensors are showing, then the HORIBA meter is placed inside the transparent calibration cup, which is covered with a black calibration cup, allowing no light to enter and create different readings. Then on the HORIBA meter's control unit, the CAL key was selected to bring up the calibration screen on the control unit. From here, the down arrow on the control unit was used to move the cursor to "Auto Calibration" and the ENTER key was pressed. Once "Auto Calibration" is selected, the HORIBA meter control unit continues to a parameter selection screen, in which "pH" was selected moving the cursor and pressing the ENTER key. For auto calibration, a one point calibration test is run, in which the HORIBA meter conducts a span and calibrates the pH to a value of 4.01. Once the pH value is calibrated to 4.01, the auto calibration is complete.

Manual calibration was also run to the HORIBA meter, specifically when there was difficulty running an auto calibration. Sometimes the HORIBA meter would not calibrate to a value of 4.01, because it was sensing a pH value typically much larger than 4.01; therefore, a manual calibration was conducted. A manual calibration is similar to an auto calibration, in which the transparent calibration cup was still washed with deionized water and then filled with a pH standard solution; however, in a manual calibration, a pH standard solution of 7 was filled to the reference line on the transparent calibration cup. The HORIBA meter was added to the transparent calibration cup, and then covered with the black calibration cup. On the control unit of the HORIBA meter, the CAL key was selected to bring up the calibration screen and the down key was used to move the cursor to "Manual Calibration" and the ENTER key was pressed. Once on the parameter selection screen, "pH" was selected by moving the cursor and hitting ENTER, which brought up a calibration point screen on the control unit. Either one point or multipoint calibration can be conducted with the HORIBA meter; however, for manual

calibration, a multipoint calibration is used, in which two pH standard solutions are used to calibrate the HORIBA meter. To select the multipoint calibration, the number “2” was highlighted on the control unit and ENTER was pressed to start the calibration.

Two different standard solution combinations were typically used for the manual multipoint calibration: either a pH 4 and 7 standard solution or pH 7 and 10 standard solution combination was used. A pH 4 and 7 standard solution combination was used the most for the manual multipoint calibration, because the instruction manual for the HORIBA meter suggests using a pH 9 standard solution, which was not available. First, the pH value of the pH 7 standard solution based on the current temperature of the solution is entered using the up and down keys on the HORIBA control unit. Table 4.1 was used to determine the pH values based on what standard solution was being used and what the temperature was. The temperature of the standard solution was typically around 25°C, so a pH value of 6.86 was entered into the control unit of the HORIBA meter. Once the “Measurement value” on the screen of the HORIBA meter’s control unit stabilized, the ENTER key was pushed to begin the calibration.

Table A. 1. The pH values for three different pH standard solutions based on temperature.

Table taken from HORIBA meter instruction manual

Temp. (°C)	pH 4 standard solution (Phthalate)	pH 7 standard solution (Neutral Phosphate)	pH 9 standard solution (Borate)
0	4.01	6.98	9.46
5	4.01	6.95	9.39
10	4.00	6.92	9.33
15	4.00	6.90	9.27
20	4.00	6.88	9.22
25	4.01	6.86	9.18
30	4.01	6.85	9.14
35	4.02	6.84	9.10
40	4.03	6.84	9.07
45	4.04	6.84	9.04

When the first calibration was complete, the ENTER key was pressed when the message “Cal complete. Press ENT to Span cal.” appeared on the screen. The HORIBA meter was then taken out of both calibration cups and the transparent calibration cup was washed 2 or 3 times with deionized water, then filled with a pH 4 standard solution to the reference line. The pH probe on the HORIBA meter was also washed with deionized water to remove any dirt, and the

HORIBA meter was placed first into the transparent calibration cup then into the black calibration cup. Using the up and down keys on the control unit of the HORIBA meter, the pH value based on temperature for a pH 4 standard solution was entered. As stated earlier, the temperature was typically 25°C, so a pH value of 4.01 was entered. Once the “Measured value” stabilized, the ENTER key was hit to begin the calibration and when the calibration was finished, the following message would appear “Cal complete. ENT to manual cal menu.” in which ENTER was hit again to bring the control unit back to the calibration parameter screen. Once pH calibration was complete and the screen showed the calibration parameters, the ESC key was hit to return the screen to the single measurement screen.

HORIBA Site Selection

On the single measurement screen, the site location is given on the top left of the screen, indicating which site the measurements were for. When moving from one of the 10 locations to the next at JEC’s CWTS, the site located on the control unit of the HORIBA meter needed to change. To change from site to site, the right key was used to change the display to the “SETTINGS” screen. By using the down key, the cursor was moved until it reached “Site” and ENTER was pressed, bringing up another screen. Using the down key again, the cursor was moved to “Select Site” and ENTER was pressed. The select site screen shows all the sites loaded onto the HORIBA meter, and there is a black circle next to the site that is currently in use. To change the site from one site to the next, the down arrow was hit until the cursor was over the site wanted and ENTER was pressed. This moved the black circle from the previous site to the site wanted. Once finished, the ESC key was hit to return to the main settings screen and the left arrow button was used to switch from the settings screen to the single measurement screen.

Data Collection Download for HORIBA

The water quality measurements were downloaded using the U-50PC Data Collection Software, which came with the HORIBA meter. The U-50PC Data Collection Software was downloaded on to a PC computer following the setup instructions in the Data Collection Software U-50PC Instruction Manual, starting on page 4. Once the Data Collection Software was installed, the HORIBA meter control unit was connected to the computer using a USB cord

and the data collected from the CWTS sites were downloaded. To download the data using the Data Collection Software, the program was first opened, then on the option [Download data] was selected from the [Data] menu on the main tool bar of the program. Next, a confirmation screen appeared on screen asking “Download all data”, in which [OK] was selected to download. A screen would appear during the download to show how much is currently being downloaded. Once the download was completed, a <Data selection> window appeared where all the data is shown in order of date. The data based on dates of water quality sampling were selected and [Download selected data] was selected. The downloaded data would then appear on the main screen of the Data Collection Software program, in which the site, date, time, and GPS were displayed, as well as the water quality measurements that were taken for the specific site. All the water quality measurement data was downloaded using this program and saved as a .csv file, which was later converted to an .xlsx file using Microsoft Excel.

Appendix B - Weather Data Download Instructions

In order to download the weather data from the WeatherLink® data logger, the WeatherLink® icon located on the desktop was selected. Once the program opened, [File] on the main toolbar was selected and the cursor was moved until [Open Station] which was clicked. Once the [Open Station] menu opened, [CWTS2] was selected and the [Open] button was pressed. After the [Open] button is pressed, the menu closes and returns to the main program, in which the [Download Weather Station] icon was selected from the sub-toolbar (the icon resembled a computer console with arrows to a computer monitor). A message appeared asking to download the files available and [OK] was selected. Once the weather data was downloaded, [Window] was selected from the main toolbar and the cursor was moved over the [Browse] option. Once selected, the weather data just downloaded appeared in the main screen of the program.

Appendix C - Reference Evapotranspiration

ASCE Penman-Monteith Method

The ASCE Penman-Monteith equation was one method used to calculate reference evapotranspiration, ET_O , for the CWTS. The equation states the following:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (C.1)$$

where ET_O is reference evapotranspiration (mm day^{-1}); T is mean daily air temperature ($^{\circ}\text{C}$); Δ is slope of the vapor pressure curve ($\text{kPa}^{\circ}\text{C}^{-1}$); e_a is actual vapor pressure (kPa); e_s is saturation vapor pressure (kPa); $e_s - e_a$ is the saturation vapor pressure deficit (kPa); R_n is net radiation at the crop surface ($\text{MJ m}^{-2} \text{day}^{-1}$); G is soil heat flux density ($\text{MJ m}^{-2} \text{day}^{-1}$); U_2 is average 24-h wind speed (m s^{-1}); and γ is the psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$) (Allen 2000). Some of these values were directly measured by the Vantage Pro2™ weather station; however, some of these values were derived through an empirical relationship. Solar radiation, air temperature, air humidity, and wind speed are all factors that can be measure by a weather station and will be used to help determine factors not directly measured.

First, the average daily temperature was determined using the temperature values from the Vantage Pro2™ weather station, in which the following equation is used:

$$T = \frac{T_{max} - T_{min}}{2} \quad (C.2)$$

where T is average daily temperature, T_{max} is the daily maximum temperature, and T_{min} is the daily minimum temperature. The temperature should be given in Celsius ($^{\circ}\text{C}$). From this average daily temperature, slope of the vapor pressure curve, Δ , was determined using the following:

$$\Delta = \frac{4098 \left[0.6108 \exp \left(\frac{17.27T}{T + 237.3} \right) \right]}{(T + 237.3)^2} \quad (C.3)$$

where T is the average daily temperature ($^{\circ}\text{C}$) and Δ is the slope of the vapor pressure curve ($\text{kPa } ^{\circ}\text{C}^{-1}$).

Actual vapor pressure, e_a , can be derived several different ways from weather data; however, actual vapor pressure was found using maximum and minimum relative humidity with the following equation:

$$e_a = \frac{e^\circ(T_{min}) \frac{RH_{max}}{100} + e^\circ(T_{max}) \frac{RH_{min}}{100}}{2} \quad (C.4)$$

where $e^\circ(T_{min})$ is saturation vapor pressure at daily minimum temperature (kPa), $e^\circ(T_{max})$ is saturation vapor pressure at daily maximum temperature, RH_{max} is maximum relative humidity (%), and RH_{min} is minimum relative humidity (%).

To determine saturation vapor pressure, e_s , the relationship between saturation vapor pressure and temperature is expressed as:

$$e^\circ(T) = 0.6108 \exp \left[\frac{17.27T}{T + 237.3} \right] \quad (C.5)$$

where $e^\circ(T)$ is saturation vapor pressure (kPa) at air temperature T (°C). With this relationship established, saturation vapor pressure can be calculated; however, it is best to compute the saturation vapor pressure as an average between the daily maximum and minimum air temperatures with the following expression:

$$e_s = \frac{e^\circ(T_{max}) + e^\circ(T_{min})}{2} \quad (C.6)$$

where $e^\circ(T_{max})$ is the maximum saturation vapor pressure and $e^\circ(T_{min})$ is the minimum saturation vapor pressure.

Solar radiation must be calculated in order to find the net radiation that will be used in equation 3.5. Solar radiation can be directly measured with different meters; however, it can also be calculated using weather data and a series of mathematical equations. First, the extraterrestrial radiation was determined with the following:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\phi) \sin(\delta) + \cos(\phi) \cos(\delta) \sin(\omega_s)] \quad (C.7)$$

where R_a is the extraterrestrial radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), G_{sc} is the solar constant = $0.0820 \text{ MJ m}^{-2} \text{ day}^{-1}$, d_r is the inverse relative distance Earth-Sun (refer to equation 3.13), ω_s is the sunset hour angle (refer to equation 3.15) (rad), ϕ is the latitude (refer to equation 3.12) (rad), and δ is the

solar decimation (refer to equation 3.14) (rad). In order to calculate latitude in radians, the following equation was used:

$$[Radians] = \frac{\pi}{180} [decimal\ degrees] \quad (C.8)$$

where decimal degrees was determined from degrees & minutes by taking the degree value from the degrees & minutes and adding it to the minutes value that should be divided by 60. The inverse relative distance Earth-Sun, d_r , was derived from:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365}J\right) \quad (C.9)$$

where J is the Julian day, which is the day of the year in between 1 (January 1) and 365 (December 31), or 366 if it is a leap year. The solar decimation was determined from the following:

$$\delta = 0.409 \sin\left(\frac{2\pi}{365}J - 1.39\right) \quad (C.10)$$

where J still stands for Julian day. The sunset hour angle, ω_s , was computed by:

$$\omega_s = \arccos[-\tan(\phi) \tan(\delta)] \quad (C.11)$$

where ϕ is the latitude (rad) and δ is the solar decimation (rad). Solar radiation, R_s , was calculated with the following equation:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad (C.12)$$

where R_s solar or shortwave radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), n is actual duration of sunshine (hr), N is maximum possible duration of sunshine or daylight hours (hr), n/N is the relative sunshine duration (-), R_a is the extraterrestrial radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), a_s is the regression constant, expressing the fraction of extraterrestrial radiation reaching earth on overcast days ($n=0$), and a_s+b_s is the fraction of extraterrestrial radiation reaching the earth on clear days ($n=N$). Daylight hours, N , can be determined from:

$$N = \frac{24}{\pi} \omega_s \quad (\text{C.13})$$

where ω_s is the sunset hour angle in radians as given by either equation 20 or 21. The clear-sky solar radiation, R_{so} , must also be determined for further use and was found using the following equation:

$$R_{so} = (0.75 + 2 \times 10^{-5}z)R_a \quad (\text{C.14})$$

where z is the elevation above sea level (m) and R_a is the extraterrestrial radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$). From the solar or shortwave radiation, R_s , the net solar or net shortwave radiation, R_{ns} , was found by:

$$R_{ns} = (1 - \alpha)R_s \quad (\text{C.15})$$

where R_{ns} is the net solar or shortwave radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), α is the albedo or canopy reflection coefficient (0.23, for a hypothetical grass reference crop), R_s is the incoming solar radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$). The net longwave radiation, R_{nl} , was also found using:

$$R_{nl} = \sigma \left[\frac{T_{max,K} + T_{min,K}}{2} \right] (0.34 - 0.14\sqrt{e_a}) \left(1.35 \frac{R_s}{R_{so}} - 0.35 \right) \quad (\text{C.16})$$

where R_{nl} is the net longwave radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), σ is the Stefan-Boltzmann constant ($4.903 \times 10^{-9} \text{ MJ m}^{-2} \text{ day}^{-1}$), $T_{max,K}$ is the daily maximum absolute temperature in which the temperature must be in Kelvin ($K = ^\circ\text{C} + 273.16$), $T_{min,K}$ is the daily minimum absolute temperature also in Kelvin, e_a is actual vapor pressure (kPa), R_s/R_{so} is the relative shortwave radiation that is less than 1.0, R_s is measured or calculated solar radiation (if calculated, refer to equation 22) ($\text{MJ m}^{-2} \text{ day}^{-1}$), and R_{so} is the clear-sky radiation calculated using equation 24 or 25 ($\text{MJ m}^{-2} \text{ day}^{-1}$). From all these mathematical expressions, net radiation, R_n , was simply determined by:

$$R_n = R_{ns} - R_{nl} \quad (\text{C.17})$$

where R_n is net radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), R_{ns} is the incoming net shortwave radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$), and R_{nl} is the outgoing longwave radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$).

The soil heat flux, G , is typically small compared to net radiation, in which a small calculation based off the idea that soil temperature trails air temperature that states:

$$G = c_s \frac{T_i - T_{i-1}}{\Delta t} \Delta z \quad (\text{C.18})$$

where G is the soil heat flux ($\text{MJ m}^{-2} \text{ day}^{-1}$), c_s is the soil heat capacity ($\text{MJ m}^{-3} \text{ }^\circ\text{C}^{-1}$), T_i is the air temperature at time i ($^\circ\text{C}$), T_{i-1} is the air temperature at time $i-1$ ($^\circ\text{C}$), Δt is the time interval length (day), and Δz is the effective soil depth (m). With this equation, the calculation time steps are only 24 hours or longer.

Wind speed, U_2 , is another factor important to the FAO 56 Penman-Monteith equation, in which wind speed was calculated using:

$$U_2 = U_z \frac{4.87}{\ln(67.8z - 5.42)} \quad (\text{C.19})$$

where U_2 is the wind speed at 2m above the ground (m s^{-1}), U_z is the measured wind speed at z m above the ground surface (m s^{-1}), and z is the height of the measurement above the ground (m). For the ASCE Penman-Monteith method, the wind speed should be at a standard of 2 m above the ground; therefore, equation 3.24 was used for wind speed that is measured at a different height than 2 m.

The psychrometric constant, γ , was computed by:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P \quad (\text{C.20})$$

where γ is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), P is atmospheric pressure (kPa), λ is the latent heat of vaporization (2.45 MJ kg^{-1}), c_p is specific heat at a constant pressure ($1.013 \times 10^{-3} \text{ MJ kg}^{-1} \text{ } ^\circ\text{C}^{-1}$), and ε is the ratio molecular weight of water vapor to dry air (0.622).

A Microsoft Excel spreadsheet, titled ET_ref_Scott.xls, was created by Scott Staggenborg, a professor in the Department of Agronomy at Kansas State University, to determine the evapotranspiration of a location using the ASCE Penman-Monteith method. This

spreadsheet was used to determine the reference evapotranspiration for the CWTS located at JEC. Users were responsible for inputting the following data about the site, including: latitude, elevation, date, month, year, DOY, maximum and minimum temperature, precipitation, wind, solar radiation, and maximum and minimum relative humidity, in which all values were given in metric units. After these values were input into the spreadsheet, the reference evapotranspiration was calculated and compared to the Hargreaves reference evapotranspiration values.

Hargreaves

The Hargreaves method for calculating evapotranspiration is similar to the original Penman method and only requires maximum and minimum temperatures to determine evapotranspiration. The Hargreaves method states:

$$ET_o = 0.0023 \times RA \times (T^{\circ}C + 17.8) \times TD^{0.50} \quad (C.21)$$

where ET_o is evapotranspiration (mm day^{-1}), RA is extraterrestrial radiation (mm day^{-1}), TD is the temperature difference between the mean maximum temperature and the mean minimum temperature ($^{\circ}C$), and $T^{\circ}C$ is the mean daily temperature ($^{\circ}C$) (Hargreaves 1994). Due to the small amount of weather data needed, Hargreaves is typically used for general use and is often used in countries where obtaining extensive weather data is difficult.

A Microsoft Excel spreadsheet, titled ET_ref_Hargreaves.xlsx, was created and used to determine the reference evapotranspiration through the Hargreaves method. Within this spreadsheet, the following data was input: date, DOY, and maximum, minimum, and mean temperature values, all in metric units. The spreadsheet already contained the extraterrestrial radiation (RA) for each day; therefore, once these values were input into the spreadsheet, the reference evapotranspiration values were calculated and given in metric units. These values were compared to the ASCE Penman-Monteith values discussed earlier.

Appendix D - Instructions to Download Effluent Flow Meter Data

To download the data, a small cord with a serial port on one end and a USB connector on the other was used. The serial port was attached to the meter and the USB connector was plugged into the USB port located on the right side of the docking station in which the laptop the

mounted was on. The HyperTerminal program was used to download the effluent flow data from the effluent flow meter. To access the program, [Start] in the bottom left of the laptop screen was selected, then [Programs], [Accessories], [Communications], and finally [HyperTerminal] was clicked and the program opened. When the program first opened, a small window always appeared, which was immediately exited out of and proceeded to download the flow data.

On the main screen of the HyperTerminal program, [File] was selected, then [Open] to open the correct file to download the effluent flow data. When the open menu appeared, the [SuperTrol-LE] file was selected and [Open] was hit. Once the SuperTrol-LE file was open, a code was entered into the HyperTerminal window to pull all effluent flow data from the effluent flow meter. In order for the code to work properly, the cursor was placed about five spaces to the right in the main window and then the code, d01v18001, was typed and [Enter] was pushed. After the code was entered, the data started to download on the screen and once was finished, was saved as a .pdf file. To save as a .pdf file, [File] on the mail tool bar was selected, then [Print]. Once in the [Print] menu, the adobe PDF printer was selected and the [Print] button was pressed, converting the data into a .pdf file. When the conversion was complete, the .pdf file was saved onto the USB drive, under the Flow folder, with the current date as its file name.

After the data was saved as .pdf file to the USB drive, the data still located on the effluent flow meter was erased, allowing more data to be stored over until the next download. In order to erase the flow meters memory, [Menu] was selected from the data logger that was attached to the flow meter. After [Menu] was selected, the password, 2000, was entered onto the main screen and [Enter] was hit. Then the cursor was moved to the [Test] command by selected the arrow button directly below the word [Test] displayed on the main screen, and [Enter] was selected. The down arrow was then used until it reached the [Data Logger Utility] command and [Enter] was selected, again. The [Data Logger Utility] screen shows the number of data logs compared to the maximum data logs the logger can hold; therefore, the [Stop] command was pushed then the [Clear] command was selected to erase the current number of logs located on the data logger. After this, the [Back] button was pushed until it went back to the screen where the [Test] command was selected. On this screen, the cursor was moved under the [Run] command and [Enter] was selected to begin taking data again.

Appendix E - Water Sampling Instructions

Beginning on April 12, 2011, water sampling was conducted every two weeks for all 10 sites (LS, AD-7, AD-8, AD-5, AD-6, AD-3, AD-4, AD-1, AD-2, and SB). At each site, 5 different water samples were taken with 5 different sampling bottles including: 1000 mL plastic with no preserve, 250 mL plastic with H₂SO₄ preserve, 120 mL plastic with NaOH/ZnAc preserve, 125 mL amber glass with H₂SO₄, and 500 mL plastic with HNO₃ preserve. Each water sampling bottle was used to test for different constituents. The 1000mL plastic with no preserve bottle was tested for BOD, alkalinity, NO₃, NO₂, TSS, TDS, TS, pH, specific conductance, hardness, Cl, F, and SO₄. The 250 mL plastic with H₂SO₄ was used to test for NH₃, total P, TKN, and COD, while the 120 mL plastic with NaOH/ZnAc preserve was tested for sulfide. TOC was tested for using the 125 mL amber glass with H₂SO₄ preserve. The 500 mL plastic with HNO₃ preserve also tested a lot of constituents like the 1000mL plastic with no preserve, including: Total-Ca, Al, B, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, Ag, Na, Tl, Sn, V, and Zn.

Before sampling began, a label was placed onto each water sampling bottle, which indicated what type of bottle it was, what it was tested for, date, location, time, and who sampled it. Once the bottles were labeled, the bottles were placed inside the cart, where the HORIBA meter was also placed, and taken to each of the 10 sites. At each site, the male connector located on the piping system on the cart was connected to the female end of the piping system located at each site. Then, the pump was turned on, allowing water to be drawn up through the pipe and through the cart system. The water was collected in the water sampling bottles through one of the exiting pipes, which released water out of the cart onto the ground.

After all the water samples were completed, a Chain of Custody (COC) form was filled out with the following information: client/reporting information, invoice information, sampler's name printed and signature, file number, project name, purchase order number, sample identification, matrix (sample type), regulatory program, date sampled, time sampled, total containers, number of preserved bottles, parameters/container type, and whom relinquished the samples, date, and time. The person sampling was responsible for signing the relinquished line,

dating and timing it before placing the COC form inside the cooler along with the water samples, which were iced down. The cooler with the water samples were then given to a mail carrier, who was required to sign the received by line and fill out the date and time on the COC form before accepting the cooler into their custody. The cooler was then taken to Continental Analytical Services, Inc. (CAS), a NELAC certified environmental laboratory, located in Salina, KS. CAS was responsible for all laboratories testing on the water samples collected.

Water sampling at all 10 site locations began April 12, 2011, in which every other week water samples were taken and sent to CAS for testing to be completed. Starting on May 12th, 2011, water samples were taken every week, in which there were two types of samplings, Type A and Type A-1, depending on which week it was. The first sampling type, Type A, required water sampling from LS, AD-7, AD-8, AD-5, AD-6, AD-3, AD-4, AD-1, AD-2, FGDWW, and RAW. Sampling from SB was taken out, while water sampling at FGDWW and RAW began. FGDWW and RAW water sampling sites were located in the wastewater treatment building, just east of the CWTS at JEC. The FGDWW site was located on the west side of the wastewater treatment building, while the RAW site was located on the south side of the building. By taking water samples of these two waters, the amount of constituents from each of these water streams could be determined before they are mixed at SB.

Type A still used 5 separate water sampling bottles to take water sampling at each site location; therefore, a total of 55 water sampling bottles were used. The 5 water sampling bottles included: 1000 mL plastic with no preserve, 250 mL plastic with H₂SO₄ preserve, 120 mL plastic with NaOH/ZnAc preserve, 125 mL amber glass with H₂SO₄, and 500 mL plastic with HNO₃ preserve. There was no change in what each bottle sampled for; therefore, the same 5 water sampling bottles still were responsible for testing the same constituents as discussed above.

The second sampling type, Type A-1, was started the week after the Type A water sampling was conducted; however, the second sampling type only required water sampling at three locations, including LS, FGDWW, and RAW. Along with the smaller number of water sampling locations, the Type A-1 only required 2 water sampling bottles, instead of 5 sampling bottles. The 2 water sampling bottles included a 1000 mL plastic with no preserve and a 500 mL plastic with HNO₃ preserve. The 1000 mL plastic with no preserve was responsible for testing

Cl, F, and SO₄, while the 500 mL plastic with HNO₃ preserve tested for Total-B, Mn, Se, and Hg. Both the Type A and Type A-1 used the cart to take the water samples; however, the cart was not used to take the FGDWW and RAW water samples, the bottles were filled directly from the water spout of these two locations. Type A and Type A-1 water sampling continued every week in which the sampling types altered; however, modifications on both Type A and Type A-1 sampling continued throughout the project.

Beginning July 19th, 2011, Type A water sampling was changed from taking water samples from 11 site locations to just 3 site locations, including FGDWW, RAW, and LS, similar to Type A-1 testing. For Type A testing, 5 water sampling bottles were still used to collect water samples; therefore, a total of 15 water sampling bottles were used for Type A testing. The bottles used for the Type A testing included: 1000 mL plastic with no preserve, 250 mL plastic with H₂SO₄ preserve, 120 mL plastic with NaOH/ZnAc preserve, 125 mL amber glass with H₂SO₄ preserve, and 500 mL plastic with HNO₃ preserve. The Type A testing bottles still test the same parameters as discussed above for each bottle; however, the 500 mL plastic with HNO₃ does not test for Total-Sb, As, Ba, Be, Co, Cu, Mo, Ni, Ag, Tl, Sn, V, and Zn any more. Type A-1 sampling did not change. It should be noted that starting July 19th, 2011, the water samples were taken from the LS location using a bucket instead of the cart. Also, the water samples were shipped to CAS through FedEx located in Manhattan, KS instead of using a mail carrier in order to cut back on cost.

Type A and Type A-1 water sampling was not changed until February 1st, 2012, in which Type A-1 water sampling remained the same; however, Type A water sampling changed. Type A water sampling still consisted of taking 5 water samples at 3 site locations with a total of 15 water sampling bottles. Two things changed within the Type A sampling. First, the 1000 mL plastic with no preserve bottle does not test for TS anymore, but instead calcium hardness was added as a testing parameter. The second change to the Type A sampling occurred with the 500 mL plastic with HNO₃ preserve bottle, which was now testing the following parameters: Total-Ca, Al, B, Cd, Cr, Fe, Mg, Mn, Hg, K, Na, Se, Sb, As, Ba, Be, Cu, Pb, Ni, Ag, Tl, and Zn.

Starting on February 28th, 2012, water sampling went from a weekly sampling to every other week, in which Type A sampling was conducted on February 28th, 2012, then two weeks

later, on March 13th, 2012, Type A-1 sampling was conducted. Along with sampling periods changing, Type A and Type A-1 sampling was changed again, starting on March 27th, 2012 and April 10th, 2012, respectively. Both Type A and Type A-1 sampling added two additional site locations, AD-7 and AD-8. Type A sampling also went from 5 water sampling bottles at each site location to 3 water sampling bottles at each site location, but 15 water sampling bottles were still used. The 3 bottles now used for Type A sampling included 250 mL plastic with no preserve, 250 mL plastic with H₂SO₄ preserve, and 500 mL plastic with HNO₃ preserve. The 250 mL plastic with no preserve bottle tested for fluoride and pH, while the 250 mL plastic with H₂SO₄ tested for NH₃ and total P. The 500 mL plastic with HNO₃ preserve tested for Total-B, Cr, Hg, and Se. Type A-1 sampling still consisted of 2 water sampling bottles for each site, with the same size and parameters for each bottle as discussed before. Due to the change in the Type A and Type A-1 sampling, water samples were taken using the cart again.

On April 10th, 2012, both Type A and Type A-1 sampling were changed for the last time, in which both sampling types were responsible for collecting water samples at eight locations, including: RAW, FGDWW, AD-7, AD-8, AD-5, AD-6, AD-3, and AD-4. The amount of bottles used at each site and the parameters were not changed for either Type A and/or Type A-1 sampling. The cart was used to obtain the water samples taken directly from the CWTS. Water sampling was completed on May 22nd, 2012.

Appendix F - Water Quality Measurements

Water Quality Measurement Data

Tables F.1 to F.8 represent overall water quality measurement data taken from the HORIBA meter for the CWTS located at JEC. Each table has a temperature value in degrees Celsius (°C) with respect to date, which is on the left hand side, and location, which is at the top of the table. Some data is missing within each table, which was a result of not enough water within the location for the HORIBA meter to accurately come up with a value.

**Table F.1. Temperature values (°C) for all site locations collected using the HORIBA meter
from 1/7/2011 to 1/10/2012**

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	5.86	4.94	4.78	7.17	7.32	5.55	5.34	6.43	7.03	5.52
2/4/2011	1.55	1.71	1.7	1.42	1.21		1.16	1.76		3.02
3/1/2011	2.55	2.18	2.31	2.72	2.34	1.99	2.5	4.93	5.69	9.85
3/17/2011	6.58	5.61	6.2	6.34	6	8.46	7.76	12.38	17.45	12.9
3/31/2011	6.68	6.51	6.32	6.31	6.33	6.35	6.37	6.02	4.8	6.08
4/12/2011	11.62	11.22	11.28	11.67	11.49	12.99	12.3	15.15	18.41	25.2
4/26/2011	11.37	11.41	12.56	11.58	11.74	12.21	12.03	11.95	12	15.2
5/12/2011	16.16	16.52	16.55	17.06	16.58	19.1	19.67	19.5	20.35	21.93
5/17/2011	15.17	14.96	14.88	14.96	14.85	15.15	15.57	14.52	13.11	15.18
5/26/2011	16.35	15.99	16.21	16.2	16.29	16.1	15.88	16.92	18.37	22.17
5/31/2011	18.71	18.21	18.45	18.18	17.98	19.06	19.76	20.67	21.8	23.43
6/7/2011	23.01	21.74	22.63	22.14	22.06	23.81	24.68	27.8	28.45	23.54
6/14/2011	20.99	20.95	21.29	21.73	21.38	23.14	23.84	25.17	26.14	27.25
6/21/2011	22.65	22.32	22.38	22.61	22.68	23.4	24.16	23.08	22.12	28.26
6/28/2011	21.92	22.17	22.2	22.33	22.26	23.4	24.52	24.02	24.03	25.46
7/5/2011	23.32	23.13	23.15	23.79	23.18	25.12	25.8	26.82	27.26	28.12
7/12/2011	23.58	23.74	23.66	23.58	23.67	26.28	27.33	29.94	29.6	28.2
7/19/2011	24.49	21.87	23.96	23.55	24.28	26.78	27.49	27.56	28.27	26.32
7/26/2011	22.14	22.11	22.06	22.26	23.01	25.51	25.59	26.15	26.41	25.39
8/2/2011	24.42	24.83	28.45	24.03	23.77	26.45	25.8	27.9	28.27	25.56
8/9/2011	24.31	24.25	25.09	24.02	24.32	24.92	25.1	25.49	25.64	28.1
8/16/2011	18.71	18.21	18.45	18.18	17.98	19.06	19.76	20.67	21.8	23.43
8/23/2011	24.27	25.78	28.41	24.9	24.45	24.52	24.16	26.53	27.37	27.37
8/30/2011	23.75	23.45	24.83	23.31	23.4	23.73	23.37	25.1	25.67	27.47
9/6/2011	22.68	22.15	21.88	21.83	21.44	21.61	21.22	20.1	19.83	23.72
9/20/2011	19.11	18.6	18.7	18.53	18.72	18.28	18.5	19.27	18.75	22.71
9/27/2011	18.65	18.38	18.98	18.85	18.39	19.05	17.97		19.77	21.14
10/4/2011	18.71	17.45	19.68	17.33	16.97	16.95	16.76	17.7	16.92	22.1
10/11/2011	18.13	17.38	17.2	17.37	17.32	17.65	17.48	18.07	17.42	22.09
10/18/2011	15.16	15.05	14.49	14.82	14.93	14.21	13.61	12.48	12.19	19.05
10/25/2011	15.44	13.72	17	13.73	16.7	13.67	15.99	16.81	17.23	20.71
11/1/2011	12.12	11.58	18.78	12.23	15.27	11.24	14.25	14.48	15.49	19.99
11/8/2011	11.39	9.82	10.92	9.92	10.67	9.91	11.99	10.15	9.86	17.33
11/15/2011	12.3	11.33	10.4	11.16	12.67	10.63	11.14	12.39	9.84	14.87
11/29/2011	10.04	9.35	9.06	8.01	8.64	6.91	7.3	5.82	5.53	14.75
12/6/2011	7.09	6.31	6.14	5.45	5.62	4.48	4.65	3.59	2.18	8.98
12/21/2011	5.5	7.24	5.18	4.45	4.55	4.4	4.05	3.55	2.83	7.31
12/27/2011	4.16	3.59	3.48	3.49	3.87	3.02	2.68	3.87	2.48	9.83

1/3/2012	4.71	4.13	4.07	3.82	3.66	3.98	3.57	3.45	1.65	7.57
1/10/2012	9.63	5.36	5.12	5.32	4.45	5.08	4.37	5.73	3.85	6.61

Table F.2. pH, based on a 0-14 scale, collected using the HORIBA meter for all sites from 1/7/2011 to 1/10/2012

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	7.61	6.19	7.19	7.09	7.13	7.43	7.34	7.69	7.78	8.45
2/4/2011	7.5	7.3	7.38	7.46	7.43		7.46	8.1		8.11
3/1/2011	7.18	7.16	7.38	7.22	7.21	7.32	7.33	8.3	8.59	8.6
3/17/2011	6.89	7.09	7.18	7.16	7.13	7.42	7.46	7.7	8.14	8.5
3/31/2011	7.04	7.22	7.11	7.12	7.03	6.98	7.05	7.82	8.6	8.58
4/12/2011	6.92	7.02	7.03	7.09	7.07	9.12	9.52	9.7	9.61	9.68
4/26/2011	6.53	6.39	5.56	6.06	7.22	7.59	7.59	7.75	8.23	8.46
5/12/2011	7.09	7	7.02	7.04	6.87	7.13	7.13	7.51	7.58	8.26
5/17/2011	7.11	7.04	6.89	7	6.96	7	7.22	7.31	7.65	7.8
5/26/2011	5.46	6.97	7.02	5.62	6.82	7.11	7.23	7.51	7.43	9.64
5/31/2011	8.08	7.21	6.13	6.41	6.33	7.15	7.22	7.44	7.02	7.97
6/7/2011	7.36	6.62	6.4	6.23	6.2	6.22	6.32	2.43	6.52	6.84
6/14/2011	6.72	5.87	5.42	5.26	5.17	5.04	5.83	6.09	5.86	6.67
6/21/2011	1.5	1.38	1.92	1.93	1.63	2.57	3.03	2.69	3.56	4.45
6/28/2011	7.03	5.86	5.53	5.16	5.36	5.17	5.77	6.33	6.65	6.74
7/5/2011	6.33	5.96	5.38	5.88	5.53	5.88	5.81	5.7	6.63	6.83
7/12/2011	6.74	6.69	6.48	6.69	6.47	6.71	6.62	7.21	7.12	9.99
7/19/2011	6.49	6.67	6.75	6.68	6.64	7	6.8	7.91	7.36	7.7
7/26/2011	6.72	6.6	6.63	6.66	6.47	8.36	7.96	8.05	7.62	7.54
8/2/2011	6.6	7.65	7.11	8.31	7.51	6.58	11.1	8.11	10.07	6.81
8/9/2011	6.42	6.86	7.19	7.78	7.63	7.7	8.02	8.14	8.11	8.82
8/16/2011	8.08	7.21	6.13	6.41	6.33	7.15	7.22	7.44	7.02	7.97
8/23/2011	4.91	4.62	3.54	3.3	3.41	3.55	3.79	3.99	4.16	4.57
8/30/2011	6.66	6.77	6.79	6.91	6.75	6.76	6.79	8.81	8.78	9.3
9/6/2011	4.94	5.4	6.26	6.45	6.56	6.62	6.76	6.96	7.05	7.52
9/20/2011	6.78	6.61	6.55	6.37	6.36	6.36	6.41	6.55	6.54	7
9/27/2011	7.44	7.16	6.86	7.06	7.17	7.3	7.1		7.36	7.5
10/4/2011	5.91	6.4	6.59	6.79	6.85	6.96	6.89	7.06	7.03	7.89
10/11/2011	6.08	6.53	6.69	6.92	6.89	7.03	7	7.19	7.2	8.12
10/18/2011	5.99	6.48	6.68	6.75	7.27	7.27	7.33	7.54	6.52	8.01
10/25/2011	5.84	6.43	6	6.79	7.36	7.35	7.59	7.61	7.31	8.06
11/1/2011	6.17	6.56	6.47	6.79	7.3	7.27	7.58	7.56	7.24	8.11
11/8/2011	5.41	6.18	6.31	6.49	6.54	6.66	7.21	7.3	7.15	7.75
11/15/2011	6	6.53	6.9	6.94	6.9	7.08	7	6.83	7.09	7.6
11/29/2011	5.61	6.27	6.61	6.81	6.82	6.93	6.92	7.04	7.1	7.87

12/6/2011	5.47	6.53	676	6.98	7.02	7.08	7.09	7.18	7.26	7.83
12/21/2011	6.63	5.13	7.39	6.65	6.94	7.23	7.23	7.17	7.23	7.56
12/27/2011	6.36	6.99	7.11	7.16	7.19	7.17	7.17	7.33	7.47	8.78
1/3/2012	6.63	6.99	7.19	7.26	7.33	7.33	7.34	7.63	7.82	8.45
1/10/2012	5.69	6.37	6.53	6.55	6.7	6.76	6.78	6.9	7.03	7.44

Table F.3. ORP, or oxidation reduction potential, was measured in millivolts (mV) from 1/7/2011 to 1/10/2012 for all sites using the HORIBA meter

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	285	307	319	327	326	298	283	296	303	285
2/4/2011	281	265	262	259	260		262	243		248
3/1/2011	267	255	232	251	249	247	254	218	166	190
3/17/2011	253	229	224	226	225	215	223	218	229	205
3/31/2011	255	243	244	242	247	249	263	230	222	223
4/12/2011	251	273	201	208	206	81	65	90	97	100
4/26/2011	230	123	165	207	81	140	54	131	201	6
5/12/2011	208	97	-40	54	6	105	-22	68	113	3
5/17/2011	246	127	-46	44	14	80	14	111	176	44
5/26/2011	265	200	188	229	179	172	181	183	206	146
5/31/2011	123	-71	18	59	-4	69	-108	67	137	-19
6/7/2011	480	-41	-165	-89	-111	56	-90	-44	83	-21
6/14/2011	170	-8	-142	-45	-89	85	-91	48	134	110
6/21/2011	481	184	20	101	92	200	65	265	271	257
6/28/2011	102	-75	-122	-70	-118	126	-29	104	139	84
7/5/2011	113	-71	-70	-92	-91	142	6	176	139	31
7/12/2011	125	-145	-157	-111	-211	31	-101	27	-23	-109
7/19/2011	167	-202	-213	-164	-213	11	69	3	80	77
7/26/2011	-9	-192	-180	-143	-85	-95	-142	-22	38	-47
8/2/2011	208	124	159	-75	-110	-77	-194	-89	-59	157
8/9/2011	239	127	-22	-8	-9	6	42	59	68	64
8/16/2011	123	-71	18	59	-4	69	-108	67	137	-19
8/23/2011	242	282	313	313	291	273	278	288	294	305
8/30/2011	121	92	18	70	50	75	125	37	45	54
9/6/2011	311	254	136	156	142	162	193	207	213	227
9/20/2011	127	97	59	96	97	121	142	166	180	192
9/27/2011	133	134	225	185	184	179	142		172	177
10/4/2011	160	121	63	70	109	120	147	166	199	177
10/11/2011	101	82	32	71	49	75	125	169	148	118
10/18/2011	284	229	194	165	86	119	84	104	198	124
10/25/2011	256	234	246	177	79	119	129	135	148	133
11/1/2011	279	258	218	123	77	132	136	150	152	146

11/8/2011	184	74	47	51	116	105	109	126	125	115
11/15/2011	78	60	18	3	26	-2	76	155	104	79
11/29/2011	190	92	50	107	40	56	127	139	151	107
12/6/2011	277	154	96	74	51	63	107	129	143	124
12/21/2011	124	222	109	116	106	110	129	127	142	127
12/27/2011	278	245	216	182	87	125	157	190	211	153
1/3/2012	248	245	229	157	92	111	142	187	219	200
1/10/2012	280	251	241	231	188	156	171	185	206	213

Table F.4. Conductivity, measured in millisiemens per centimeter (mS/cm), was collected using the HORIBA meter for all sites from 1/7/2011 to 1/10/2012

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	1.99	1.96	2.16	2.29	2.56	1.27	1.35	1.15	1.37	1.02
2/4/2011	1.12	0.95	1.05	1.02	1.06		0.99	1.03		1.01
3/1/2011	2.4	2.42	1.33	2.35	2.33	2.98	2.49	2.84	2.85	3.33
3/17/2011	3.24	2.74	3.45	3.63	3.54	3.28	3.46	3.42	2.25	2.76
3/31/2011	2.8	2.62	2.6	3.29	3.25	4.3	3.84	3.13	1.64	3.58
4/12/2011	3.18	3.27	3.17	3.4	3.03	3.65	3.41	2.97	3.46	7.09
4/26/2011	3.82	3.79	2.6	3.7	3.16	3.35	1.53	1.62	2.1	2.89
5/12/2011	3.86	3.26	4.12	3.43	3.27	5.09	5	3.2	4.09	4.01
5/17/2011	2.69	4.26	2.84	2.89	3.27	3.67	3.08	3.35	3.9	2.63
5/26/2011	3.38	0.13	0.03	0.05	0.03	0.05	0.02	0.07	0.05	6
5/31/2011	3.4	3.35	1.89	2.8	2.42	4.41	3.79	4.64	3.57	5.29
6/7/2011	2.25	2.44	2.48	2.62	2.42	3.92	3.13	4.57	4.21	2.13
6/14/2011	4.11	4.32	3.35	3.56	3.68	5.47	5.17	3.59	3.79	6.96
6/21/2011	4.32	3.59	4.36	3.62	3.35	5.08	4.71	4.43	5.37	10.5
6/28/2011	3.53	3.1	2.75	3.3	3.34	3.56	3.15	3.27	3.54	3.01
7/5/2011	9.61	8.8	8.1	7.15	9.08	9.41	9.1	6.13	9.61	7.71
7/12/2011	3.65	3.01	3.56	3.56	3.62	3.49	3.4	3.98	3.65	3.45
7/19/2011	4.96	4.6	4.59	4.37	4.41	6.02	6.19	2.36	6.16	0.91
7/26/2011	5.49	5.15	5.02	5.3	2.42	0	5.88	0	6.17	0.69
8/2/2011	5.79	5.91	0	5.76	5.4	0	4.85	0	6.45	0.81
8/9/2011	6.43	6.38	6.31	6.18	6.12	5.39	4.95	5.49	5.28	6.1
8/16/2011	3.4	3.35	1.89	2.8	2.42	4.41	3.79	4.64	3.57	5.29
8/23/2011	5.57	5.37	3.39	5.35	5.14	5.02	4.98	5.38	5.01	4.48
8/30/2011	5.59	5.33	5.38	5.48	5.46	5.86	5.71	5.67	5.62	6
9/6/2011	6.53	6.64	6.57	6.54	6.64	6.17	6.37	5.45	5.74	5.17
9/20/2011	6.06	5.96	5.77	5.57	5.5	5.14	5.3	5.56	5.64	4.89
9/27/2011	13.4	13.2	6.24	13.2	13.3	12.7	13.1		14.4	18.4
10/4/2011	6.07	6.18	5.93	6.11	5.95	5.94	6.12	5.57	5.32	4.82
10/11/2011	6.31	6.25	6.5	6.01	5.93	5.23	5.6	5.21	5.06	4.82

10/18/2011	5.76	5.72	2.66	5.6	6.55	5.17	6.39	5.21	0	4.76
10/25/2011	5.21	5.23	0	5.05	7.19	4.91	7.67	5.17	0	5.16
11/1/2011	5.21	4.98	0	5.07	6.32	5.04	5.64	5.19	0	7.04
11/8/2011	5.73	5.66	0	5.27	2.09	4.82	6.23	4.51	0	5.3
11/15/2011	5.54	4.86	4.84	5.74	2.9	5.12	4.21	2.68	3.32	4.38
11/29/2011	4.79	4.59	4.84	4.78	4.46	4.4	4.33	4.14	4.11	6.76
12/6/2011	4.14	4.16	4.2	4.1	3.95	3.93	3.98	3.92	4.03	4.55
12/21/2011	3.34	0.008	0.03	0.016	3.24	2.87	3.27	0.058	3.89	3.23
12/27/2011	3.61	3.62	3.75	3.47	3.25	3.4	3.51	3.49	3.78	3.68
1/3/2012	3.57	3.56	3.56	3.43	3.34	3.06	3.25	3.66	3.7	2.53
1/10/2012	3.18	3.3	3.41	3.28	3.42	3.46	3.47	3.82	3.94	0.907

Table F.5. Turbidity, measured in Nephelometric Turbidity Units (NTU), collected using the HORIBA meter for all sites from 1/7/2011 to 1/10/2012

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	24	4	15.3	3.9	2.7	3	4.2	6	6.5	24
2/4/2011	1.4	47.1	19.6	28	32.3		19.8	15.1		11.4
3/1/2011	84.2	116	66.1	67.8	54.2	403	398	178	295	48.8
3/17/2011	53.9	54.4	175	368	188	560	304	494	101	101
3/31/2011	324	269	216	225	214	315	454	425	97.4	184
4/12/2011	59.1	202	170	71.5	435	407	248	173	126	315
4/26/2011	89.1	68.8	448	89.6	478	356	378	504	140	267
5/12/2011	79.4	401	449	434	98.9	272	524	775	368	209
5/17/2011	255	295	0	208	367	39.6	511	362	401	151
5/26/2011	26.9	253	249	257	208	254	260	259	48.3	46.2
5/31/2011	204	467	496	603	681	115	715	800	800	114
6/7/2011	101	121	214	206	270	275	338	182	130	208
6/14/2011	146	108	103	350	69.6	597	570	62.7	448	23.7
6/21/2011	193	391	142	218	295	204	200	606	603	43.9
6/28/2011	105	221	221	172	172	128	307	413	200	148
7/5/2011	145	245	179	321	423	322	578	452	323	135
7/12/2011	80.5	332	42.2	53.1	225	31.7	91.6	190	345	313
7/19/2011	217	207	800	70	221	7.1	2.4	27.9	7.1	79.3
7/26/2011	35.6	93	56.4	194	194	720	22.5	259	164	94.9
8/2/2011	2.7	182	282	21.2	104	286	23.8	236	61.8	118
8/9/2011	5.2	2.3	20.5	3.2	22.4	1.2	1.1	3.3	2.5	23.3
8/16/2011	204	467	496	603	681	115	715	800	800	114
8/23/2011	3.4	23.9	19.1	4.4	9.6	1.5	0.9	0.2	6	40.2
8/30/2011	1.2	2	2.5	0.1	6.1	3.3	63.1	2.2	3.4	42.6
9/6/2011	1.8	2	58.2	10.1	40.2	2.7	72	3.4	1.9	45.4
9/20/2011	1.6	0.2	1.9	12.6	9.8	2.7	1.1	2.1	3.5	38.2

9/27/2011	2.9	62.6	23.3	24	8	95.8	60.6		33.9	7
10/4/2011	2.3	3.8	23.4	3.7	10.2	6.7	7.8	7.5	5.4	27.2
10/11/2011	1.6	7.7	21.1	4.5	5.1	3	4.2	10.3	7.8	42.6
10/18/2011	1.6	15.1	199	6.8	10.1	11.8	140	9.5	262	33.6
10/25/2011	0.8	4.5	354	8.9	76.3	2.8	69.5	7.1	262	29.3
11/1/2011	0	8.2	268	4.6	24.5	3.1	10.1	380	270	35
11/8/2011	3.7	8	245	73.5	34.6	18	104	14.9	189	34.4
11/15/2011	5.6	5.4	12.1	20.2	13.9	19	9.3	15	24.4	14.9
11/29/2011	2.7	2.4	8.3	5	10.2	5.3	10.4	11.2	14.4	14.6
12/6/2011	3.5	4	3.5	3.5	18.4	222	6.2	9.3	15.3	37.4
12/21/2011	9.9	237	355	198	57.1	71.9	163	224	21	88.3
12/27/2011	83.5	3.2	3.3	5	6.5	81.4	5.7	7.9	12.2	79
1/3/2012	1.2	3.1	3.1	4.8	151	48.3	4.9	7.6	10.7	15.5
1/10/2012	2	2.4	8.6	6.6	6.4	3.1	5.2	10.5	9	22.5

Table F.6. DO, or dissolved oxygen, was measured in mg/L using the HORIBA meter for all sites from 1/7/2011 to 1/10/2012

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	13.77	5.06	6.1	3	4.12	7.05	6.34	10.61	10.2	13.46
2/4/2011	11.4	12.78	12.21	12.8	11.08		13.9	18.21		12.16
3/1/2011	26.49	16.5	16.4	15.94	15.01	16.45	16.11	15.12	17.56	11.77
3/17/2011	20.92	15.64	12.08	11.17	3.57	11.36	11.48	6.83	9.5	11.08
3/31/2011	10.65	8.65	8.32	1.73	4.26	6	10.75	10.26	11.41	9.84
4/12/2011	13.59	6.41	6.32	2.16	11.58	10.73	11.26	7.7	8.05	6.87
4/26/2011	13.39	8.47	14.05	11.14	13.57	13.93	14.45	14.16	14.04	12.44
5/12/2011	11.82	11.29	10.22	10.15	10.25	8.87	9.45	9.66	9.01	8.82
5/17/2011	14.58	9.98	10.21	7.51	2.8	11.92	14.08	10.43	2.68	5.82
5/26/2011	10.73	8.57	10.01	6.8	10.33	9.24	10.07	9.7	9.14	4.44
5/31/2011	9.83	10.31	10.51	10.27	9.92	9.48	9.99	9.18	9.46	7.69
6/7/2011	8.93	4.57	9.21	6.97	4.57	8.94	8.52	4.36	4.22	6.26
6/14/2011	8.05	1.32	9.19	4.96	1	9.15	9.07	3.74	7.92	4.36
6/21/2011	8.57	9.54	8.27	8	7.76	9.01	9.17	9.38	9.8	4.52
6/28/2011	15.95	17.99	16.96	12.57	10.16	16.82	15.68	12.96	17.23	15.37
7/5/2011	9.98	9.16	8.62	8.82	5.95	8.03	8.12	7.22	4.71	7.38
7/12/2011	8.6	7.63	6.9	5.51	6.67	5.56	5.46	4.41	6.52	8.11
7/19/2011	8.21	4.14	7.96	2.81	6.88	8.04	7.84	4.16	4.72	5.09
7/26/2011	8.54	6.53	7.66	7.34	8.05	7.81	4.35	7.81	4.82	7.64
8/2/2011	6.12	8.45	6.76	8.29	7.42	6.74	7	6.61	6.49	5.24
8/9/2011	6.4	4	6.96	8.01	7.73	4.03	5.77	7.29	7.26	2.92
8/16/2011	9.83	10.13	10.51	10.27	9.92	9.84	9.99	9.18	9.46	7.69
8/23/2011	6.6	8.57	8.98	10.22	5.25	5.49	9.35	8.49	8.26	8.97

8/30/2011	10.4	9.3	8.58	8.83	3.43	6.65	8.41	7.73	7.42	7.28
9/6/2011	6.62	5.93	9.08	4.54	5.44	8.97	4.81	10.01	10.12	5.84
9/20/2011	12.25	11.33	11.4	9.42	7.07	10.7	10.43	10	6.71	5.41
9/27/2011	13.4	12.4	6.81	11.74	12.11	11.5	12.05		6.63	10.44
10/4/2011	13.31	6.2	10.73	11.12	10.99	11.18	11.13	10.81	10.98	8.87
10/11/2011	11.95	10.76	10.94	10.61	5.89	10.23	10.4	10.14	10.53	8.65
10/18/2011	9.49	10.3	10.78	9.87	10.23	9.49	10.66	11.19	11.5	7.58
10/25/2011	10.46	12.42	11.21	10.1	7.42	10.69	6.33	9.68	10.14	7.87
11/1/2011	13.62	13.42	9.7	12.88	11.03	12.42	11.13	10.46	10.72	8.48
11/8/2011	10.93	10.81	11.99	10.76	11.12	10.89	9.84	10.94	11.32	6.15
11/15/2011	15.63	15.16	13.15	11.46	8.55	12.16	10.68	5.62	12.7	9.56
11/29/2011	14.47	12.38	11.88	12.06	9.95	12.78	12.37	13.05	13.52	7.31
12/6/2011	14.82	13.48	13.14	13.17	11.77	12.07	13.26	14.33	15.19	8.92
12/21/2011	13.65	14.09	13.97	14.21	12.56	9.73	10.04	14.67	13.93	12.47
12/27/2011	19.83	8.92	13.98	11.55	12.98	14.03	14.21	13.73	9.07	11.74
1/3/2012	11.51	11.58	12.98	11.73	12.38	12.53	13.39	13.51	14.99	11.89
1/10/2012	15.83	17.85	15.87	14.58	13.12	10.38	14.31	13.29	14.41	12.01

Table F.7. TDS, or total dissolved solids, was measured in g/L for all sites from 1/7/2011 to 1/10/2012 using the HORIBA meter

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	1.27	1.25	1.33	1.47	1.64	0.812	0.667	0.966	0.88	0.652
2/4/2011	0.718	0.611	0.67	0.653	0.677		0.633	0.658		0.644
3/1/2011	1.43	1.2	0.8	1.47	1.48	1.92	1.72	1.53	1.97	2.14
3/17/2011	2.07	1.75	2.19	2.32	2.27	2.08	2.22	2.19	1.46	1.77
3/31/2011	1.79	1.7	1.67	2.1	2.13	2.75	2.47	2.06	1.03	2.38
4/12/2011	2.03	2.09	2.05	2.19	1.92	2.3	2.18	1.91	2.2	4.47
4/26/2011	2.44	2.43	1.56	2.34	1.95	2.13	0.978	0.955	1.24	1.79
5/12/2011	2.47	2.06	2.63	2.16	2.09	3.2	3.18	1.94	2.62	2.54
5/17/2011	1.71	2.73	1.78	1.9	2.14	2.31	1.97	2.2	2.5	1.76
5/26/2011	2.1	0.085	0.021	0.032	0.016	0.03	0.01	0.044	0.033	3.78
5/31/2011	2.16	2.11	1.11	1.69	1.44	2.82	2.42	2.96	2.15	3.33
6/7/2011	1.43	1.55	1.58	1.68	1.55	2.5	2	2.93	2.68	1.35
6/14/2011	2.63	2.76	2.14	2.27	2.35	3.45	3.25	2.3	2.86	4.38
6/21/2011	2.69	2.16	2.75	2.23	2	3.19	3	2.64	3.36	6.51
6/28/2011	2.26	1.98	1.74	2.09	2.13	2.26	2.01	2.08	2.26	1.89
7/5/2011	6.04	5.5	5.1	4.5	5.73	5.91	5.73	3.64	5.98	4.9
7/12/2011	2.33	1.93	2.28	2.27	2.32	2.23	2.18	2.55	2.34	2.07
7/19/2011	3.17	2.93	2.93	2.79	2.83	3.74	3.9	1.51	3.88	0.584
7/26/2011	3.46	3.24	3.16	3.34	1.39	0	3.7	0	3.89	0.441
8/2/2011	3.65	3.73	0	3.63	3.4	0	3.1	0	4.06	0.518

8/9/2011	4.05	4.02	3.98	3.89	3.86	3.39	3.17	3.46	3.33	3.84
8/16/2011	2.16	2.11	1.11	1.69	1.44	2.82	2.42	2.96	2.15	3.33
8/23/2011	3.51	3.38	2.17	3.37	3.24	3.17	3.18	3.39	3.16	2.87
8/30/2011	3.52	3.36	3.39	3.45	3.44	3.69	3.59	3.57	3.54	3.78
9/6/2011	4.11	4.18	4.14	4.12	4.18	3.89	4.01	3.43	3.62	3.26
9/20/2011	3.82	3.75	3.64	3.51	3.46	3.23	3.34	3.5	3.55	3.13
9/27/2011	8.34	8.19	3.93	8.18	8.27	7.86	8.14		8.91	11.4
10/4/2011	3.82	3.89	3.74	3.85	3.75	3.74	3.85	3.51	3.35	3.09
10/11/2011	3.97	3.94	4.09	3.79	3.74	3.3	3.53	3.28	3.18	3.08
10/18/2011	3.63	3.61	1.7	3.53	4.13	3.26	4.03	3.28	0	3.05
10/25/2011	3.28	3.29	0	3.17	4.53	3.14	4.83	3.26	0	3.26
11/1/2011	3.28	3.18	0	3.19	3.98	3.18	3.56	3.27	0	4.44
11/8/2011	3.6	3.56	0	3.31	1.33	3.09	3.92	2.89	0	3.35
11/15/2011	3.48	3.11	3.1	3.61	1.86	3.22	2.7	1.71	2.12	2.8
11/29/2011	3.06	2.94	3.1	3.06	2.85	2.82	2.77	2.65	2.63	4.28
12/6/2011	2.64	2.66	2.69	2.63	2.52	2.51	2.55	2.51	2.58	2.91
12/21/2011	2.1	0.004	0.018	0.01	2.03	1.74	2.08	0.034	2.41	1.91
12/27/2011	2.31	2.32	2.4	2.22	2.08	2.17	2.25	2.23	2.42	2.36
1/3/2012	2.29	2.28	2.28	2.2	2.14	1.96	2.08	2.35	2.37	1.62
1/10/2012	2.03	2.11	2.18	2.09	2.19	2.21	2.22	2.44	2.52	0.581

Table F.8. Salinity, measured in parts per trillion (ppt), was measured for all sites using the HORIBA meter from 1/7/2011 to 1/10/2012

Date	LS	AD-7	AD-8	AD-5	AD-6	AD-3	AD-4	AD-1	AD-2	SB
1/7/2011	1	1	1.1	1.2	1.3	0.6	0.7	0.7	0.7	0.4
2/4/2011	0.5	0.4	0.5	0.5	0.5		0.5	0.5		0.5
3/1/2011	1.1	0.9	0.6	1.1	1.1	1.5	1.3	1.2	1.6	1.7
3/17/2011	1.7	1.4	1.8	1.9	1.8	1.7	1.8	1.6	1.2	1.5
3/31/2011	1.4	1.3	1.3	1.7	1.7	2.2	2	1.6	0.8	1.8
4/12/2011	1.7	1.7	1.7	1.8	1.6	1.9	1.8	1.5	1.8	3.7
4/26/2011	2.8	2	1.3	2	1.6	1.7	0.8	0.8	1	1.4
5/12/2011	2	1.7	2.2	1.8	1.7	2.7	2.7	1.7	2.2	2.1
5/17/2011	1.4	2.3	1.5	1.5	1.7	1.9	1.6	1.8	2	1.3
5/26/2011	1.8	0.1	0	0	0	0	0	0	0	3.3
5/31/2011	1.9	1.8	0.9	1.4	1.2	2.3	2	2.5	1.8	2.8
6/7/2011	1.2	1.3	1.3	1.4	1.3	2.1	1.6	2.4	2.2	1.1
6/14/2011	2.2	2.3	1.8	1.9	1.9	2.9	2.8	1.9	2	3.8
6/21/2011	2.3	1.9	2.3	1.9	1.7	2.7	2.7	2.5	2.4	2.9
6/28/2011	1.9	1.6	1.4	1.7	1.8	1.9	1.6	1.7	1.9	1.5
7/5/2011	5.5	5	4.5	4	5.1	5.3	5.1	3.3	5.3	4.2
7/12/2011	1.9	1.6	1.9	1.9	1.9	1.8	1.8	2.1	1.9	1.8

7/19/2011	2.7	2.5	2.4	2.3	2.4	3.2	3.4	1.2	3.3	0.4
7/26/2011	3	2.8	2.7	2.9	1.2	0	3.2	0	3.4	0.3
8/2/2011	3.1	3.2	0	3.1	2.9	0	2.6	0	3.5	0.4
8/9/2011	3.5	3.5	3.4	3.4	3.3	2.9	2.6	3	2.8	3.3
8/16/2011	1.9	1.8	0.9	1.4	1.2	2.3	2	2.5	1.8	2.8
8/23/2011	3	2.9	1.8	2.9	2.8	2.7	2.7	2.9	2.7	2.4
8/30/2011	3	2.9	2.9	3	2.9	3.2	3.1	3.1	3	3.2
9/6/2011	3.6	3.6	3.6	3.6	3.6	3.4	3.5	2.9	3.1	2.8
9/20/2011	3.3	3.2	3.2	3	3	2.8	2.9	3	3	2.6
9/27/2011	7.7	7.6	3.4	7.6	7.7	7.2	7.5		8.3	10.9
10/4/2011	3.3	3.4	3.2	3.3	3.3	3.3	3.3	3	2.9	2.6
10/11/2011	3.4	3.4	3.6	3.3	3.2	2.8	3	2.8	2.7	2.6
10/18/2011	3.1	3.1	1.4	3	3.5	2.8	3.4	2.8	0	2.5
10/25/2011	2.8	2.8	0	2.7	3.9	2.6	4.2	2.8	0	2.7
11/1/2011	2.8	2.7	0	2.8	3.4	2.7	3	2.8	0	3.8
11/8/2011	3.1	3.1	0	2.8	1.1	2.6	3.4	2.4	0	2.8
11/15/2011	3	2.6	2.6	3.1	1.5	2.8	2.2	1.4	1.7	2.3
11/29/2011	2.5	2.4	2.6	2.5	2.3	2.3	2.3	2.2	2.1	3.5
12/6/2011	2.2	2.2	2.2	2.1	2	2	2	2	2	2.4
12/21/2011	1.8	0	0	0	1.6	1.4	1.6	0	2	1.5
12/27/2011	1.8	1.8	1.9	1.7	1.6	1.7	1.8	1.8	1.9	1.9
1/3/2012	1.8	1.8	1.8	1.7	1.7	1.5	1.6	1.8	1.8	1.3
1/10/2012	1.6	1.7	1.7	1.7	1.7	1.8	1.8	2	2	0.4

Water Quality Measurement Results

Temperature

Temperature is an important factor to measure in a constructed wetland, because it is a highly fluctuating and important abiotic factor. Temperature itself is “highly variable over daily, seasonal, and latitudinal gradients” (Kadlec and Knight 1996); therefore, temperature is typically measured to determine the potential thermal condition of water leaving the constructed wetland into receiving waters, which might be temperature sensitive (Kadlec and Knight 1996). For the CWTS located at JEC, temperature was measured with the HORIBA meter in degrees Celsius (°C). The following figures (Figure F.1-F.7) show the relationship between temperature and one of the seven main pollutants to determine if there was a relationship between these two values in order to eliminate using the HORIBA meter and/or the water sampling, and simply use one to determine the other. All the figures represent a time frame from 1/7/2011, when the HORIBA

meter was first run at the CWTS, until 1/10/2012 when the HORIBA meter was last used at the CWTS.

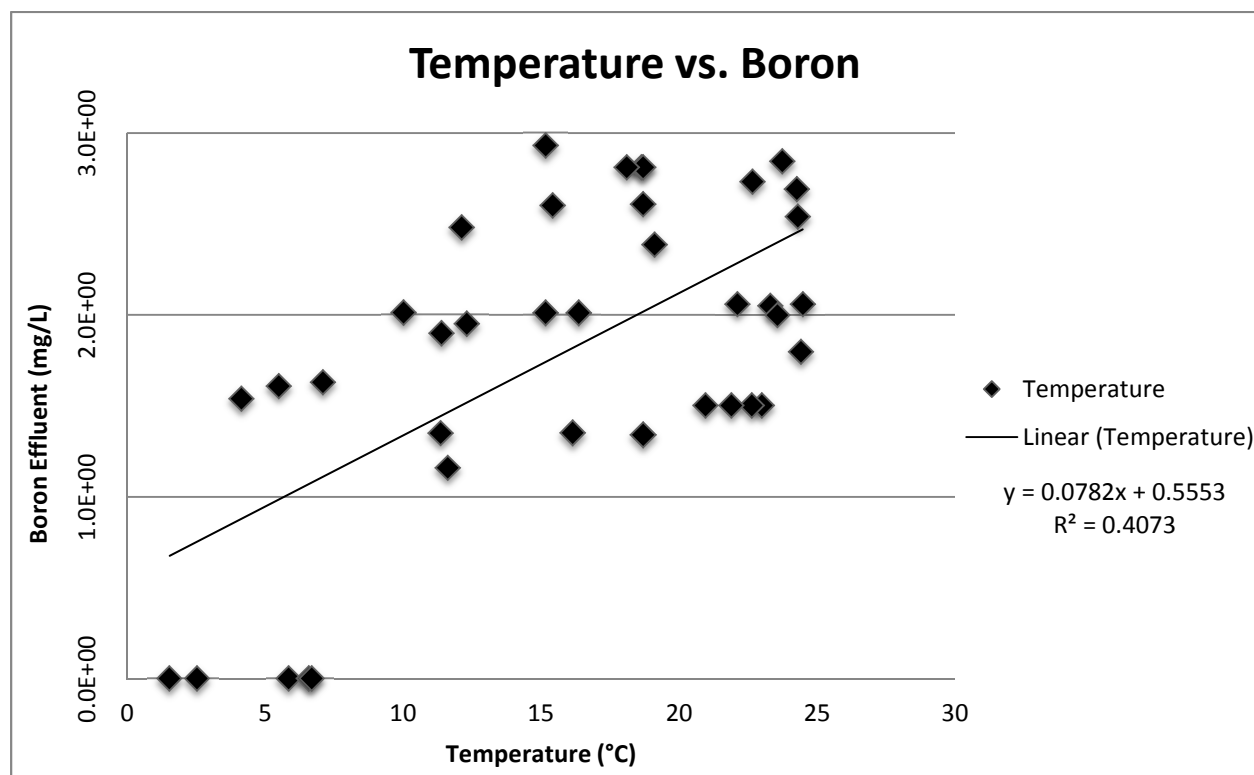


Figure F.1. Temperature (°C) plotted against effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

From Figure F.1, temperature was plotted against the effluent boron concentrations in grams from 1/7/2011 to 1/10/2012. A linear trend line was used to determine if there was a strong correlation between temperature and boron; however, the coefficient of determination, R^2 , is 0.4073 or 40.73%. The R^2 determines the linear correlation between plots of values in which the closer the R^2 value is to 1, the more accurate and/or less variance the values have from the line. Typically, to have a strong coefficient of determination, the value needs to be closer to 1; however, because the R^2 for temperature vs. boron is less than 50%, showing there is not a strong relationship between these two values.

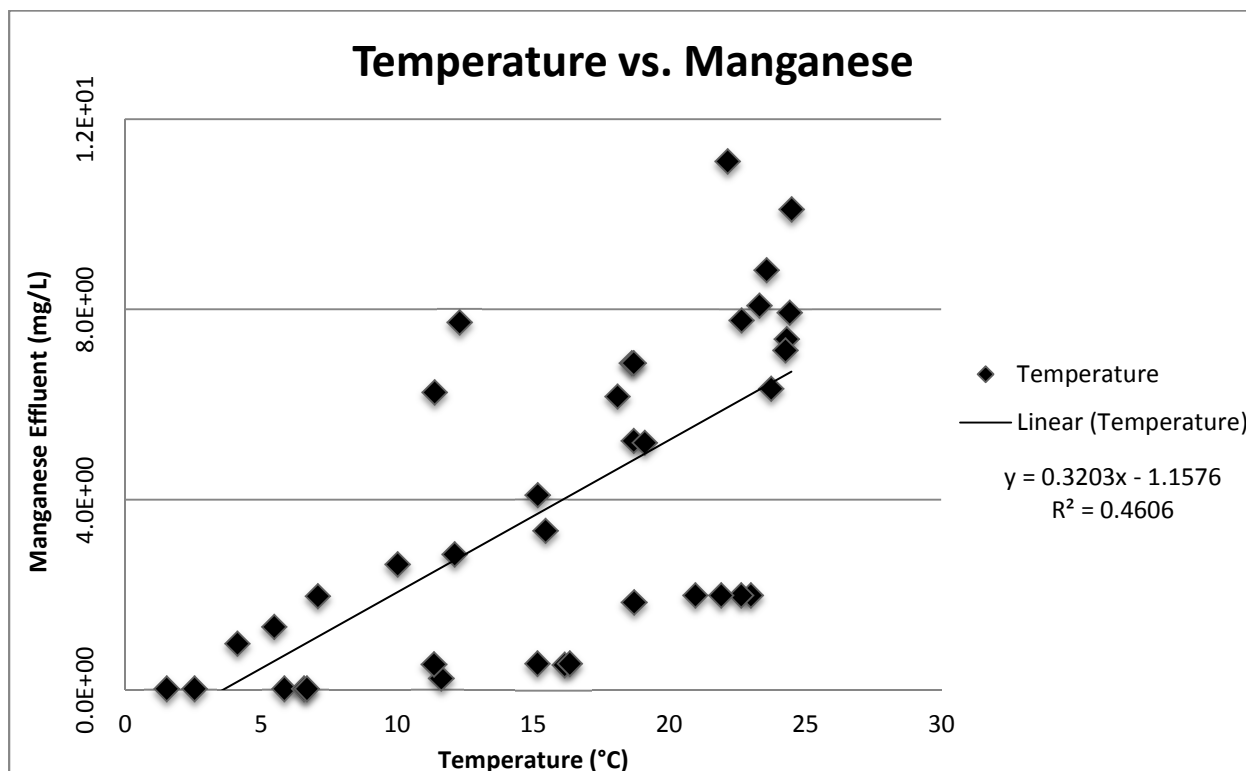


Figure F.2. Temperature (°C) plotted versus effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

Temperature was also plotted against the effluent manganese concentrations, in grams, from 1/7/2011 to 1/10/2012 which can be seen in Figure F.2. A linear trend line is shown within this figure to determine how strong of a correlation there is, if any, between temperature and manganese. Between manganese and boron, there is a higher correlation between temperature and the effluent manganese concentration compared to the effluent boron concentrations. The R^2 for temperature vs. manganese is about 46%; however, 46% is not a strong enough relationship between these two values.

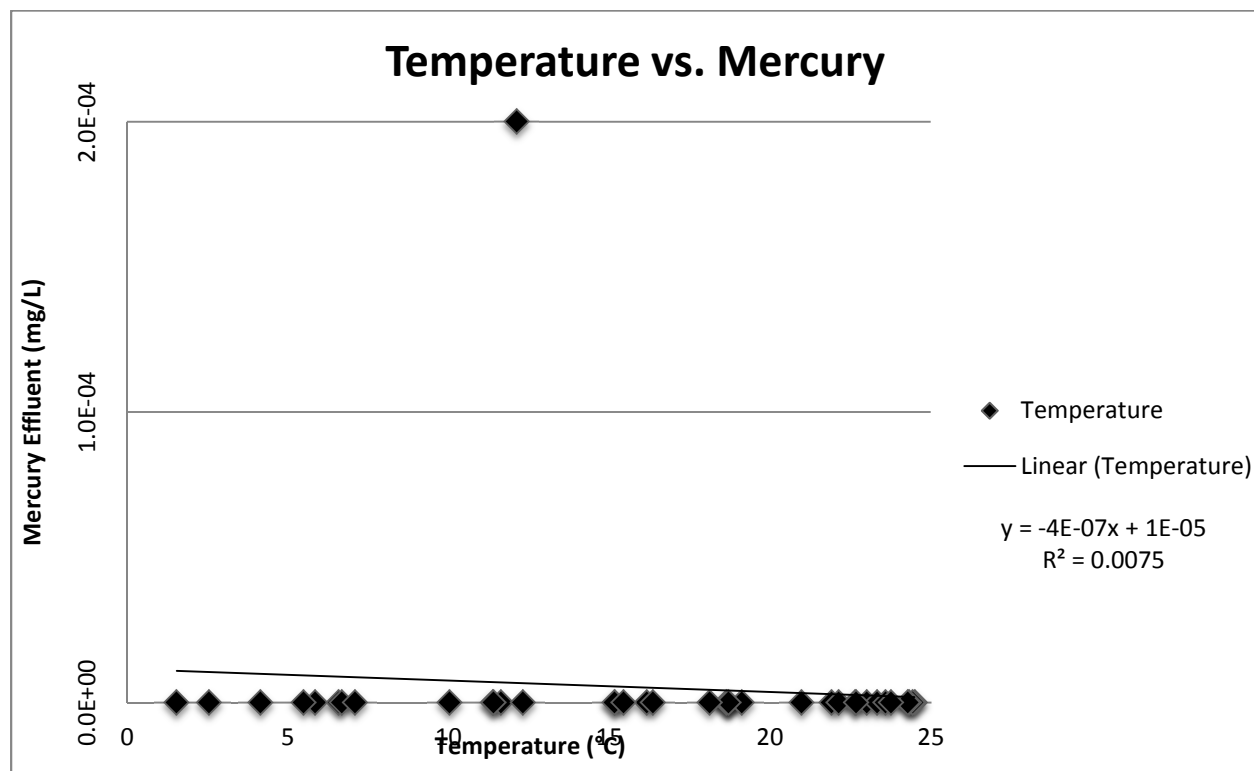


Figure F.3. Temperature (°C) plotted against effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

In Figure F.3, temperature was plotted against mercury effluent concentrations with a time frame from 1/7/2011 to 1/10/2012. Mercury effluents concentrations were typically zero; therefore, when comparing mercury effluent concentrations to temperature, the values all show up on the zero line. The R^2 correlation between these two values is less than 1%, which is due to no mercury leaving the CWTS; therefore, there is no correlation to the temperature of the water leaving the CWTS and the effluent mercury concentrations.

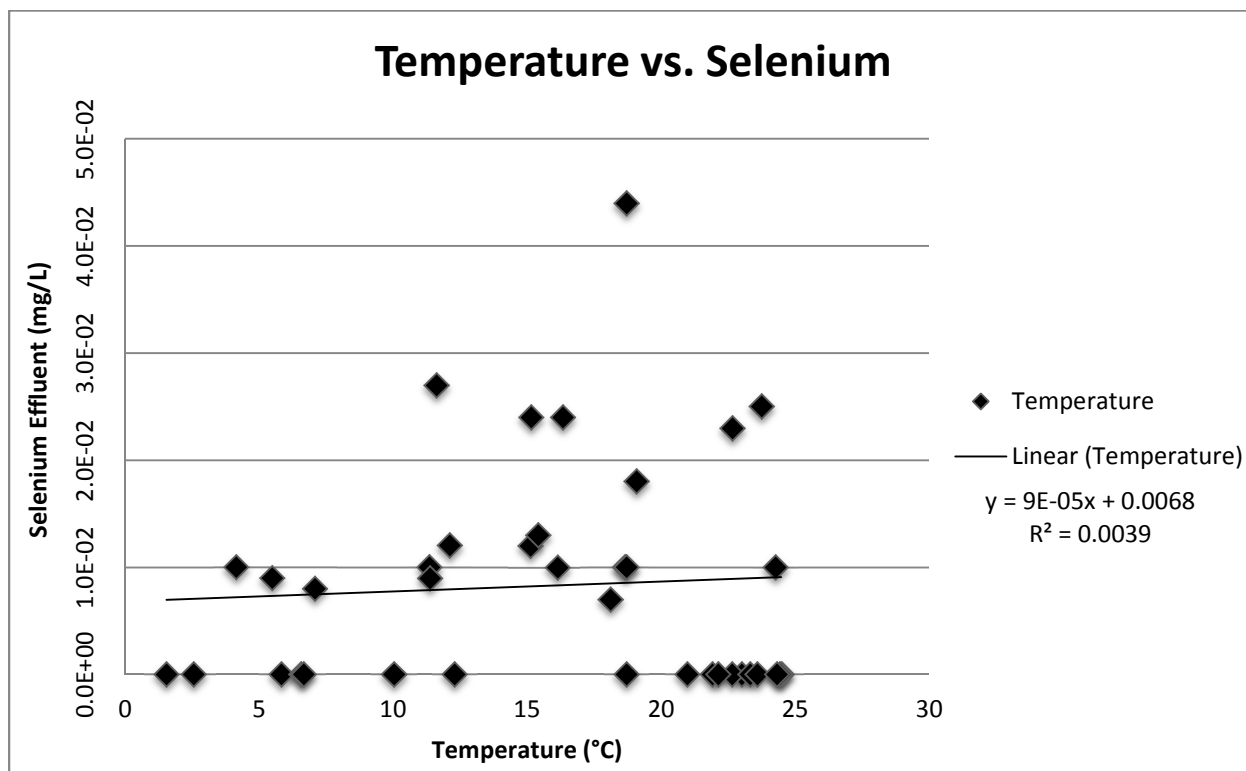


Figure F.4. Temperature (°C) plotted against effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

Temperature values were plotted against effluent selenium concentrations from 1/7/2011 to 1/10/2012 found in Figure F.4. The linear trend line is shown within the figure and it's relatively horizontal; therefore, a horizontal trend line depicts little to no correlation between the two values being compared. For temperature and effluent selenium concentrations, the R^2 value is less than 1%, almost 0%. Because of this small R^2 value, there is not a strong relationship between temperature and selenium; therefore, changes in temperature cannot be accounted for by changes in effluent selenium concentrations and vice versa.

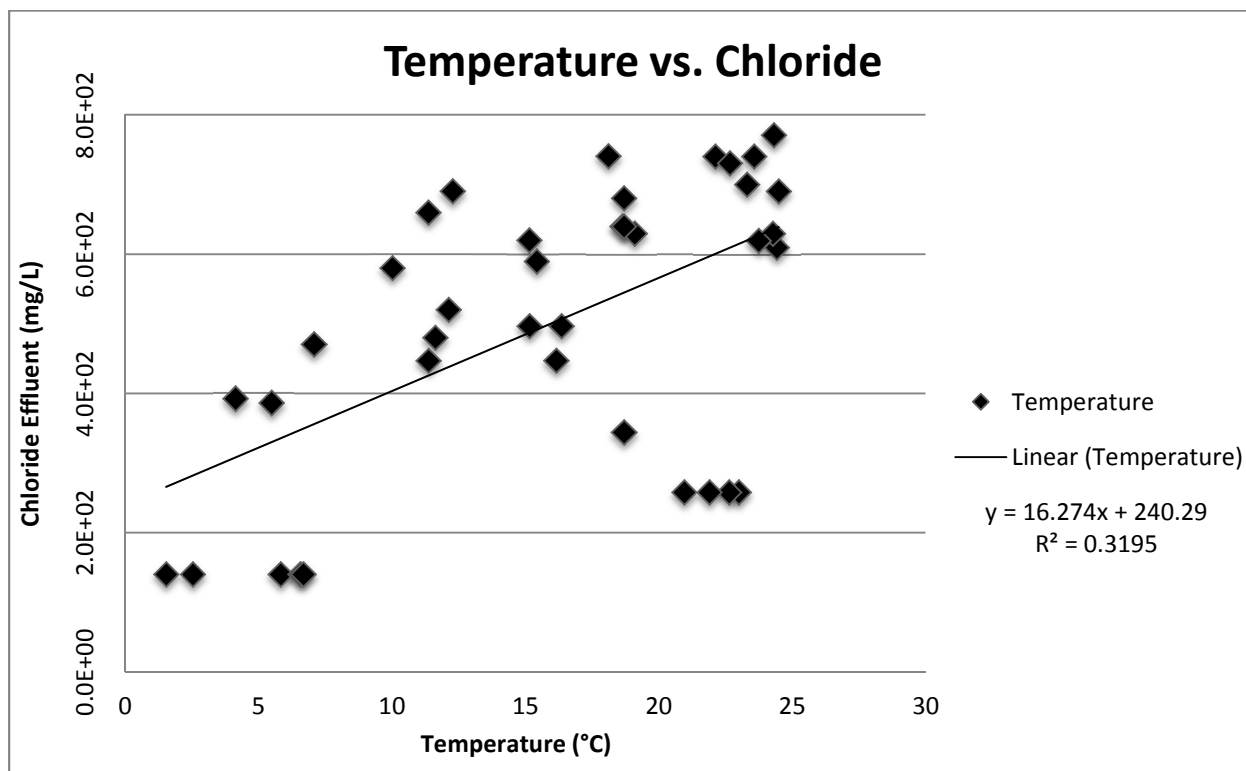


Figure F.5. Temperature (°C) plotted against effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Temperature determined by the HORIBA meter was plotted against chloride effluent concentrations from 1/7/2011 to 1/10/2012 in Figure F.5. The R^2 value for temperature vs. chloride is 0.3195 or about 32%. Temperature and chloride do not have a strong relationship between these two values based on the small R^2 value.

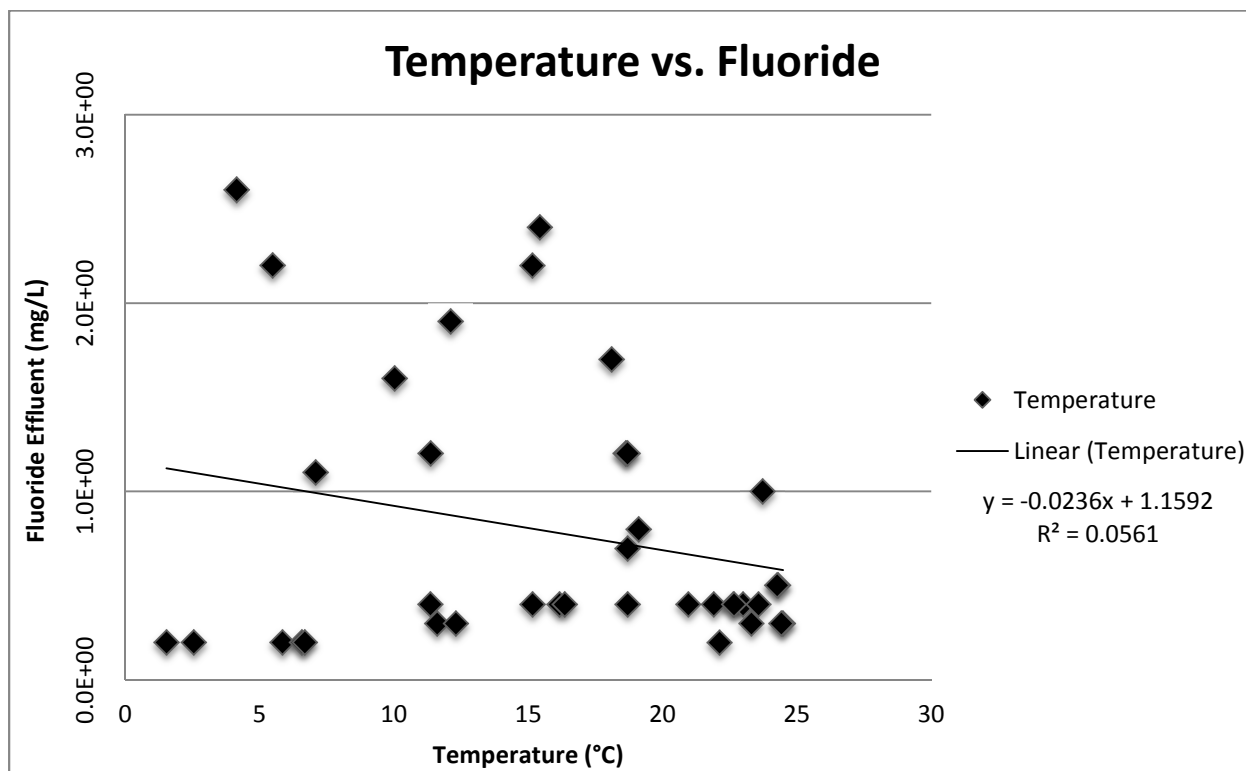


Figure F.6. Temperature (°C) plotted against effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.6 displays temperature plotted against the effluent fluoride concentrations from 1/7/2011 to 1/10/2012. The R^2 value for temperature versus fluoride effluent concentrations is about 6%, which does not represent a strong relationship between these two values.

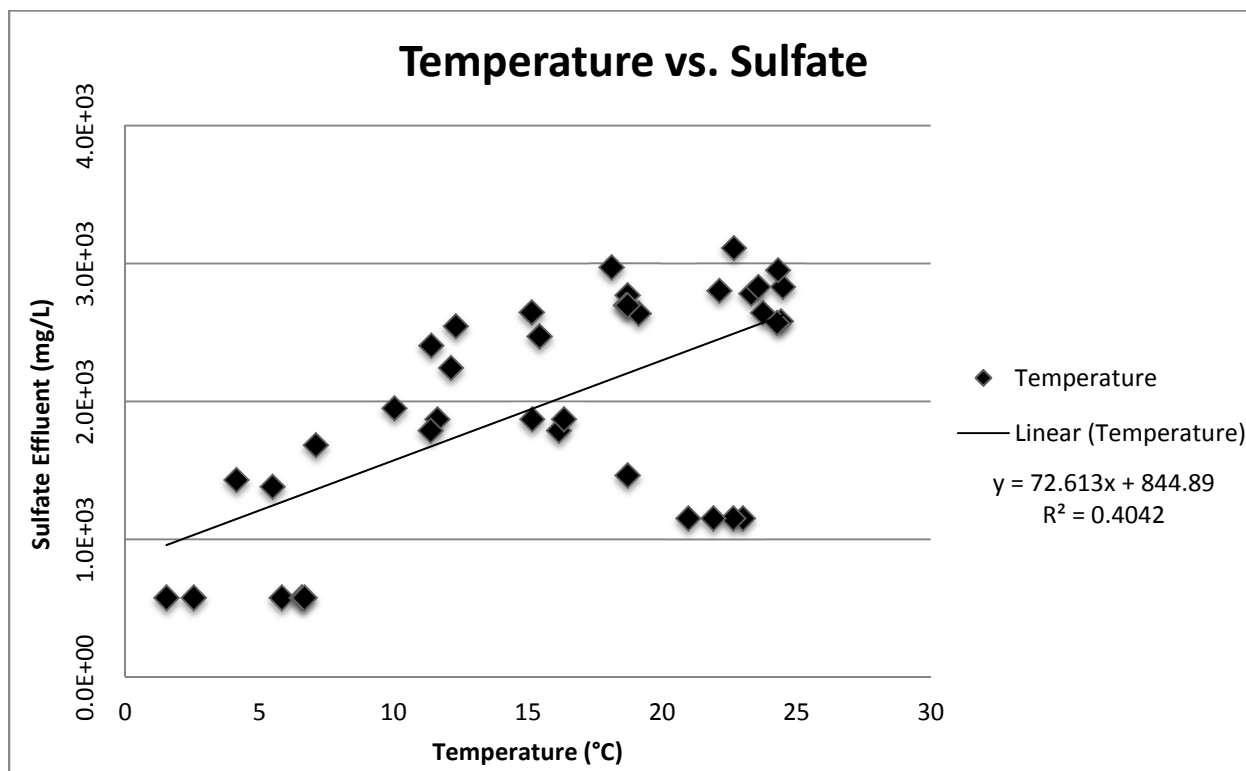


Figure F.7. Temperature (°C) plotted against effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

Temperature was plotted against effluent sulfate concentrations from 1/7/2011 to 1/10/2012, which is displayed in Figure F.7. Similar to some of other figures like temperature versus boron and manganese, the linear trend line for this figure has positive sloped line; however, the trend line represents an R^2 value of 40%. Due to the small R^2 value, there is not a strong relationship between temperature and sulfate.

All the temperature values from 1/7/2011 to 1/10/2012 from the LS location on the CWTS at JEC were plotted with one of the seven main pollutants tested for to determine if there was a strong relationship between one another in order to save money on the project. For temperature, boron, manganese, and sulfate had R^2 above 40%, compared to the other five pollutants that averaged an R^2 value below 30%. However, these R^2 values are not high enough to justify a relationship between temperature and pollutant concentration.

pH

The pH of the wetland system reflects the amount of hydrogen ions present and can influence many difference chemical and biochemical processes within the water. Typically, clean natural waters have a pH range of 4.5 to 8.3 given by the equilibrium between free and bonded CO₂; therefore, the pH can be affected by “humic substances, a higher content of cations easily undergoing hydrolysis, a higher content of hydrogen sulfide and its ionic forms, and a higher content of phosphates, etc.” (Tölgyessy 1993). An increase in water pH above 8.3 is caused by waters containing CO₃⁻² or OH⁻ ions or organic bases, while a decrease in water pH below 4.5 is caused by free inorganic and organic acids (Tölgyessy 1993).

The pH of water can also be influenced through biological processes present within the wetland system such as biological nitrification. During biological nitrification, hydrogen ions are released, reacting with hydrogen carbonates present to release free CO₂ and water pH decreases consequently (Tölgyessy 1993). Likewise, if pH increases, biological denitrification or the reduction of sulfates could be occurring (Tölgyessy 1993). Along with sulfate concentrations, calcium content is strongly correlated with pH; therefore, by understanding these concepts this, the following figures (Figure F.8-F.14) were plotted comparing pH versus one of the seven main pollutants tested for.

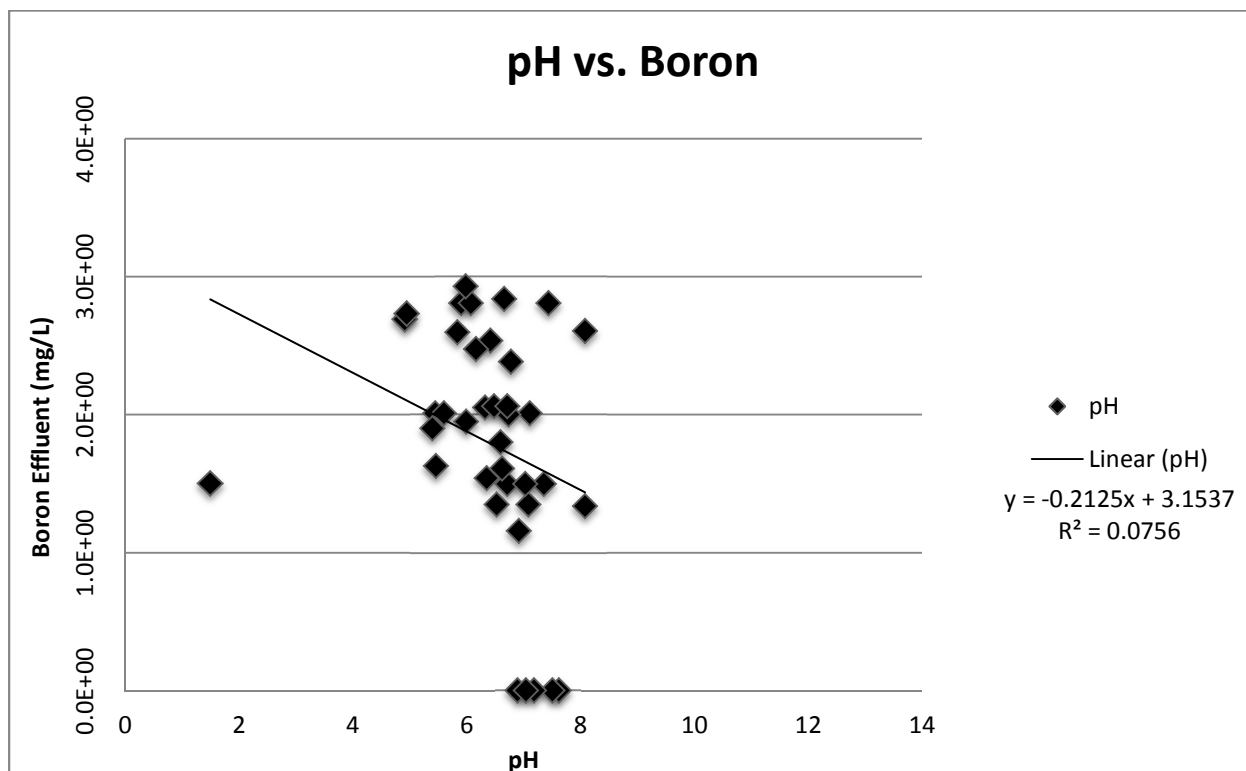


Figure F.8. The pH (0-14 scale) plotted against effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

From Figure F.8, pH was plotted against the effluent boron concentrations from 1/7/2011 to 1/10/2012. The linear trend line found in this figure has a negative slope and represents an R^2 value of about 8%. With such a small R^2 value, there was not a strong relationship between pH and the amount of boron leaving the CWTS.

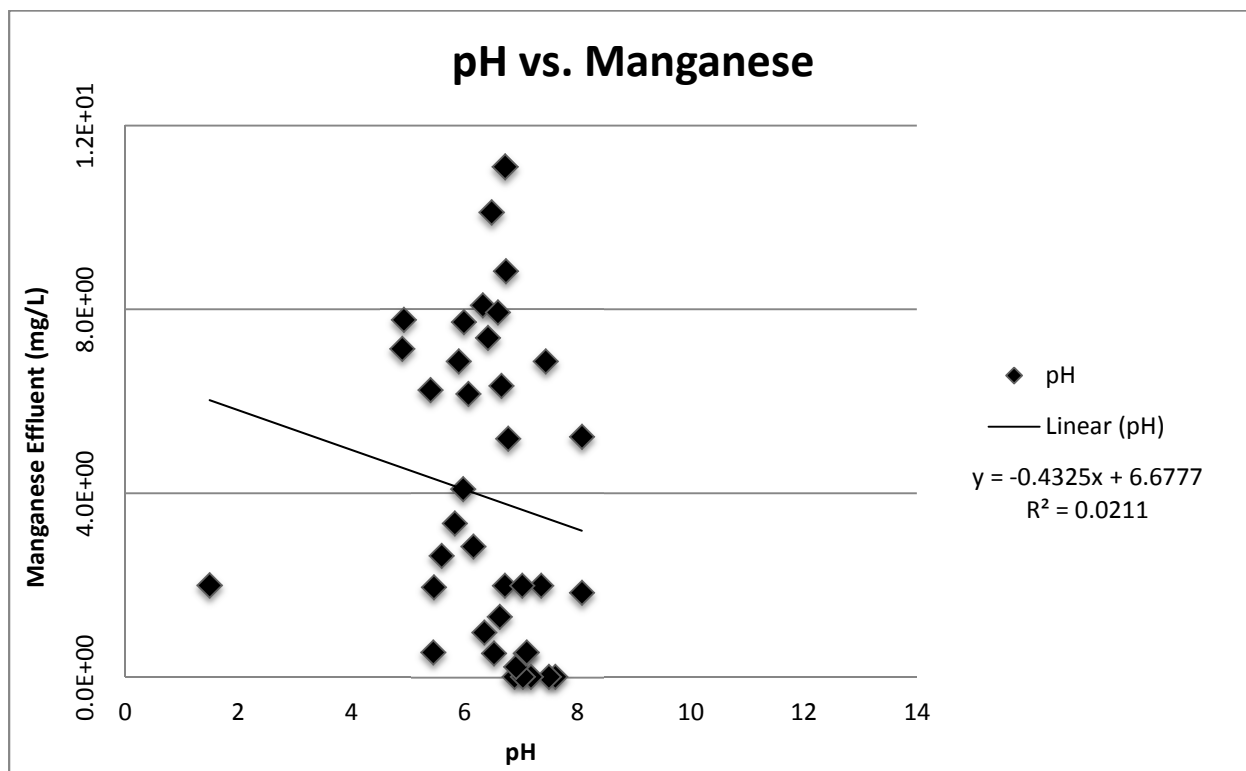


Figure F.9. The pH (0-14 scale) plotted versus effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

The pH taken by the HORIBA meter was also plotted against the effluent manganese concentrations from 1/7/2011 to 1/10/2012, which was displayed in Figure F.9. Similar to the pH vs. boron figure discussed above, pH versus manganese also has a negative sloping linear trend line with an R^2 value of 2%. The R^2 value is too low to represent a strong relationship between pH and effluent manganese concentrations. With manganese, it is typically present in surface waters as Mn (IV), but if wetland conditions have low redox potentials (ORP) and low pH, manganese is present as Mn (II) (Kadlec and Knight 1996); therefore, depending on what manganese ion was tested for by CAS, lower pH values would should more Mn (II) ions present in the effluent manganese concentrations.

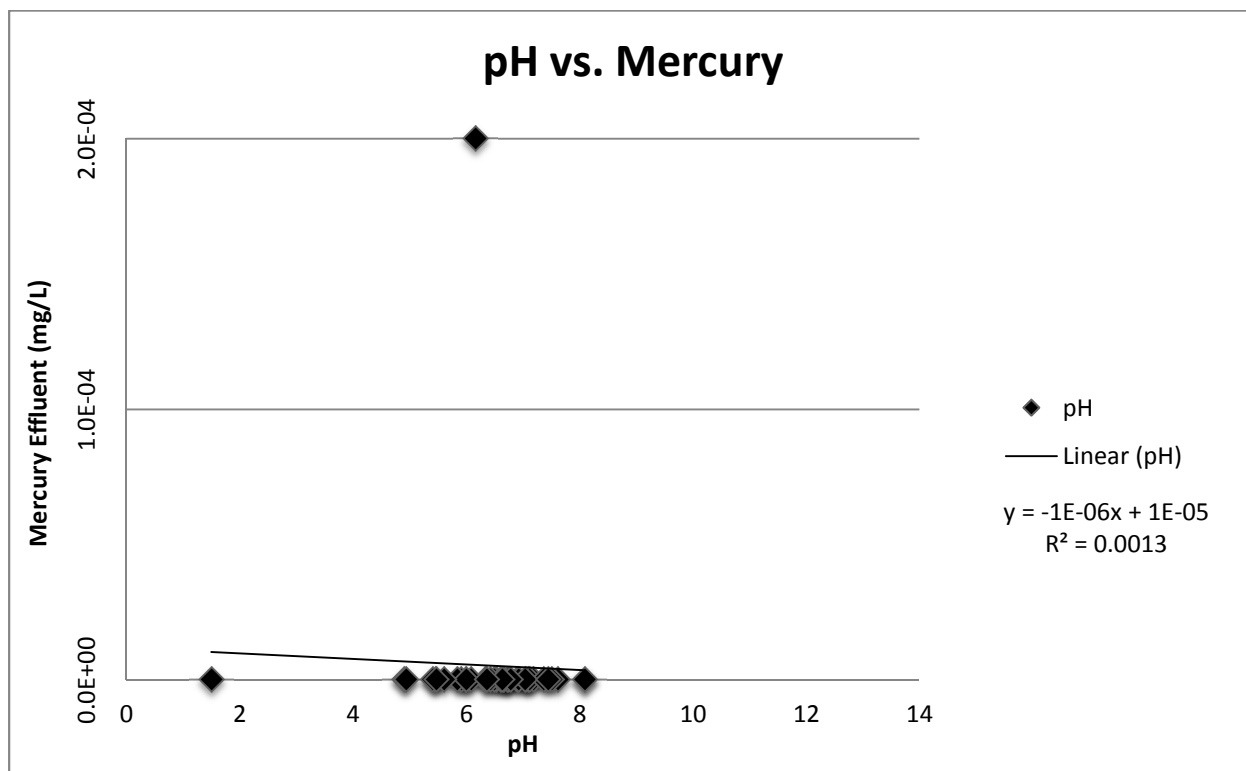


Figure F.10. The pH (0-14 scale) plotted versus effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

The pH was plotted against the effluent mercury concentrations in Figure F.10 from 1/7/2011 to 1/10/2012. Similar to the figure for temperature versus mercury, effluent mercury concentrations were often zero; therefore, the linear trend line does not vary that much, but does have a slightly negative slope. The R^2 value for this figure is less than 1%, representing no relationship between pH and effluent mercury concentrations.

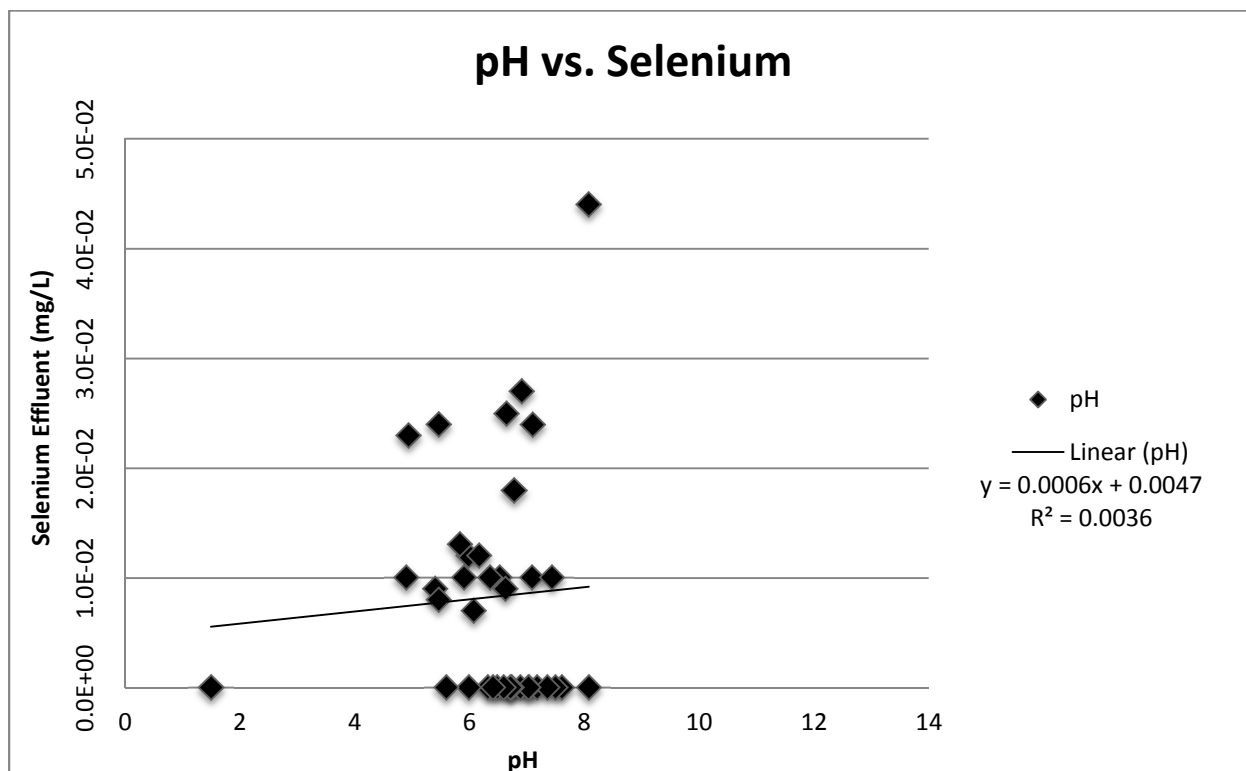


Figure F.11. The pH (0-14 scale) plotted against effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

From Figure F.11, pH was plotted against the effluent selenium concentrations from 1/7/2011 to 1/10/2012. The linear trend line displayed on the graph has a slight positive slope, but is ultimately horizontal relative to the points. The R^2 value between pH and effluent selenium concentrations are also less than 1% as many of the other figures discussed before; therefore, there is no relationship between pH and effluent selenium concentrations.

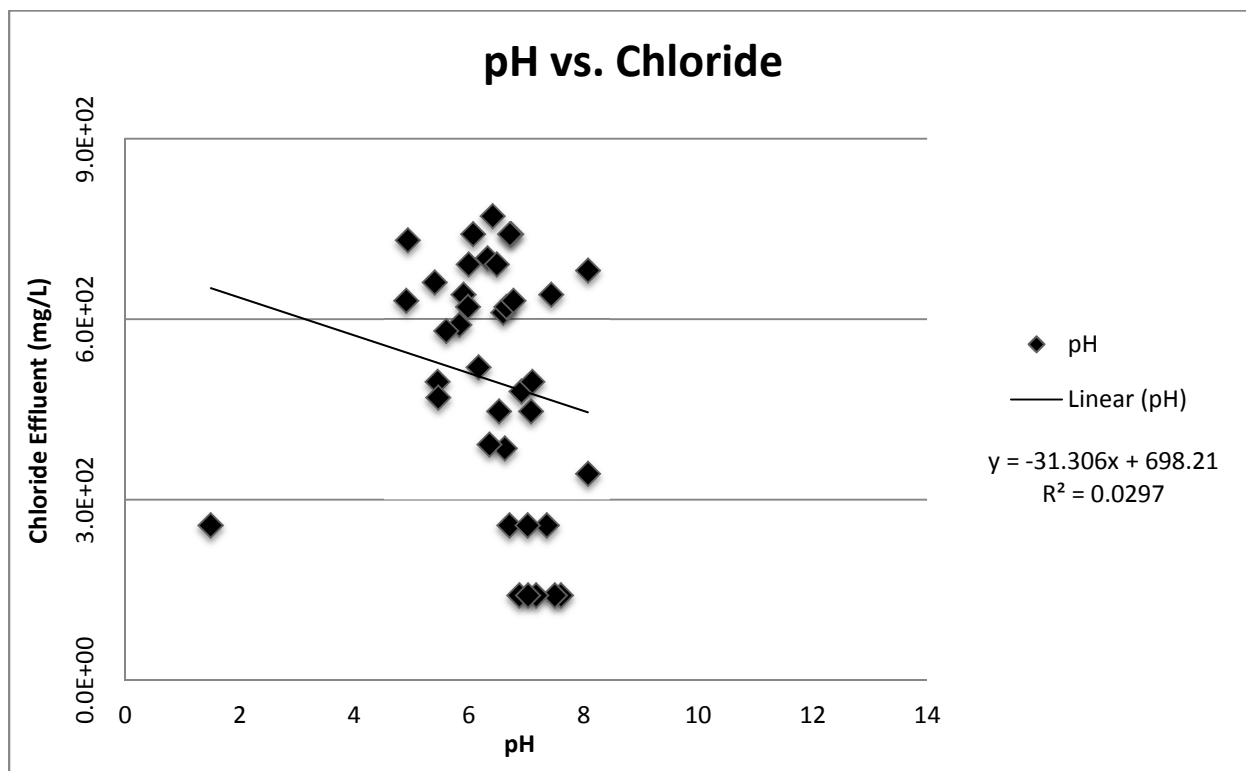


Figure F.12. The pH (0-14 scale) plotted versus effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

The pH taken by the HORIBA meter was plotted against the effluent chloride concentrations in Figure F.12 from 1/7/2011 to 1/10/2012 to determine a relationship between these two values. The linear trend line present on the figure has a strong negative slope to it and represents an R^2 value of about 3%. Despite the strong negative slope on the trend line, the R^2 value is too low to represent a strong relationship between pH and effluent chloride concentrations.

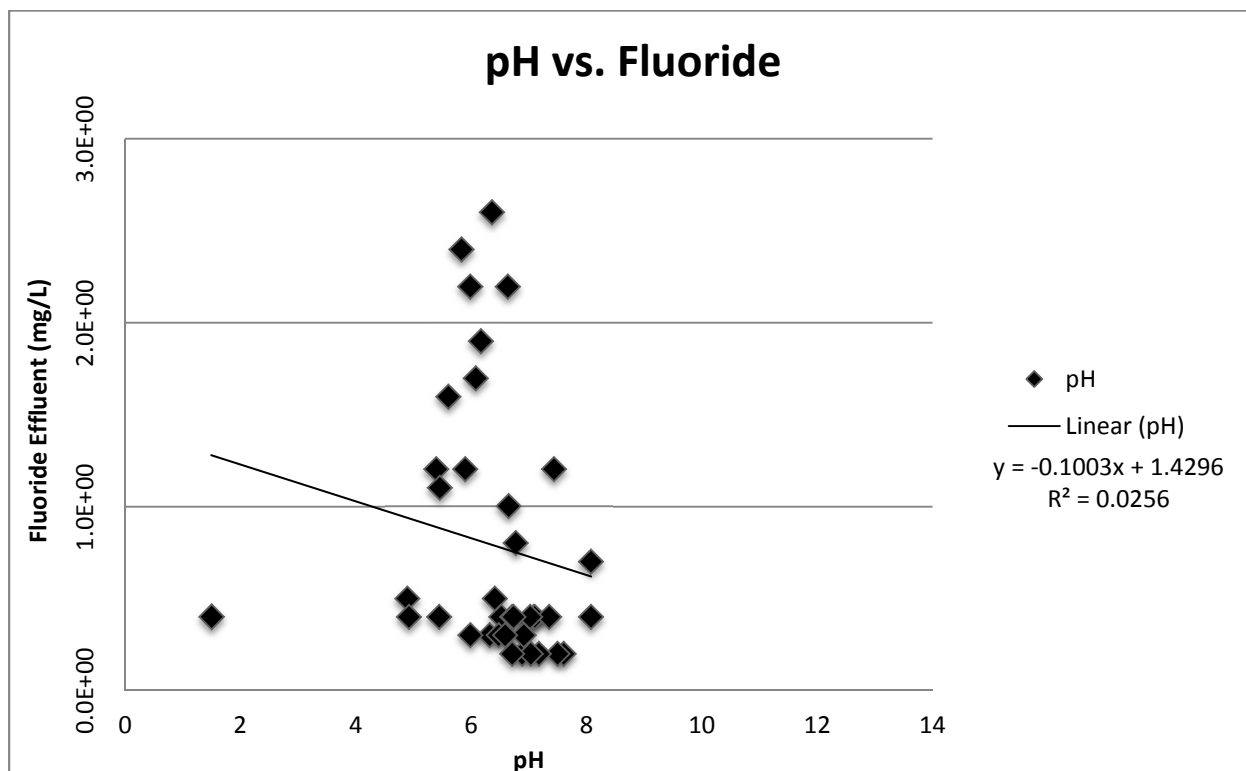


Figure F.13. The pH (0-14 scale) plotted against effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

The pH was plotted against effluent fluoride concentrations from 1/7/2011 to 1/10/2012 in Figure F.13. These two values create a linear trend line with a slight negative slope and an R^2 value of about 3%. Similar to pH and chloride, the R^2 value is not high enough to represent a strong correlation between pH and fluoride.

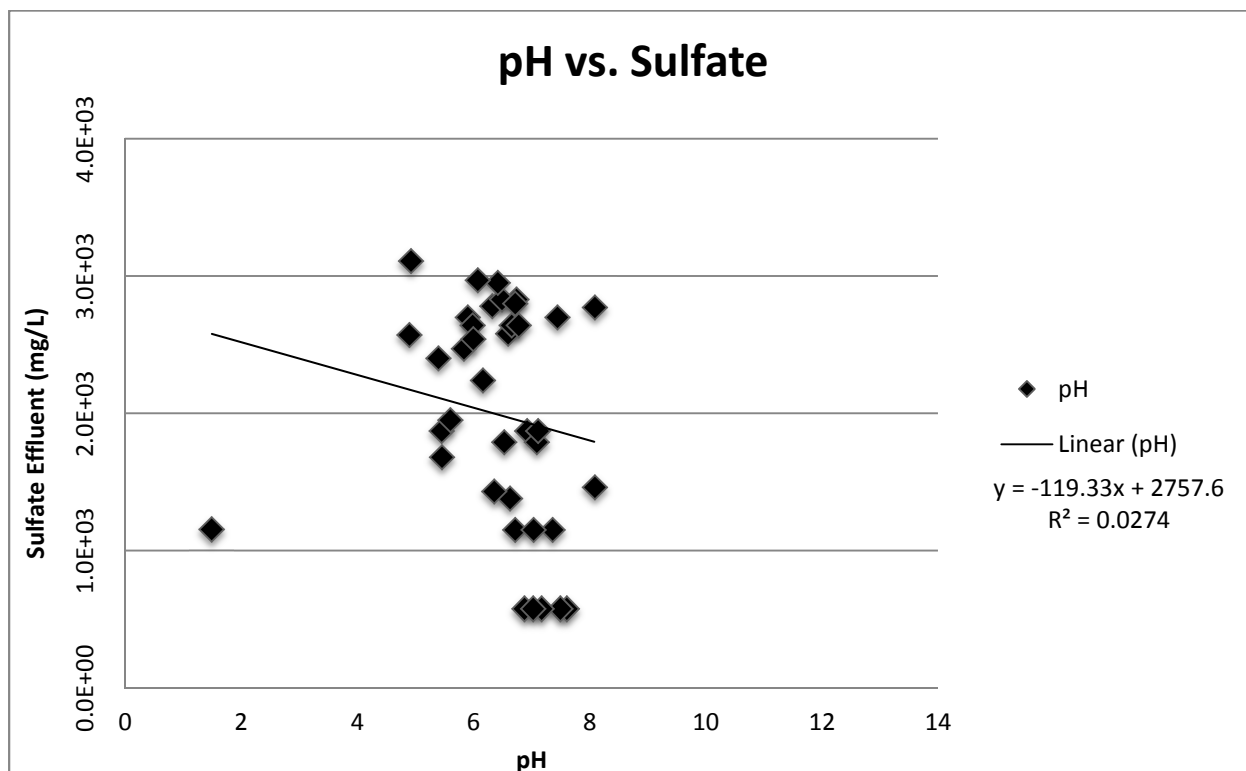


Figure F.14. The pH (0-14 scale) plotted against effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

In Figure F.14, pH was plotted against the effluent sulfate concentrations from 1/7/2011 to 1/10/2012. Similar to the past two figures, the linear trend line found on Figure F.14 has a moderate negative slope, with an R^2 value of about 3%. With this weak R^2 value, there is not a strong relationship between pH and the effluent sulfate concentrations. As stated before, typically pH increases as a result of the reduction of sulfates; however, this relationship did not occur here due to several possible reasons. The reduction of sulfates could mean two possibilities: (1) sulfates reducing to sulfide or (2) lower amount of sulfate are present. If pH increases based on sulfates changing to sulfide, this would not be present on this graph, because it represents sulfate, not sulfide; however, if lower amounts of sulfate result in higher pH values, then the graph does not represent that theory, possibly due to the pH levels staying constant between 6 and 8. The relationship between pH and sulfate also could have been jeopardized by precipitation, adding more sulfates to the CWTS or changing the water pH.

ORP

Oxidation reduction potential, or ORP, was measured using the HORIBA meter for the CWTS located at JEC, and was compared to the seven pollutants being tested for to determine a relationship between any of these two values. ORP is a measure of electric potential of free oxygen within the soil, which is determined using a standard platinum electrode and the concentration of oxygen in the soil. If the ORP is greater than 300 mV, the system is termed aerobic, because dissolved oxygen is available; however, if the ORP is less than -100 mV, the system is anaerobic, because there is no dissolved oxygen (Kadlec and Knight 1996). Typically, “oxidation-reduction potentials are used in theoretical studies for checking the iron and manganese removal...however, this quantity is not widely used in practice particularly because of the difficulties over its accurate measurement” (Tölgyessy 1993). Therefore, ORP was plotted against each of the seven pollutants tested for in the CWTS to determine any relationships between one another, if any.

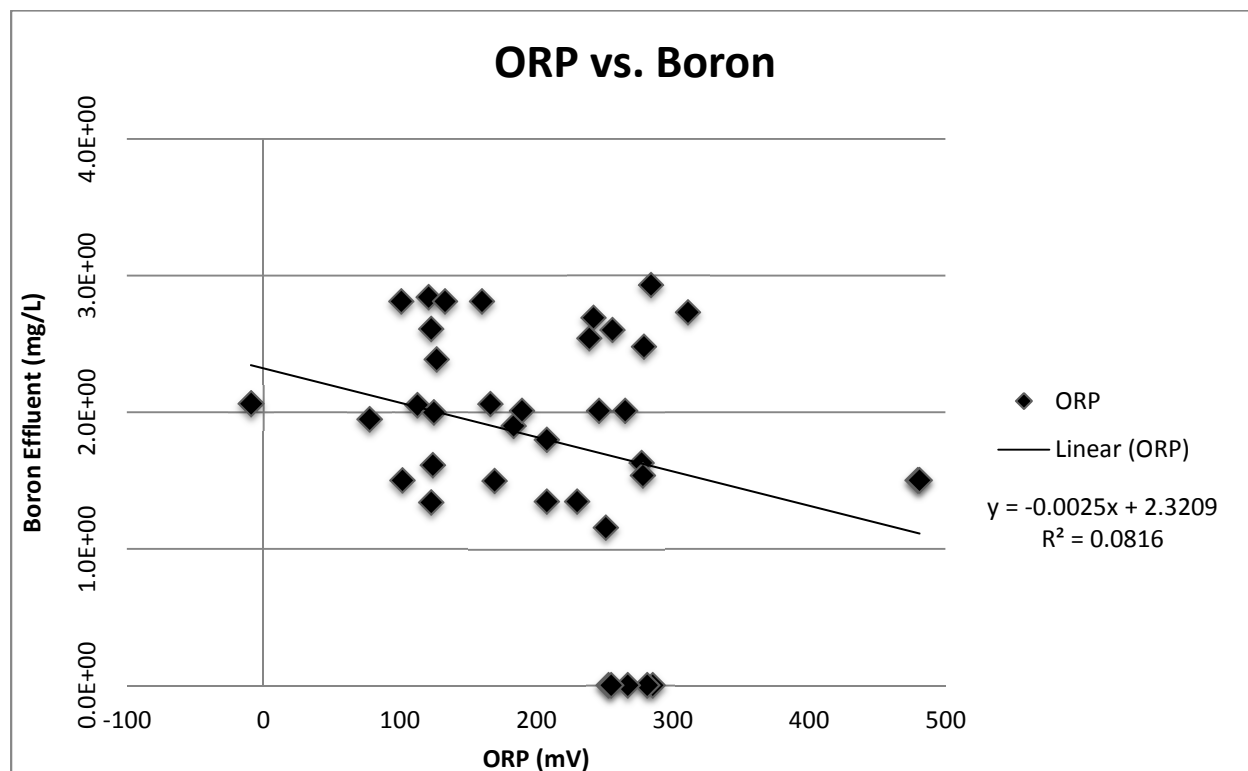


Figure F.15. ORP (mV) plotted versus effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

ORP was plotted against the effluent boron concentrations from 1/7/2011 to 1/10/2012 in Figure F.15. Similar to other figures discussed, the linear trend line located on this graph is relatively horizontal with a small negative slope. The R^2 value between ORP and effluent boron concentrations is 8%; therefore, effluent boron concentrations have no effect on ORP and vice versa.

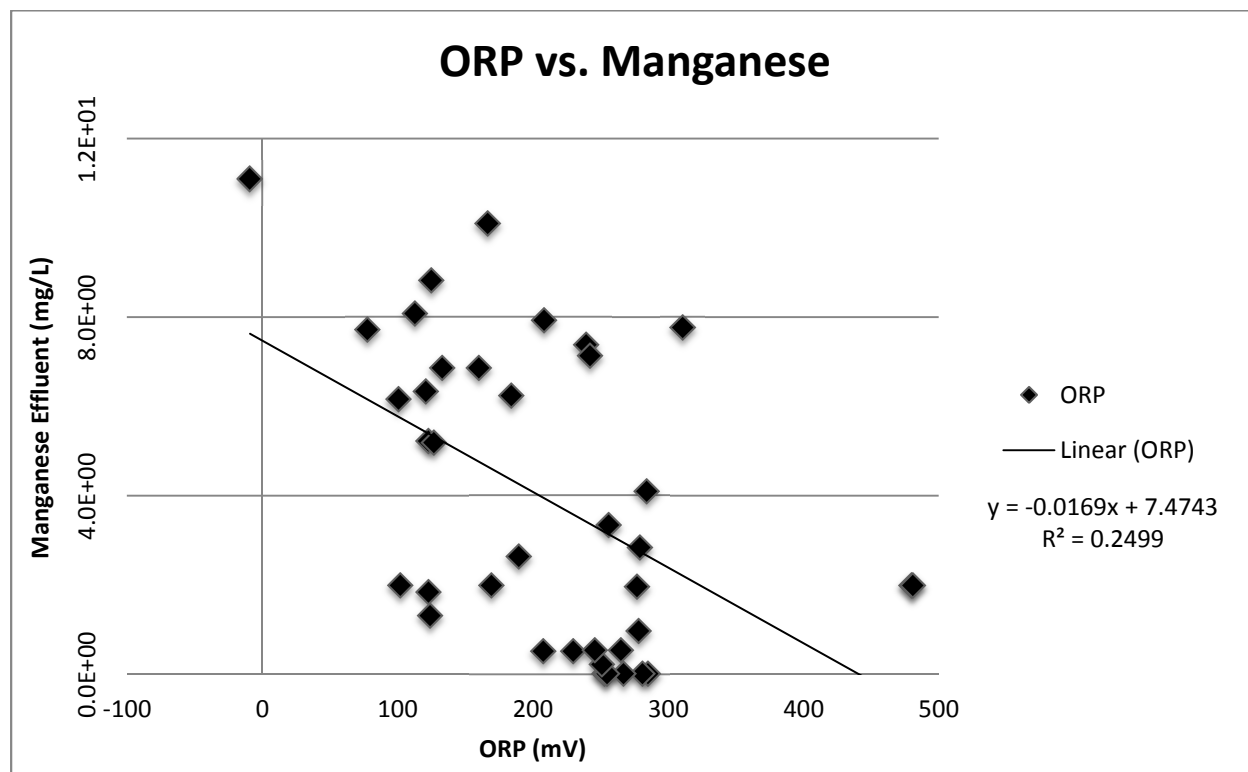


Figure F.16. ORP (mV) plotted against effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

Effluent manganese concentrations were also plotted against ORP from 1/7/2011 to 1/10/2012 in Figure F.16. Compared to the figure above, the linear trend line present on this figure has a greater negative slope to it, allowing it to have a greater R^2 value of about 25%; however, even though there is about a 15% increase from effluent boron concentrations to effluent manganese concentrations compared to ORP, the R^2 value is not high enough to represent a high relationship between these two factors. The effluent concentrations of manganese do not and are not affected by ORP; however, the chemical transformations of protons and electrons of manganese are affected by ORP. According to Kadlec and Knight, in positive ORP environments, or aerobic, manganic manganese (Mn^{+4}) is reduced to manganous manganese (Mn^{+2}); therefore, the amount of electrons present in the manganese ion determines

the ORP values, not the concentration of manganese leaving the CWTS. Despite the use of oxidation-reduction potentials to determine the amount of manganese removal, it is not often used to due to its inaccuracy, which can be shown from this figure.

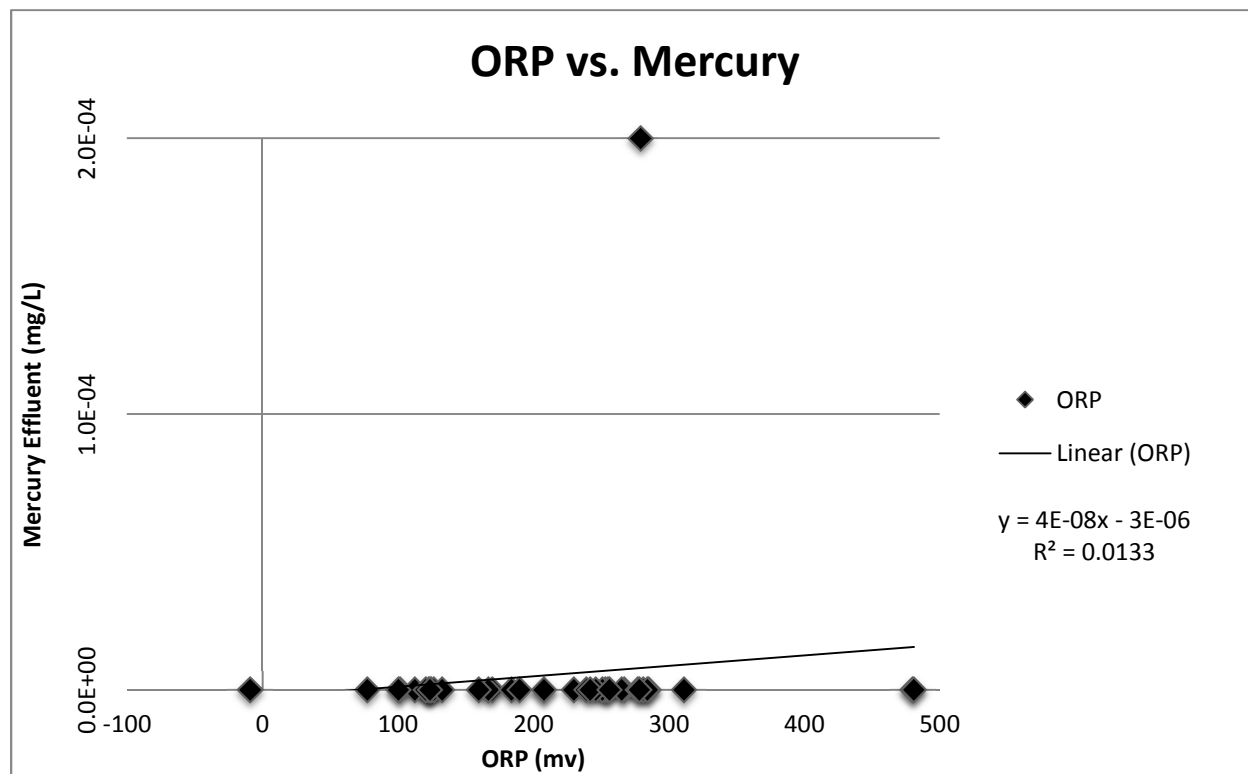


Figure F.17. ORP (mV) plotted versus effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.17 represents ORP versus effluent mercury concentrations from 1/7/2011 to 1/10/2012. Surprisingly, the linear trend line represented in this figure has a positive sloping line. The R^2 value between these two factors is about 1%, which is not a strong correlation; therefore, ORP is not affected by effluent mercury concentrations and vice versa.

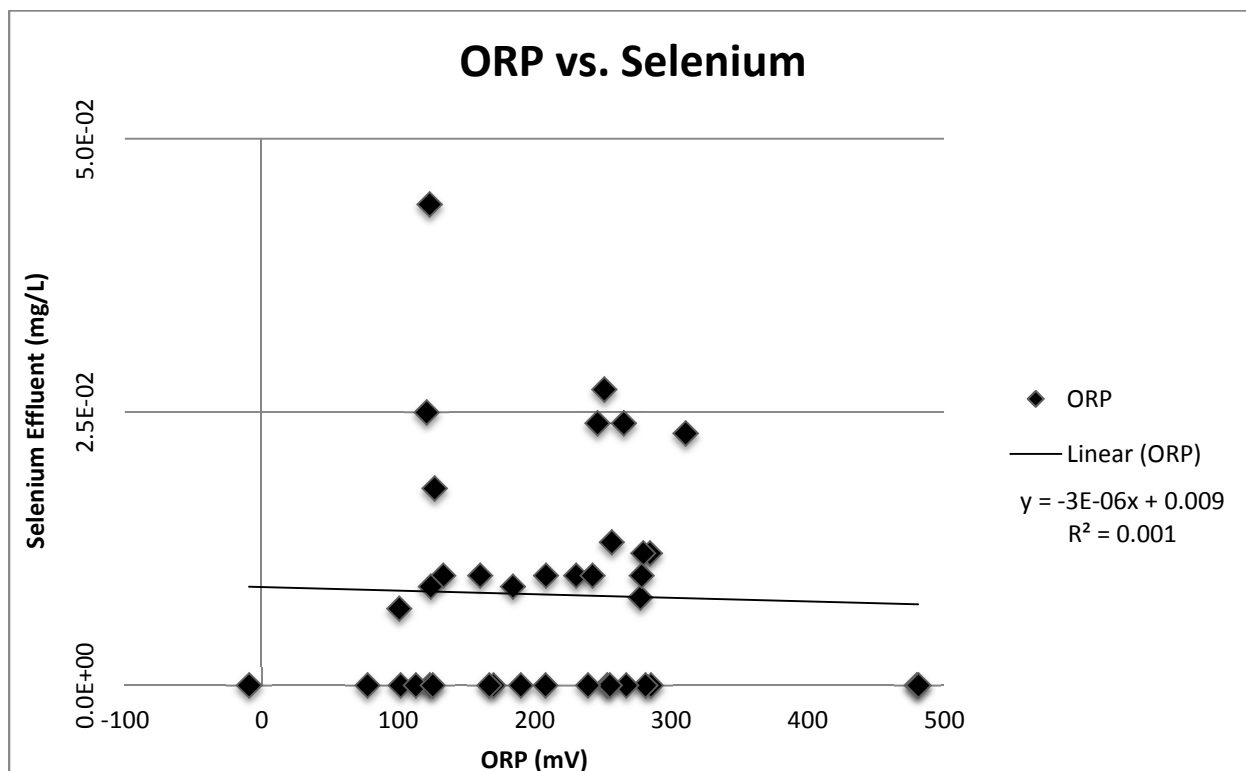


Figure F.18. ORP (mV) plotted versus effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

Effluent selenium concentrations were plotted versus ORP for the CWTS from 1/7/2011 to 1/10/2012 in Figure F.18. The linear trend line within this figure has a minimal negative slope, but practically parallel with the points. The R^2 value is less than 1%, almost 0%, which shows that there is no relationship between the effluent selenium concentrations and ORP.

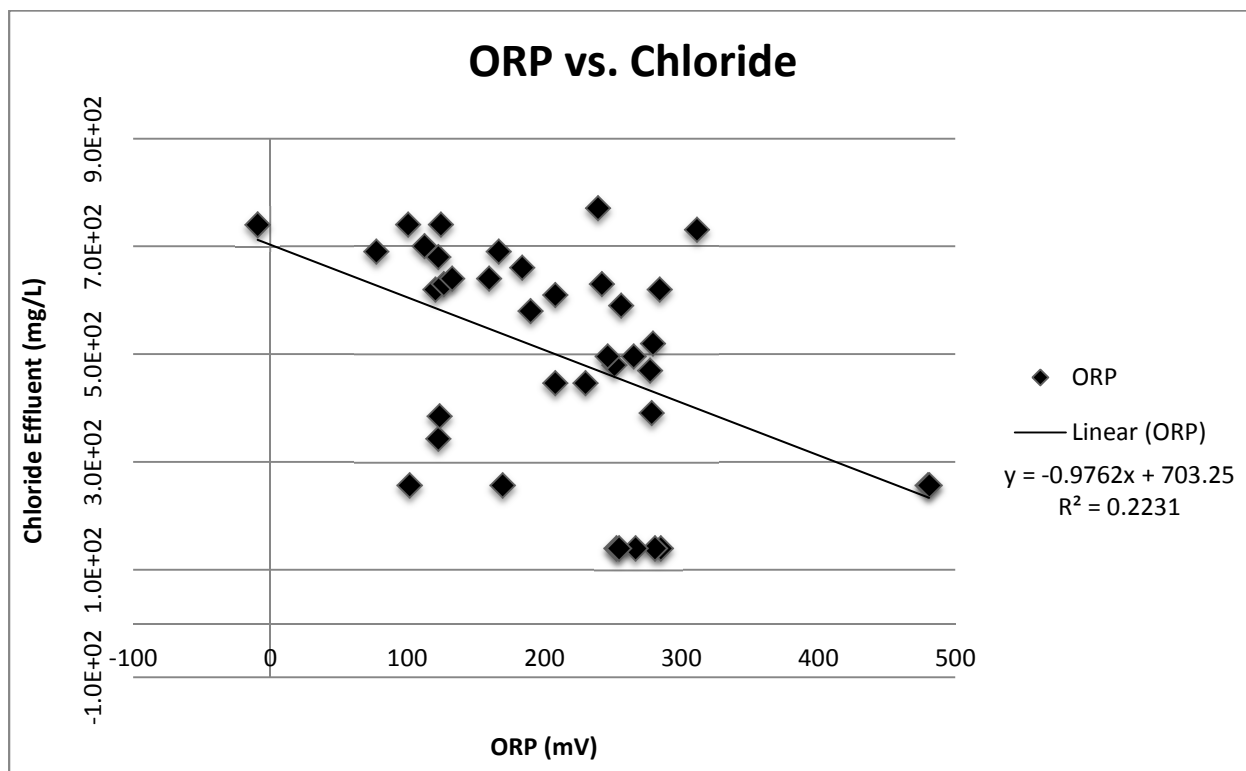


Figure F.19. ORP (mV) plotted against effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.19 shows ORP versus effluent chloride concentrations from 1/7/2011 to 1/10/2012. The linear trend line located on this figure has a negative slope, with an R^2 value of about 22%; therefore, the effluent chloride concentrations and ORP do not have a strong correlation.

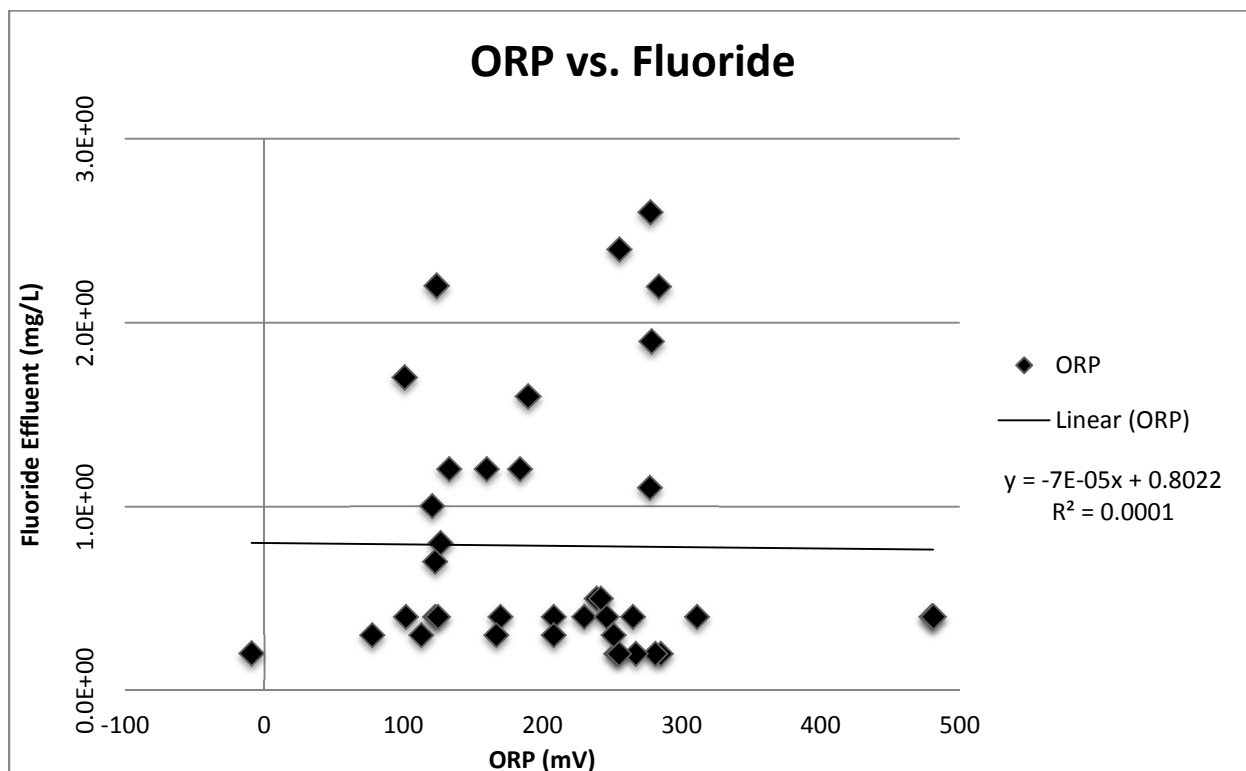


Figure F.20. ORP (mV) plotted versus effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

ORP was plotted against effluent fluoride concentrations in Figure F.20 from 1/7/2011 to 1/10/2012. The linear trend line has a slight negative slope, but is practically horizontal. The R^2 value between ORP and effluent fluoride concentrations is less than 1%; therefore, these two factors do not have a strong correlation between each other.

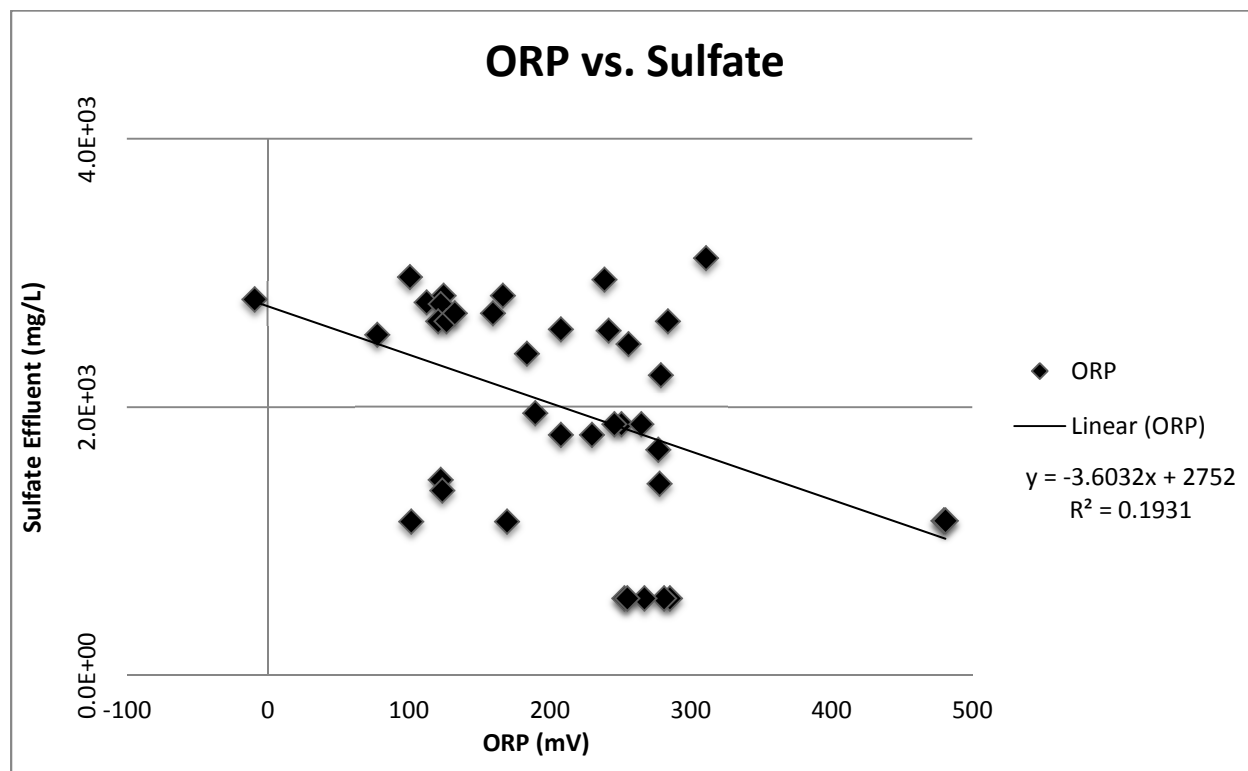


Figure F.21. ORP (mV) plotted versus effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

ORP was plotted against effluent sulfate concentrations from 1/7/2011 to 1/10/2012 in Figure F.21. The linear trend line has a negative slope and has an R^2 value of about 20%; therefore, effluent sulfate concentrations and ORP do not have a strong correlation. According to Kadlec and Knight, sulfates are reduced to sulfides in anaerobic conditions, which are conditions with an ORP of less than -100 mV; however, this figure does not show a good representation of this theory. At aerobic conditions, there are varying sulfate concentrations, even some very low sulfate concentrations at higher ORP values; therefore, this CWTS located at JEC did not represent a strong relationship between ORP and effluent sulfate concentrations.

Conductivity

Conductivity, also known as electrical conductivity or specific conductance, was measured using the HORIBA meter by determining the “reciprocal of the resistance between two platinum electrodes 1 cm apart and with a surface area of 1 cm²”, according to Kadlec and Knight. The electrical conductivity is represented by the reciprocal of resistance and is

represented a “function of the total quantity of ionized materials in a surface water sample” (Kadlec and Knight 1996). Kadlec and Knight state, “specific conductance is proportional to the total dissolved solids or salinity in many surface waters and is a convenient measure of the salt content of wastewaters”; however, Kadlec and Knight also state that specific conductance is altered by biological and physical environmental conditions, especially in wetlands, and is typically an “inaccurate indicator of dilution and concentration effects by rainfall, runoff, and evapotranspiration in wetland treatment systems”. Despite this knowledge, Figures F.22 thru F.28 represents conductivity and each of the seven pollutants of concern to determine a correlation between these two values.

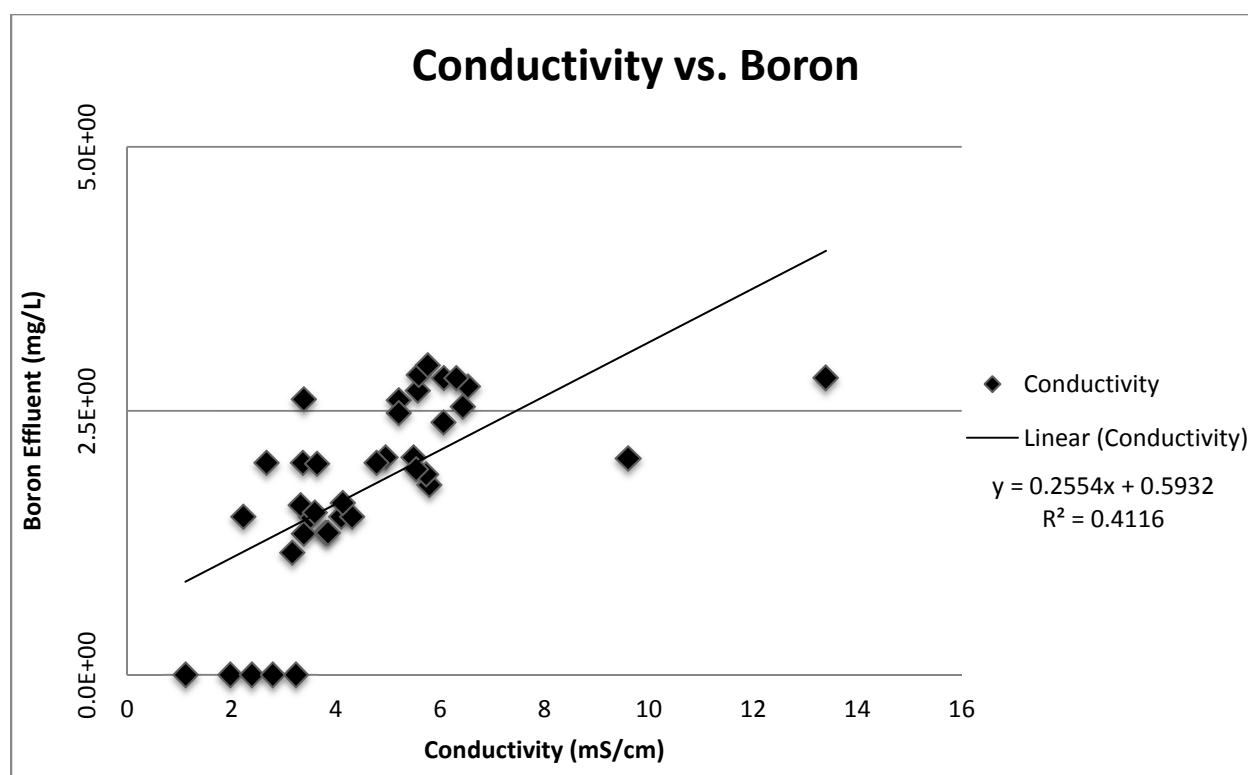


Figure F.22. Conductivity (mS/cm) plotted versus effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

Conductivity was plotted against effluent boron concentrations in Figure F.22 from 1/7/2011 to 1/10/2012. From this figure, the linear trend line present has a positive slope with an R^2 value of about 41%; therefore, effluent boron concentrations and conductivity have a slight relationship, but not strong enough to use conductivity as a measurement of boron concentrations.

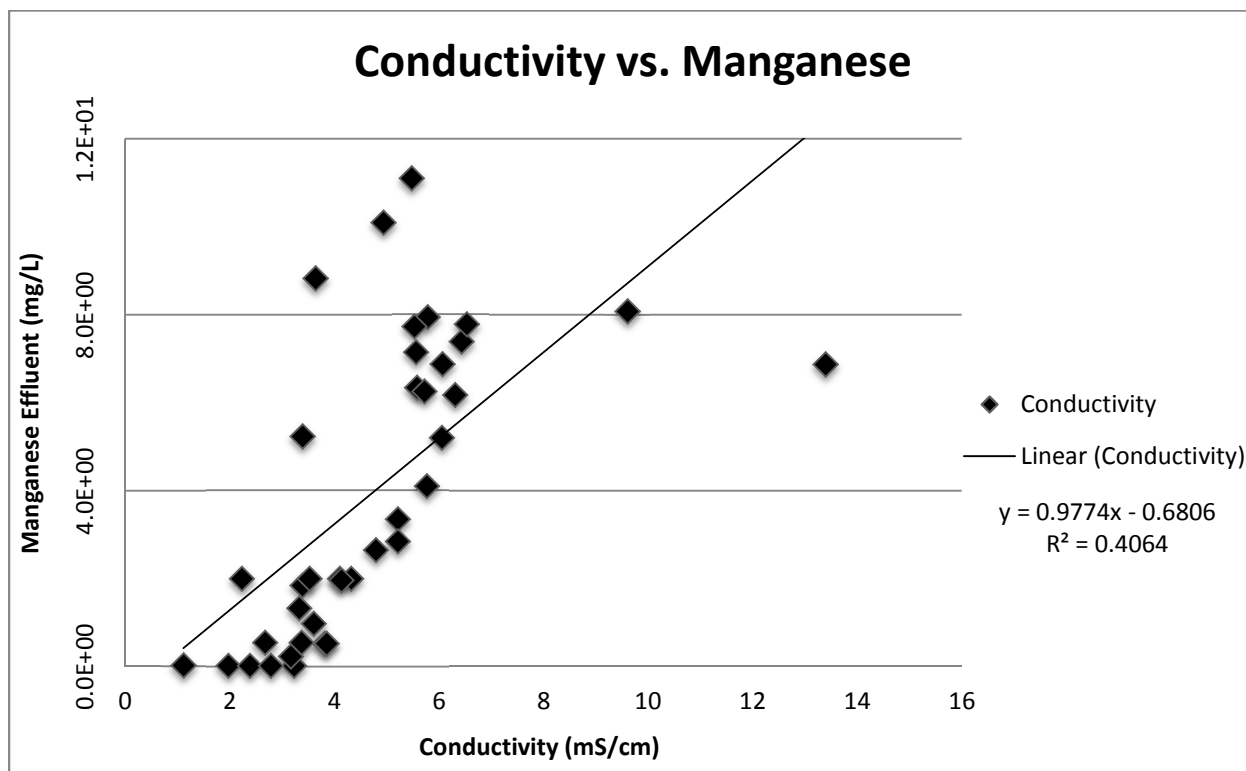


Figure F.23. Conductivity (mS/cm) plotted against effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

Effluent manganese concentrations were plotted against conductivity in Figure F.23 from 1/7/2011 to 1/10/2012. Despite the previous figure, the linear trend line located in Figure F.23 has a much greater positive slope compared to the one shown for conductivity versus effluent boron concentrations. Also, the R^2 value of this figure is around 41%, which is one of the highest correlations seen throughout all the figures previous discussed; however, 41% is not a strong enough correlation between conductivity and effluent manganese concentrations to state the two values have a good relationship. Despite the low R^2 value, the figure depicts a minimal relationship between conductivity and effluent manganese concentrations in which the lower the conductivity the lower the effluent manganese concentrations, but this the R^2 value is still too low to determine this kind of relationship.

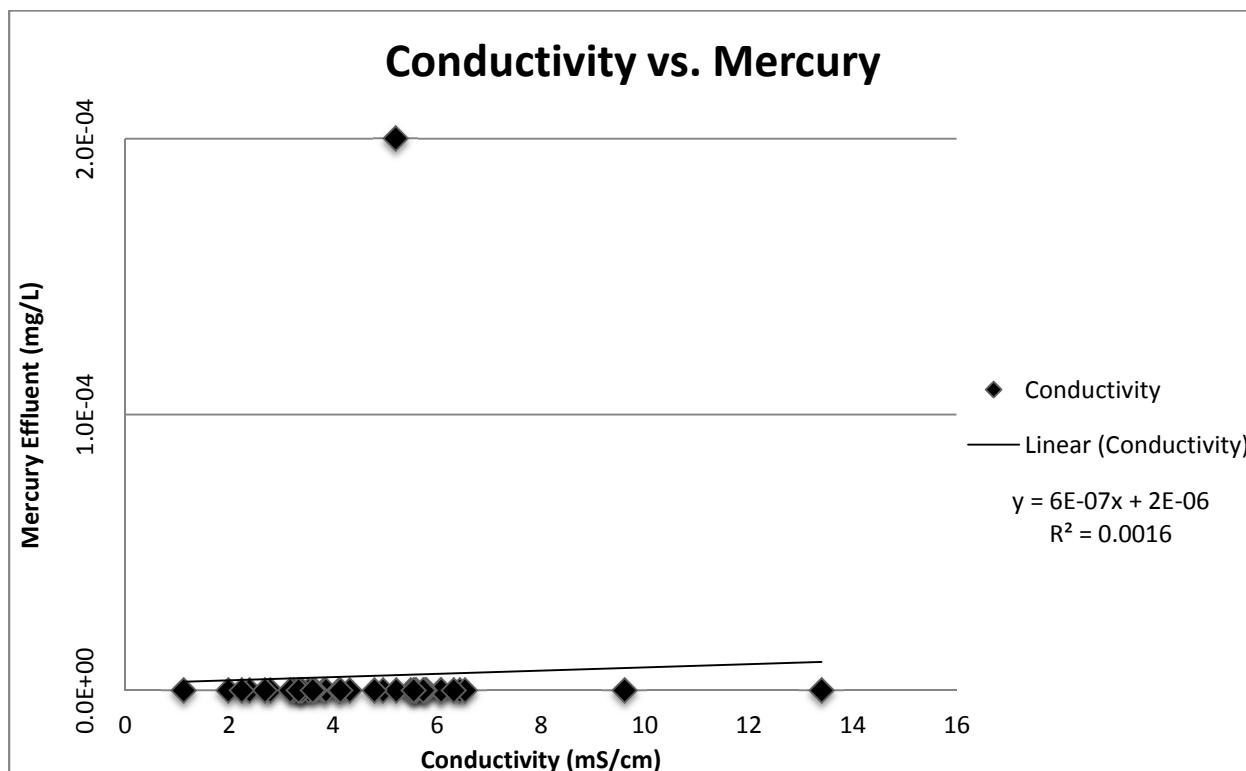


Figure F.24. Conductivity (mS/cm) plotted against effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.24 represents conductivity plotted against the effluent mercury concentrations from 1/7/2011 to 1/10/2012. Similar to other figures with effluent mercury concentrations, the linear trend line has a very small slope along with a relatively low R^2 value of less than 1%. Because of this low R^2 value, conductivity and effluent mercury concentrations do not have a strong correlation between each other.

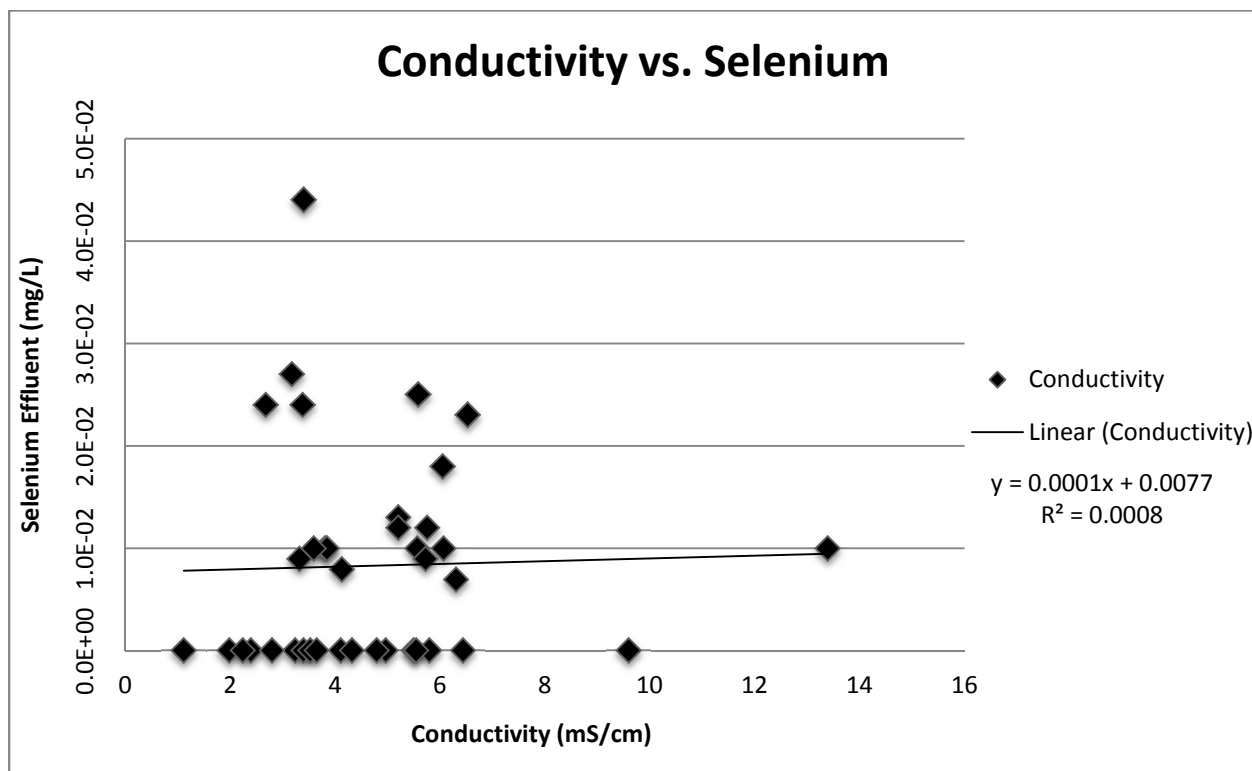


Figure F.25. Conductivity (mS/cm) plotted against effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.25 shows conductivity versus effluent selenium concentrations from 1/7/2011 to 1/10/2012. The linear trend line has a slight positive slope, but still has a small R^2 value of less than 1%; therefore, conductivity and effluent selenium concentrations do not have a strong relationship between each other.

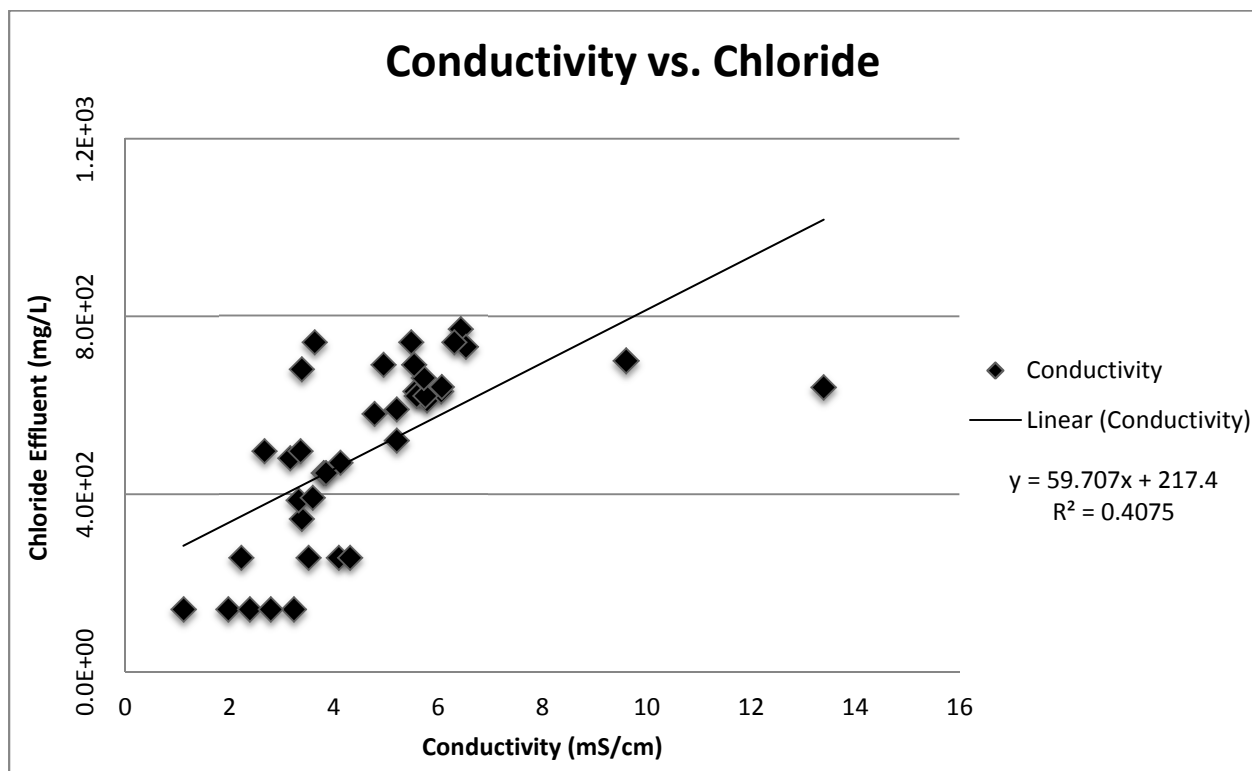


Figure F.26. Conductivity (mS/cm) plotted versus effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Conductivity was plotted against the effluent chloride concentrations from 1/7/2011 to 1/10/2012 shown in Figure F.26. The linear trend line is has a high positive slope, but still have a low R^2 value of only about 41%; therefore, conductivity and effluent chloride concentrations do not have a good relationship. Conductivity should be effected more by chloride concentrations, because conductivity is dependent on chloride concentrations.

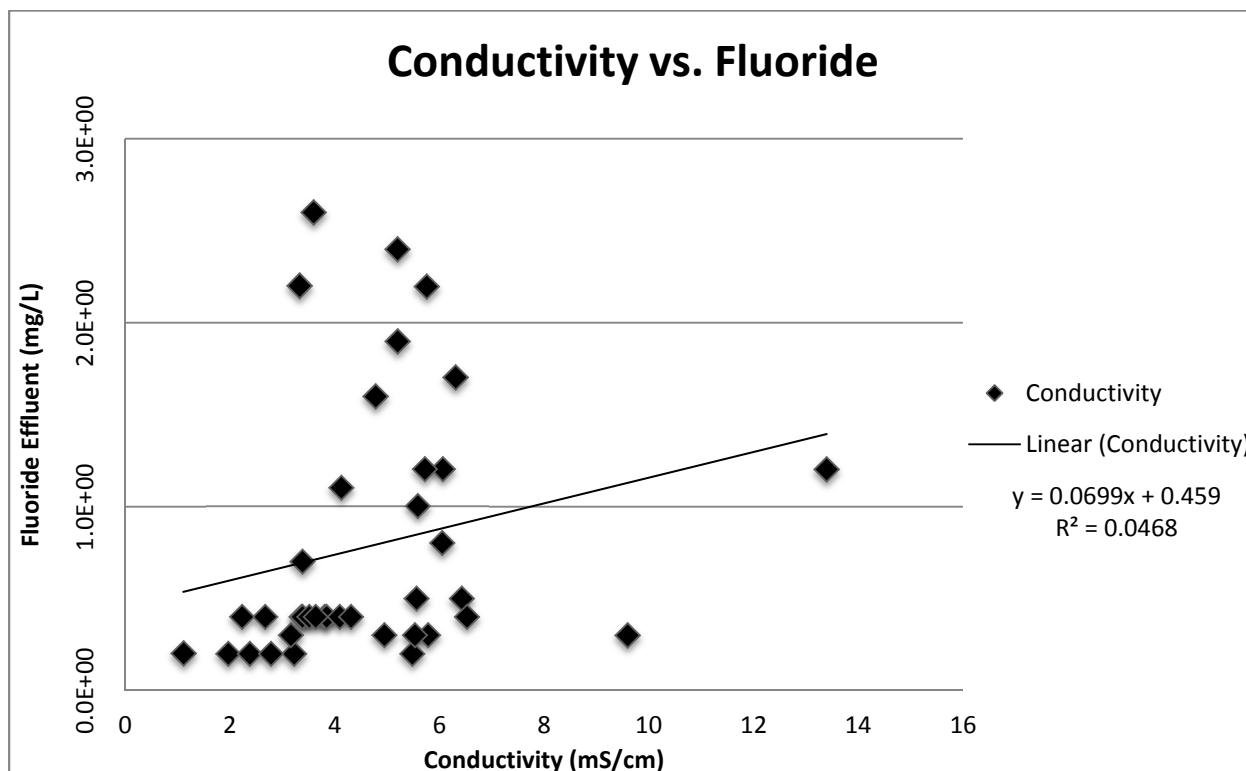


Figure F.27. Conductivity (mS/cm) plotted versus effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.27 represents conductivity against effluent fluoride concentrations from 1/7/2011 to 1/10/2012. The linear trend line located on this figure has a positive slope and has a small R^2 value of about 5%. The small R^2 value determines that there is no relationship between conductivity and the effluent fluoride concentrations.

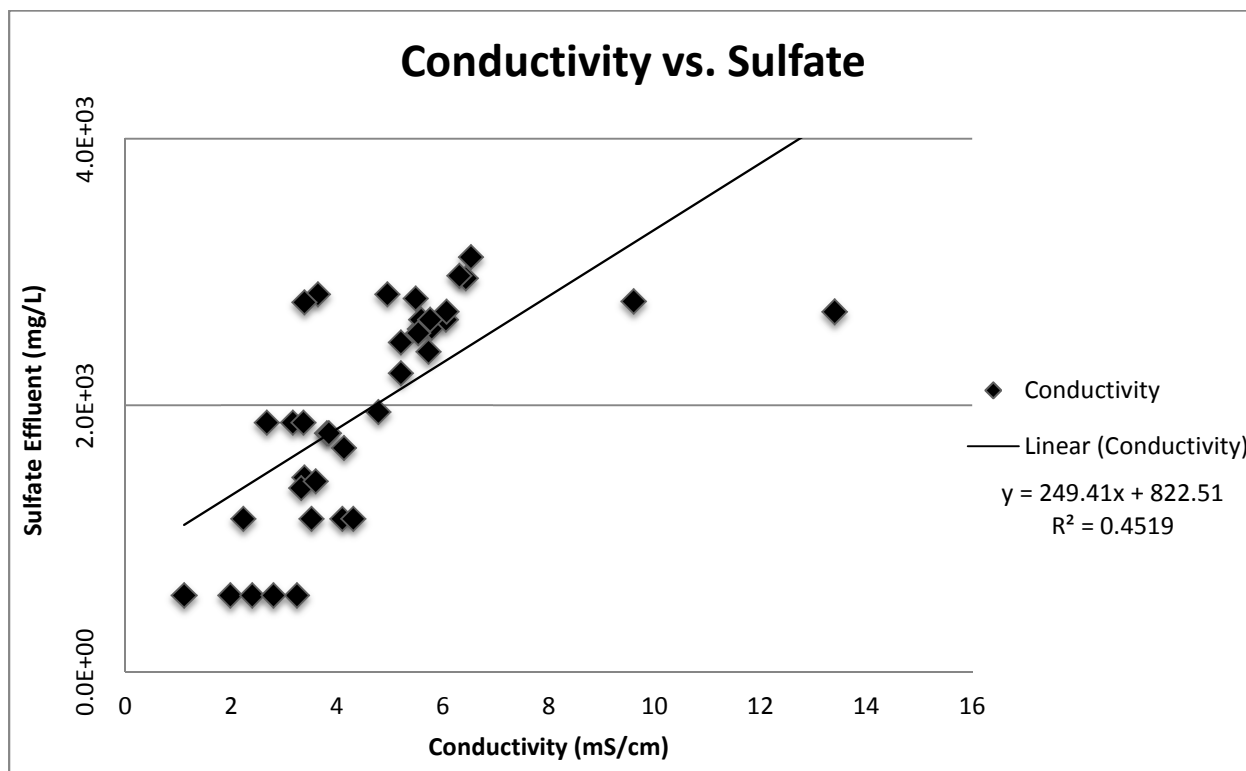


Figure F.28. Conductivity (mS/cm) plotted against effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

Conductivity was plotted versus the effluent sulfate concentrations in Figure F.28 from 1/7/2011 to 1/10/2012. The linear trend line present in this figure has a positive slope with a R^2 value of 45%; therefore, the conductivity and effluent sulfate concentrations do not have strong relationship towards each other. Overall, none of the pollutants from this section have a strong correlation between conductivity; therefore, conductivity and effluent concentrations of the seven pollutants should not be used to determine one another. The relationship between chloride concentration and conductivity should have been stronger than observed, because conductivity is dependent on chloride concentrations; however, only a 41% R^2 value was determined between these two variables. On the other hand, conductivity is proportional to the amount of TDS and/or salinity within waters and could be used to determine one of these factors and/or vice versa.

Turbidity

Turbidity was one of the eight water quality data measurements taken by the HORIBA meter for the CWTS at JEC. According to water treatment solutions Lenntech, turbidity is a

measure of the degree to which the water loses its transparency due to the presence of suspended particles. There are several factors that influence how turbid the water is including: phytoplankton, sediments from erosion, resuspended sediments from the bottom, waste discharge, algae growth, and urban runoff. All seven pollutants were plotted against turbidity to determine a correlation between these two values in Figures F.29 thru F.35; however, it is more than likely that for each figure there will be no correlation between pollutant concentration and turbidity, because turbidity is effected by suspended solids, not concentration of pollutants.

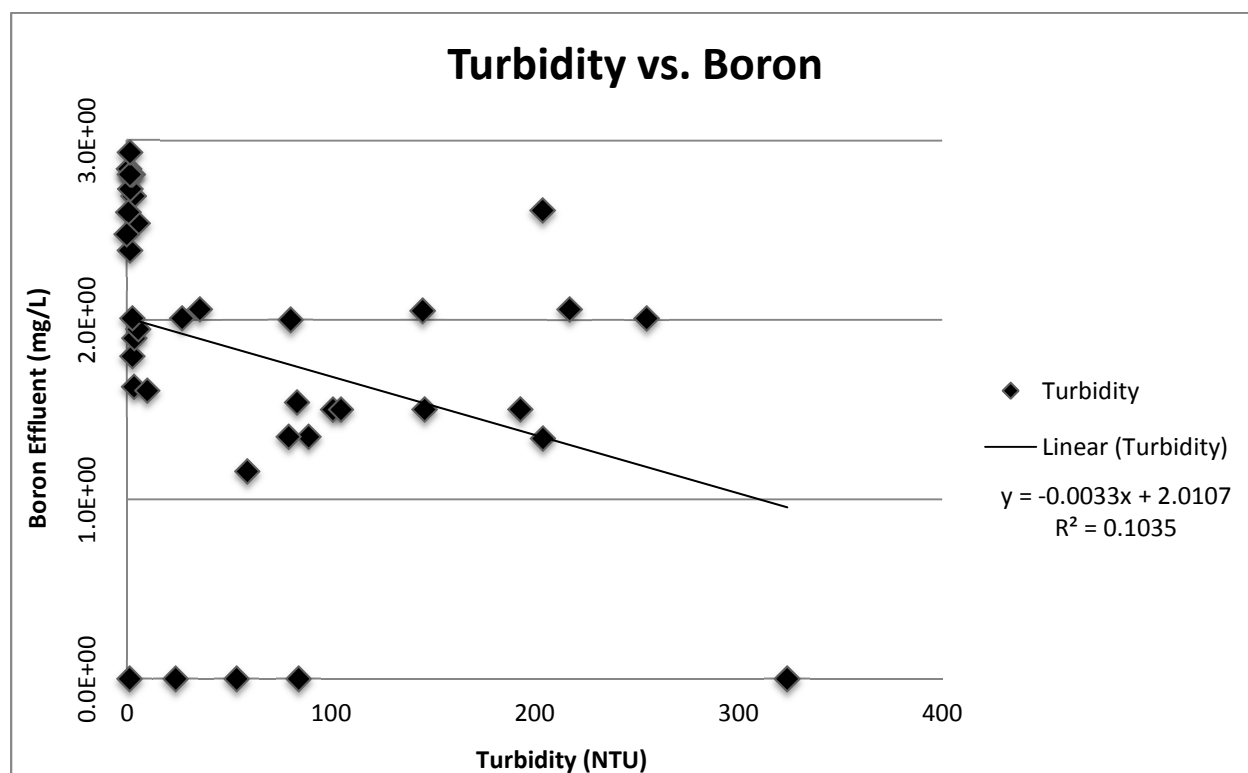


Figure F.29. Turbidity (NTU) plotted against effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

First, turbidity was plotted against effluent boron concentrations from 1/7/2011 to 1/10/2012 in Figure F.29. The linear trend line present in this figure has a negative slope and a small R^2 value of about 10%; therefore, there was not a strong relationship between turbidity and the effluent boron concentrations.

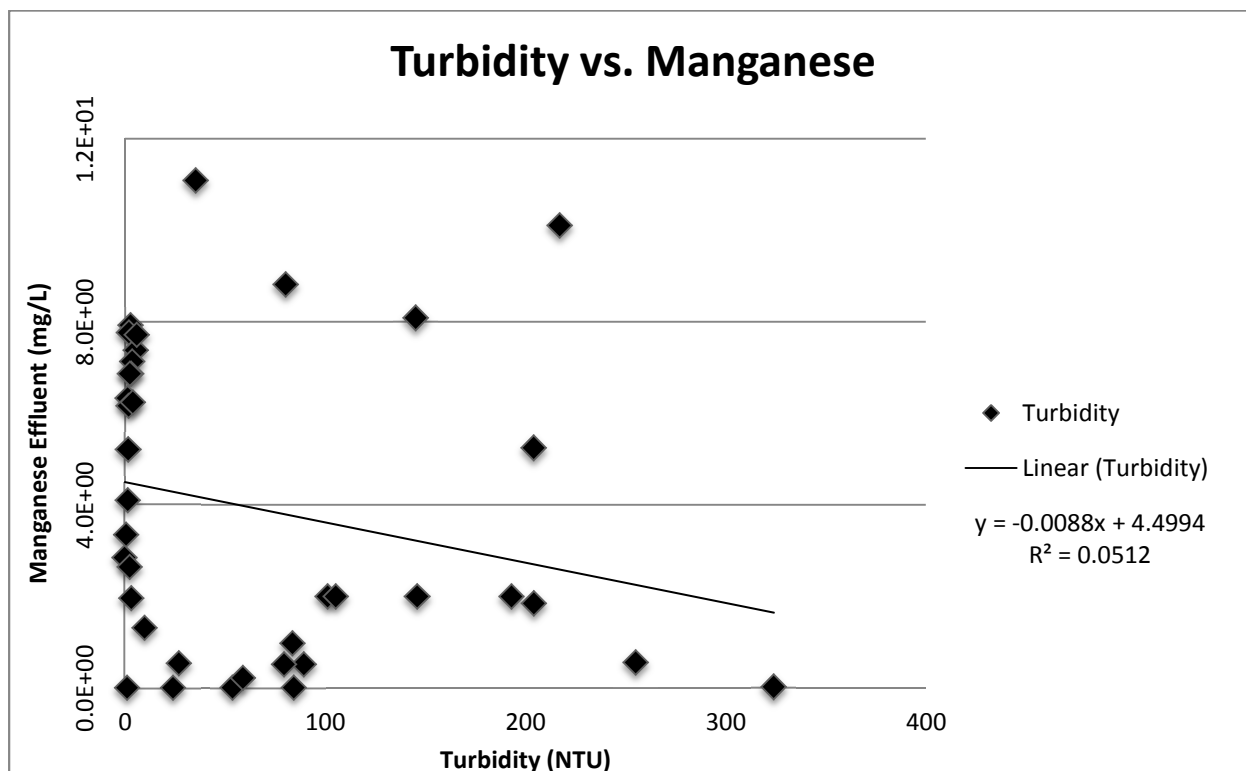


Figure F.30. Turbidity (NTU) plotted against effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

Turbidity was also plotted against the effluent manganese concentrations from 1/7/2011 to 1/10/2012 in Figure F.30. Similar to the figure above, the linear trend line in this figure also has a negative slope with a relatively small R^2 value of 5%. Despite the 4% increase in the R^2 value for manganese, turbidity and effluent manganese concentrations do not have a strong correlation between each other.

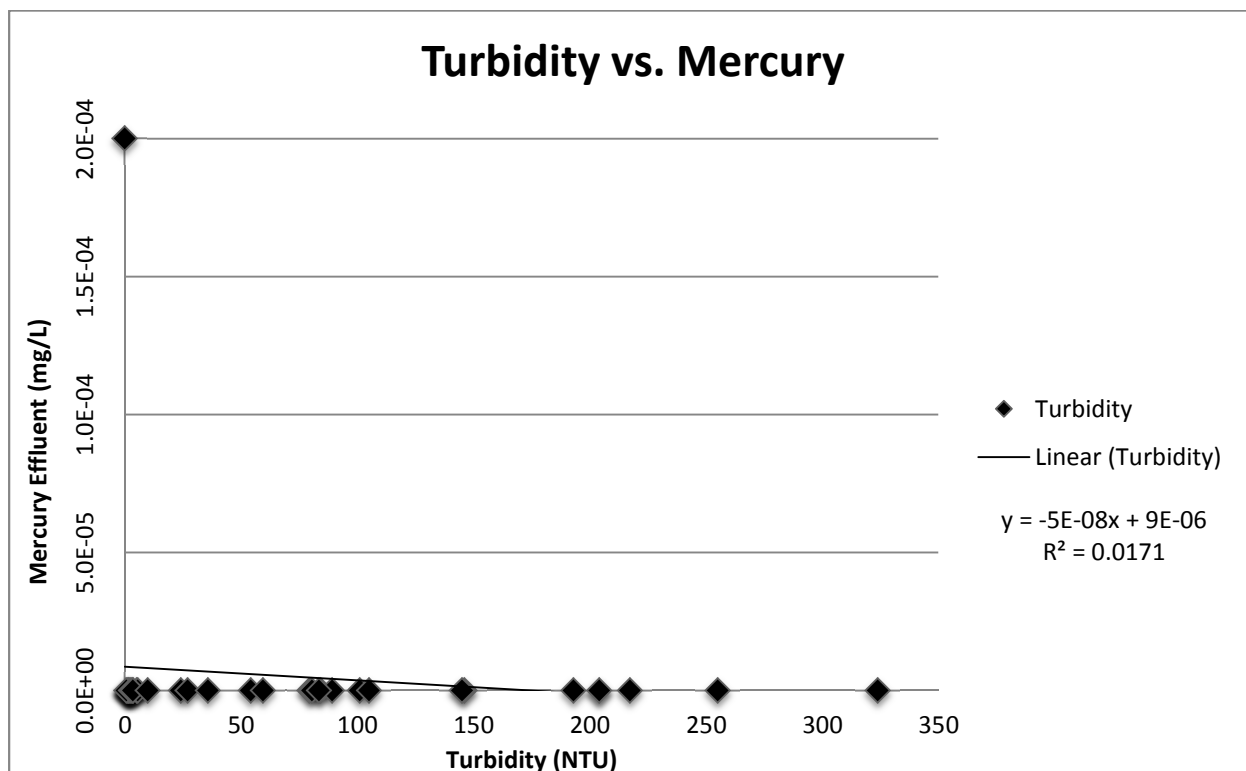
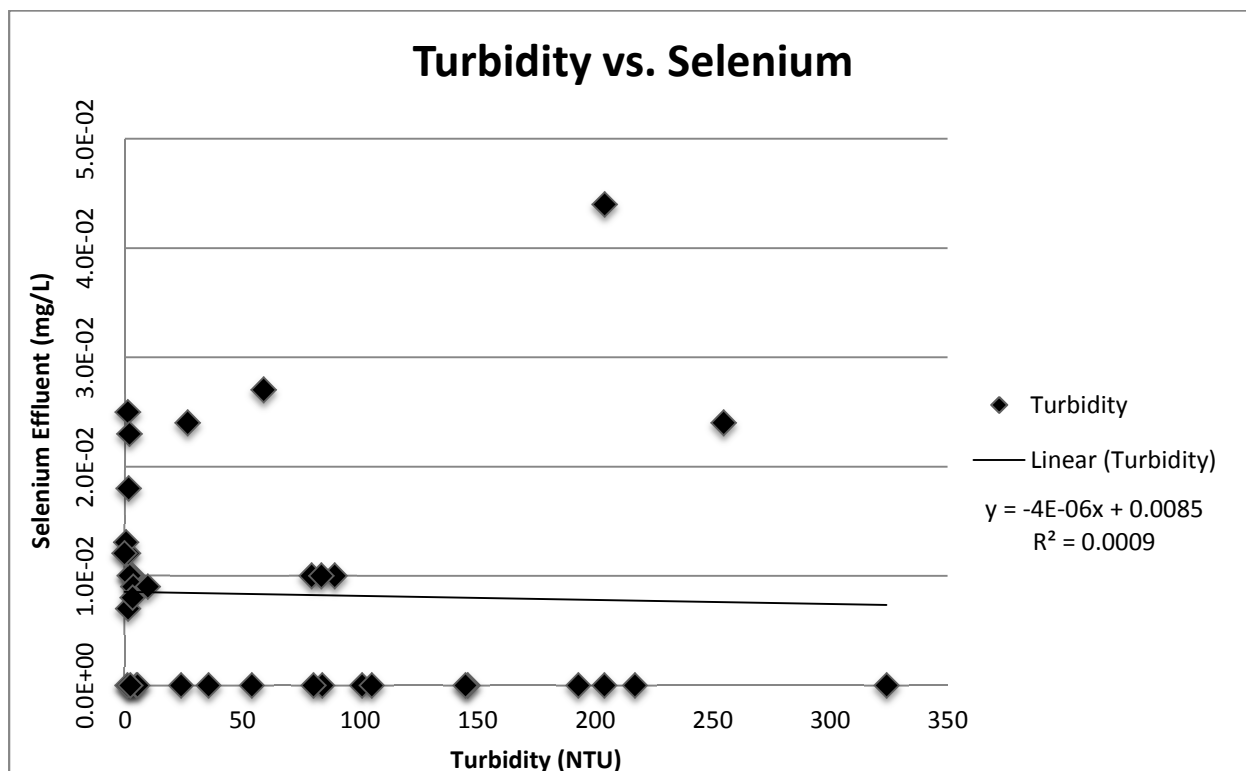


Figure F.31. Turbidity (NTU) plotted against effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

Turbidity was plotted against the effluent mercury concentrations in Figure F.31 from 1/7/2011 to 1/10/2012. Although it is difficult to see, the linear trend line present on this figure has a slight negative slope to it and an R^2 value of about 2%; therefore, turbidity and effluent mercury concentrations do not have a strong correlation between each other.



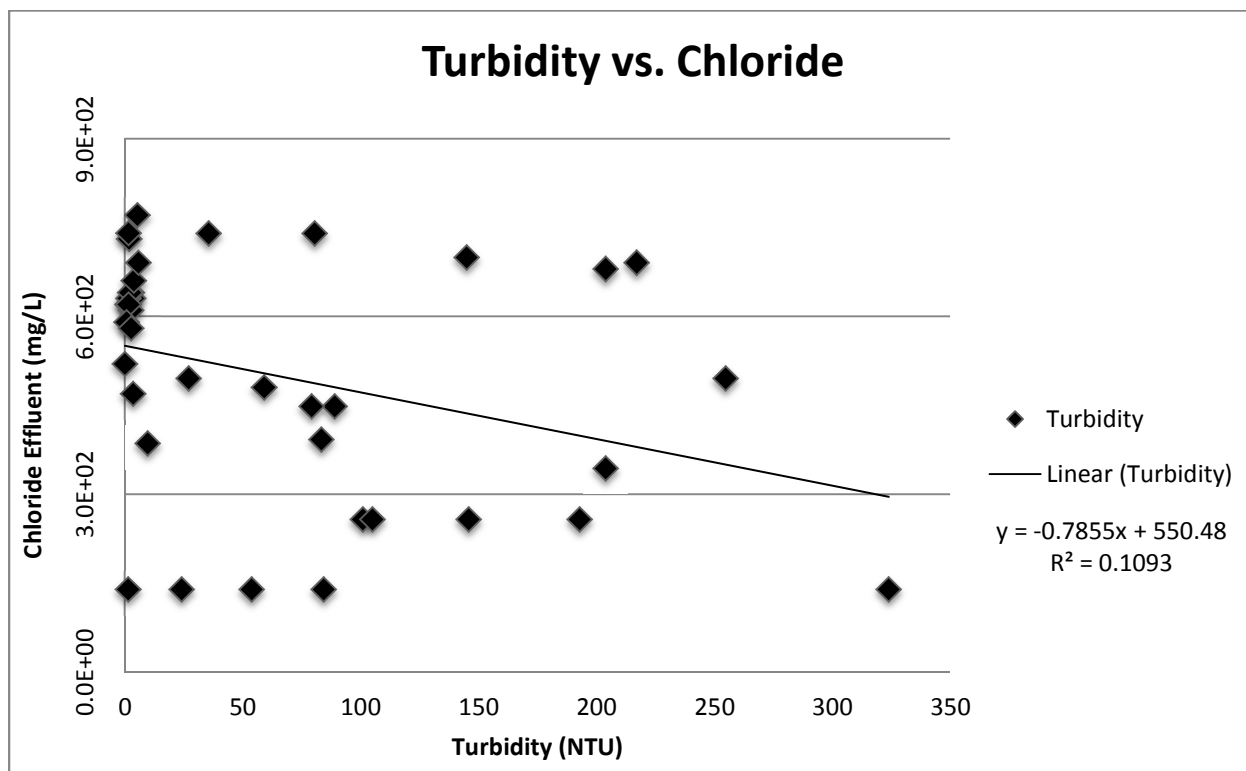


Figure F.33. Turbidity (NTU) plotted against effluent chloride concentrations (mg/L) 1/7/2011 to 1/10/2012

Turbidity and effluent chloride concentrations were plotted against one another in Figure F.33 from 1/7/2011 to 1/10/2012. The linear trend line located on the figure has a negative slope and an R^2 value of about 11%; therefore, there is not a strong correlation between turbidity and effluent chloride concentrations.

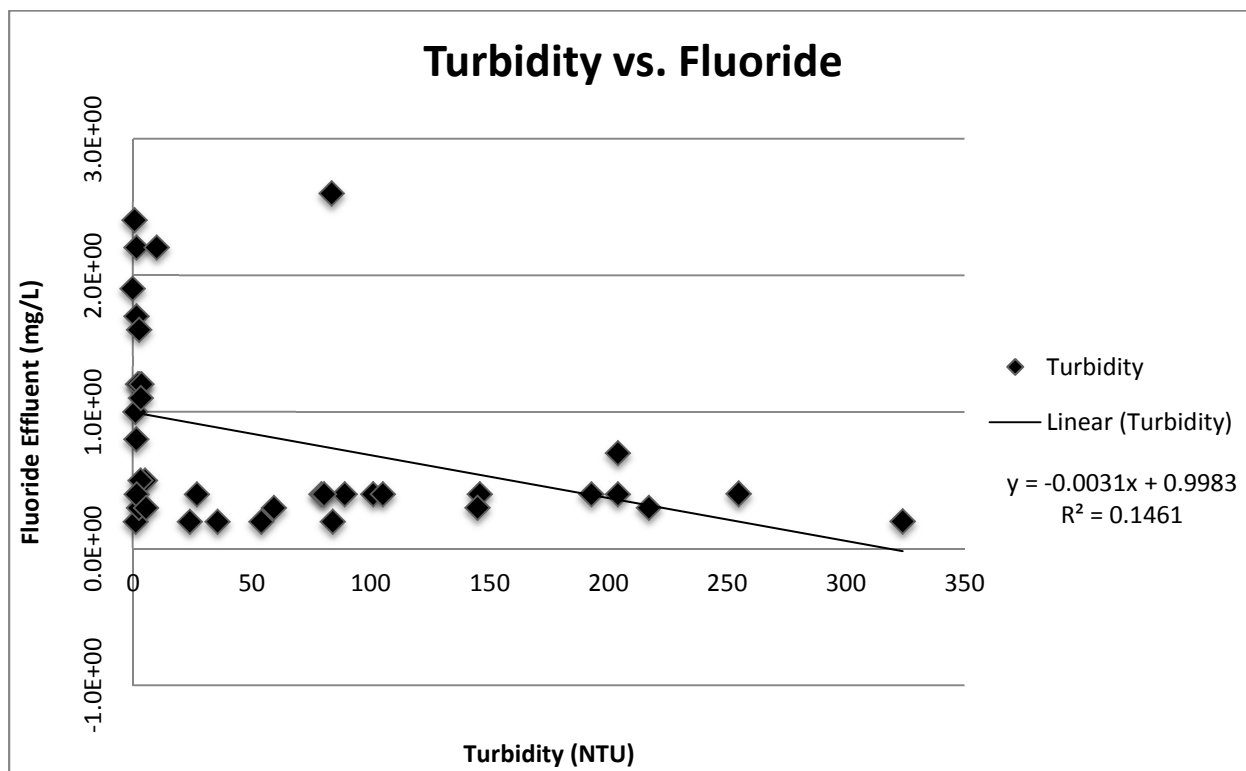


Figure F.34. Turbidity (NTU) plotted against effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.34 shows turbidity versus effluent fluoride concentrations from 1/7/2011 to 1/10/2012. The linear trend line located on the figure has a slight negative slope with an R^2 value of about 15%, which is the highest R^2 value seen for turbidity versus any other pollutant; however, the R^2 value is still too low for turbidity and effluent fluoride concentrations to have a strong correlation.

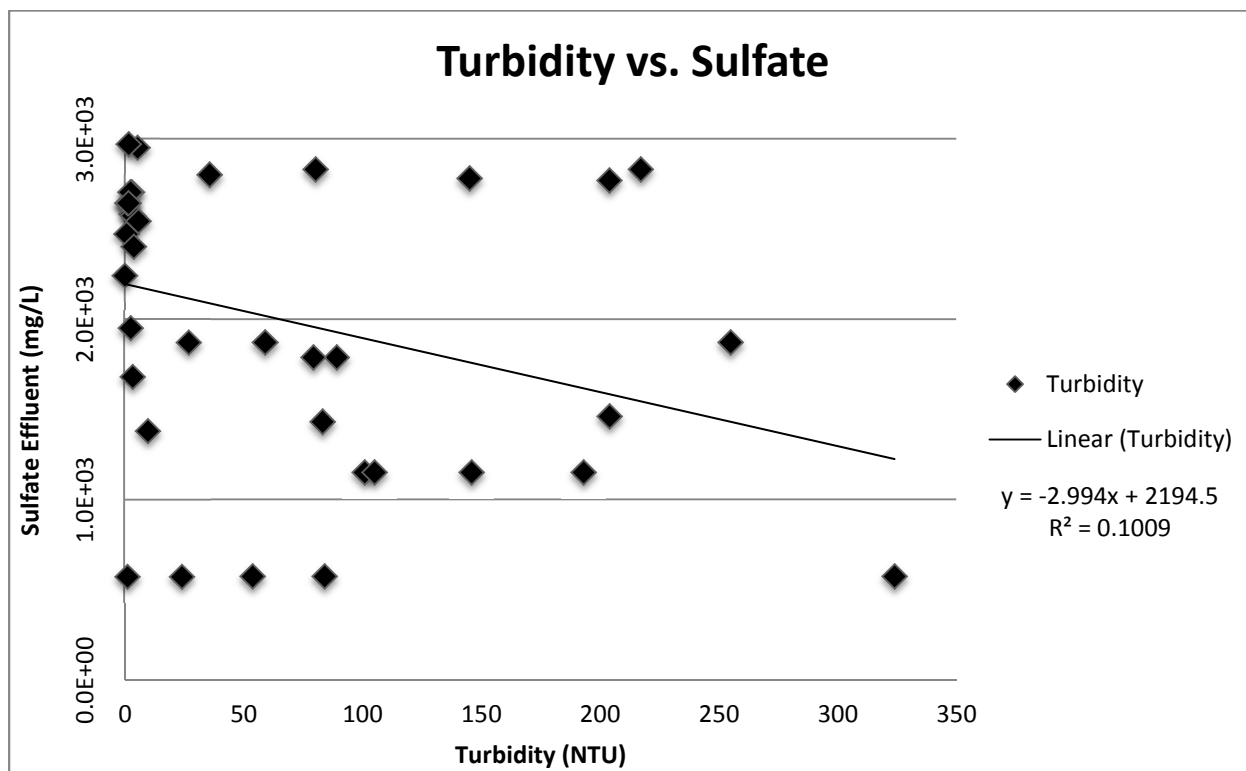


Figure F.35. Turbidity (NTU) plotted against effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

Turbidity was plotted against effluent sulfate concentrations in Figure F.35 from 1/7/2011 to 1/10/2012. The linear trend line present has a negative slope with an R^2 value of about 10%; therefore, there is no strong relationship between turbidity and effluent sulfate concentrations. As stated above, turbidity is reliant on the amount of suspended solids are present within the water; therefore, if there is a high amount of suspended solids, the turbidity should be higher. Turbidity is not dependent on concentrations of any pollutant, which can be seen in the figures discussed above. Effluent fluoride concentrations had the strongest relationship out of the other seven pollutants discussed between itself and turbidity at about a 7% relationship; however, this R^2 value is not large enough to state turbidity and effluent fluoride concentrations depend on each other.

DO

Dissolved oxygen, or DO, is responsible for determining the oxidation potential in the water, ranging “from zero to more than twice the theoretical solubility in response to many ecosystem variables” (Kadlec and Knight 1996). DO changes amounts within wetland

ecosystems, with higher DO at the air water interface and lower DO at the sediment-water interface (Kadlec and Knight 1996). DO typically increases to very high levels due to algal processes occurring during bloom conditions due to photosynthetic production, but DO is typically not depended on the concentration of pollutants. Figures F.36 thru F.42 represent DO plotted against each of the seven pollutants tested for in the CWTS at JEC.

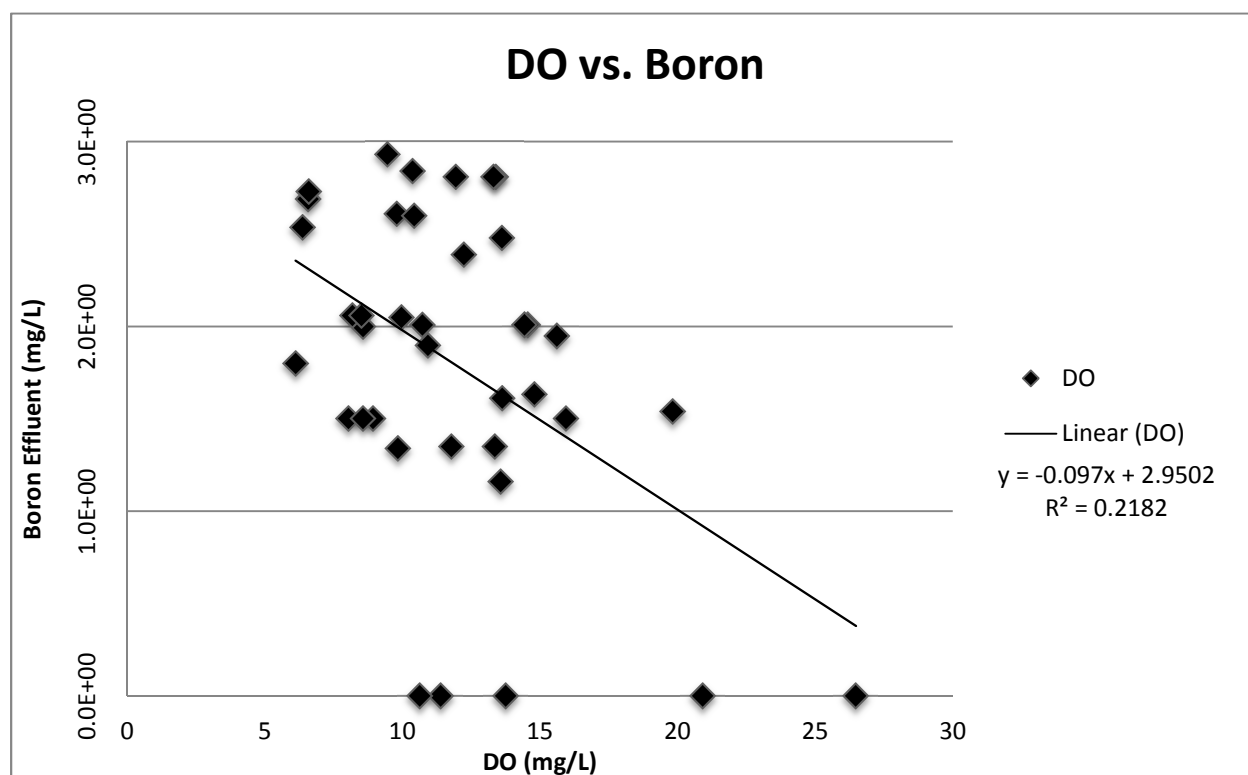


Figure F.36. DO (mg/L) plotted against effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.36 represents DO versus the effluent boron concentrations from 1/7/2011 to 1/10/2012. The linear trend line represented on the graphs has a strong negative slope with an R^2 value of about 22%; therefore, DO and effluent boron concentrations do not have a strong relationship towards each other.

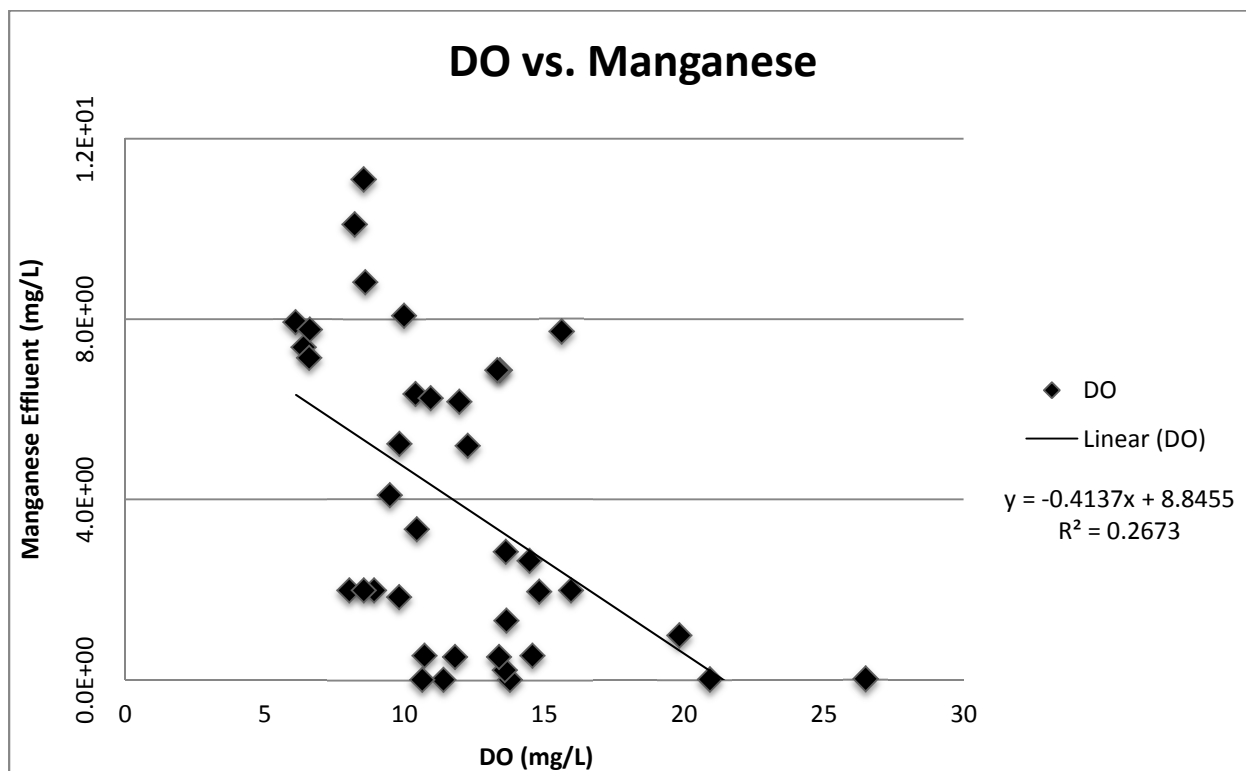


Figure F.37. DO (mg/L) plotted versus effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

DO was plotted against the effluent manganese concentrations in Figure F.37 from 1/7/2011 to 1/10/2012. Similar to the figure above, the linear trend line also has a negative slope, and an R^2 value of about 27%. The effluent manganese concentrations still do not have a strong relationship with DO; however, it does appear on the figure that as DO decreases, the effluent manganese concentration also decreases.

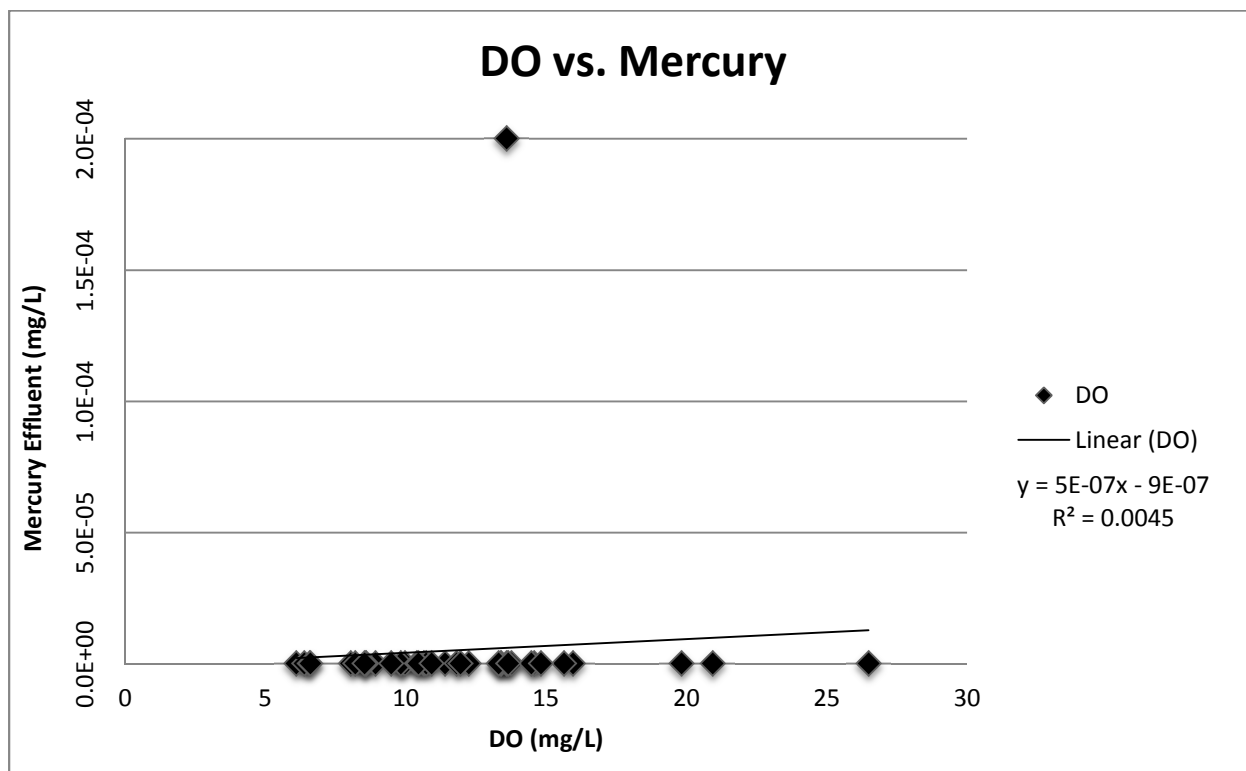


Figure F.38. DO (mg/L) plotted versus effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

In Figure F.38, DO was plotted against effluent mercury concentrations from 1/7/2011 to 1/10/2012. Unlike the figures above, the linear trend line has a slightly positive slope and an R^2 value of less than 1%; therefore, DO and effluent mercury concentrations do not have a correlation between each other.

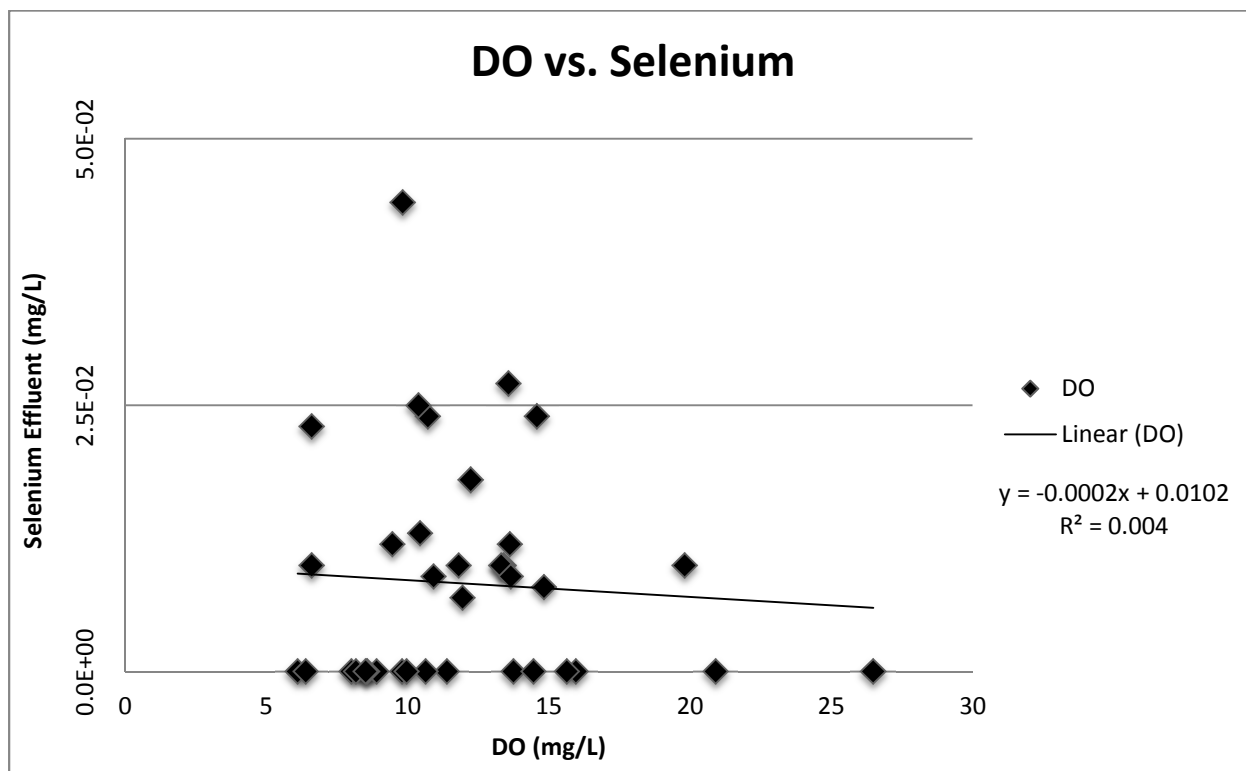


Figure F.39. DO (mg/L) plotted versus effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

DO was plotted against effluent selenium concentrations from 1/7/2011 to 1/10/2012 in Figure F.39. The linear trend line has a slightly negative slope and a relatively small R^2 value at less than 1%. Due to the small R^2 value, there is no relationship between DO and effluent selenium concentrations.

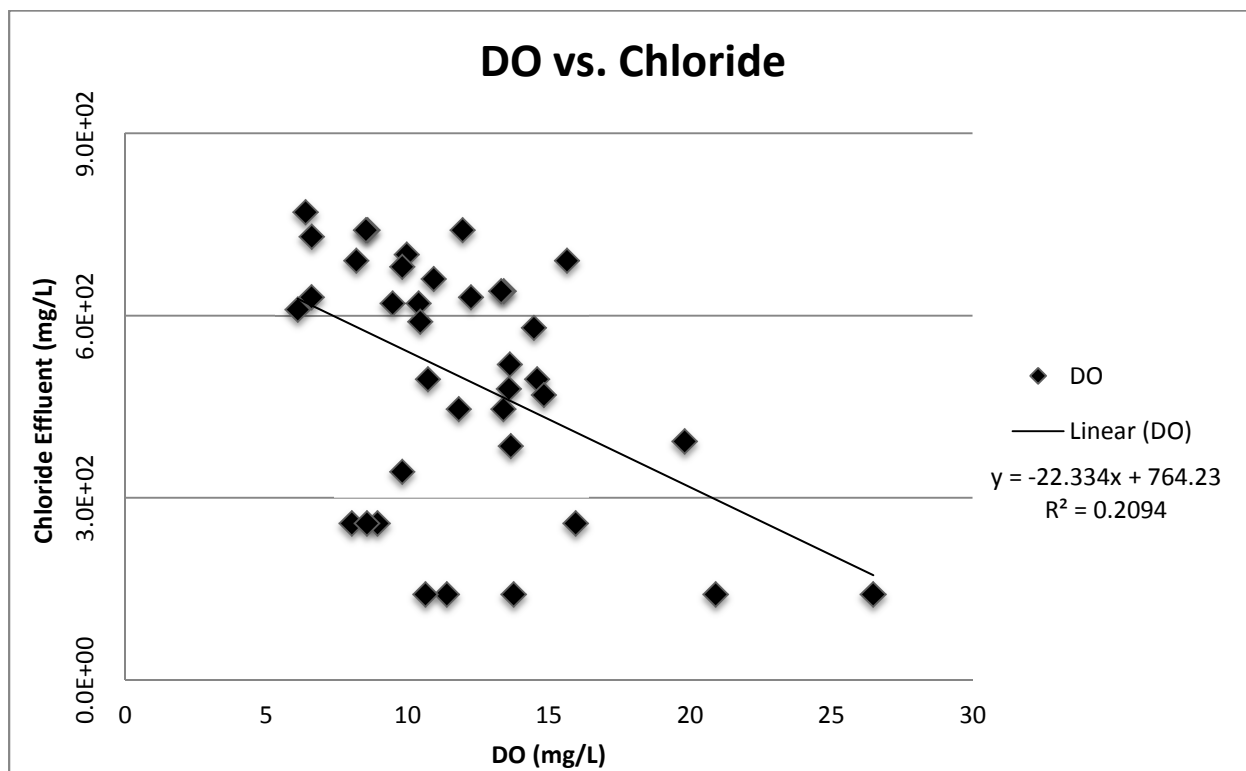


Figure F.40. DO (mg/L) plotted versus effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.40 represents DO versus effluent chloride concentrations from 1/7/2011 to 1/10/2012. The linear trend line has a large negative slope and an R^2 value of about 21%; therefore, DO and effluent chloride concentrations do not have an effect on one another.

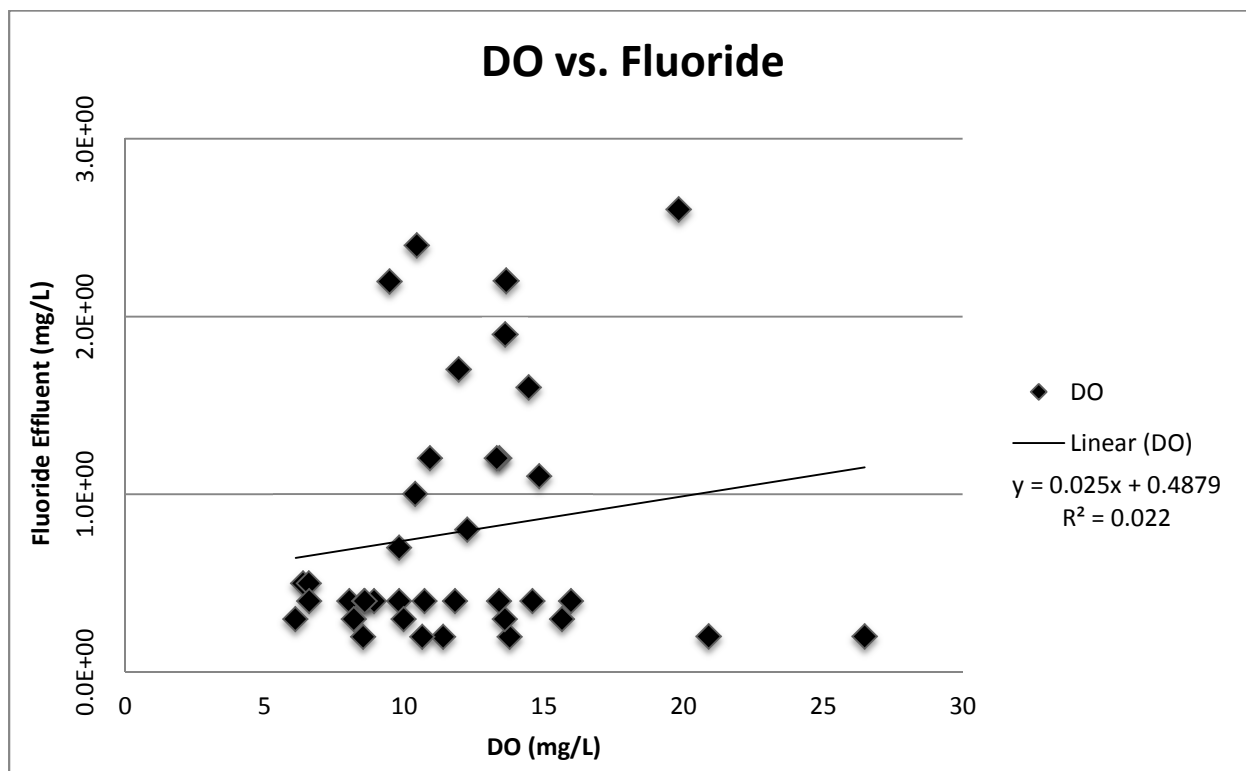


Figure F.41. DO (mg/L) plotted versus effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.41 shows DO versus effluent fluoride concentrations from 1/7/2011 to 1/10/2012. The linear trend line shown within the figure has a positive slope similar to the DO versus effluent mercury concentrations seen before. The R^2 value for this figure is only about 2%; therefore, there is not a strong correlation between the DO and effluent fluoride concentrations.

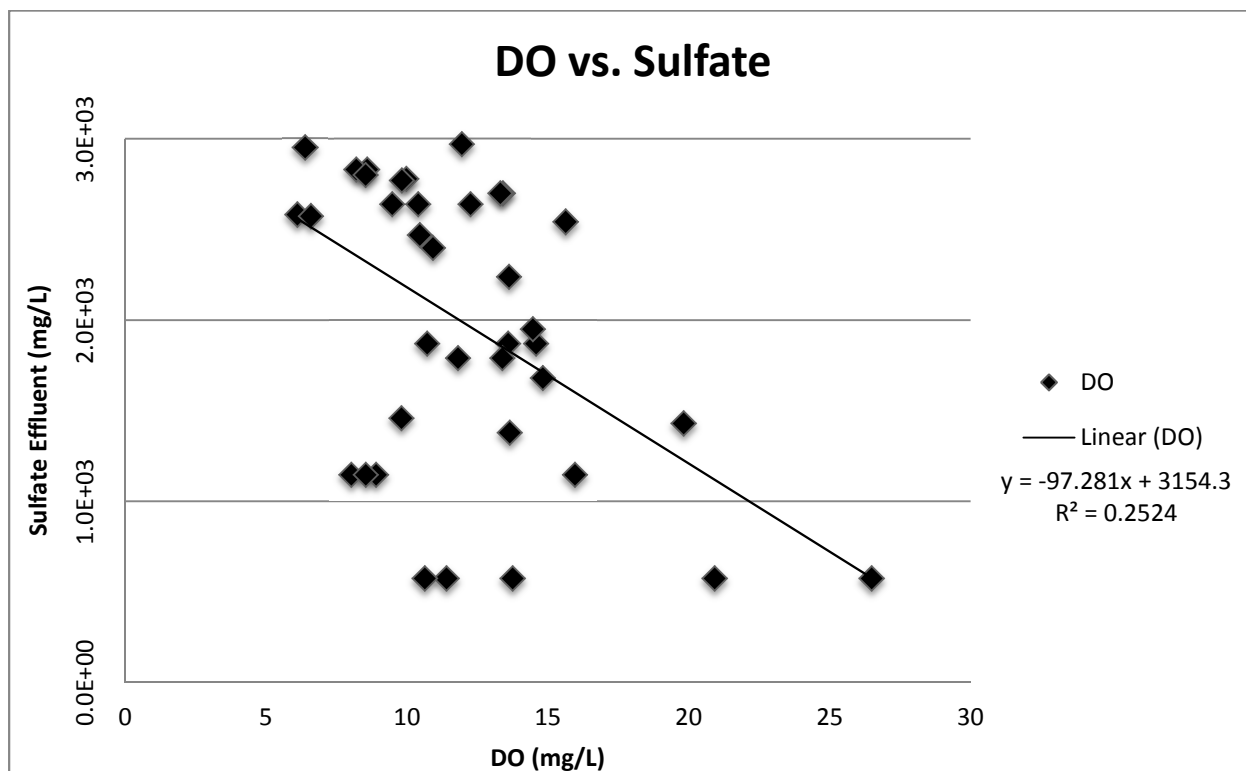


Figure F.42. DO (mg/L) plotted versus effluent sulfate concentrations (mg/L) 1/7/2011 to 1/10/2012

DO was plotted against effluent sulfate concentrations in Figure F.42 from 1/7/2011 to 1/10/2012. The linear trend line like many of the other figures in the DO section has a large negative slope with an R^2 value of about 25%. Despite the larger R^2 value compared to DO versus other pollutants, DO and the effluent sulfate concentrations do not have a strong correlation between them. Overall, none of the seven pollutants had a strong enough correlation with DO.

TDS

Total dissolved solids, or TDS, are any minerals, salts, metals, cations, or anions dissolved in water and are directly related to the purity of water. TDS typically increases with chemical constituents such as calcium, phosphates, nitrates, sodium, potassium, and chloride, which are typically found in nutrient runoff from urban and rural settings. TDS was compared to the seven pollutants tested for the CWTS at JEC and can be seen in Figure F.43 thru F.49.

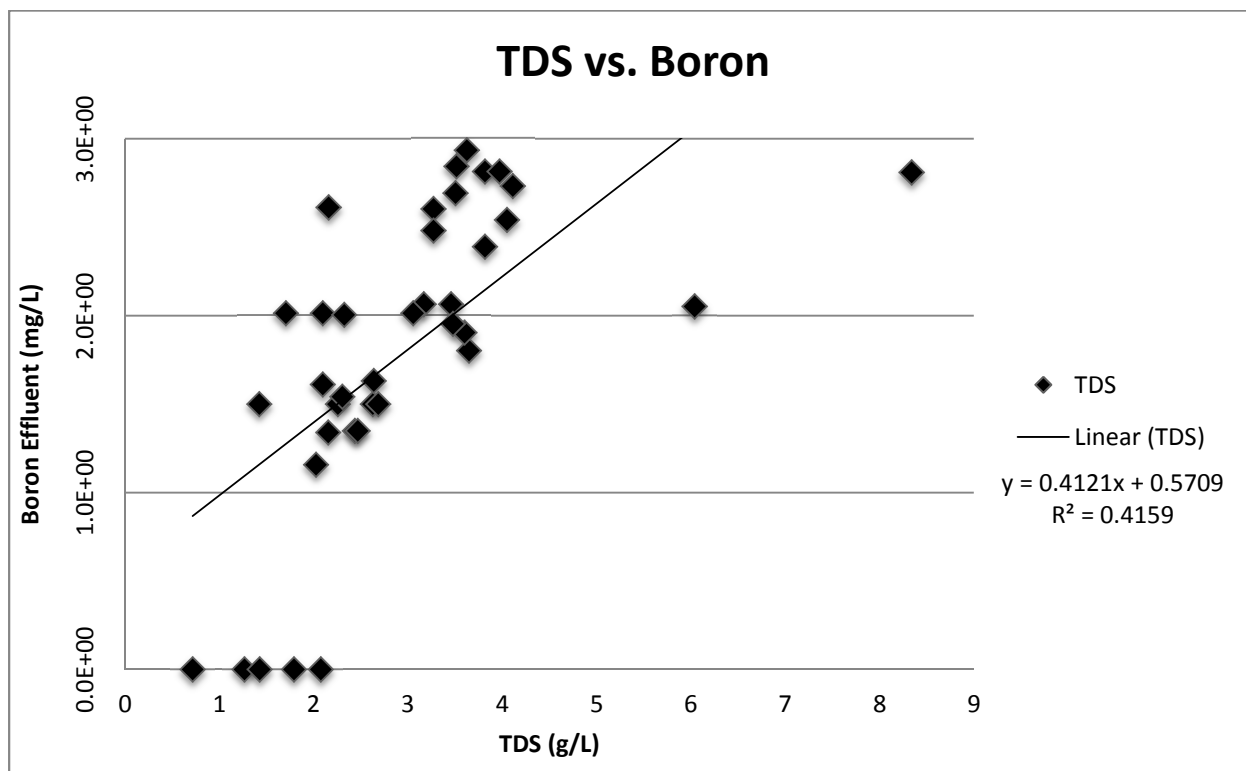


Figure F.43. TDS (g/L) plotted against effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.43 represents TDS versus effluent boron concentrations from 1/7/2011 to 1/10/2012. The linear trend line has a positive slope with an R^2 value of about 42%; therefore, TDS and effluent boron concentrations do not have a strong relationship between each other and cannot be used to determine one or the other, despite a larger R^2 value compared to others that have been developed.

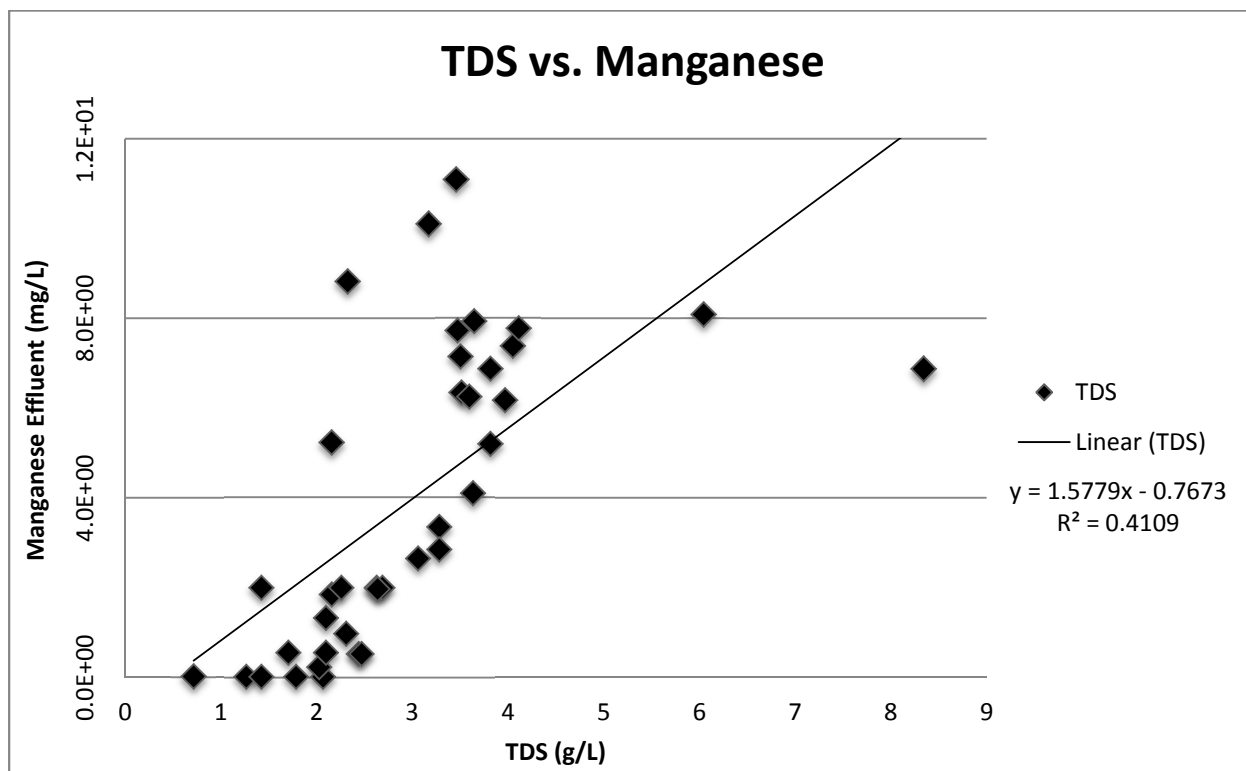


Figure F.44. TDS (g/L) plotted versus effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

TDS was plotted against effluent manganese concentrations from 1/7/2011 to 1/10/2012 in Figure F.44. The linear trend line for this figure has a positive slope with a 41% R^2 value. The R^2 value is a high value similar to TDS vs. effluent boron concentrations; however, TDS and effluent manganese concentrations do not have a strong correlation between each other. The figure does show a small relationship that states if the TDS is low, then the effluent manganese concentrations are low; however, that relationship is not strong enough to confirm.

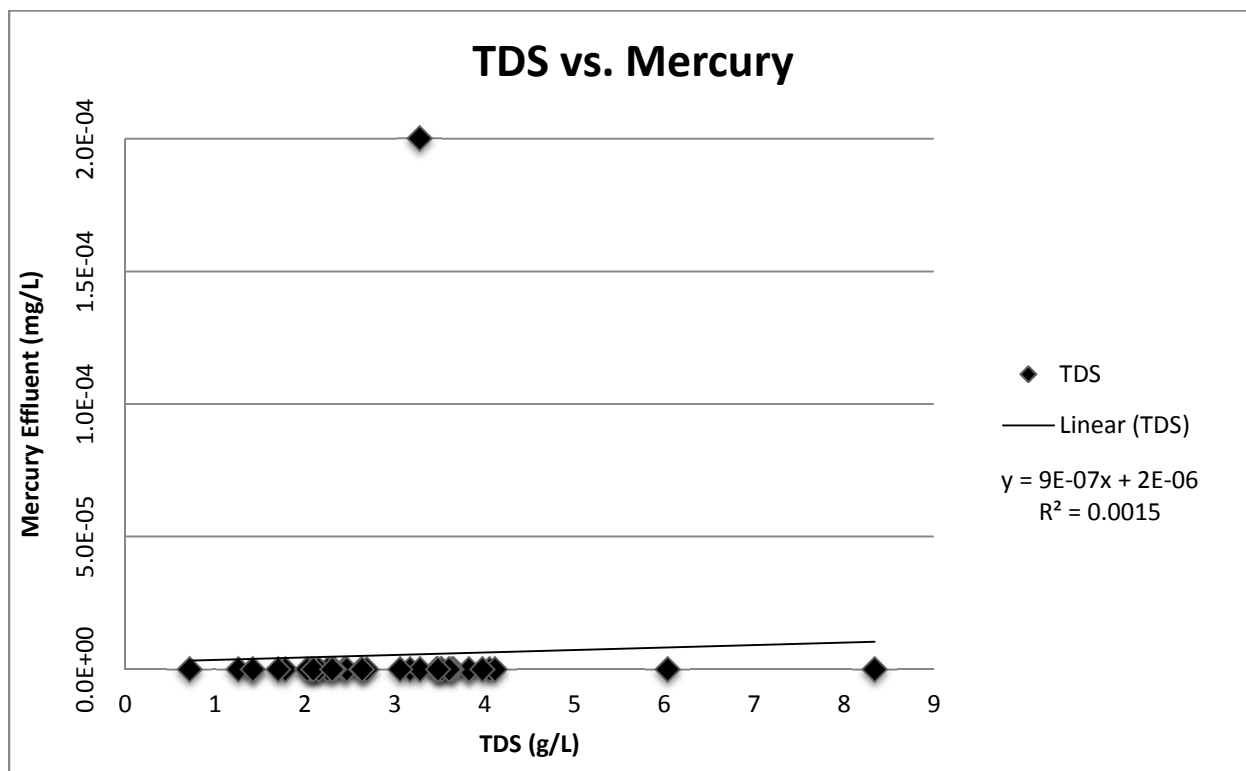


Figure F.45. TDS (g/L) plotted against effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

TDS was plotted against the effluent mercury concentrations from 1/7/2011 to 1/10/2012 in Figure F.45. The linear trend line, similar to the other effluent mercury concentration figures, has a slight positive slope and a very small R^2 value of less than 1%; therefore, TDS and effluent mercury concentrations do not have a strong correlation and should not be used to determine one or the other.

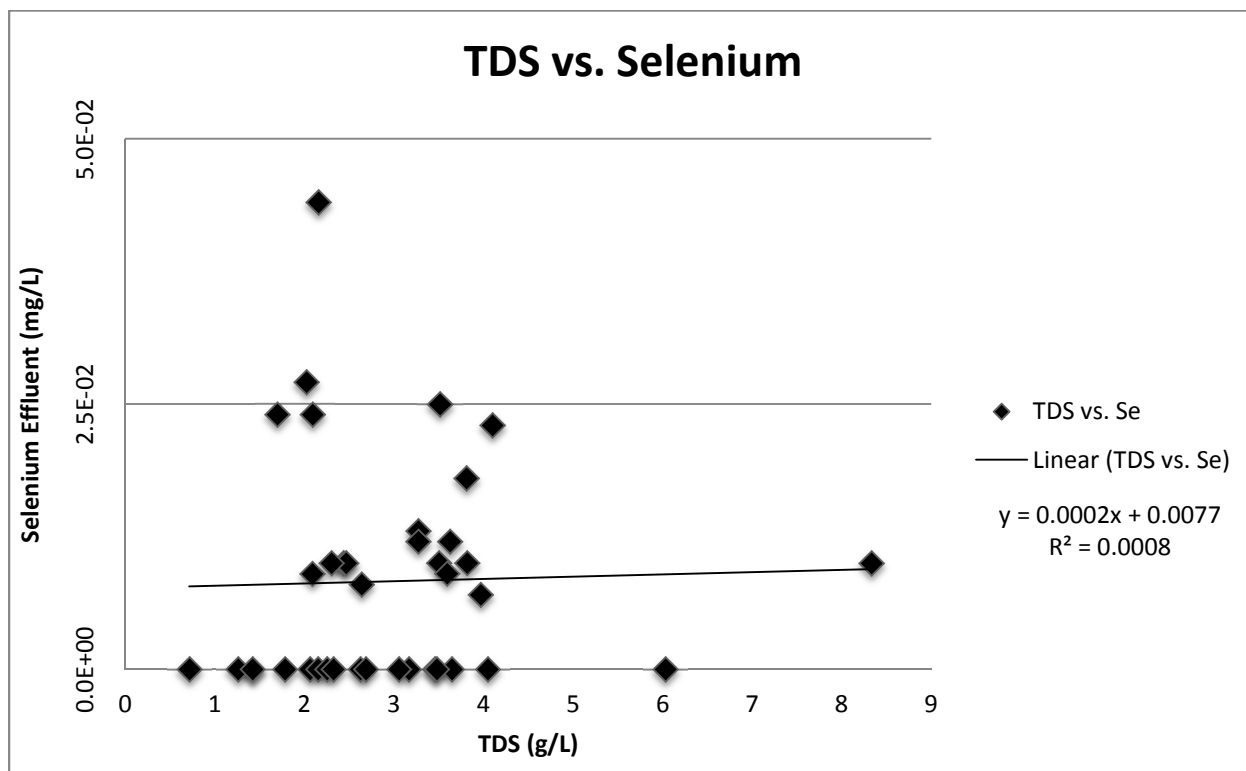


Figure F.46. TDS (g/L) plotted versus effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.46 shows TDS versus effluent selenium concentrations from 1/7/2011 to 1/10/2012. The linear trend line for this figure has a negative slope and also a small R^2 value of less than 1%; therefore, TDS and effluent selenium concentrations do not have a strong correlation between one another.

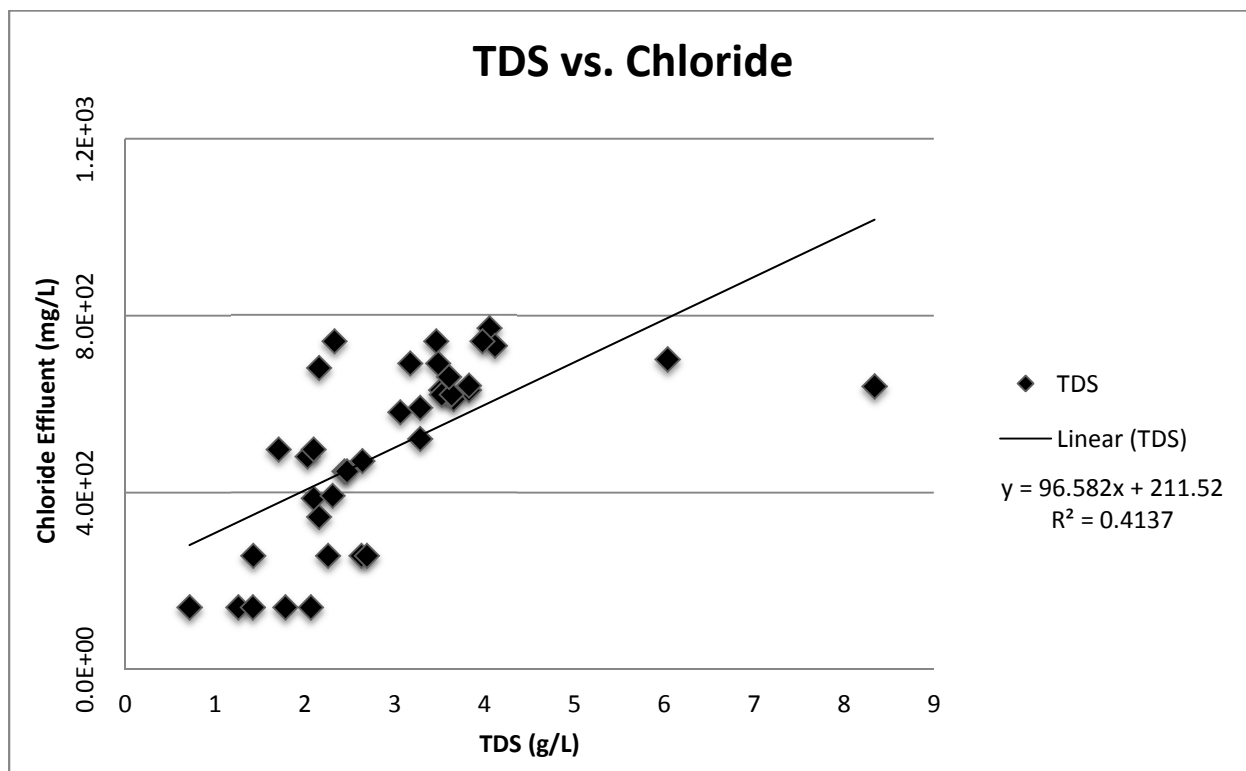


Figure F.47. TDS (g/L) plotted against effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.47 represents TDS versus effluent chloride concentrations from 1/7/2011 to 1/10/2012. The linear trend line present on the figure has a large positive slope and a R^2 value of about 41%. This R^2 value is surprisingly low for this situation, because chloride is considered a TDS; however, because the R^2 value is not large enough, there is not a strong correlation between TDS and effluent chloride concentrations. TDS was taken using the HORIBA meter; however, total dissolved solids are typically measured by filtration followed by sample evaporation to determine the quantity of dissolved solids in a water sample. The quantity measurement might have been a more accurate way to measure TDS instead of using the HORIBA meter and better results could have been obtained if this method would have been used possibly giving TDS and effluent chloride concentrations a strong correlation between one another.

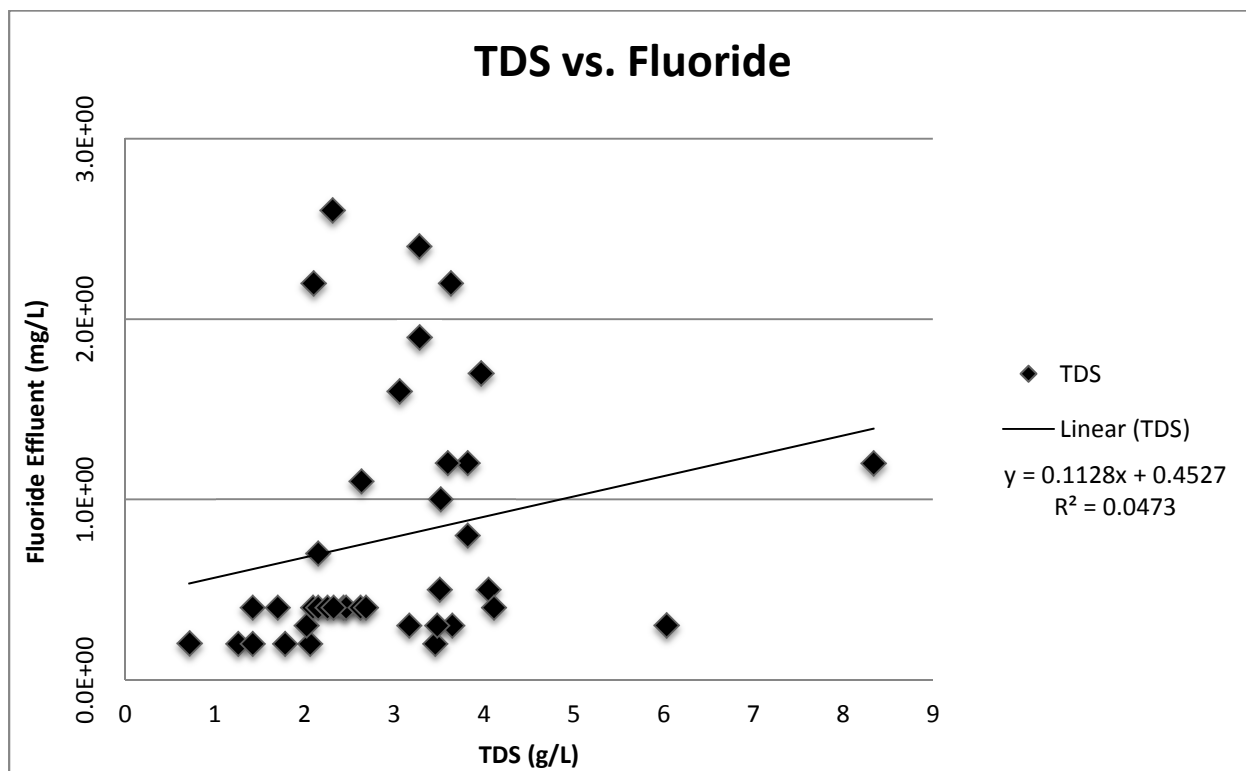


Figure F.48. TDS (g/L) plotted versus effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.48 represents TDS versus the effluent fluoride concentrations from 1/7/2011 to 1/10/2012. The linear trend line present on the figure is horizontal with a small positive slope, with a very small R^2 value of about 1% and almost approaching 0%; therefore, there is not a strong relationship between TDS and the effluent fluoride concentrations.

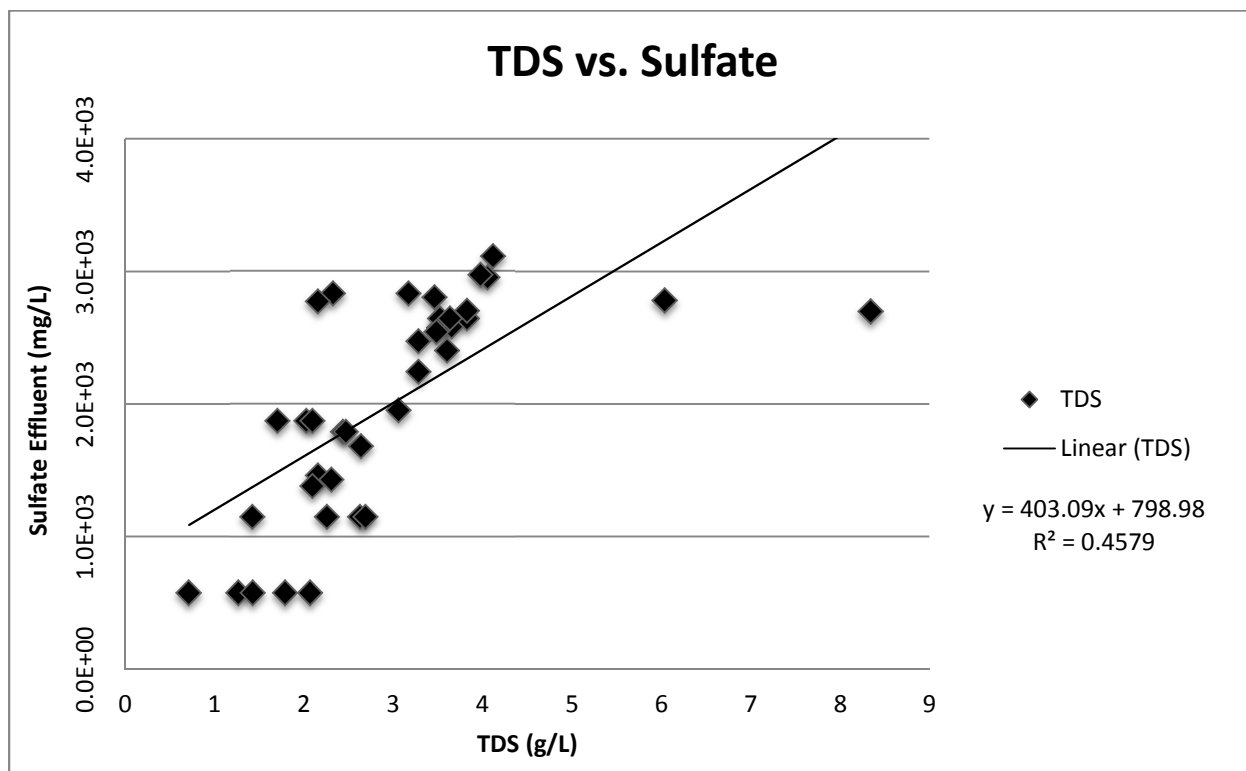


Figure F.49. TDS (g/L) plotted versus effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

TDS was plotted against the effluent sulfate concentrations from 1/7/2011 to 1/10/2012 in Figure F.49. The linear trend line present on the figure has a large positive slope with an R^2 value of about 48%; therefore, TDS and effluent sulfate concentrations do not affect one another despite having the largest R^2 value between each pollutant and TDS. TDS should have had a strong relationship with effluent chloride concentrations, but this did not occur. Precipitation might have had an effect on the dilution of chloride concentration, allowing less TDS to occur, and/or TDS was not tested for correctly using the HORIBA meter. TDS is typically tested for using filtration/evaporation methods, which is more accurate compared to the sensor used on the HORIBA meter.

Salinity

Salinity is the measurement of the dissolved salt content within a body of water or soil. Different types of dissolved salt affect salinity including sodium chloride, magnesium, calcium sulfates, and bicarbonates, which can increase or decrease salinity based on how much is present. Water salinity is broken down into four different categories based on how much salinity is

present. For the CWTS present at JEC, the water ranges in salinity from 0 to 8 ppt, classifying the water present in this wetland system to be brackish water, because it is in the brackish water salinity range of 0.5 to 30 ppt. In order to determine what is affecting the salinity content within the CWTS, the following seven figures (Figure F.50- F.56) show the relationship between salinity and one of the main seven pollutants tested for.

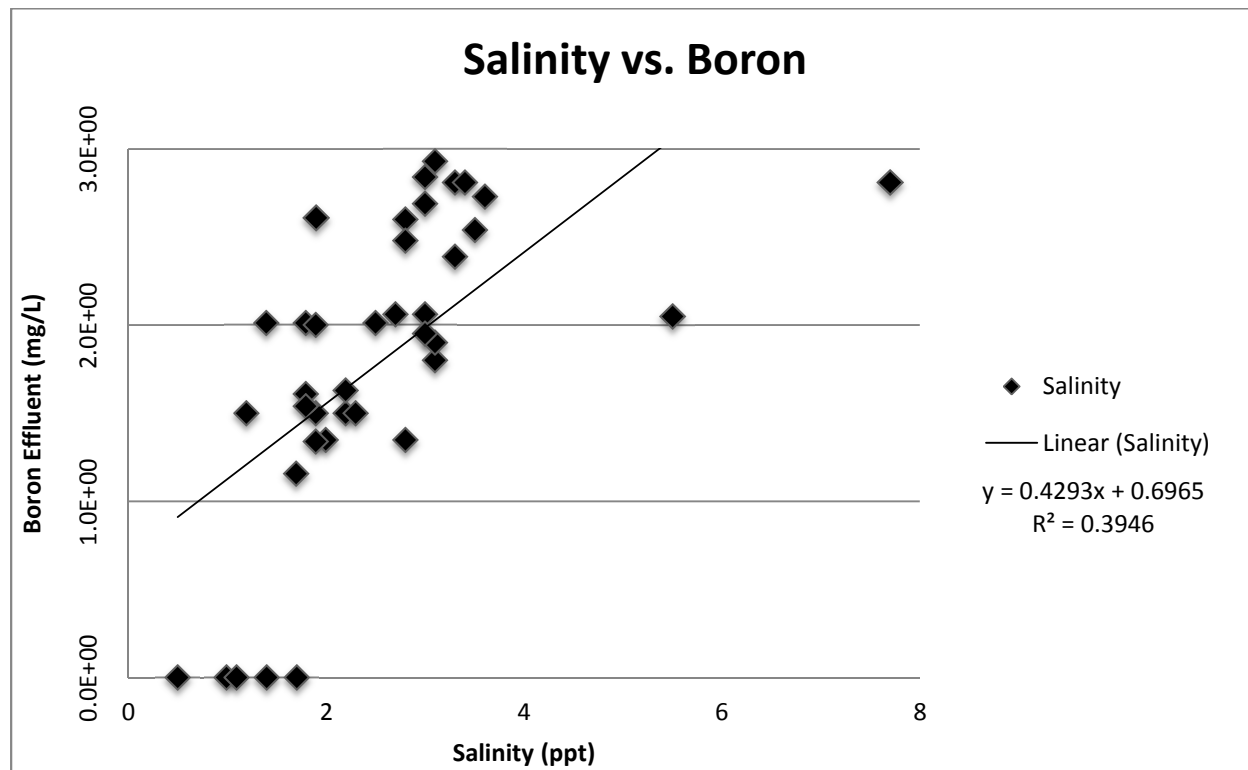


Figure F.50. Salinity (ppt) plotted versus effluent boron concentrations (mg/L) from 1/7/2011 to 1/10/2012

In Figure F.50, salinity was plotted against the effluent boron concentrations from 1/7/2011 to 1/10/2012. The linear trend line present on the figure has a positive slope with a R^2 value of about 40%; therefore, salinity is not affected by the effluent boron concentrations.

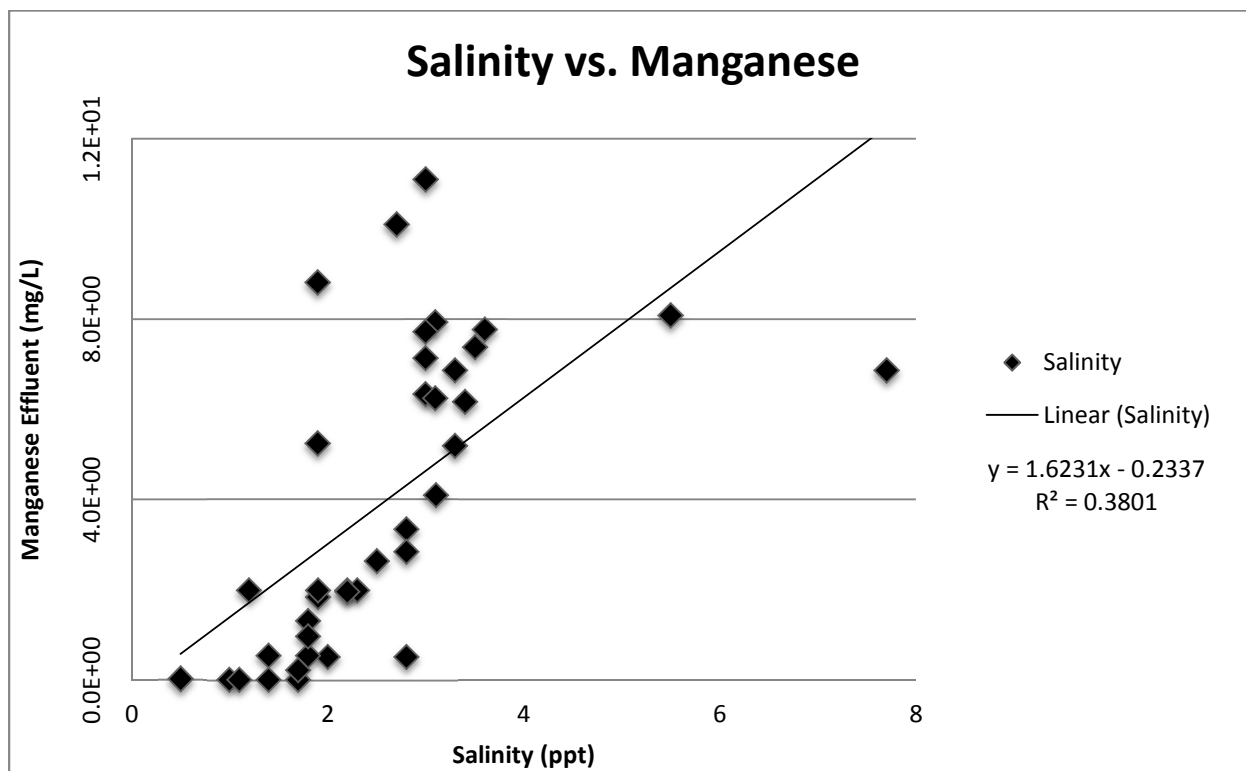


Figure F.51. Salinity (ppt) plotted against effluent manganese concentrations (mg/L) from 1/7/2011 to 1/10/2012

Salinity was plotted against the effluent manganese concentrations from 1/7/2011 to 1/10/2012 in Figure F.51. The linear trend line located on the figure has a positive slope and an R^2 value of about 38%. Salinity and the effluent manganese concentrations do not have a strong correlation; however, on the figure, it does appear that with less manganese there is a smaller salinity.

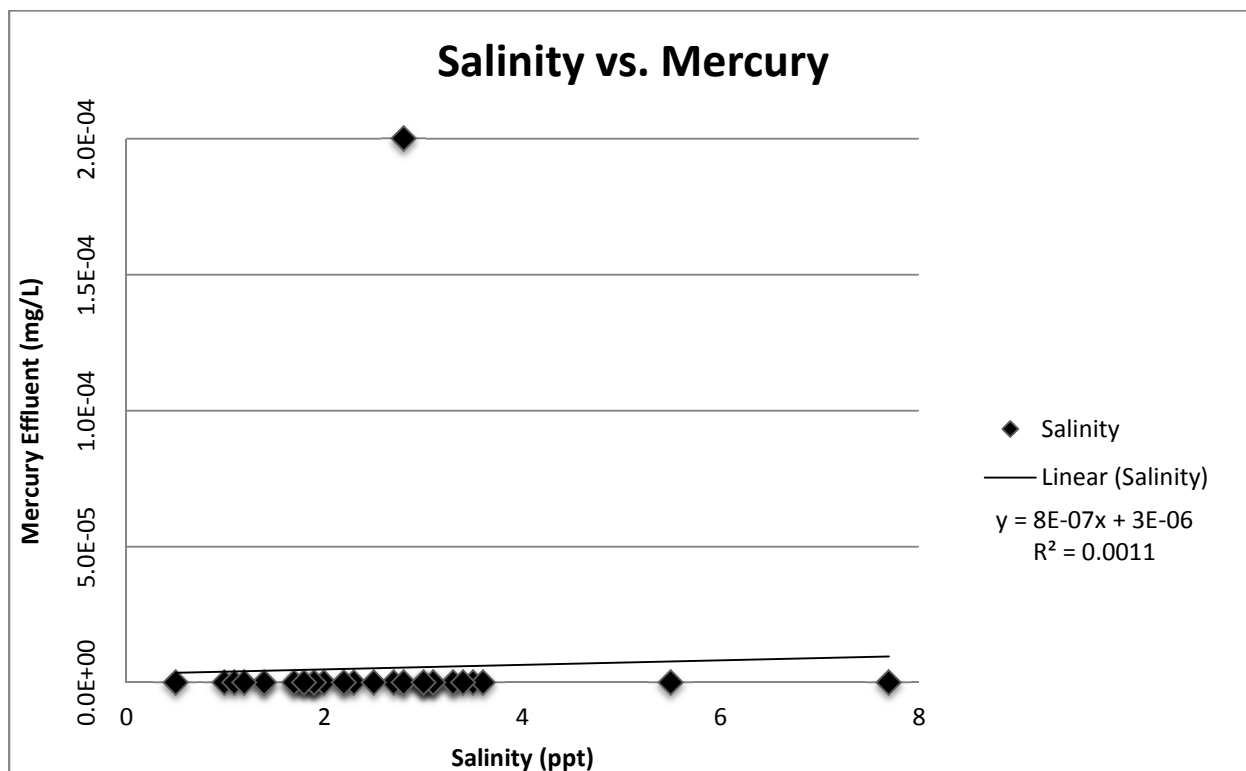


Figure F.52. Salinity (ppt) plotted against effluent mercury concentrations (mg/L) from 1/7/2011 to 1/10/2012

Figure F.52 shows salinity plotted against the effluent mercury concentrations from 1/7/2011 to 1/10/2012. The linear trend line present on the figure has a slight positive slope that is almost horizontal to the points. The R^2 value is also very small, being less than 1%, saying that there is not a strong relationship between salinity and effluent mercury concentrations.

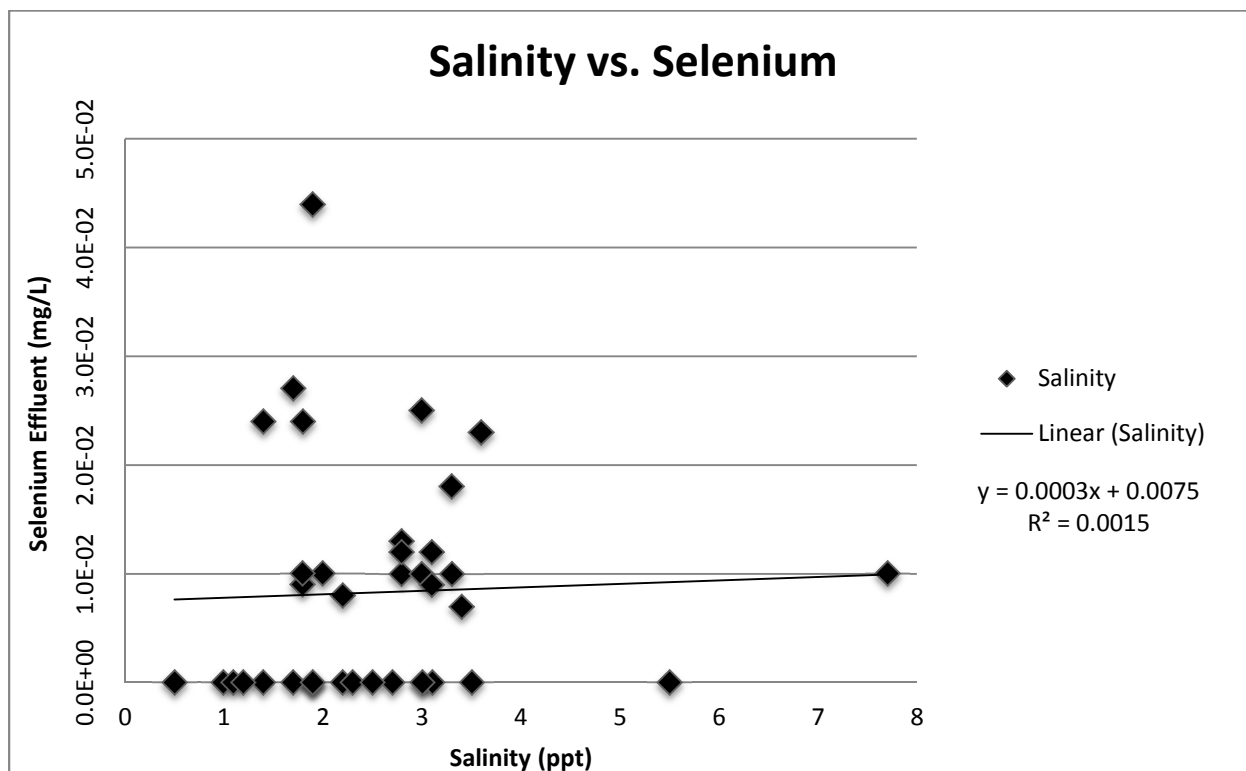


Figure F.53. Salinity (ppt) plotted against effluent selenium concentrations (mg/L) from 1/7/2011 to 1/10/2012

Salinity was plotted against the effluent selenium concentrations from 1/7/2011 to 1/10/2012 in Figure F.53. The linear trend line has a negative slope with an R^2 value of about 1%; therefore, salinity and effluent selenium concentrations do not have a strong correlation to affect one another.

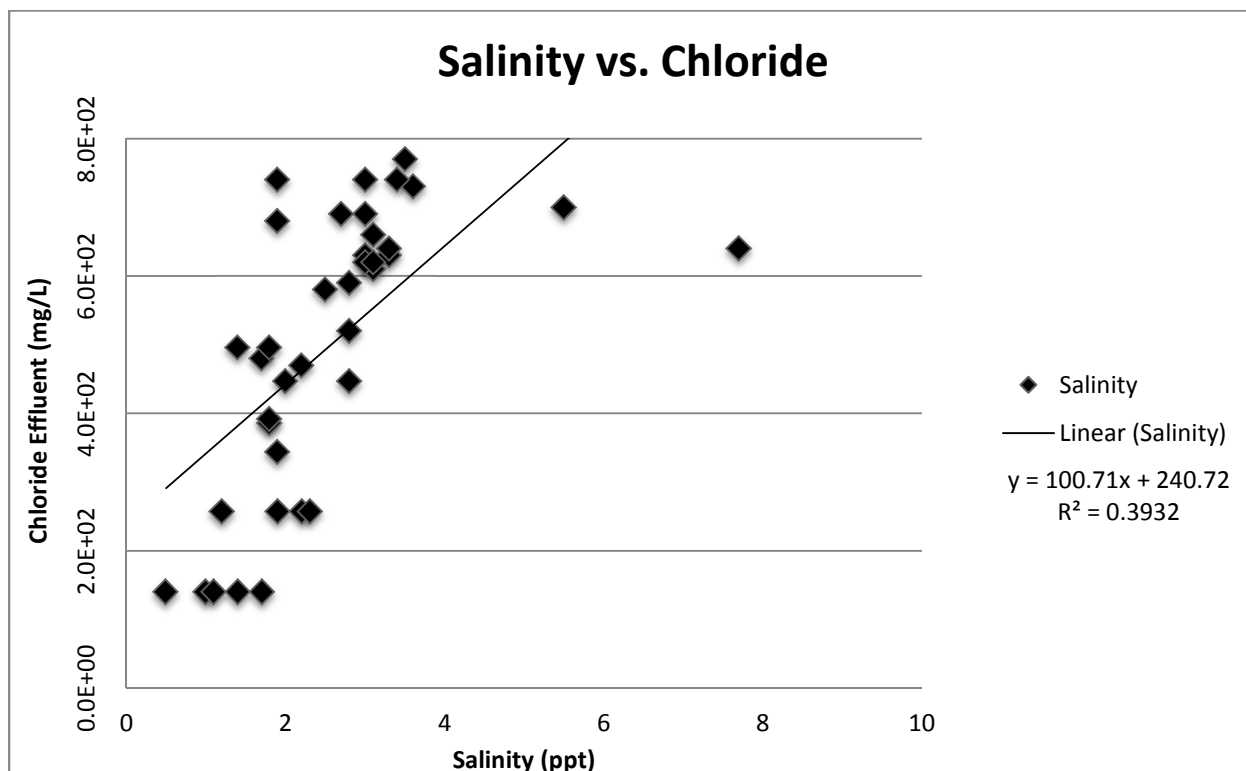


Figure F.54. Salinity (ppt) plotted against effluent chloride concentrations (mg/L) from 1/7/2011 to 1/10/2012

In Figure F.54, salinity was plotted versus the effluent chloride concentrations from 1/7/2011 to 1/10/2012. The linear trend line located on the figure has a positive slope and an R^2 value of about 40%; therefore, salinity and effluent chloride concentrations do not have a strong correlation between each other. Salinity should be effected more by chloride concentrations, in which salinity should increase as chloride concentration increases.

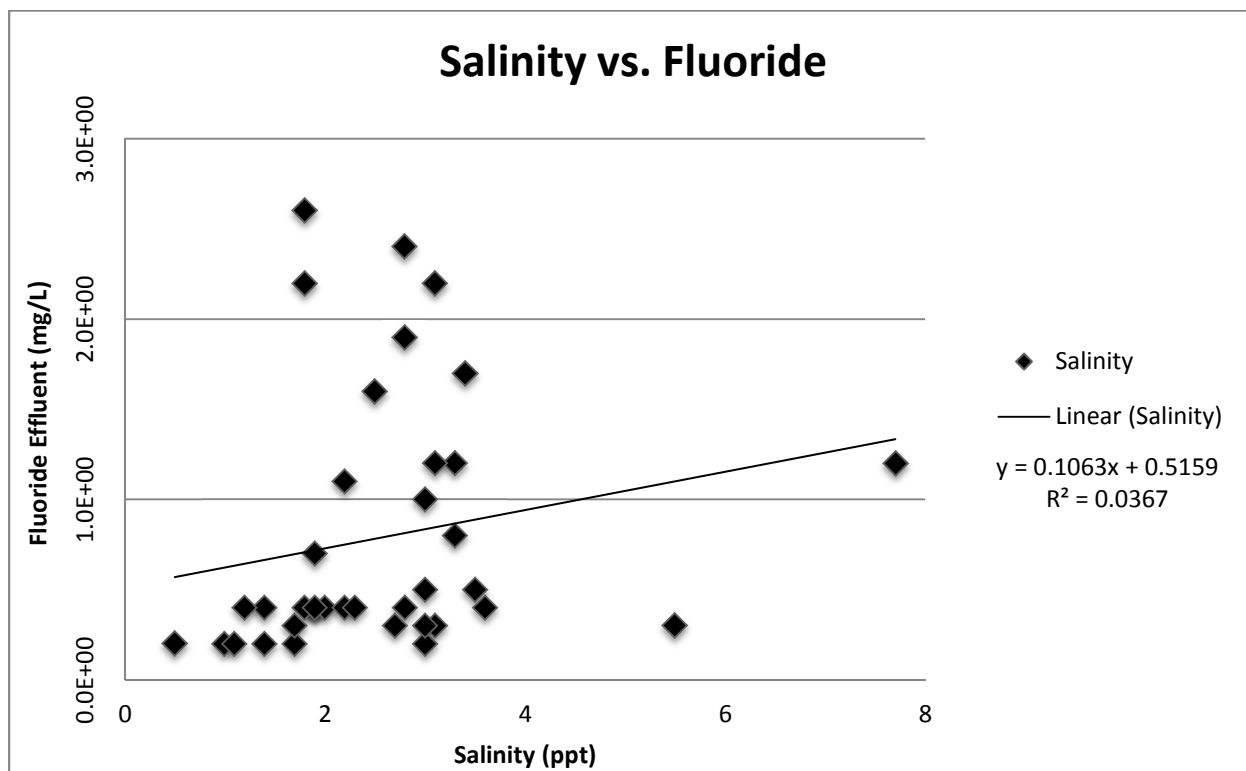


Figure G.55. Salinity (ppt) plotted versus effluent fluoride concentrations (mg/L) from 1/7/2011 to 1/10/2012

Salinity was plotted against effluent fluoride concentrations from 1/7/2011 to 1/10/2012 in Figure F.55. The linear trend line on the figure is relatively horizontal, with a slight negative slope and an R^2 value of about 4%. There is not a strong correlation between salinity and effluent fluoride concentrations.

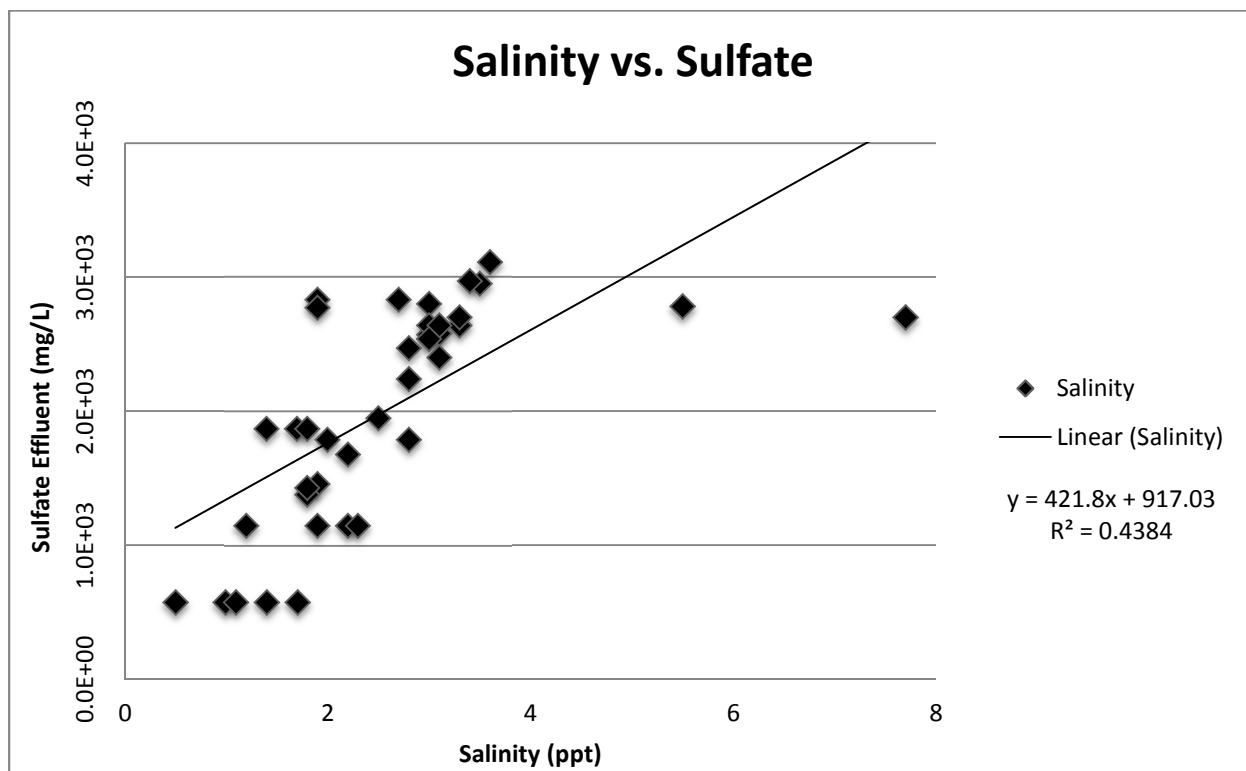


Figure F.56. Salinity (ppt) plotted versus effluent sulfate concentrations (mg/L) from 1/7/2011 to 1/10/2012

In Figure F.56, salinity was plotted versus the effluent sulfate concentrations from 1/7/2011 to 1/10/2012. The linear trend line present on the figure has a large positive slope, but has an R^2 value of about 44%; therefore, salinity and effluent sulfate concentrations do not have a good correlation between one another. Salinity should have been affected more by chloride and sulfate concentrations, because they are types of salts; however, their correlations between each other were about 40% which was probably due to large rain fall events diluting the water, inaccurate water sampling, and/or inaccurate readings from the HORIBA meter

Overall, none of the water quality measurements had a positive correlation between one of the seven main pollutants tested for within the CWTS at JEC; therefore, no water quality measurement should be used to determine how much of a pollutant is located within the CWTS, because it would not be accurate. Due to this finding, water quality measurements continued to be taken for the CWTS, but by Burns & McDonnell themselves, while water sampling was still conducted by Kansas State University to determine the effluent concentrations of each of the seven pollutants.

Appendix G - The Water Balance

The following three tables, Table G.1, G.2, and G.3, represent the daily water balance from January 1, 2011 to May 22, 2012, while the other two tables represent the weekly water balances for 2011 and 2012, respectively. The bold red values for precipitation within the table represent times where the Vantage Pro2™ weather station was not working properly; therefore, weather data was taken from the Kansas State Weather Data Library for Manhattan, KS and used in place of the Vantage Pro2™ weather station.

Table G.1. Daily water balance for CWTS at JEC with RAW, FGDWW, and Precip. all incoming amounts of water and LS are leaving amounts of water from January 1, 2011 to May 22, 2012. These values were used to determine the system evapotranspiration, which will be shown later.

Date	RAW (L)	FGDWW (L)	Precip. (mm)	LS (L)
1/1/2011	0	0	0	0
1/2/2011	0	0	0	0
1/3/2011	0	0	0	0
1/4/2011	0	0	0	0
1/5/2011	0	0	0	0
1/6/2011	0	0	0	0
1/7/2011	3838	0	0	0
1/8/2011	0	0	0	0
1/9/2011	0	0	1	0
1/10/2011	0	0	1	0
1/11/2011	0	0	0	0
1/12/2011	0	0	0	0
1/13/2011	0	0	0	0
1/14/2011	0	0	0	0
1/15/2011	0	0	0	0
1/16/2011	0	0	0	0
1/17/2011	74928	0	0	0
1/18/2011	161168	0	0	0
1/19/2011	0	0	6	0
1/20/2011	0	0	0	0
1/21/2011	0	0	0	0
1/22/2011	0	0	0	0
1/23/2011	0	0	0	0

1/24/2011	83620	2458	0	0
1/25/2011	136252	0	0	0
1/26/2011	136237	0	0	0
1/27/2011	136252	0	0	0
1/28/2011	190864	8063	0	0
1/29/2011	268954	0	0	0
1/30/2011	263968	0	0	0
1/31/2011	272447	0	0	0
2/1/2011	272421	0	2	0
2/2/2011	272410	0	0	0
2/3/2011	272565	0	0	0
2/4/2011	271482	0	0	0
2/5/2011	269234	0	0	0
2/6/2011	136494	0	0	0
2/7/2011	233041	0	0	0
2/8/2011	202130	5925	4	0
2/9/2011	135991	0	0	0
2/10/2011	135991	0	0	0
2/11/2011	135987	0	0	0
2/12/2011	135991	0	0	0
2/13/2011	135991	0	0	0
2/14/2011	135991	36146	0	0
2/15/2011	135991	68149	0	0
2/16/2011	90772	68151	0	0
2/17/2011	0	0	0	0
2/18/2011	26765	24661	0	0
2/19/2011	0	0	0	0
2/20/2011	0	0	0	0
2/21/2011	91827	45909	0	0
2/22/2011	94677	54984	0	0
2/23/2011	97647	68151	0	0
2/24/2011	135991	68151	10	0
2/25/2011	135991	44064	0	0
2/26/2011	135991	68151	0	0
2/27/2011	135987	68151	0	0
2/28/2011	68141	68147	0	0
3/1/2011	72004	68147	0	0
3/2/2011	135991	68147	0	0
3/3/2011	74768	47868	0	0
3/4/2011	68147	68147	0	0
3/5/2011	68149	68145	0	0
3/6/2011	68149	68147	0	0

3/7/2011	68147	65170	1	0
3/8/2011	68149	65198	5	0
3/9/2011	68147	64140	0	0
3/10/2011	68149	51144	0	53814
3/11/2011	68153	68147	0	129448
3/12/2011	68147	68149	0	102767
3/13/2011	68147	64010	0	80766
3/14/2011	68149	68147	11	310135
3/15/2011	68149	68147	0	120799
3/16/2011	68149	49633	0	97856
3/17/2011	68149	63750	0	98289
3/18/2011	40971	17355	0	65982
3/19/2011	68147	68147	11	191160
3/20/2011	68149	68147	0	151072
3/21/2011	68149	68147	0	69470
3/22/2011	68149	68147	0	63775
3/23/2011	68149	68151	0	182355
3/24/2011	68149	68149	2	124410
3/25/2011	68149	68149	1	116102
3/26/2011	68147	68147	0	130253
3/27/2011	68151	68149	0	109837
3/28/2011	68149	68151	1	125110
3/29/2011	68147	68149	0	182698
3/30/2011	68149	68151	0	143359
3/31/2011	68149	68145	3	121288
4/1/2011	68147	68149	0	132761
4/2/2011	68147	33909	0	100477
4/3/2011	68149	68149	0	97537
4/4/2011	68149	68151	0	145988
4/5/2011	68149	52180	0	4437
4/6/2011	68149	68149	0	0
4/7/2011	1018	329	3	0
4/8/2011	61952	17033	4	0
4/9/2011	68147	68147	0	0
4/10/2011	68149	59630	0	0
4/11/2011	68149	68151	0	0
4/12/2011	68149	68145	0	0
4/13/2011	68149	68147	0	0
4/14/2011	68151	68147	10	106364
4/15/2011	68149	68153	7	217387
4/16/2011	66404	20665	0	66068
4/17/2011	68147	68151	0	109126

4/18/2011	68147	68151	0	119672
4/19/2011	68149	68147	0	100854
4/20/2011	68141	46005	0	59114
4/21/2011	68141	68139	0	84926
4/22/2011	68141	68139	10	255281
4/23/2011	57181	54201	0	92224
4/24/2011	39376	33088	0	73637
4/25/2011	60614	59550	12	132508
4/26/2011	55396	55068	1	157338
4/27/2011	56592	56299	0	39715
4/28/2011	68141	68143	0	88831
4/29/2011	68141	68143	0	81026
4/30/2011	68141	68139	0	92149
5/1/2011	61004	60410	0	8366
5/2/2011	68141	68139	0	88632
5/3/2011	68141	68141	0	74941
5/4/2011	68143	68141	0	80394
5/5/2011	68141	68141	2	109864
5/6/2011	68141	68141	5	84143
5/7/2011	68141	68139	9	93123
5/8/2011	68141	68141	0	121389
5/9/2011	68141	68141	0	28266
5/10/2011	68141	68141	0	100717
5/11/2011	68141	68139	1	32310
5/12/2011	68141	68143	2	91668
5/13/2011	27859	27519	2	77116
5/14/2011	68141	68139	0	74518
5/15/2011	68141	68141	0	54354
5/16/2011	68141	68143	0	110517
5/17/2011	64180	63665	1	92529
5/18/2011	68141	68143	21	121693
5/19/2011	68141	68143	4	345024
5/20/2011	68141	68139	12	289140
5/21/2011	68141	68141	0	174986
5/22/2011	68141	68141	0	89952
5/23/2011	68141	68139	0	68986
5/24/2011	68141	68141	40	247613
5/25/2011	68141	68143	49	689403
5/26/2011	68141	68141	0	768931
5/27/2011	68141	68139	1	380919
5/28/2011	68141	68139	1	91057
5/29/2011	68141	68141	0	79899

5/30/2011	68141	68139	16	54632
5/31/2011	68141	68143	0	210316
6/1/2011	68143	68141	93	235818
6/2/2011	68143	68139	0	718769
6/3/2011	66568	64717	0	726849
6/4/2011	68141	66949	0	407318
6/5/2011	68141	68141	0	163321
6/6/2011	58187	57434	0	49204
6/7/2011	68141	68141	0	53410
6/8/2011	68141	68139	1	18568
6/9/2011	68141	68141	3	67419
6/10/2011	68141	68139	0	84067
6/11/2011	68141	68141	0	99174
6/12/2011	68141	57431	1	75670
6/13/2011	68141	56128	1	53929
6/14/2011	68143	68141	0	62269
6/15/2011	68143	68141	0	93737
6/16/2011	68141	68141	7	134401
6/17/2011	68141	68141	1	130489
6/18/2011	68141	68141	24	334323
6/19/2011	68141	68141	0	147530
6/20/2011	68141	68141	4	71112
6/21/2011	68141	68141	0	96199
6/22/2011	68141	68141	0	34541
6/23/2011	68141	68141	0	76630
6/24/2011	68141	68141	0	62247
6/25/2011	68143	68143	8	125640
6/26/2011	68143	68143	0	85978
6/27/2011	68143	68145	3	218023
6/28/2011	68141	68143	0	70970
6/29/2011	68143	68145	0	69107
6/30/2011	68141	30586	0	32924
7/1/2011	68141	14339	0	32634
7/2/2011	68141	68145	0	26825
7/3/2011	68145	68145	0	119316
7/4/2011	68141	68145	0	103386
7/5/2011	68141	68145	0	68564
7/6/2011	68141	68149	1	121739
7/7/2011	68141	68145	1	255020
7/8/2011	68141	68145	1	131390
7/9/2011	68141	68141	0	76908
7/10/2011	68141	68145	0	63356

7/11/2011	68145	68141	0	49102
7/12/2011	68145	59033	3	29563
7/13/2011	68145	68145	1	116088
7/14/2011	68145	68145	0	48634
7/15/2011	68145	68149	0	31711
7/16/2011	68141	68145	0	27624
7/17/2011	68145	68141	0	27443
7/18/2011	63576	63262	0	22909
7/19/2011	0	0	0	20470
7/20/2011	0	0	0	245
7/21/2011	0	0	0	282
7/22/2011	0	0	0	226
7/23/2011	0	0	0	102
7/24/2011	0	0	1	15
7/25/2011	0	0	11	3
7/26/2011	0	0	0	0
7/27/2011	0	0	0	0
7/28/2011	0	0	0	0
7/29/2011	0	0	18	0
7/30/2011	0	0	3	0
7/31/2011	0	0	1	0
8/1/2011	0	0	0	0
8/2/2011	0	0	0	0
8/3/2011	50369	33395	0	0
8/4/2011	136286	68156	1	0
8/5/2011	136282	68156	7	0
8/6/2011	68149	68156	1	20986
8/7/2011	83457	68156	0	222657
8/8/2011	68147	68156	1	148876
8/9/2011	68143	68147	0	71062
8/10/2011	68143	68147	0	110865
8/11/2011	63381	63311	0	85140
8/12/2011	62917	62043	1	185305
8/13/2011	68141	68145	0	218139
8/14/2011	68001	65571	0	82963
8/15/2011	64674	64079	12	218996
8/16/2011	68143	53066	0	108056
8/17/2011	68143	68149	0	131495
8/18/2011	68143	68145	1	115691
8/19/2011	68143	68145	0	322549
8/20/2011	68143	68145	1	544099
8/21/2011	68143	68147	1	102897

8/22/2011	68143	68145	1	125284
8/23/2011	68143	68145	0	45445
8/24/2011	68143	68147	0	82121
8/25/2011	68143	67814	0	50339
8/26/2011	68075	67695	0	67607
8/27/2011	68143	68147	0	33995
8/28/2011	68143	68145	0	101368
8/29/2011	68143	68145	0	53303
8/30/2011	60103	59909	2	101639
8/31/2011	68143	68147	0	133743
9/1/2011	68143	68143	0	45459
9/2/2011	68143	68147	0	15720
9/3/2011	68141	68145	3	59247
9/4/2011	68143	68143	0	94934
9/5/2011	68141	68143	0	83157
9/6/2011	68141	68149	0	55707
9/7/2011	68141	68145	0	86836
9/8/2011	68143	68141	0	161296
9/9/2011	68141	4569	4	142259
9/10/2011	68141	0	3	166269
9/11/2011	68143	0	0	96352
9/12/2011	68143	0	0	85206
9/13/2011	68143	0	0	70356
9/14/2011	68143	0	0	118753
9/15/2011	68143	0	0	101017
9/16/2011	68143	0	5	148684
9/17/2011	68143	0	1	151646
9/18/2011	68143	0	8	480815
9/19/2011	68141	0	2	207422
9/20/2011	68143	0	1	107654
9/21/2011	68143	0	0	95501
9/22/2011	68141	0	0	102183
9/23/2011	0	0	0	119254
9/24/2011	0	0	0	78870
9/25/2011	0	0	0	90607
9/26/2011	0	0	0	51185
9/27/2011	0	0	0	7690
9/28/2011	11130	0	0	2524
9/29/2011	68141	0	0	0
9/30/2011	68141	0	0	5063
10/1/2011	68141	0	0	67144
10/2/2011	68141	0	0	99077

10/3/2011	68145	0	0	71143
10/4/2011	57129	66067	0	63154
10/5/2011	38024	21206	0	64849
10/6/2011	68141	85849	0	31643
10/7/2011	48177	55952	0	45420
10/8/2011	68141	80395	0	79142
10/9/2011	68141	79887	0	70399
10/10/2011	68141	68648	2	229545
10/11/2011	61891	78313	0	122865
10/12/2011	33963	41458	1	115062
10/13/2011	68141	89075	0	94080
10/14/2011	62050	69943	0	107637
10/15/2011	65560	51364	0	105706
10/16/2011	68141	96396	0	134245
10/17/2011	68141	82908	1	126338
10/18/2011	68141	60684	0	100633
10/19/2011	68145	87943	0	148011
10/20/2011	68141	77635	0	125739
10/21/2011	68137	71022	0	129717
10/22/2011	61074	72282	0	111583
10/23/2011	68141	62664	0	88126
10/24/2011	68141	82719	0	143015
10/25/2011	68141	52072	0	112261
10/26/2011	68141	87170	0	125453
10/27/2011	68141	74826	0	64947
10/28/2011	68141	84555	0	136037
10/29/2011	68141	97667	0	132864
10/30/2011	68141	96278	0	138701
10/31/2011	68141	94268	0	149114
11/1/2011	68141	100105	0	146233
11/2/2011	68141	94677	1	146226
11/3/2011	68141	85051	1	134253
11/4/2011	68141	98886	0	154537
11/5/2011	68141	98019	0	152060
11/6/2011	68141	94049	0	152247
11/7/2011	68141	88075	7	200710
11/8/2011	68141	85062	12	354596
11/9/2011	68141	101922	5	307390
11/10/2011	68141	100760	28	180749
11/11/2011	68141	99977	0	161539
11/12/2011	68141	101373	0	158532
11/13/2011	68141	87867	0	146939

11/14/2011	7620	8529	0	239874
11/15/2011	0	0	0	185013
11/16/2011	0	0	0	17791
11/17/2011	0	0	0	4903
11/18/2011	0	0	0	0
11/19/2011	41530	23148	0	0
11/20/2011	68141	97474	0	48256
11/21/2011	68141	92595	0	140638
11/22/2011	68141	98705	7	184456
11/23/2011	68141	81780	0	167314
11/24/2011	68141	37233	0	96241
11/25/2011	68141	80061	2	138089
11/26/2011	68141	77393	10	234928
11/27/2011	68141	87791	0	142315
11/28/2011	68141	88140	0	130319
11/29/2011	68141	91974	0	155116
11/30/2011	68141	76087	0	134666
12/1/2011	68141	72812	0	98034
12/2/2011	115217	78634	0	157220
12/3/2011	135987	84767	3	461672
12/4/2011	134098	917190	6	357812
12/5/2011	135991	77041	0	201914
12/6/2011	135987	75439	0	183334
12/7/2011	135991	82412	1	195220
12/8/2011	135991	89801	0	217508
12/9/2011	135987	95169	1	217721
12/10/2011	135991	93197	2	225506
12/11/2011	135991	82863	0	227380
12/12/2011	135991	87602	0	234694
12/13/2011	135991	72135	15	256005
12/14/2011	135991	78979	18	558696
12/15/2011	135802	79395	0	236620
12/16/2011	135991	88590	0	220196
12/17/2011	134382	75197	0	189604
12/18/2011	135991	82514	0	216937
12/19/2011	135987	80890	8	311853
12/20/2011	8862	78097	0	417006
12/21/2011	135991	79172	3	326757
12/22/2011	135991	66105	0	239819
12/23/2011	135991	4153	0	161059
12/24/2011	135802	69784	0	178800
12/25/2011	135995	82003	0	207047

12/26/2011	135991	71885	0	194215
12/27/2011	135991	29201	0	213579
12/28/2011	135991	87371	0	194192
12/29/2011	135987	72267	0	200547
12/30/2011	135987	55267	0	195043
12/31/2011	135991	36336	1	181601
1/1/2012	135991	56637	0	148593
1/2/2012	135802	90808	0	194214
1/3/2012	135991	94586	0	214163
1/4/2012	135991	80156	0	216851
1/5/2012	135987	73225	0	200880
1/6/2012	135991	60816	0	187261
1/7/2012	135987	64893	0	182404
1/8/2012	135991	64704	0	205283
1/9/2012	135991	127319	0	199173
1/10/2012	135983	74493	0	210545
1/11/2012	135991	111836	0	201255
1/12/2012	135991	71064	0	159650
1/13/2012	135991	119324	0	204159
1/14/2012	135987	63886	0	212744
1/15/2012	135987	76549	0	217199
1/16/2012	135991	73763	0	227564
1/17/2012	135991	87364	0	184982
1/18/2012	135991	90918	0	178539
1/19/2012	135991	90112	0	207611
1/20/2012	135987	109190	0	174659
1/21/2012	135991	88068	0	190724
1/22/2012	135234	99129	1	235214
1/23/2012	135987	76723	0	230410
1/24/2012	135991	117480	0	229801
1/25/2012	135987	71821	0	238621
1/26/2012	135991	62274	0	213244
1/27/2012	135991	53382	0	190247
1/28/2012	135802	63496	0	170491
1/29/2012	135991	68815	0	197231
1/30/2012	135987	63023	0	191822
1/31/2012	135991	52928	0	199431
2/1/2012	135991	47149	0	120475
2/2/2012	135995	62155	0	111662
2/3/2012	135612	101667	23	374619
2/4/2012	135987	69127	4	323993
2/5/2012	134189	72483	0	229335

2/6/2012	135991	83245	0	203621
2/7/2012	135802	72279	0	206540
2/8/2012	135987	94251	0	209856
2/9/2012	110120	26223	0	200971
2/10/2012	67992	38861	0	133697
2/11/2012	67990	37305	0	71344
2/12/2012	67990	55518	0	80270
2/13/2012	67988	73159	0	107369
2/14/2012	67990	59402	1	180594
2/15/2012	67990	64405	1	203757
2/16/2012	67990	23742	0	165002
2/17/2012	67990	50994	0	135185
2/18/2012	67990	67889	0	129048
2/19/2012	67992	50153	0	121500
2/20/2012	67994	52692	5	124771
2/21/2012	67992	68575	0	184792
2/22/2012	67992	45306	1	189861
2/23/2012	67990	47997	0	126543
2/24/2012	67990	69296	0	105681
2/25/2012	67990	61163	0	111768
2/26/2012	67994	69970	0	112733
2/27/2012	67990	70210	0	105450
2/28/2012	67994	53126	2	127637
2/29/2012	67994	34251	0	111215
3/1/2012	67992	34292	0	87507
3/2/2012	67992	68478	2	101146
3/3/2012	67990	69313	0	91092
3/4/2012	67992	38061	0	95722
3/5/2012	67990	55483	0	87348
3/6/2012	67992	17094	0	85891
3/7/2012	67992	33656	0	102520
3/8/2012	67990	68461	1	60752
3/9/2012	67990	31278	0	78131
3/10/2012	67990	51252	0	86239
3/11/2012	65338	36887	8	148214
3/12/2012	67992	44561	3	145371
3/13/2012	67992	44556	0	105867
3/14/2012	67992	70695	0	104417
3/15/2012	67992	70696	0	117140
3/16/2012	68141	70199	0	108240
3/17/2012	53320	54856	0	108940
3/18/2012	50402	49121	0	108005

3/19/2012	68141	73893	14	184917
3/20/2012	63093	69731	6	191493
3/21/2012	68143	69387	5	213660
3/22/2012	68143	78381	5	333014
3/23/2012	68141	75723	3	243640
3/24/2012	68141	72388	2	141090
3/25/2012	68141	72890	1	119267
3/26/2012	68143	74041	0	137865
3/27/2012	0	2827	0	124116
3/28/2012	0	0	0	53287
3/29/2012	0	0	0	27675
3/30/2012	13	0	0	10539
3/31/2012	40877	38638	0	1855
4/1/2012	46137	46056	0	9320
4/2/2012	68143	68145	0	23326
4/3/2012	67066	66782	0	69360
4/4/2012	66619	66425	5	112756
4/5/2012	68143	68143	1	145489
4/6/2012	49451	49324	0	103826
4/7/2012	68143	68145	7	124922
4/8/2012	68143	68149	0	116364
4/9/2012	59544	59206	0	88991
4/10/2012	68143	68145	0	72551
4/11/2012	68143	68145	0	88927
4/12/2012	68143	68143	2	103311
4/13/2012	68143	68147	0	107506
4/14/2012	45425	45193	4	118915
4/15/2012	68143	68145	3	163129
4/16/2012	60294	60214	0	83207
4/17/2012	68143	68147	0	92039
4/18/2012	68143	68147	0	69739
4/19/2012	68143	68147	0	75027
4/20/2012	68145	68141	0	99908
4/21/2012	45474	45043	0	69300
4/22/2012	68143	68147	0	40905
4/23/2012	53169	52903	0	57868
4/24/2012	63833	63266	0	50058
4/25/2012	58670	58191	0	50123
4/26/2012	32847	32588	0	41564
4/27/2012	47260	46997	0	37888
4/28/2012	68145	68143	0	49339
4/29/2012	45898	45221	0	252858

4/30/2012	50348	49805	0	110224
5/1/2012	64320	63917	0	81693
5/2/2012	68143	68154	0	84615
5/3/2012	63090	62849	0	84998
5/4/2012	60392	60043	0	67782
5/5/2012	62030	61963	0	67202
5/6/2012	34456	34287	0	74338
5/7/2012	68143	68143	0	82340
5/8/2012	63366	63161	0	52462
5/9/2012	55420	52503	0	50418
5/10/2012	45356	45261	0	47469
5/11/2012	68143	68147	0	44993
5/12/2012	60270	60146	0	119460
5/13/2012	33696	33484	0	74993
5/14/2012	67918	67753	0	50319
5/15/2012	42874	42542	0	47817
5/16/2012	57307	57169	0	22580
5/17/2012	64271	64140	0	27819
5/18/2012	57080	56846	0	31154
5/19/2012	60965	60671	0	25177
5/20/2012	45365	45164	0	33755
5/21/2012	53986	53794	0	25181
5/22/2012	68143	68143	0	17674

Table G.2. Weekly water budget for the CWTS at JEC for 2011. These values were used to determine the weekly mass removal of pollutants within the CWTS.

Date	Week	RAW (L)	FGDWW (L)	Precip. (L)	LS (L)
1/4-1/10	1	3838	0	15043	0
1/11-1/17	2	74928	0	2507	0
1/18-1/24	3	244787	2458	57666	0
1/25-1/31	4	1404975	8063	0	0
2/1-2/7	5	1727647	0	20058	0
2/8-2/14	6	1018071	42071	35101	0
2/15-2/21	7	345354	206869	2507	0
2/22-2/28	8	804425	439798	100269	0
3/1-3/7	9	555354	453771	5014	0
3/8-3/14	10	477039	448934	163009	676930
3/15-3/21	11	449862	403326	106211	794629
3/22-3/28	12	477041	477041	30087	851842
3/29-4/4	13	477036	442801	32594	924108
4/5-4/11	14	403712	333618	65188	4437
4/12-4/18	15	475294	429557	167984	618617

4/19-4/25	16	429744	397270	215621	798544
4/26-5/2	17	445556	444342	7522	556057
5/3-5/9	18	476990	476986	152940	592120
5/10-5/16	19	436706	436367	42623	541199
5/17-5/23	20	473027	472512	376083	1182311
5/24-5/30	21	476988	476985	1048018	2312454
5/31-6/6	22	465465	461665	917643	2511595
6/7-6/13	23	476988	454262	45130	452238
6/14-6/20	24	476992	476988	361040	973860
6/21-6/27	25	476994	476996	105303	699257
6/28-7/4	26	476994	385648	0	455161
7/5-7/11	27	476992	477011	25072	766080
7/12-7/18	28	472442	463020	37608	303972
7/19-7/25	29	0	0	122854	21343
7/26-8/1	30	0	0	213114	1
8/2-8/8	31	542690	374177	87753	392520
8/9-8/15	32	463401	459443	130336	972470
8/16-8/22	33	477002	461941	30087	1450070
8/23-8/29	34	476933	476237	10029	434178
8/30-9/5	35	468958	468777	45130	533899
9/6-9/12	36	476994	209004	65188	793925
9/13-9/19	37	477000	0	152940	1278692
9/20-9/26	38	204427	0	17551	645253
9/27-10/3	39	351840	0	0	252640
10/4-10/10	40	415896	458005	20058	584152
10/11-10/17	41	427888	509456	17551	805933
10/18-10/24	42	469921	514948	0	846823
10/25-10/31	43	476988	586837	2507	859377
11/1-11/7	44	476988	658862	77724	1086266
11/8-11/14	45	416467	585490	441271	1549620
11/15-11/21	46	177812	213217	2507	396601
11/22-11/28	47	476988	551103	188042	1093661
11/29-12/5	48	725716	1398505	90260	1566433
12/6-12/12	49	951929	606484	37608	1501363
12/13-12/19	50	950135	557701	403663	1989910
12/20-12/26	51	824622	451198	40116	1724703
12/27-1/2/2012	52	679947	280442	7522	984962

Table G.3. Weekly water budget for the CWTS at JEC for 2012 until May 22. These values were used to determine the weekly mass removal of pollutants within the CWTS.

Date	Week	RAW	FGDWW	Precip.	LS
------	------	-----	-------	---------	----

		(L)	(L)	(L)	(L)
1/3-1/9	1	951929	565700	0	1406015
1/10-1/16	2	951921	590914	0	1433115
1/17-1/23	3	951172	641502	5014	1402139
1/24-1/30	4	951740	500291	0	1431457
1/31-2/6	5	949756	488753	265765	1563137
2/7-2/13	6	653867	397596	2507	1010046
2/14-2/20	7	475934	369277	57666	1059859
2/21-2/27	8	475936	432515	10029	936829
2/28-3/5	9	475942	353005	37608	701668
3/6-3/12	10	473283	283189	115332	707119
3/13-3/19	11	443980	434017	142912	837526
3/20-3/26	12	471946	512541	203085	1380029
3/27-4/2	13	155169	155666	5014	250117
4/3-4/9	14	447109	446173	125361	761708
4/10-4/16	15	446434	446132	85246	737546
4/17-4/23	16	439360	438674	0	504785
4/24-4/30	17	367001	364210	0	592054
5/1-5/7	18	420572	419357	0	542968
5/8-5/14	19	394169	390456	0	440115
5/15-5/21	20	381848	380327	0	213482
5/22-5/28	21	428581	427920	0	17674

Appendix H - Water Use Coefficient Curve Data

The first two tables, Table H.1 and H.2, show the system ET for the CWTS which was determined by taking the influent amount of water and subtracting it by the effluent amount of water for both 2011 and 2012, respectively. The data taken from the weather station to determine the reference ET for both the FAO56 Penman-Monteith and Hargreaves methods are presented in Table H.3-H.4 and Table H.5-H.6, respectively, for 2011 and 2012. From all four tables, the water use coefficient was determined and can be seen in Table H.7 from January 1, 2011 to May 22, 2012.

Table H. 1. The system ET for 2011 was determined using the following data. System ET was later used in order to determine the water use coefficient for the CWTS at JEC.

Date	RAW (gal)	FGD (gal)	Precip. (gal)	LS (gal)	ET _{sys} (gal)	ET _{sys} (mm)
1/1/2011	0	0	0		0	0

1/2/2011	0	0	0	0	0
1/3/2011	0	0	0	0	0
1/4/2011	0	0	0	0	0
1/5/2011	0	0	0	0	0
1/6/2011	0	0	0	0	0
1/7/2011	1014	0	0	1014	0
1/8/2011	0	0	0	0	0
1/9/2011	0	0	2304	2304	1
1/10/2011	0	0	1152	1152	1
1/11/2011	0	0	0	0	0
1/12/2011	0	0	0	0	0
1/13/2011	0	0	0	0	0
1/14/2011	0	0	0	0	0
1/15/2011	0	0	0	0	0
1/16/2011	0	0	576	576	0
1/17/2011	19794	0	0	19794	9
1/18/2011	42576	0	0	42576	19
1/19/2011	0	0	13248	13248	6
1/20/2011	0	0	0	0	0
1/21/2011	0	0	0	0	0
1/22/2011	0	0	0	0	0
1/23/2011	0	0	0	0	0
1/24/2011	22090	649	0	22739	10
1/25/2011	35994	0	0	35994	16
1/26/2011	35990	0	0	35990	16
1/27/2011	35994	0	0	35994	16
1/28/2011	50421	2130	0	52551	23
1/29/2011	71050	0	0	71050	31
1/30/2011	69733	0	0	69733	31
1/31/2011	71973	0	0	71973	32
2/1/2011	71966	0	4608	76574	34
2/2/2011	71963	0	0	71963	32
2/3/2011	72004	0	0	72004	32
2/4/2011	71718	0	0	71718	32
2/5/2011	71124	0	0	71124	31
2/6/2011	36058	0	0	36058	16
2/7/2011	61563	0	0	61563	27
2/8/2011	53397	1565	8064	63026	28
2/9/2011	35925	0	0	35925	16
2/10/2011	35925	0	0	35925	16
2/11/2011	35924	0	0	35924	16
2/12/2011	35925	0	0	35925	16

2/13/2011	35925	0	0		35925	16
2/14/2011	35925	9549	0		45474	20
2/15/2011	35925	18003	0		53928	24
2/16/2011	23980	18004	576		42559	19
2/17/2011	0	0	0		0	0
2/18/2011	7071	6515	0		13585	6
2/19/2011	0	0	0		0	0
2/20/2011	0	0	0		0	0
2/21/2011	24258	12128	0		36386	16
2/22/2011	25011	14525	0		39536	17
2/23/2011	25796	18004	0		43799	19
2/24/2011	35925	18004	21888		75816	33
2/25/2011	35925	11641	0		47566	21
2/26/2011	35925	18004	576		54504	24
2/27/2011	35924	18004	576		54503	24
2/28/2011	18001	18003	0		36004	16
3/1/2011	19022	18003	0		37024	16
3/2/2011	35925	18003	0		53928	24
3/3/2011	19752	12646	0		32397	14
3/4/2011	18003	18003	0		36005	16
3/5/2011	18003	18002	0		36005	16
3/6/2011	18003	18003	0		36006	16
3/7/2011	18003	17216	1152		36370	16
3/8/2011	18003	17224	11520		46746	21
3/9/2011	18003	16944	0		34947	15
3/10/2011	18003	13511	0	14216	17298	8
3/11/2011	18004	18003	0	34197	1810	1
3/12/2011	18003	18003	0	27148	8857	4
3/13/2011	18003	16910	576	21336	14152	6
3/14/2011	18003	18003	25344	81929	-20580	-9
3/15/2011	18003	18003	0	31912	4094	2
3/16/2011	18003	13112	0	25851	5264	2
3/17/2011	18003	16841	0	25965	8879	4
3/18/2011	10824	4585	0	17431	-2022	-1
3/19/2011	18003	18003	24192	50499	9698	4
3/20/2011	18003	18003	0	39909	-3903	-2
3/21/2011	18003	18003	0	18352	17654	8
3/22/2011	18003	18003	0	16848	19158	8
3/23/2011	18003	18004	0	48173	-12167	-5
3/24/2011	18003	18003	3456	32866	6596	3
3/25/2011	18003	18003	1152	30671	6487	3
3/26/2011	18003	18003	0	34409	1596	1

3/27/2011	18004	18003	576	29016	7567	3
3/28/2011	18003	18004	1728	33051	4684	2
3/29/2011	18003	18003	576	48264	-11682	-5
3/30/2011	18003	18004	0	37871	-1865	-1
3/31/2011	18003	18002	6336	32041	10300	5
4/1/2011	18003	18003	0	35072	934	0
4/2/2011	18003	8958	0	26543	417	0
4/3/2011	18003	18003	576	25766	10816	5
4/4/2011	18003	18004	0	38566	-2560	-1
4/5/2011	18003	13785	0	1172	30615	14
4/6/2011	18003	18003	0	0	36006	16
4/7/2011	269	87	0	0	356	0
4/8/2011	16366	4500	8064		28930	13
4/9/2011	18003	18003	0		36005	16
4/10/2011	18003	15753	0		33756	15
4/11/2011	18003	18004	0		36007	16
4/12/2011	18003	18002	0		36005	16
4/13/2011	18003	18003	0		36006	16
4/14/2011	18004	18003	21888	28098	29796	13
4/15/2011	18003	18004	16704	57428	-4717	-2
4/16/2011	17542	5459	0	17453	5548	2
4/17/2011	18003	18004	0	28828	7178	3
4/18/2011	18003	18004	0	31614	4392	2
4/19/2011	18003	18003	576	26643	9939	4
4/20/2011	18001	12153	0	15616	14538	6
4/21/2011	18001	18001	0	22435	13566	6
4/22/2011	18001	18001	22464	67438	-8973	-4
4/23/2011	15106	14319	0	24363	5061	2
4/24/2011	10402	8741	0	19453	-310	0
4/25/2011	16013	15732	26496	35005	23235	10
4/26/2011	14634	14548	1728	41564	-10655	-5
4/27/2011	14950	14873	0	10492	19331	9
4/28/2011	18001	18002	0	23467	12536	6
4/29/2011	18001	18002	0	21405	14598	6
4/30/2011	18001	18001	0	24343	11658	5
5/1/2011	16116	15959	0	2210	29864	13
5/2/2011	18001	18001	0	23414	12587	6
5/3/2011	18001	18001	0	19797	16205	7
5/4/2011	18002	18001	0	21238	14765	7
5/5/2011	18001	18001	4032	29023	11011	5
5/6/2011	18001	18001	10944	22228	24718	11
5/7/2011	18001	18001	20160	24600	31561	14

5/8/2011	18001	18001	0	32068	3934	2
5/9/2011	18001	18001	0	7467	28535	13
5/10/2011	18001	18001	0	26607	9395	4
5/11/2011	18001	18001	2880	8535	30346	13
5/12/2011	18001	18002	3456	24216	15242	7
5/13/2011	7360	7270	3456	20372	-2286	-1
5/14/2011	18001	18001	0	19686	16316	7
5/15/2011	18001	18001	0	14359	21643	10
5/16/2011	18001	18002	0	29196	6807	3
5/17/2011	16955	16819	1728	24444	11057	5
5/18/2011	18001	18002	47808	32148	51663	23
5/19/2011	18001	18002	8640	91146	-46503	-21
5/20/2011	18001	18001	28224	76383	-12157	-5
5/21/2011	18001	18001	0	46227	-10225	-5
5/22/2011	18001	18001	0	23763	12239	5
5/23/2011	18001	18001	0	18224	17777	8
5/24/2011	18001	18001	91008	65412	61598	27
5/25/2011	18001	18002	110592	182121	-35527	-16
5/26/2011	18001	18001	0	203130	-167128	-74
5/27/2011	18001	18001	1728	100628	-62899	-28
5/28/2011	18001	18001	1152	24055	13099	6
5/29/2011	18001	18001	0	21107	14895	7
5/30/2011	18001	18001	36288	14432	57857	26
5/31/2011	18001	18002	0	55560	-19557	-9
6/1/2011	18002	18001	210816	62297	184522	81
6/2/2011	18002	18001	0	189879	-153877	-68
6/3/2011	17586	17097	0	192013	-157331	-69
6/4/2011	18001	17686	0	107602	-71915	-32
6/5/2011	18001	18001	0	43145	-7143	-3
6/6/2011	15371	15173	0	12998	17546	8
6/7/2011	18001	18001	0	14110	21893	10
6/8/2011	18001	18001	1152	4905	32248	14
6/9/2011	18001	18001	5760	17810	23952	11
6/10/2011	18001	18001	0	22208	13793	6
6/11/2011	18001	18001	0	26199	9803	4
6/12/2011	18001	15172	2304	19990	15487	7
6/13/2011	18001	14828	1152	14247	19734	9
6/14/2011	18002	18001	0	16450	19553	9
6/15/2011	18002	18001	0	24763	11240	5
6/16/2011	18001	18001	16704	35505	17201	8
6/17/2011	18001	18001	2880	34472	4410	2
6/18/2011	18001	18001	55296	88319	2979	1

6/19/2011	18001	18001	0	38973	-2971	-1
6/20/2011	18001	18001	8064	18786	25280	11
6/21/2011	18001	18001	0	25413	10589	5
6/22/2011	18001	18001	0	9125	26877	12
6/23/2011	18001	18001	0	20243	15759	7
6/24/2011	18001	18001	0	16444	19558	9
6/25/2011	18002	18002	18432	33191	21244	9
6/26/2011	18002	18002	0	22713	13290	6
6/27/2011	18002	18002	5760	57596	-15832	-7
6/28/2011	18001	18002	0	18748	17254	8
6/29/2011	18002	18002	0	18256	17747	8
6/30/2011	18001	8080	0	8698	17384	8
7/1/2011	18001	3788	0	8621	13168	6
7/2/2011	18001	18002	0	7086	28917	13
7/3/2011	18002	18002	0	31520	4484	2
7/4/2011	18001	18002	0	27312	8691	4
7/5/2011	18001	18002	0	18113	17890	8
7/6/2011	18001	18003	1728	32160	5572	2
7/7/2011	18001	18002	2880	67369	-28486	-13
7/8/2011	18001	18002	1152	34710	2445	1
7/9/2011	18001	18001	0	20317	15685	7
7/10/2011	18001	18002	0	16737	19266	8
7/11/2011	18002	18001	0	12972	23032	10
7/12/2011	18002	15595	5760	7810	31547	14
7/13/2011	18002	18002	2304	30667	7641	3
7/14/2011	18002	18002	0	12848	23156	10
7/15/2011	18002	18003	0	8377	27628	12
7/16/2011	18001	18002	576	7298	29281	13
7/17/2011	18002	18001	0	7250	28753	13
7/18/2011	16795	16712	0	6052	27455	12
7/19/2011	0	0	0	5408	-5408	-2
7/20/2011	0	0	0	65	-65	0
7/21/2011	0	0	0	74	-74	0
7/22/2011	0	0	0	60	-60	0
7/23/2011	0	0	0	27	-27	0
7/24/2011	0	0	2304	4	2300	1
7/25/2011	0	0	25920	1	25919	11
7/26/2011	0	0	0	0	0	0
7/27/2011	0	0	0	0	0	0
7/28/2011	0	0	0	0	0	0
7/29/2011	0	0	41472	0	41472	18
7/30/2011	0	0	5760	0	5760	3

7/31/2011	0	0	1152	0	1152	1
8/1/2011	0	0	576	0	576	0
8/2/2011	0	0	0	0	0	0
8/3/2011	13306	8822	0	0	22128	10
8/4/2011	36003	18005	1728	0	55736	25
8/5/2011	36002	18005	14976	0	68983	30
8/6/2011	18003	18005	1152	5544	31616	14
8/7/2011	22047	18005	576	58820	-18192	-8
8/8/2011	18003	18005	1728	39329	-1593	-1
8/9/2011	18002	18003	576	18773	17807	8
8/10/2011	18002	18003	576	29287	7293	3
8/11/2011	16744	16725	0	22492	10977	5
8/12/2011	16621	16390	2304	48953	-13638	-6
8/13/2011	18001	18002	0	57626	-21623	-10
8/14/2011	17964	17322	0	21916	13370	6
8/15/2011	17085	16928	26496	57853	2656	1
8/16/2011	18002	14019	0	28546	3475	2
8/17/2011	18002	18003	0	34737	1267	1
8/18/2011	18002	18002	1152	30562	6593	3
8/19/2011	18002	18002	576	85208	-48629	-21
8/20/2011	18002	18002	1728	143736	-106004	-47
8/21/2011	18002	18003	1728	27182	10550	5
8/22/2011	18002	18002	1728	33097	4635	2
8/23/2011	18002	18002	576	12005	24574	11
8/24/2011	18002	18003	576	21694	14886	7
8/25/2011	18002	17915	576	13298	23194	10
8/26/2011	17984	17883	576	17860	18583	8
8/27/2011	18002	18003	0	8981	27023	12
8/28/2011	18002	18002	0	26779	9225	4
8/29/2011	18002	18002	0	14081	21922	10
8/30/2011	15878	15826	4032	26850	8885	4
8/31/2011	18002	18003	0	35331	673	0
9/1/2011	18002	18002	576	12009	24570	11
9/2/2011	18002	18003	0	4153	31851	14
9/3/2011	18001	18002	5760	15652	26111	12
9/4/2011	18002	18002	0	25079	10924	5
9/5/2011	18001	18002	0	21968	14035	6
9/6/2011	18001	18003	0	14716	21288	9
9/7/2011	18001	18002	0	22940	13063	6
9/8/2011	18002	18001	0	42610	-6607	-3
9/9/2011	18001	1207	8064	37581	-10309	-5
9/10/2011	18001	0	6912	43924	-19011	-8

9/11/2011	18002	0	0	25454	-7452	-3
9/12/2011	18002	0	0	22509	-4508	-2
9/13/2011	18002	0	0	18586	-585	0
9/14/2011	18002	0	0	31371	-13370	-6
9/15/2011	18002	0	0	26686	-8684	-4
9/16/2011	18002	0	10368	39278	-10909	-5
9/17/2011	18002	0	2304	40061	-19755	-9
9/18/2011	18002	0	18432	127018	-90584	-40
9/19/2011	18001	0	4032	54795	-32762	-14
9/20/2011	18002	0	1728	28439	-8710	-4
9/21/2011	18002	0	576	25229	-6651	-3
9/22/2011	18001	0	576	26994	-8417	-4
9/23/2011	0	0	576	31504	-30928	-14
9/24/2011	0	0	0	20835	-20835	-9
9/25/2011	0	0	0	23936	-23936	-11
9/26/2011	0	0	576	13522	-12946	-6
9/27/2011	0	0	0	2031	-2031	-1
9/28/2011	2940	0	0	667	2274	1
9/29/2011	18001	0	0	0	18001	8
9/30/2011	18001	0	0	1337	16664	7
10/1/2011	18001	0	0	17738	263	0
10/2/2011	18001	0	0	26173	-8172	-4
10/3/2011	18002	0	0	18794	-792	0
10/4/2011	15092	17453	0	16684	15862	7
10/5/2011	10045	5602	0	17131	-1484	-1
10/6/2011	18001	22679	0	8359	32321	14
10/7/2011	12727	14781	0	11999	15509	7
10/8/2011	18001	21238	0	20907	18332	8
10/9/2011	18001	21104	0	18597	20508	9
10/10/2011	18001	18135	4608	60640	-19896	-9
10/11/2011	16350	20688	576	32458	5156	2
10/12/2011	8972	10952	1152	30396	-9320	-4
10/13/2011	18001	23531	576	24853	17255	8
10/14/2011	16392	18477	576	28435	7010	3
10/15/2011	17319	13569	0	27925	2964	1
10/16/2011	18001	25465	0	35464	8002	4
10/17/2011	18001	21902	1152	33375	7680	3
10/18/2011	18001	16031	0	26585	7448	3
10/19/2011	18002	23232	0	39100	2134	1
10/20/2011	18001	20509	0	33217	5293	2
10/21/2011	18000	18762	0	34268	2494	1
10/22/2011	16134	19095	0	29477	5752	3

10/23/2011	18001	16554	0	23280	11275	5
10/24/2011	18001	21852	0	37781	2073	1
10/25/2011	18001	13756	0	29656	2101	1
10/26/2011	18001	23028	576	33141	8464	4
10/27/2011	18001	19767	0	17157	20611	9
10/28/2011	18001	22337	0	35937	4401	2
10/29/2011	18001	25801	0	35099	8703	4
10/30/2011	18001	25434	0	36641	6794	3
10/31/2011	18001	24903	0	39392	3512	2
11/1/2011	18001	26445	0	38631	5815	3
11/2/2011	18001	25011	1728	38629	6111	3
11/3/2011	18001	22468	1152	35466	6155	3
11/4/2011	18001	26123	0	40824	3300	1
11/5/2011	18001	25894	0	40170	3725	2
11/6/2011	18001	24845	0	40219	2627	1
11/7/2011	18001	23267	14976	53022	3222	1
11/8/2011	18001	22471	26496	93674	-26706	-12
11/9/2011	18001	26925	11520	81204	-24758	-11
11/10/2011	18001	26618	62784	47749	59654	26
11/11/2011	18001	26411	576	42674	2314	1
11/12/2011	18001	26780	0	41880	2901	1
11/13/2011	18001	23212	0	38817	2396	1
11/14/2011	2013	2253	0	63368	-59102	-26
11/15/2011	0	0	0	48875	-48875	-22
11/16/2011	0	0	0	4700	-4700	-2
11/17/2011	0	0	576	1295	-719	0
11/18/2011	0	0	0	0	0	0
11/19/2011	10971	6115	0	0	17086	8
11/20/2011	18001	25750	0	12748	31003	14
11/21/2011	18001	24461	0	37153	5310	2
11/22/2011	18001	26075	14976	48728	10324	5
11/23/2011	18001	21604	576	44200	-4019	-2
11/24/2011	18001	9836	0	25424	2413	1
11/25/2011	18001	21150	5184	36479	7856	3
11/26/2011	18001	20445	22464	62061	-1151	-1
11/27/2011	18001	23192	0	37596	3597	2
11/28/2011	18001	23284	0	34427	6858	3
11/29/2011	18001	24297	0	40977	1321	1
11/30/2011	18001	20100	0	35575	2526	1
12/1/2011	18001	19235	0	25898	11338	5
12/2/2011	30437	20773	576	41533	10253	5
12/3/2011	35924	22393	6336	121961	-57308	-25

12/4/2011	35425	24296	13824	94524	-20979	-9
12/5/2011	35925	20352	0	53340	2937	1
12/6/2011	35924	19929	0	48432	7421	3
12/7/2011	35925	21771	1152	51572	7276	3
12/8/2011	35925	23723	576	57460	2764	1
12/9/2011	35924	25141	1728	57516	5277	2
12/10/2011	35925	24620	4608	59572	5581	2
12/11/2011	35925	21890	576	60068	-1677	-1
12/12/2011	35925	23142	0	62000	-2933	-1
12/13/2011	35925	19056	35136	67629	22488	10
12/14/2011	35925	20864	40320	147592	-50483	-22
12/15/2011	35875	20974	0	62508	-5659	-2
12/16/2011	35925	23403	0	58170	1158	1
12/17/2011	35500	19865	0	50088	5277	2
12/18/2011	35925	21798	0	57309	414	0
12/19/2011	35924	21369	17280	82383	-7810	-3
12/20/2011	2341	20631	576	110161	-86613	-38
12/21/2011	35925	20915	7488	86320	-21992	-10
12/22/2011	35925	17463	576	63354	-9390	-4
12/23/2011	35925	1097	0	42547	-5525	-2
12/24/2011	35875	18435	576	47234	7652	3
12/25/2011	35926	21663	0	54696	2893	1
12/26/2011	35925	18990	0	51306	3609	2
12/27/2011	35925	7714	0	56422	-12783	-6
12/28/2011	35925	23081	0	51300	7706	3
12/29/2011	35924	19091	0	52979	2036	1
12/30/2011	35924	14600	0	51525	-1001	0
12/31/2011	35925	9599	1728	47974	-722	0

Table H.2. The system ET for 2012 until May 22 was determined using the following data. System ET was later used in order to determine the water use coefficient for the CWTS at JEC.

Date	RAW (gal)	FGD (gal)	Precip. (gal)	LS (gal)	ET _{sys} (gal)	ET _{sys} (mm)
1/1/2012	35925	14962	0	39254	11633	5
1/2/2012	35875	23989	0	51306	8558	4
1/3/2012	35925	24987	0	56576	4336	2
1/4/2012	35925	21175	0	57286	-186	0
1/5/2012	35924	19344	0	53067	2201	1
1/6/2012	35925	16066	0	49469	2522	1
1/7/2012	35924	17143	0	48186	4881	2
1/8/2012	35925	17093	0	54230	-1212	-1

1/9/2012	35925	33634	0	52616	16943	7
1/10/2012	35923	19679	0	55620	-18	0
1/11/2012	35925	29544	0	53166	12303	5
1/12/2012	35925	18773	0	42175	12523	6
1/13/2012	35925	31522	0	53933	13514	6
1/14/2012	35924	16877	0	56201	-3400	-1
1/15/2012	35924	20222	0	57378	-1232	-1
1/16/2012	35925	19486	0	60116	-4705	-2
1/17/2012	35925	23079	0	48867	10137	4
1/18/2012	35925	24018	0	47165	12778	6
1/19/2012	35925	23805	0	54845	4885	2
1/20/2012	35924	28845	0	46140	18629	8
1/21/2012	35925	23265	0	50384	8806	4
1/22/2012	35725	26187	1152	62137	927	0
1/23/2012	35924	20268	0	60868	-4676	-2
1/24/2012	35925	31035	0	60707	6253	3
1/25/2012	35924	18973	0	63037	-8140	-4
1/26/2012	35925	16451	0	56333	-3957	-2
1/27/2012	35925	14102	0	50258	-231	0
1/28/2012	35875	16774	0	45039	7610	3
1/29/2012	35925	18179	0	52103	2001	1
1/30/2012	35924	16649	0	50674	1899	1
1/31/2012	35925	13982	0	52684	-2777	-1
2/1/2012	35925	12456	0	31826	16555	7
2/2/2012	35926	16420	0	29498	22848	10
2/3/2012	35825	26858	51264	98964	14982	7
2/4/2012	35924	18262	9216	85590	-22189	-10
2/5/2012	35449	19148	0	60584	-5987	-3
2/6/2012	35925	21991	576	53791	4701	2
2/7/2012	35875	19094	0	54562	407	0
2/8/2012	35924	24899	0	55438	5385	2
2/9/2012	29091	6928	0	53091	-17073	-8
2/10/2012	17962	10266	0	35319	-7092	-3
2/11/2012	17961	9855	0	18847	8969	4
2/12/2012	17961	14666	0	21205	11422	5
2/13/2012	17961	19327	576	28364	9499	4
2/14/2012	17961	15692	1152	47708	-12903	-6
2/15/2012	17961	17014	1152	53827	-17700	-8
2/16/2012	17961	6272	0	43589	-19356	-9
2/17/2012	17961	13471	0	35712	-4280	-2
2/18/2012	17961	17935	0	34091	1805	1
2/19/2012	17962	13249	0	32097	-887	0

2/20/2012	17962	13920	10944	32961	9865	4
2/21/2012	17962	18116	576	48817	-12164	-5
2/22/2012	17962	11969	1728	50156	-18498	-8
2/23/2012	17961	12680	0	33429	-2789	-1
2/24/2012	17961	18306	0	27918	8349	4
2/25/2012	17961	16158	0	29526	4593	2
2/26/2012	17962	18484	0	29781	6665	3
2/27/2012	17961	18548	0	27857	8652	4
2/28/2012	17962	14035	5184	33718	3462	2
2/29/2012	17962	9048	0	29380	-2370	-1
3/1/2012	17962	9059	0	23117	3904	2
3/2/2012	17962	18090	3456	26720	12787	6
3/3/2012	17961	18311	0	24064	12208	5
3/4/2012	17962	10055	0	25287	2729	1
3/5/2012	17961	14657	0	23075	9543	4
3/6/2012	17962	4516	0	22690	-213	0
3/7/2012	17962	8891	0	27083	-231	0
3/8/2012	17961	18086	2304	16049	22301	10
3/9/2012	17961	8263	0	20640	5584	2
3/10/2012	17961	13539	0	22782	8718	4
3/11/2012	17261	9745	18432	39154	6283	3
3/12/2012	17962	11772	5760	38403	-2910	-1
3/13/2012	17962	11771	0	27967	1765	1
3/14/2012	17962	18676	0	27584	9053	4
3/15/2012	17962	18676	0	30945	5693	3
3/16/2012	18001	18545	0	28594	7952	4
3/17/2012	14086	14492	0	28779	-202	0
3/18/2012	13315	12977	0	28532	-2241	-1
3/19/2012	18001	19521	32832	48850	21503	9
3/20/2012	16668	18421	13248	50587	-2251	-1
3/21/2012	18002	18330	10368	56443	-9744	-4
3/22/2012	18002	20706	10944	87973	-38322	-17
3/23/2012	18001	20004	6912	64363	-19446	-9
3/24/2012	18001	19123	3456	37272	3308	1
3/25/2012	18001	19256	1728	31507	7477	3
3/26/2012	18002	19560	0	36420	1141	1
3/27/2012	0	747	0	32788	-32041	-14
3/28/2012	0	0	576	14077	-13501	-6
3/29/2012	0	0	576	7311	-6735	-3
3/30/2012	3	0	0	2784	-2781	-1
3/31/2012	10799	10207	0	490	20516	9
4/1/2012	12188	12167	0	2462	21893	10

4/2/2012	18002	18002	0	6162	29842	13
4/3/2012	17717	17642	0	18323	17036	8
4/4/2012	17599	17548	10368	29787	15727	7
4/5/2012	18002	18002	2304	38434	-127	0
4/6/2012	13064	13030	0	27428	-1335	-1
4/7/2012	18002	18002	16128	33001	19130	8
4/8/2012	18002	18003	0	30740	5265	2
4/9/2012	15730	15641	0	23509	7861	3
4/10/2012	18002	18002	0	19166	16838	7
4/11/2012	18002	18002	0	23492	12512	6
4/12/2012	18002	18002	4608	27292	13319	6
4/13/2012	18002	18003	0	28400	7604	3
4/14/2012	12000	11939	8640	31414	1165	1
4/15/2012	18002	18002	6336	43094	-755	0
4/16/2012	15928	15907	0	21981	9854	4
4/17/2012	18002	18003	0	24314	11690	5
4/18/2012	18002	18003	0	18423	17581	8
4/19/2012	18002	18003	0	19820	16184	7
4/20/2012	18002	18001	0	26393	9610	4
4/21/2012	12013	11899	0	18307	5605	2
4/22/2012	18002	18003	0	10806	25198	11
4/23/2012	14046	13976	0	15287	12734	6
4/24/2012	16863	16713	0	13224	20352	9
4/25/2012	15499	15373	0	13241	17631	8
4/26/2012	8677	8609	0	10980	6306	3
4/27/2012	12485	12415	0	10009	14891	7
4/28/2012	18002	18002	1152	13034	24121	11
4/29/2012	12125	11946	0	66798	-42727	-19
4/30/2012	13301	13157	0	29118	-2661	-1
5/1/2012	16992	16885	0	21581	12296	5
5/2/2012	18002	18005	1152	22353	14805	7
5/3/2012	16667	16603	576	22454	11391	5
5/4/2012	15954	15862	0	17906	13910	6
5/5/2012	16387	16369	0	17753	15003	7
5/6/2012	9102	9058	0	19638	-1478	-1
5/7/2012	18002	18002	0	21752	14251	6
5/8/2012	16740	16686	0	13859	19566	9
5/9/2012	14641	13870	0	13319	15191	7
5/10/2012	11982	11957	0	12540	11399	5
5/11/2012	18002	18003	0	11886	24118	11
5/12/2012	15922	15889	0	31558	253	0
5/13/2012	8902	8846	0	19811	-2064	-1

5/14/2012	17942	17899	0	13293	22548	10
5/15/2012	11326	11239	0	12632	9933	4
5/16/2012	15139	15103	0	5965	24277	11
5/17/2012	16979	16944	0	7349	26574	12
5/18/2012	15079	15017	0	8230	21866	10
5/19/2012	16105	16028	0	6651	25482	11
5/20/2012	11984	11931	0	8917	14998	7
5/21/2012	14262	14211	0	6652	21821	10
5/22/2012	18002	18002	0	4669	31334	14

Table H.3. Daily reference ET values were calculated using the FAO56 Penman-Monteith method for 2011. Weather data from the VantagePro2™ did not start collecting data until April 7, 2011; therefore, the bold red values represent Manhattan's weather data taken from the Kansas State Weather Data Library, beginning on January 27, 2011 due to technical difficulties from the first of January to this date.

Date	MaxT (°C)	MinT (°C)	Precip. (mm)	Wind (m/s)	Solar (MJ m ⁻² d ⁻¹)	Max RH (%)	Min RH (%)	ET _o (mm/day)
1/27/2011	10	-6	0	2	13	92	53	1.33
1/28/2011	15	-3	0	2	12	99	41	1.46
1/29/2011	8	-3	0	2	9	98	59	1.06
1/30/2011	0	-7	0	4	10	93	55	0.90
1/31/2011	-3	-13	0	4	2	99	82	0.38
2/1/2011	-12	-15	2	7	4	92	80	0.30
2/2/2011	-10	-19	0	4	11	84	49	0.61
2/3/2011	-4	-20	0	2	15	86	35	0.85
2/4/2011	3	-13	0	3	14	73	29	1.37
2/5/2011	8	-6	0	2	11	88	56	1.20
2/6/2011	4	-1	0	4	5	87	74	0.91
2/7/2011	0	-9	0	4	11	86	51	1.05
2/8/2011	-9	-16	4	4	5	89	65	0.49
2/9/2011	-4	-17	0	2	14	89	38	0.83
2/10/2011	-3	-19	0	3	15	82	42	0.95
2/11/2011	5	-10	0	3	14	86	49	1.34
2/12/2011	10	-3	0	3	16	87	33	1.94
2/13/2011	17	1	0	2	16	84	28	2.67
2/14/2011	12	-2	0	1	10	82	39	1.55
2/15/2011	15	-2	0	2	17	100	54	1.72
2/16/2011	21	-2	0	2	13	100	32	2.74
2/17/2011	22	8	0	5	14	88	23	4.40
2/18/2011	14	-2	0	1	14	84	23	1.95
2/19/2011	12	5	0	3	7	89	52	1.66
2/20/2011	22	-2	0	5	12	90	22	4.74

2/21/2011	1	-8	0	4	17	78	37	1.59
2/22/2011	7	-10	0	2	15	88	29	1.63
2/23/2011	15	-2	0	3	16	83	31	2.68
2/24/2011	2	-6	10	5	4	100	75	0.70
2/25/2011	-5	-10	0	3	12	89	68	0.72
2/26/2011	-1	-8	0	1	7	100	79	0.60
2/27/2011	2	-1	0	3	7	100	81	0.69
2/28/2011	7	-6	0	3	17	86	34	1.96
3/1/2011	19	1	0	2	15	84	24	2.94
3/2/2011	8	-6	0	3	12	89	48	1.68
3/3/2011	20	1	0	2	17	91	32	2.87
3/4/2011	6	-5	0	5	7	95	61	1.24
3/5/2011	5	-8	0	3	16	83	36	1.86
3/6/2011	10	-6	0	3	18	88	26	2.43
3/7/2011	7	2	1	2	6	88	66	1.15
3/8/2011	4	1	5	3	4	99	81	0.70
3/9/2011	6	-1	0	4	7	95	57	1.36
3/10/2011	15	-5	0	1	17	87	26	2.41
3/11/2011	23	2	0	3	17	80	19	4.26
3/12/2011	15	-1	0	0	21	94	26	1.89
3/13/2011	5	-1	0	3	6	100	61	1.05
3/14/2011	8	-2	11	2	12	100	56	1.49
3/15/2011	14	-5	0	1	19	100	45	2.20
3/16/2011	23	1	0	4	19	100	33	4.47
3/17/2011	24	10	0	5	13	86	27	4.95
3/18/2011	18	7	0	3	16	68	30	3.45
3/19/2011	12	4	11	4	8	98	62	1.65
3/20/2011	27	12	0	4	17	87	23	5.68
3/21/2011	29	12	0	4	18	94	41	4.98
3/22/2011	29	11	0	5	18	80	12	7.36
3/23/2011	15	1	0	5	16	77	32	3.71
3/24/2011	8	0	2	4	17	91	46	2.21
3/25/2011	6	1	1	3	6	98	76	0.97
3/26/2011	3	0	0	3	4	98	70	0.86
3/27/2011	3	0	0	3	8	98	70	1.03
3/28/2011	4	-1	1	3	7	100	76	0.91
3/29/2011	9	1	0	3	6	92	58	1.44
3/30/2011	9	-2	0	1	8	100	54	1.34
3/31/2011	11	0	3	2	6	97	71	1.21
4/1/2011	19	4	0	2	20	99	27	3.54
4/2/2011	26	5	0	3	25	90	19	5.65
4/3/2011	33	9	0	7	19	75	14	10.07

4/4/2011	13	3	0	6	22	70	18	4.42
4/5/2011	23	-1	0	4	21	67	14	5.90
4/6/2011	23	6	0	3	22	68	23	5.20
4/7/2011	12	9	3	3	13	90	80	1.78
4/8/2011	17	8	4	2	22	97	83	2.66
4/9/2011	31	14	0	4	23	95	45	5.88
4/10/2011	27	14	0	5	19	76	21	6.81
4/11/2011	19	6	0	4	15	88	26	4.04
4/12/2011	23	6	0	2	11	54	20	3.76
4/13/2011	25	11	0	3	15	61	29	4.87
4/14/2011	25	13	10	3	19	83	38	4.58
4/15/2011	15	3	7	7	24	96	78	2.37
4/16/2011	19	1	0	4	17	87	30	4.23
4/17/2011	23	6	0	2	16	68	33	4.16
4/18/2011	15	6	0	4	19	88	64	2.87
4/19/2011	10	5	0	5	20	94	83	1.84
4/20/2011	15	3	0	2	16	90	36	2.87
4/21/2011	16	7	0	4	17	95	36	3.51
4/22/2011	21	9	10	3	24	97	28	4.56
4/23/2011	16	7	0	3	18	81	34	3.70
4/24/2011	17	3	0	2	18	93	50	2.98
4/25/2011	13	9	12	3	23	95	73	2.74
4/26/2011	16	7	1	3	22	94	58	3.19
4/27/2011	16	6	0	5	21	93	45	3.65
4/28/2011	22	5	0	3	18	87	30	4.45
4/29/2011	25	11	0	5	17	58	32	6.30
4/30/2011	20	10	0	5	15	79	20	5.29
5/1/2011	18	7	0	3	14	66	21	4.14
5/2/2011	19	3	0	2	18	91	20	3.83
5/3/2011	22	1	0	1	23	89	21	4.07
5/4/2011	27	7	0	5	26	79	16	7.25
5/5/2011	21	7	2	2	11	90	29	3.42
5/6/2011	28	4	5	3	20	96	19	5.98
5/7/2011	28	13	9	2	25	99	25	5.27
5/8/2011	31	16	0	5	27	89	45	6.81
5/9/2011	37	23	0	4	20	76	16	9.00
5/10/2011	33	20	0	4	22	91	38	6.49
5/11/2011	28	14	1	3	24	95	51	5.25
5/12/2011	25	9	2	2	21	93	58	4.02
5/13/2011	11	7	2	7	21	92	68	2.53
5/14/2011	13	5	0	6	17	87	54	2.98
5/15/2011	13	6	0	4	18	89	67	2.60

5/16/2011	20	9	0	1	14	67	33	3.20
5/17/2011	20	10	1	2	15	76	29	3.88
5/18/2011	18	10	21	3	22	95	58	3.53
5/19/2011	20	14	4	4	32	93	86	4.13
5/20/2011	24	17	12	3	34	95	76	5.27
5/21/2011	28	18	0	3	29	91	45	6.07
5/22/2011	27	16	0	4	21	81	39	5.99
5/23/2011	28	16	0	1	23	93	48	4.73
5/24/2011	22	14	40	3	28	95	83	4.05
5/25/2011	16	9	49	4	27	95	67	3.45
5/26/2011	20	12	0	3	20	89	42	4.14
5/27/2011	15	12	1	3	29	97	86	3.49
5/28/2011	23	17	1	2	28	97	53	4.95
5/29/2011	31	22	0	4	29	85	58	6.64
5/30/2011	27	15	16	7	28	95	62	5.53
5/31/2011	27	16	0	2	20	75	34	5.15
6/1/2011	25	18	93	2	30	96	54	5.41
6/2/2011	29	21	0	4	30	90	61	6.28
6/3/2011	33	23	0	4	25	78	45	7.20
6/4/2011	31	22	0	1	23	71	53	5.24
6/5/2011	33	23	0	3	21	71	40	6.64
6/6/2011	35	24	0	4	22	79	38	7.34
6/7/2011	33	25	0	1	22	67	49	5.43
6/8/2011	33	19	1	3	22	87	48	5.97
6/9/2011	33	16	3	2	24	95	51	5.68
6/10/2011	24	13	0	2	26	96	82	4.10
6/11/2011	25	17	0	2	22	85	49	4.65
6/12/2011	25	18	1	3	26	92	72	4.69
6/13/2011	34	23	1	3	14	88	46	4.81
6/14/2011	30	19	0	3	24	93	54	5.48
6/15/2011	29	15	0	2	21	91	35	5.21
6/16/2011	26	18	7	4	23	91	54	5.08
6/17/2011	31	19	1	4	26	91	52	6.35
6/18/2011	27	17	24	3	27	93	68	5.15
6/19/2011	31	20	0	3	28	95	62	6.01
6/20/2011	31	19	4	6	24	74	53	7.05
6/21/2011	25	18	0	6	25	84	58	5.53
6/22/2011	27	15	0	5	21	81	45	5.87
6/23/2011	27	15	0	2	21	87	45	4.90
6/24/2011	29	17	0	4	22	85	57	5.41
6/25/2011	29	18	8	4	27	92	73	5.22
6/26/2011	32	21	0	5	30	96	65	6.45

6/27/2011	28	18	3	4	27	94	59	5.67
6/28/2011	27	16	0	3	22	86	50	4.99
6/29/2011	33	20	0	4	24	87	58	6.35
6/30/2011	38	25	0	4	22	80	34	8.44
7/1/2011	37	25	0	4	20	73	34	8.23
7/2/2011	30	22	0	3	22	87	56	5.39
7/3/2011	28	21	0	3	28	92	74	5.23
7/4/2011	30	20	0	2	27	96	62	5.58
7/5/2011	33	22	0	3	25	92	52	6.31
7/6/2011	30	21	1	2	26	90	54	5.66
7/7/2011	28	21	1	2	28	95	70	5.28
7/8/2011	30	20	1	2	27	93	56	5.62
7/9/2011	32	21	0	4	26	89	58	6.16
7/10/2011	37	25	0	3	25	86	44	7.11
7/11/2011	36	24	0	2	21	78	46	6.07
7/12/2011	37	24	3	3	20	83	39	6.41
7/13/2011	30	21	1	3	26	94	67	5.43
7/14/2011	34	23	0	4	26	94	56	6.62
7/15/2011	36	25	0	4	26	88	51	7.48
7/16/2011	37	26	0	3	23	82	48	7.16
7/17/2011	37	25	0	3	22	78	41	7.03
7/18/2011	37	26	0	3	21	75	44	6.53
7/19/2011	37	26	0	3	20	71	35	6.99
7/20/2011	39	25	0	4	18	67	33	7.91
7/21/2011	38	28	0	3	19	62	37	7.35
7/22/2011	39	27	0	3	18	67	30	7.57
7/23/2011	40	27	0	3	17	64	30	7.55
7/24/2011	38	22	1	3	20	89	42	6.94
7/25/2011	33	20	11	2	25	94	50	5.61
7/26/2011	36	25	0	2	23	82	44	6.32
7/27/2011	41	27	0	5	19	66	31	9.55
7/28/2011	36	23	0	2	20	88	43	5.96
7/29/2011	29	22	18	2	29	95	71	5.65
7/30/2011	34	22	3	2	31	95	61	6.63
7/31/2011	36	24	1	3	29	96	47	7.15
8/1/2011	40	26	0	3	24	89	32	7.51
8/2/2011	39	27	0	3	19	83	30	7.32
8/3/2011	32	25	0	2	26	89	54	6.06
8/4/2011	32	23	1	1	26	88	60	5.52
8/5/2011	31	21	7	2	28	94	63	5.70
8/6/2011	34	23	1	1	28	95	60	6.07
8/7/2011	31	19	0	3	26	93	58	5.80

8/8/2011	30	20	1	3	27	90	61	5.62
8/9/2011	31	20	0	1	25	90	57	5.13
8/10/2011	27	18	0	2	24	93	56	4.75
8/11/2011	30	18	0	2	22	83	49	5.14
8/12/2011	25	17	0	4	17	95	76	3.33
8/13/2011	32	18	0	2	26	100	36	5.59
8/14/2011	31	15	0	1	30	100	29	5.57
8/15/2011	31	18	12	3	26	99	44	6.05
8/16/2011	36	22	0	2	27	94	43	6.56
8/17/2011	30	22	0	2	29	95	64	5.65
8/18/2011	33	21	1	4	27	93	59	6.26
8/19/2011	29	19	0	4	31	95	71	5.60
8/20/2011	27	19	1	3	32	95	71	5.44
8/21/2011	31	20	1	1	30	93	62	5.75
8/22/2011	33	22	1	4	28	89	56	6.53
8/23/2011	37	23	0	3	25	85	48	6.71
8/24/2011	33	22	0	3	25	85	43	6.35
8/25/2011	28	17	0	2	21	86	44	4.61
8/26/2011	32	18	0	3	21	79	42	5.64
8/27/2011	31	19	0	3	23	91	50	5.47
8/28/2011	30	20	0	3	24	88	54	5.47
8/29/2011	28	17	0	4	25	92	64	4.94
8/30/2011	33	21	2	3	25	92	51	6.06
8/31/2011	35	22	0	3	23	83	44	6.33
9/1/2011	39	27	0	5	18	55	25	9.34
9/2/2011	37	25	0	4	17	63	29	7.28
9/3/2011	29	19	3	3	23	81	53	5.11
9/4/2011	23	13	0	4	18	85	39	4.74
9/5/2011	22	10	0	2	16	88	42	3.37
9/6/2011	23	12	0	2	16	75	41	3.55
9/7/2011	24	12	0	2	16	79	43	3.49
9/8/2011	24	13	0	2	17	81	42	3.76
9/9/2011	26	14	4	3	21	92	46	4.33
9/10/2011	26	15	3	2	25	93	54	4.29
9/11/2011	29	16	0	1	23	93	40	4.01
9/12/2011	34	18	0	3	20	77	30	6.39
9/13/2011	26	17	0	4	19	83	36	5.14
9/14/2011	19	10	0	4	20	87	55	3.54
9/15/2011	13	6	0	2	18	72	49	2.66
9/16/2011	14	9	5	3	24	94	57	2.98
9/17/2011	17	11	1	4	34	96	88	3.26
9/18/2011	21	15	8	3	36	97	82	4.25
9/19/2011	27	12	2	1	30	97	35	4.44

9/20/2011	28	15	1	3	22	78	42	4.89
9/21/2011	21	11	0	2	19	85	41	3.48
9/22/2011	23	9	0	1	20	90	37	3.22
9/23/2011	22	9	0	3	20	89	41	3.60
9/24/2011	22	11	0	3	18	74	41	3.85
9/25/2011	19	7	0	2	18	82	45	2.89
9/26/2011	22	7	0	1	18	86	42	2.88
9/27/2011	26	10	0	2	19	84	40	3.62
9/28/2011	30	13	0	0	19	83	31	2.81
9/29/2011	25	13	0	4	16	74	20	5.15
9/30/2011	22	7	0	2	15	79	33	3.30
10/1/2011	23	10	0	2	14	58	26	3.87
10/2/2011	25	12	0	3	15	57	24	4.46
10/3/2011	28	13	0	4	15	59	26	6.04
10/4/2011	31	15	0	4	15	58	26	6.72
10/5/2011	27	14	0	4	15	58	24	5.80
10/6/2011	28	15	0	6	16	62	27	6.85
10/7/2011	27	19	0	7	19	62	48	6.26
10/8/2011	26	18	0	4	22	91	52	4.25
10/9/2011	27	16	0	4	23	92	43	4.60
10/10/2011	22	14	2	1	26	96	64	3.12
10/11/2011	24	13	0	3	24	93	44	3.82
10/12/2011	23	14	1	3	24	94	55	3.60
10/13/2011	23	9	0	3	18	78	28	3.94
10/14/2011	18	10	0	2	17	74	34	2.88
10/15/2011	24	7	0	2	16	65	31	3.67
10/16/2011	20	11	0	4	19	81	43	3.50
10/17/2011	14	7	1	3	19	78	43	2.61
10/18/2011	12	5	0	5	19	86	38	2.81
10/19/2011	11	0	0	4	16	80	30	2.65
10/20/2011	12	-3	0	2	17	88	42	1.88
10/21/2011	22	4	0	1	18	75	33	2.62
10/22/2011	22	9	0	1	19	68	36	2.63
10/23/2011	25	8	0	2	18	82	30	3.26
10/24/2011	28	8	0	4	17	71	25	4.96
10/25/2011	26	13	0	6	19	72	33	5.69
10/26/2011	15	7	0	4	19	80	50	2.61
10/27/2011	13	2	0	2	17	85	31	2.07
10/28/2011	16	1	0	2	16	81	29	2.26
10/29/2011	20	4	0	4	15	63	21	4.02
10/30/2011	16	8	0	4	15	68	24	3.29
10/31/2011	22	5	0	1	15	66	26	2.38

11/1/2011	24	10	0	4	20	78	46	3.57
11/2/2011	19	3	1	6	26	93	66	2.53
11/3/2011	10	0	1	5	24	83	37	2.46
11/4/2011	14	-1	0	3	21	83	48	2.17
11/5/2011	15	6	0	6	25	89	57	2.45
11/6/2011	17	8	0	3	19	86	30	2.93
11/7/2011	14	5	7	5	23	92	49	2.42
11/8/2011	7	1	12	6	30	95	92	0.88
11/9/2011	11	0	5	4	17	96	39	2.00
11/10/2011	10	-3	28	2	10	80	35	1.38
11/11/2011	17	2	0	3	11	83	37	2.32
11/12/2011	18	5	0	5	13	84	38	3.12
11/13/2011	18	8	0	3	11	65	31	2.94
11/14/2011	14	6	0	2	10	73	40	1.92
11/15/2011	18	3	0	3	10	78	32	2.44
11/16/2011	6	-2	0	2	9	90	34	1.28
11/17/2011	9	-5	0	3	9	93	34	1.76
11/18/2011	15	4	0	6	12	72	50	2.66
11/19/2011	17	-2	0	6	13	83	51	2.72
11/20/2011	1	-3	0	3	13	85	73	0.77
11/21/2011	4	0	0	1	11	87	78	0.56
11/22/2011	5	2	7	2	12	95	88	0.58
11/23/2011	17	-1	0	2	11	96	49	1.54
11/24/2011	21	7	0	5	13	84	41	3.13
11/25/2011	17	7	2	6	17	94	69	1.72
11/26/2011	12	2	10	5	16	96	52	1.81
11/27/2011	5	-4	0	3	9	73	46	1.31
11/28/2011	9	-4	0	1	7	82	38	0.80
11/29/2011	8	0	0	3	9	85	28	1.78
11/30/2011	12	-2	0	3	7	60	32	2.20
12/1/2011	6	-3	0	4	11	79	53	1.37
12/2/2011	4	-8	0	2	11	93	66	0.62
12/3/2011	9	0	3	3	16	96	94	0.45
12/4/2011	2	-5	6	2	11	92	67	0.64
12/5/2011	-4	-7	0	4	13	91	79	0.45
12/6/2011	-3	-10	0	2	10	86	55	0.58
12/7/2011	5	-10	1	2	9	84	54	0.81
12/8/2011	4	-6	0	2	11	91	65	0.62
12/9/2011	1	-4	1	1	11	87	64	0.53
12/10/2011	7	-6	2	3	11	94	61	0.87
12/11/2011	8	-1	0	5	14	95	66	1.01
12/12/2011	9	5	0	3	13	74	66	1.15
12/13/2011	7	3	15	3	15	96	77	0.60
12/14/2011	17	5	18	3	16	98	77	0.98

12/15/2011	5	-3	0	4	10	92	58	0.98
12/16/2011	5	-5	0	1	9	88	60	0.52
12/17/2011	11	-3	0	1	9	100	49	0.71
12/18/2011	16	1	0	3	10	83	50	1.85
12/19/2011	8	0	8	4	16	94	73	0.81
12/20/2011	0	-1	0	2	18	95	91	0.26
12/21/2011	6	-4	3	1	13	95	74	0.44
12/22/2011	1	-7	0	4	14	92	66	0.67
12/23/2011	2	-10	0	2	10	92	53	0.70
12/24/2011	8	-6	0	2	9	88	49	0.87
12/25/2011	10	-4	0	1	8	88	43	0.85
12/26/2011	7	-3	0	1	10	88	65	0.64
12/27/2011	7	0	0	3	8	81	52	1.31
12/28/2011	10	-1	0	2	8	81	48	1.19
12/29/2011	11	0	0	2	9	84	55	1.03
12/30/2011	13	3	0	4	8	79	30	2.38
12/31/2011	16	3	1	5	10	88	41	2.59

Table H.4. Daily reference ET values were calculated using the FAO56 Penman-Monteith method for 2012.

Date	MaxT (°C)	MinT (°C)	Precip. (mm)	Wind (m/s)	Solar (MJ m ⁻² d ⁻¹)	Max RH (%)	Min RH (%)	ET _o (mm/day)
1/1/2012	7	-2	0	6	8	75	33	2.14
1/2/2012	2	-7	0	2	4	68	24	1.20
1/3/2012	6	-6	0	2	7	71	44	1.22
1/4/2012	13	1	0	3	8	78	32	2.04
1/5/2012	18	0	0	2	8	87	27	2.08
1/6/2012	14	3	0	3	8	75	30	2.19
1/7/2012	8	-2	0	1	7	67	41	1.03
1/8/2012	7	0	0	1	8	76	53	0.81
1/9/2012	11	-4	0	1	7	89	41	0.97
1/10/2012	14	0	0	1	6	81	35	1.15
1/11/2012	6	-4	0	6	10	85	64	0.63
1/12/2012	-4	-10	0	5	7	69	50	1.02
1/13/2012	2	-12	0	1	4	60	34	1.66
1/14/2012	8	0	0	3	7	70	38	1.09
1/15/2012	20	-1	0	5	9	71	17	3.43
1/16/2012	9	-2	0	3	10	92	56	1.51
1/17/2012	-2	-9	0	4	7	81	59	0.76
1/18/2012	5	-11	0	4	8	85	39	1.47
1/19/2012	0	-11	0	3	9	80	52	0.94
1/20/2012	-4	-12	0	3	8	78	66	0.63

1/21/2012	-2	-12	0	2	8	88	71	0.52
1/22/2012	15	-5	1	6	14	93	54	2.28
1/23/2012	7	1	0	2	8	91	53	1.11
1/24/2012	10	-4	0	4	8	86	45	1.70
1/25/2012	11	0	0	2	9	81	48	1.29
1/26/2012	12	-1	0	3	8	90	34	1.95
1/27/2012	7	-3	0	3	9	80	54	1.32
1/28/2012	9	-6	0	3	6	83	22	2.04
1/29/2012	12	-4	0	1	5	59	21	1.58
1/30/2012	21	4	0	4	10	73	23	4.04
1/31/2012	16	8	0	3	11	93	36	2.14
2/1/2012	16	2	0	1	8	73	26	1.36
2/2/2012	15	4	0	2	8	62	30	2.03
2/3/2012	11	5	23	4	14	95	48	1.89
2/4/2012	5	0	4	5	17	96	91	0.71
2/5/2012	8	-3	0	2	11	94	51	1.23
2/6/2012	10	-5	0	1	9	94	41	1.16
2/7/2012	6	-1	0	1	11	94	59	1.01
2/8/2012	0	-2	0	1	10	93	81	0.65
2/9/2012	4	-1	0	2	11	93	73	0.89
2/10/2012	3	-11	0	5	9	93	48	1.30
2/11/2012	-3	-15	0	3	6	73	34	1.01
2/12/2012	1	-13	0	3	7	81	32	1.28
2/13/2012	1	-4	0	3	16	96	79	0.82
2/14/2012	9	-5	1	1	13	96	65	1.09
2/15/2012	5	1	1	2	13	96	83	0.93
2/16/2012	10	-3	0	1	9	92	44	1.12
2/17/2012	14	1	0	3	10	82	50	2.00
2/18/2012	6	-4	0	3	10	83	48	1.46
2/19/2012	10	-3	0	3	8	82	39	1.90
2/20/2012	8	3	5	5	14	94	64	1.58
2/21/2012	12	-1	0	4	12	93	38	2.34
2/22/2012	17	3	1	2	10	73	37	2.26
2/23/2012	13	3	0	7	12	76	58	2.46
2/24/2012	8	-4	0	5	9	92	34	2.22
2/25/2012	9	-5	0	3	9	93	45	1.68
2/26/2012	16	4	0	5	9	58	17	4.12
2/27/2012	8	-4	0	3	9	83	36	1.91
2/28/2012	15	3	2	6	14	93	51	2.77
2/29/2012	13	3	0	6	12	64	37	3.44
3/1/2012	19	-1	0	4	11	86	30	3.69
3/2/2012	11	1	2	4	12	92	27	2.69

3/3/2012	8	-4	0	3	8	78	31	1.93
3/4/2012	17	-1	0	5	9	70	34	3.52
3/5/2012	16	-3	0	4	9	79	28	3.25
3/6/2012	21	12	0	8	13	68	37	5.41
3/7/2012	20	4	0	7	15	77	54	3.77
3/8/2012	11	-1	1	3	10	86	26	2.28
3/9/2012	17	-1	0	2	8	60	20	2.49
3/10/2012	19	3	0	4	10	72	26	3.77
3/11/2012	11	7	8	4	14	96	47	2.28
3/12/2012	24	8	3	4	16	95	31	4.26
3/13/2012	26	10	0	4	15	82	40	4.34
3/14/2012	28	16	0	5	18	91	45	4.94
3/15/2012	26	15	0	3	20	95	50	4.00
3/16/2012	25	15	0	4	21	96	60	3.96
3/17/2012	26	17	0	6	22	90	62	4.48
3/18/2012	23	19	0	6	22	81	68	4.36
3/19/2012	20	13	14	4	23	95	72	3.15
3/20/2012	14	13	6	2	21	96	88	2.33
3/21/2012	16	10	5	3	22	96	92	2.22
3/22/2012	17	8	5	2	19	96	62	2.64
3/23/2012	18	9	3	2	16	96	57	2.57
3/24/2012	24	7	2	1	16	94	39	2.88
3/25/2012	26	12	1	1	16	85	38	3.30
3/26/2012	26	15	0	5	16	75	42	5.37
3/27/2012	26	16	0	4	18	87	40	4.71
3/28/2012	26	13	0	3	17	85	37	4.19
3/29/2012	27	16	0	4	22	91	56	4.72
3/30/2012	26	12	0	2	19	96	35	3.83
3/31/2012	30	14	0	2	18	83	35	4.75
4/1/2012	32	16	0	4	21	94	32	6.21
4/2/2012	31	20	0	6	20	85	32	7.10
4/3/2012	22	12	0	3	18	90	57	3.47
4/4/2012	16	12	5	3	21	94	79	2.67
4/5/2012	16	8	1	2	19	95	59	2.81
4/6/2012	19	6	0	3	16	85	44	3.31
4/7/2012	18	10	7	3	17	94	38	3.45
4/8/2012	20	5	0	2	13	75	33	2.97
4/9/2012	22	9	0	1	13	72	32	3.04
4/10/2012	17	5	0	2	11	57	31	2.98
4/11/2012	15	5	0	1	10	50	34	2.51
4/12/2012	15	9	2	4	15	85	43	3.15
4/13/2012	24	11	0	3	18	86	37	4.42

4/14/2012	23	16	4	5	25	94	74	3.90
4/15/2012	22	11	3	8	23	88	34	5.76
4/16/2012	18	7	0	4	15	83	43	3.69
4/17/2012	22	9	0	4	16	76	44	4.18
4/18/2012	24	12	0	4	18	80	47	4.54
4/19/2012	23	9	0	6	20	83	52	4.60
4/20/2012	16	6	0	4	14	82	35	3.44
4/21/2012	22	5	0	2	13	76	37	3.67
4/22/2012	17	6	0	5	12	76	33	3.95
4/23/2012	20	5	0	1	12	82	35	2.48
4/24/2012	33	11	0	3	16	77	25	5.90
4/25/2012	34	16	0	3	17	85	25	6.27
4/26/2012	26	17	0	3	16	56	39	5.18
4/27/2012	19	14	0	6	21	93	58	3.86
4/28/2012	20	10	1	3	24	93	52	4.12
4/29/2012	15	12	0	3	30	96	85	3.43
4/30/2012	19	11	0	1	30	97	80	4.14
5/1/2012	28	14	0	4	31	95	65	5.50
5/2/2012	28	20	1	5	31	87	65	5.95
5/3/2012	29	17	0	4	29	91	67	5.50
5/4/2012	32	21	0	3	29	93	55	6.21
5/5/2012	31	20	0	3	28	96	58	5.94
5/6/2012	25	17	0	3	27	91	71	4.77
5/7/2012	22	12	0	5	24	92	39	5.03
5/8/2012	23	9	0	2	18	83	27	4.06
5/9/2012	22	9	0	1	17	74	34	3.53
5/10/2012	27	12	0	3	21	75	45	5.22
5/11/2012	25	15	0	1	21	88	45	4.13
5/12/2012	18	9	1	3	23	85	52	3.85
5/13/2012	24	12	0	1	21	81	40	3.78
5/14/2012	26	14	0	0	20	80	34	3.66
5/15/2012	30	14	0	2	19	77	26	4.85
5/16/2012	27	12	0	2	15	56	23	4.86
5/17/2012	30	15	0	4	18	65	33	6.66
5/18/2012	30	18	0	5	20	75	41	6.70
5/19/2012	30	21	0	7	21	67	43	7.60
5/20/2012	24	12	0	3	20	91	47	4.27
5/21/2012	24	10	0	2	16	71	33	3.89
5/22/2012	18	13	0	2	8	67	49	2.80

Table H.5. Daily reference ET values were calculated using the Hargreaves method for 2011. Weather data from the VantagePro2™ did not start collecting data until April 7,

2011; therefore, the bold red values represent Manhattan's weather data taken from the Kansas State Weather Data Library, beginning on January 27, 2011 due to technical difficulties from the first of January to this date.

Date	MaxT (°C)	MinT (°C)	MeanT (°C)	Solar (MJ m ⁻² d ⁻¹)	ET ₀ (mm/day)
1/27/2011	10	-6	2	17.11	3.07
1/28/2011	15	-3	6	17.28	3.92
1/29/2011	8	-3	2	17.44	2.74
1/30/2011	0	-7	-4	17.61	1.47
1/31/2011	-3	-13	-8	17.79	1.31
2/1/2011	-12	-15	-13	17.97	0.32
2/2/2011	-10	-19	-15	18.15	0.41
2/3/2011	-4	-20	-12	18.33	0.98
2/4/2011	3	-13	-5	18.52	2.11
2/5/2011	8	-6	1	18.71	2.94
2/6/2011	4	-1	2	18.90	1.73
2/7/2011	0	-9	-4	19.10	1.73
2/8/2011	-9	-16	-12	19.30	0.66
2/9/2011	-4	-17	-10	19.51	1.16
2/10/2011	-3	-19	-11	19.71	1.27
2/11/2011	5	-10	-2	19.92	2.77
2/12/2011	10	-3	3	20.13	3.49
2/13/2011	17	1	9	20.35	5.05
2/14/2011	12	-2	5	20.56	4.11
2/15/2011	15	-2	7	20.78	4.78
2/16/2011	21	-2	9	21.01	6.25
2/17/2011	22	8	15	21.23	6.05
2/18/2011	14	-2	6	21.46	4.80
2/19/2011	12	5	8	21.68	3.42
2/20/2011	22	-2	10	21.91	6.87
2/21/2011	1	-8	-4	22.15	2.21
2/22/2011	7	-10	-1	22.38	3.50
2/23/2011	15	-2	7	22.62	5.24
2/24/2011	2	-6	-2	22.86	2.36
2/25/2011	-5	-10	-8	23.10	1.24
2/26/2011	-1	-8	-4	23.34	1.94
2/27/2011	2	-1	1	23.58	1.73
2/28/2011	7	-6	1	23.82	3.65
3/1/2011	19	1	10	24.07	6.55
3/2/2011	8	-6	1	24.31	3.95
3/3/2011	20	1	10	24.56	6.91
3/4/2011	6	-5	0	24.81	3.33
3/5/2011	5	-8	-1	25.06	3.38

3/6/2011	10	-6	2	25.31	4.70
3/7/2011	7	2	5	25.56	2.92
3/8/2011	4	1	3	25.81	2.05
3/9/2011	6	-1	2	26.06	3.28
3/10/2011	15	-5	5	26.31	6.29
3/11/2011	23	2	13	26.56	8.60
3/12/2011	15	-1	7	26.82	6.14
3/13/2011	5	-1	2	27.07	2.85
3/14/2011	8	-2	3	27.32	4.13
3/15/2011	14	-5	5	27.57	6.28
3/16/2011	23	1	12	27.83	9.08
3/17/2011	24	10	17	28.08	8.56
3/18/2011	18	7	12	28.33	6.56
3/19/2011	12	4	8	28.58	4.72
3/20/2011	27	12	19	28.83	9.85
3/21/2011	29	12	20	29.08	10.39
3/22/2011	29	11	20	29.33	10.77
3/23/2011	15	1	8	29.57	6.47
3/24/2011	8	0	4	29.82	4.25
3/25/2011	6	1	3	30.07	3.12
3/26/2011	3	0	2	30.31	2.33
3/27/2011	3	0	2	30.56	2.35
3/28/2011	4	-1	2	30.80	3.19
3/29/2011	9	1	5	31.04	4.49
3/30/2011	9	-2	3	31.28	5.10
3/31/2011	11	0	6	31.52	5.50
4/1/2011	19	4	12	31.75	8.32
4/2/2011	26	5	15	31.99	11.09
4/3/2011	33	9	21	32.22	14.14
4/4/2011	13	3	8	32.45	6.13
4/5/2011	23	-1	11	32.68	10.55
4/6/2011	23	6	14	32.91	9.88
4/7/2011	12	9	10	33.14	3.65
4/8/2011	17	8	11	33.36	7.02
4/9/2011	31	14	23	33.58	12.90
4/10/2011	27	14	23	33.80	11.34
4/11/2011	19	6	13	34.02	8.68
4/12/2011	23	6	15	34.23	10.62
4/13/2011	25	11	19	34.44	10.73
4/14/2011	25	13	18	34.65	9.92
4/15/2011	15	3	8	34.86	7.24
4/16/2011	19	1	9	35.07	9.16

4/17/2011	23	6	15	35.27	10.68
4/18/2011	15	6	11	35.47	7.14
4/19/2011	10	5	6	35.67	4.47
4/20/2011	15	3	8	35.86	7.32
4/21/2011	16	7	11	36.05	7.11
4/22/2011	21	9	14	36.24	8.98
4/23/2011	16	7	11	36.43	7.03
4/24/2011	17	3	10	36.61	8.65
4/25/2011	13	9	11	36.79	4.98
4/26/2011	16	7	10	36.97	6.99
4/27/2011	16	6	10	37.14	7.58
4/28/2011	22	5	13	37.32	10.85
4/29/2011	25	11	19	37.49	12.00
4/30/2011	20	10	16	37.65	9.46
5/1/2011	18	7	12	37.81	8.81
5/2/2011	19	3	11	37.97	9.98
5/3/2011	22	1	11	38.13	11.56
5/4/2011	27	7	17	38.28	13.39
5/5/2011	21	7	14	38.43	10.44
5/6/2011	28	4	16	38.58	14.77
5/7/2011	28	13	20	38.73	13.35
5/8/2011	31	16	23	38.87	14.20
5/9/2011	37	23	28	39.01	15.28
5/10/2011	33	20	26	39.14	13.96
5/11/2011	28	14	21	39.27	13.17
5/12/2011	25	9	18	39.40	12.95
5/13/2011	11	7	9	39.53	4.33
5/14/2011	13	5	10	39.65	7.03
5/15/2011	13	6	9	39.77	6.39
5/16/2011	20	9	15	39.88	10.16
5/17/2011	20	10	15	39.99	9.39
5/18/2011	18	10	15	40.10	8.22
5/19/2011	20	14	18	40.21	8.00
5/20/2011	24	17	19	40.31	9.06
5/21/2011	28	18	22	40.41	11.63
5/22/2011	27	16	22	40.51	12.33
5/23/2011	28	16	22	40.60	12.41
5/24/2011	22	14	17	40.69	9.33
5/25/2011	16	9	13	40.77	7.70
5/26/2011	20	12	16	40.86	8.79
5/27/2011	15	12	14	40.94	5.69
5/28/2011	23	17	19	41.01	8.55

5/29/2011	31	22	26	41.09	12.74
5/30/2011	27	15	23	41.15	13.54
5/31/2011	27	16	22	41.22	12.75
6/1/2011	25	18	22	41.28	9.53
6/2/2011	29	21	26	41.34	11.75
6/3/2011	33	23	28	41.40	13.58
6/4/2011	31	22	27	41.45	13.21
6/5/2011	33	23	28	41.50	13.98
6/6/2011	35	24	29	41.55	14.79
6/7/2011	33	25	29	41.59	12.96
6/8/2011	33	19	28	41.63	16.26
6/9/2011	33	16	23	41.67	16.33
6/10/2011	24	13	18	41.70	11.14
6/11/2011	25	17	21	41.73	10.77
6/12/2011	25	18	21	41.76	9.98
6/13/2011	34	23	29	41.78	15.32
6/14/2011	30	19	25	41.80	13.84
6/15/2011	29	15	23	41.82	14.83
6/16/2011	26	18	22	41.83	10.87
6/17/2011	31	19	25	41.84	14.16
6/18/2011	27	17	23	41.85	12.44
6/19/2011	31	20	25	41.85	13.98
6/20/2011	31	19	27	41.85	15.20
6/21/2011	25	18	21	41.85	9.52
6/22/2011	27	15	21	41.85	12.80
6/23/2011	27	15	22	41.84	13.20
6/24/2011	29	17	23	41.82	13.08
6/25/2011	29	18	23	41.81	13.05
6/26/2011	32	21	26	41.79	14.32
6/27/2011	28	18	23	41.77	12.80
6/28/2011	27	16	22	41.74	12.52
6/29/2011	33	20	26	41.71	15.35
6/30/2011	38	25	31	41.68	17.01
7/1/2011	37	25	31	41.64	16.07
7/2/2011	30	22	27	41.61	12.85
7/3/2011	28	21	25	41.56	10.59
7/4/2011	30	20	25	41.52	13.01
7/5/2011	33	22	27	41.47	14.45
7/6/2011	30	21	25	41.42	12.57
7/7/2011	28	21	24	41.36	10.59
7/8/2011	30	20	25	41.31	12.64
7/9/2011	32	21	27	41.25	13.83

7/10/2011	37	25	31	41.18	15.86
7/11/2011	36	24	31	41.11	15.83
7/12/2011	37	24	30	41.04	16.31
7/13/2011	30	21	25	40.97	12.69
7/14/2011	34	23	28	40.89	14.07
7/15/2011	36	25	30	40.81	15.23
7/16/2011	37	26	31	40.73	15.61
7/17/2011	37	25	31	40.64	15.68
7/18/2011	37	26	31	40.55	15.03
7/19/2011	37	26	31	40.46	15.73
7/20/2011	39	25	32	40.36	16.76
7/21/2011	38	28	32	40.26	15.04
7/22/2011	39	27	33	40.16	16.29
7/23/2011	40	27	33	40.05	16.72
7/24/2011	38	22	30	39.95	17.52
7/25/2011	33	20	27	39.83	14.70
7/26/2011	36	25	30	39.72	14.78
7/27/2011	41	27	33	39.60	16.83
7/28/2011	36	23	30	39.48	15.56
7/29/2011	29	22	24	39.35	10.55
7/30/2011	34	22	27	39.23	13.75
7/31/2011	36	24	29	39.10	14.86
8/1/2011	40	26	33	38.96	16.93
8/2/2011	39	27	32	38.83	15.68
8/3/2011	32	25	28	38.69	10.96
8/4/2011	32	23	26	38.54	11.78
8/5/2011	31	21	26	38.40	12.48
8/6/2011	34	23	28	38.25	13.02
8/7/2011	31	19	26	38.10	13.09
8/8/2011	30	20	25	37.94	11.84
8/9/2011	31	20	26	37.79	12.61
8/10/2011	27	18	23	37.63	10.36
8/11/2011	30	18	24	37.46	12.87
8/12/2011	29	18	24	37.30	11.86
8/13/2011	32	18	25	37.13	13.28
8/14/2011	31	15	23	36.96	14.06
8/15/2011	31	18	24	36.78	12.71
8/16/2011	36	22	29	36.60	14.95
8/17/2011	30	22	25	36.42	9.82
8/18/2011	33	21	27	36.24	13.34
8/19/2011	29	19	24	36.05	11.09
8/20/2011	27	19	23	35.87	9.50

8/21/2011	31	20	25	35.68	11.58
8/22/2011	33	22	26	35.48	11.65
8/23/2011	37	23	29	35.29	14.12
8/24/2011	33	22	28	35.09	12.50
8/25/2011	28	17	23	34.89	10.54
8/26/2011	32	18	25	34.68	12.78
8/27/2011	31	19	26	34.48	11.96
8/28/2011	30	20	25	34.27	10.91
8/29/2011	28	17	23	34.06	10.54
8/30/2011	33	21	26	33.85	11.54
8/31/2011	35	22	29	33.63	12.84
9/1/2011	39	27	32	33.42	13.69
9/2/2011	37	25	31	33.20	12.81
9/3/2011	29	19	26	32.98	10.16
9/4/2011	23	13	19	32.76	8.55
9/5/2011	22	10	16	32.53	8.82
9/6/2011	23	12	17	32.30	8.59
9/7/2011	24	12	18	32.08	9.32
9/8/2011	24	13	18	31.85	8.77
9/9/2011	26	14	19	31.61	9.55
9/10/2011	26	15	20	31.38	9.24
9/11/2011	29	16	22	31.15	10.49
9/12/2011	34	18	25	30.91	12.02
9/13/2011	26	17	22	30.67	8.48
9/14/2011	19	10	16	30.43	6.80
9/15/2011	13	6	10	30.19	4.69
9/16/2011	14	9	11	29.95	4.78
9/17/2011	17	11	14	29.71	5.14
9/18/2011	21	15	17	29.47	5.90
9/19/2011	27	12	19	29.22	9.83
9/20/2011	28	15	20	28.98	9.02
9/21/2011	21	11	16	28.73	6.99
9/22/2011	23	9	16	28.49	8.21
9/23/2011	22	9	15	28.24	7.63
9/24/2011	22	11	16	27.99	6.95
9/25/2011	19	7	13	27.75	6.81
9/26/2011	22	7	15	27.50	8.41
9/27/2011	26	10	18	27.25	8.99
9/28/2011	30	13	22	27.00	10.10
9/29/2011	25	13	20	26.75	7.88
9/30/2011	22	7	15	26.51	7.62
10/1/2011	23	10	16	26.26	7.26

10/2/2011	25	12	19	26.01	7.91
10/3/2011	28	13	20	25.76	8.78
10/4/2011	29	15	19	25.51	8.23
10/5/2011	27	14	21	25.27	8.11
10/6/2011	28	15	21	25.02	7.95
10/7/2011	27	19	23	24.78	6.63
10/8/2011	26	18	21	24.53	6.19
10/9/2011	27	16	20	24.29	6.88
10/10/2011	22	14	17	24.05	5.23
10/11/2011	24	13	18	23.80	6.58
10/12/2011	23	14	18	23.56	5.96
10/13/2011	23	9	16	23.32	6.70
10/14/2011	18	10	14	23.09	4.91
10/15/2011	24	7	15	22.85	7.00
10/16/2011	20	11	16	22.61	5.46
10/17/2011	14	7	10	22.38	3.81
10/18/2011	12	5	9	22.15	3.67
10/19/2011	11	0	5	21.92	3.68
10/20/2011	12	-3	5	21.69	4.31
10/21/2011	22	4	12	21.47	6.26
10/22/2011	22	9	16	21.24	5.95
10/23/2011	25	8	17	21.02	7.01
10/24/2011	28	8	19	20.80	7.77
10/25/2011	26	13	20	20.58	6.54
10/26/2011	15	7	10	20.37	3.63
10/27/2011	13	2	8	20.16	3.91
10/28/2011	16	1	8	19.95	4.59
10/29/2011	20	4	11	19.74	5.43
10/30/2011	16	8	11	19.53	3.79
10/31/2011	22	5	12	19.33	5.51
11/1/2011	24	10	17	19.13	5.56
11/2/2011	19	3	8	18.94	4.53
11/3/2011	10	0	5	18.74	3.08
11/4/2011	14	-1	7	18.55	4.08
11/5/2011	15	6	10	18.37	3.62
11/6/2011	17	8	12	18.18	3.86
11/7/2011	14	5	8	18.00	3.20
11/8/2011	7	1	5	17.83	2.47
11/9/2011	11	0	4	17.65	2.86
11/10/2011	10	-3	4	17.48	3.15
11/11/2011	17	2	9	17.32	4.05
11/12/2011	18	5	10	17.15	4.02

11/13/2011	18	8	13	16.99	3.81
11/14/2011	14	6	10	16.84	2.98
11/15/2011	18	3	9	16.68	3.84
11/16/2011	6	-2	2	16.54	2.02
11/17/2011	9	-5	2	16.39	2.79
11/18/2011	15	4	10	16.25	3.36
11/19/2011	17	-2	7	16.11	4.09
11/20/2011	1	-3	-1	15.98	1.17
11/21/2011	4	0	2	15.85	1.45
11/22/2011	5	2	4	15.73	1.44
11/23/2011	17	-1	7	15.61	3.71
11/24/2011	21	7	12	15.49	3.96
11/25/2011	17	7	12	15.38	3.20
11/26/2011	12	2	8	15.27	2.86
11/27/2011	5	-4	0	15.16	1.81
11/28/2011	9	-4	1	15.06	2.35
11/29/2011	8	0	3	14.97	2.11
11/30/2011	12	-2	4	14.87	2.79
12/1/2011	6	-3	3	14.79	2.09
12/2/2011	4	-8	-3	14.70	1.77
12/3/2011	9	0	5	14.62	2.18
12/4/2011	2	-5	-2	14.55	1.46
12/5/2011	-4	-7	-5	14.48	0.79
12/6/2011	-3	-10	-7	14.41	0.97
12/7/2011	5	-10	-3	14.35	1.79
12/8/2011	4	-6	-1	14.30	1.69
12/9/2011	1	-4	-2	14.24	1.25
12/10/2011	7	-6	0	14.19	2.07
12/11/2011	8	-1	3	14.15	2.10
12/12/2011	9	5	6	14.11	1.52
12/13/2011	7	3	5	14.08	1.39
12/14/2011	17	5	10	14.05	3.09
12/15/2011	5	-3	1	14.02	1.75
12/16/2011	5	-5	0	14.00	1.83
12/17/2011	11	-3	3	13.98	2.49
12/18/2011	16	1	7	13.97	3.08
12/19/2011	8	0	4	13.96	2.01
12/20/2011	0	-1	-1	13.96	0.58
12/21/2011	6	-4	1	13.96	1.94
12/22/2011	1	-7	-2	13.97	1.41
12/23/2011	2	-10	-4	13.98	1.53
12/24/2011	8	-6	0	13.99	2.19

12/25/2011	10	-4	3	14.01	2.50
12/26/2011	7	-3	2	14.04	2.05
12/27/2011	7	0	3	14.07	1.88
12/28/2011	10	-1	3	14.10	2.24
12/29/2011	11	0	6	14.14	2.54
12/30/2011	13	3	8	14.18	2.58
12/31/2011	16	3	9	14.22	3.07

Table H.6. Daily reference ET values were calculated using the Hargreaves method for 2012.

Date	MaxT (°C)	MinT (°C)	MeanT (°C)	Solar (MJ m ⁻² d ⁻¹)	ET _o (mm/day)
1/1/2012	7	-2	3	14.28	2.07
1/2/2012	2	-7	-2	14.33	1.61
1/3/2012	6	-6	0	14.39	2.00
1/4/2012	13	1	6	14.46	2.77
1/5/2012	18	0	8	14.52	3.70
1/6/2012	14	3	7	14.60	2.84
1/7/2012	8	-2	3	14.67	2.19
1/8/2012	7	0	3	14.76	1.80
1/9/2012	11	-4	3	14.84	2.83
1/10/2012	14	0	8	14.93	3.26
1/11/2012	6	-4	1	15.03	2.05
1/12/2012	-4	-10	-7	15.13	0.94
1/13/2012	2	-12	-5	15.23	1.69
1/14/2012	8	0	4	15.34	2.20
1/15/2012	20	-1	7	15.45	4.04
1/16/2012	9	-2	6	15.57	2.73
1/17/2012	-2	-9	-6	15.69	1.12
1/18/2012	5	-11	-2	15.81	2.26
1/19/2012	0	-11	-7	15.94	1.34
1/20/2012	-4	-12	-8	16.07	0.93
1/21/2012	-2	-12	-7	16.21	1.25
1/22/2012	15	-5	5	16.35	3.86
1/23/2012	7	1	3	16.50	1.91
1/24/2012	10	-4	3	16.64	2.91
1/25/2012	11	0	5	16.80	2.82
1/26/2012	12	-1	5	16.95	3.23
1/27/2012	7	-3	2	17.11	2.49
1/28/2012	9	-6	0	17.28	2.84
1/29/2012	12	-4	5	17.44	3.64
1/30/2012	21	4	10	17.61	4.71

1/31/2012	16	8	11	17.79	3.31
2/1/2012	16	2	10	17.97	4.27
2/2/2012	15	4	9	18.15	3.68
2/3/2012	11	5	6	18.33	2.48
2/4/2012	5	0	2	18.52	1.76
2/5/2012	8	-3	2	18.71	2.77
2/6/2012	10	-5	3	18.90	3.50
2/7/2012	6	-1	3	19.10	2.35
2/8/2012	0	-2	-1	19.30	1.11
2/9/2012	4	-1	1	19.51	1.94
2/10/2012	3	-11	-5	19.71	2.23
2/11/2012	-3	-15	-10	19.92	1.19
2/12/2012	1	-13	-5	20.13	2.22
2/13/2012	1	-4	-1	20.35	1.64
2/14/2012	9	-5	2	20.56	3.54
2/15/2012	5	1	3	20.78	2.06
2/16/2012	10	-3	3	21.01	3.68
2/17/2012	14	1	6	21.23	4.18
2/18/2012	6	-4	1	21.46	2.85
2/19/2012	10	-3	3	21.68	3.79
2/20/2012	8	3	5	21.91	2.80
2/21/2012	12	-1	5	22.15	4.15
2/22/2012	17	3	9	22.38	5.19
2/23/2012	13	3	8	22.62	4.22
2/24/2012	8	-4	2	22.86	3.63
2/25/2012	9	-5	2	23.10	3.92
2/26/2012	16	4	10	23.34	5.11
2/27/2012	8	-4	2	23.58	3.81
2/28/2012	15	3	10	23.82	5.22
2/29/2012	13	3	8	24.07	4.44
3/1/2012	19	-1	8	24.31	6.51
3/2/2012	11	1	6	24.56	4.22
3/3/2012	8	-4	2	24.81	3.93
3/4/2012	17	-1	7	25.06	6.01
3/5/2012	16	-3	7	25.31	6.15
3/6/2012	21	12	16	25.56	6.07
3/7/2012	20	4	13	25.81	7.15
3/8/2012	11	-1	4	26.06	4.53
3/9/2012	17	-1	8	26.31	6.66
3/10/2012	19	3	11	26.56	6.86
3/11/2012	11	7	9	26.82	3.36
3/12/2012	24	8	14	27.07	7.76

3/13/2012	26	10	18	27.32	8.86
3/14/2012	28	16	21	27.57	8.33
3/15/2012	26	15	20	27.83	8.11
3/16/2012	25	15	19	28.08	7.71
3/17/2012	26	17	20	28.33	7.25
3/18/2012	23	19	20	28.58	5.32
3/19/2012	20	13	17	28.83	5.88
3/20/2012	14	13	13	29.08	2.50
3/21/2012	16	10	14	29.33	5.14
3/22/2012	17	8	11	29.57	5.86
3/23/2012	18	9	12	29.82	6.44
3/24/2012	24	7	16	30.07	9.53
3/25/2012	26	12	19	30.31	9.46
3/26/2012	26	15	20	30.56	9.17
3/27/2012	26	16	21	30.80	8.37
3/28/2012	26	13	20	31.04	9.40
3/29/2012	27	16	21	31.28	9.02
3/30/2012	26	12	19	31.52	9.73
3/31/2012	30	14	21	31.75	11.23
4/1/2012	32	16	22	31.99	11.76
4/2/2012	31	20	24	32.22	10.39
4/3/2012	22	12	16	32.45	8.24
4/4/2012	16	12	13	32.68	4.71
4/5/2012	16	8	12	32.91	6.22
4/6/2012	19	6	13	33.14	8.25
4/7/2012	18	10	13	33.36	6.63
4/8/2012	20	5	13	33.58	9.13
4/9/2012	22	9	15	33.80	9.15
4/10/2012	17	5	12	34.02	8.07
4/11/2012	15	5	11	34.23	7.11
4/12/2012	15	9	11	34.44	5.19
4/13/2012	24	11	19	34.65	10.69
4/14/2012	23	16	19	34.86	8.04
4/15/2012	22	11	18	35.07	9.63
4/16/2012	18	7	12	35.27	7.89
4/17/2012	22	9	16	35.47	9.67
4/18/2012	24	12	18	35.67	10.18
4/19/2012	23	9	17	35.86	10.82
4/20/2012	16	6	11	36.05	7.23
4/21/2012	22	5	13	36.24	10.72
4/22/2012	17	6	12	36.43	8.21
4/23/2012	20	5	14	36.61	10.57

4/24/2012	33	11	20	36.79	15.06
4/25/2012	34	16	25	36.97	15.34
4/26/2012	26	17	22	37.14	10.02
4/27/2012	19	14	17	37.32	6.91
4/28/2012	20	10	15	37.49	9.09
4/29/2012	15	12	13	37.65	5.06
4/30/2012	19	11	14	37.81	8.19
5/1/2012	28	14	21	37.97	12.23
5/2/2012	28	20	23	38.13	10.12
5/3/2012	29	17	23	38.28	12.38
5/4/2012	32	21	26	38.43	12.54
5/5/2012	31	20	25	38.58	12.33
5/6/2012	25	17	22	38.73	10.23
5/7/2012	22	12	17	38.87	9.55
5/8/2012	23	9	16	39.01	11.03
5/9/2012	22	9	15	39.14	10.92
5/10/2012	27	12	21	39.27	13.87
5/11/2012	25	15	20	39.40	10.37
5/12/2012	18	9	14	39.53	8.60
5/13/2012	24	12	18	39.65	10.94
5/14/2012	26	14	20	39.77	12.32
5/15/2012	30	14	22	39.88	14.80
5/16/2012	27	12	20	39.99	13.32
5/17/2012	30	15	22	40.10	14.58
5/18/2012	30	18	24	40.21	13.36
5/19/2012	30	21	25	40.31	11.83
5/20/2012	24	12	18	40.41	11.46
5/21/2012	24	10	17	40.51	12.35
5/22/2012	18	13	15	40.60	7.15

Table H.7. Two water use coefficients (K_c) were determined by dividing the system ET from both the FAO56 Penman-Monteith and Hargreaves reference ET values from January 27, 2011 to May 22, 2012. From January 1 to January 27, there was missing weather data creating the error message #DIV/0!.

Date	ET _{act} (mm/day)	FAO56 ET _o (mm/day)	Hargreaves ET _o (mm/day)	FAO56K _c (mm/mm)	Hargreaves K _c (mm/mm)
1/1/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/2/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/3/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/4/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/5/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/6/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!

1/7/2011	0.39	0.00	0.00	#DIV/0!	#DIV/0!
1/8/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/9/2011	1.02	0.00	0.00	#DIV/0!	#DIV/0!
1/10/2011	0.51	0.00	0.00	#DIV/0!	#DIV/0!
1/11/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/12/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/13/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/14/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/15/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/16/2011	0.25	0.00	0.00	#DIV/0!	#DIV/0!
1/17/2011	7.59	0.00	0.00	#DIV/0!	#DIV/0!
1/18/2011	16.33	0.00	0.00	#DIV/0!	#DIV/0!
1/19/2011	5.84	0.00	0.00	#DIV/0!	#DIV/0!
1/20/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/21/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/22/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/23/2011	0.00	0.00	0.00	#DIV/0!	#DIV/0!
1/24/2011	8.72	0.00	0.00	#DIV/0!	#DIV/0!
1/25/2011	13.80	0.00	0.00	#DIV/0!	#DIV/0!
1/26/2011	13.80	0.00	0.00	#DIV/0!	#DIV/0!
1/27/2011	13.80	1.33	3.07	11.96	5.16
1/28/2011	20.15	1.46	3.92	15.89	5.91
1/29/2011	27.25	1.06	2.74	29.64	11.45
1/30/2011	26.74	0.90	1.47	34.20	20.89
1/31/2011	27.60	0.38	1.31	83.37	24.30
2/1/2011	29.63	0.30	0.32	113.86	104.84
2/2/2011	27.60	0.61	0.41	52.01	76.80
2/3/2011	27.61	0.85	0.98	37.44	32.28
2/4/2011	27.50	1.37	2.11	23.10	14.99
2/5/2011	27.28	1.20	2.94	26.10	10.67
2/6/2011	13.83	0.91	1.73	17.56	9.20
2/7/2011	23.61	1.05	1.73	25.77	15.69
2/8/2011	24.63	0.49	0.66	57.12	42.42
2/9/2011	13.78	0.83	1.16	19.04	13.66
2/10/2011	13.78	0.95	1.27	16.65	12.48
2/11/2011	13.78	1.34	2.77	11.82	5.72
2/12/2011	13.78	1.94	3.49	8.18	4.54
2/13/2011	13.78	2.67	5.05	5.93	3.13
2/14/2011	17.44	1.55	4.11	12.98	4.88
2/15/2011	20.68	1.72	4.78	13.83	4.97
2/16/2011	16.35	2.74	6.25	6.84	3.00
2/17/2011	0.00	4.40	6.05	0.00	0.00

2/18/2011	5.21	1.95	4.80	3.08	1.25
2/19/2011	0.00	1.66	3.42	0.00	0.00
2/20/2011	0.00	4.74	6.87	0.00	0.00
2/21/2011	13.95	1.59	2.21	10.11	7.26
2/22/2011	15.16	1.63	3.50	10.70	4.98
2/23/2011	16.80	2.68	5.24	7.21	3.68
2/24/2011	30.33	0.70	2.36	47.94	14.19
2/25/2011	18.24	0.72	1.24	29.18	16.90
2/26/2011	20.94	0.60	1.94	40.39	12.41
2/27/2011	20.93	0.69	1.73	34.67	13.91
2/28/2011	13.81	1.96	3.65	8.11	4.34
3/1/2011	14.20	2.94	6.55	5.55	2.49
3/2/2011	20.68	1.68	3.95	14.12	6.01
3/3/2011	12.42	2.87	6.91	4.98	2.07
3/4/2011	13.81	1.24	3.33	12.77	4.77
3/5/2011	13.81	1.86	3.38	8.54	4.70
3/6/2011	13.81	2.43	4.70	6.54	3.38
3/7/2011	14.01	1.15	2.92	13.99	5.49
3/8/2011	18.59	0.70	2.05	29.57	10.07
3/9/2011	13.40	1.36	3.28	11.31	4.70
3/10/2011	6.63	2.41	6.29	3.16	1.21
3/11/2011	0.69	4.26	8.60	0.19	0.09
3/12/2011	3.40	1.89	6.14	2.07	0.64
3/13/2011	5.46	1.05	2.85	5.95	2.19
3/14/2011	-6.44	1.49	4.13	-6.07	-2.20
3/15/2011	1.57	2.20	6.28	0.82	0.29
3/16/2011	2.02	4.47	9.08	0.52	0.26
3/17/2011	3.40	4.95	8.56	0.79	0.46
3/18/2011	-0.78	3.45	6.56	-0.26	-0.14
3/19/2011	5.11	1.65	4.72	2.60	0.91
3/20/2011	-1.50	5.68	9.85	-0.30	-0.17
3/21/2011	6.77	4.98	10.39	1.56	0.75
3/22/2011	7.35	7.36	10.77	1.15	0.78
3/23/2011	-4.67	3.71	6.47	-1.45	-0.83
3/24/2011	2.73	2.21	4.25	1.31	0.68
3/25/2011	2.55	0.97	3.12	2.96	0.92
3/26/2011	0.61	0.86	2.33	0.82	0.30
3/27/2011	2.93	1.03	2.35	3.25	1.42
3/28/2011	1.90	0.91	3.19	2.26	0.65
3/29/2011	-4.45	1.44	4.49	-3.58	-1.15
3/30/2011	-0.72	1.34	5.10	-0.61	-0.16
3/31/2011	4.31	1.21	5.50	3.77	0.83

4/1/2011	0.36	3.54	8.32	0.12	0.05
4/2/2011	0.16	5.65	11.09	0.03	0.02
4/3/2011	4.18	10.07	14.14	0.47	0.34
4/4/2011	-0.98	4.42	6.13	-0.26	-0.18
4/5/2011	11.74	5.90	10.55	2.29	1.28
4/6/2011	13.81	5.20	9.88	3.05	1.61
4/7/2011	0.14	1.76	3.65	0.09	0.04
4/8/2011	11.56	2.93	7.02	4.35	1.82
4/9/2011	13.81	3.70	12.90	4.30	1.23
4/10/2011	12.94	2.76	11.34	5.40	1.31
4/11/2011	13.81	2.04	8.68	7.79	1.83
4/12/2011	13.81	1.66	10.62	9.57	1.49
4/13/2011	13.81	2.31	10.73	6.86	1.48
4/14/2011	12.68	2.86	9.92	4.60	1.32
4/15/2011	-0.85	2.89	7.24	-0.72	-0.29
4/16/2011	2.13	2.12	9.16	1.15	0.27
4/17/2011	2.75	2.32	10.68	1.36	0.30
4/18/2011	1.68	2.51	7.14	0.77	0.27
4/19/2011	3.84	2.36	4.47	1.85	0.98
4/20/2011	5.58	2.00	7.32	3.21	0.88
4/21/2011	5.20	2.34	7.11	2.56	0.84
4/22/2011	-2.15	3.27	8.98	-1.21	-0.44
4/23/2011	1.94	2.40	7.03	0.93	0.32
4/24/2011	-0.12	2.39	8.65	-0.06	-0.02
4/25/2011	10.43	3.02	4.98	3.40	2.06
4/26/2011	-3.99	2.94	6.99	-1.60	-0.67
4/27/2011	7.41	2.70	7.58	3.16	1.13
4/28/2011	4.81	2.52	10.85	2.19	0.51
4/29/2011	5.60	2.63	12.00	2.45	0.54
4/30/2011	4.47	2.27	9.46	2.27	0.54
5/1/2011	11.45	4.14	8.81	3.18	1.49
5/2/2011	4.83	3.83	9.98	1.45	0.56
5/3/2011	6.21	4.07	11.56	1.76	0.62
5/4/2011	5.66	7.25	13.39	0.90	0.49
5/5/2011	4.45	3.42	10.44	1.42	0.47
5/6/2011	10.11	5.98	14.77	1.82	0.74
5/7/2011	13.26	5.27	13.35	2.64	1.04
5/8/2011	1.51	6.81	14.20	0.25	0.12
5/9/2011	10.94	3.77	15.28	3.34	0.82
5/10/2011	3.60	4.07	13.96	1.02	0.30
5/11/2011	11.80	4.05	13.17	3.30	1.02
5/12/2011	6.04	3.35	12.95	2.01	0.52

5/13/2011	-0.68	2.78	4.33	-0.36	-0.23
5/14/2011	6.26	2.29	7.03	3.14	1.02
5/15/2011	8.30	2.49	6.39	3.83	1.49
5/16/2011	2.61	2.23	10.16	1.35	0.30
5/17/2011	4.34	2.35	9.39	2.07	0.52
5/18/2011	22.56	3.28	8.22	6.95	2.77
5/19/2011	-17.34	5.05	8.00	-4.06	-2.56
5/20/2011	-3.04	5.74	9.06	-0.93	-0.59
5/21/2011	-3.92	5.01	11.63	-0.90	-0.39
5/22/2011	4.69	3.66	12.33	1.48	0.44
5/23/2011	6.82	4.11	12.41	1.91	0.63
5/24/2011	28.85	4.57	9.33	5.94	2.91
5/25/2011	-7.27	3.73	7.70	-4.20	-2.03
5/26/2011	-64.09	3.17	8.79	-23.26	-8.38
5/27/2011	-24.02	4.24	5.69	-6.55	-4.87
5/28/2011	5.09	4.66	8.55	1.24	0.68
5/29/2011	5.71	5.47	12.74	1.20	0.52
5/30/2011	24.27	4.83	13.54	5.28	1.88
5/31/2011	-7.50	3.50	12.75	-2.47	-0.68
6/1/2011	82.88	5.12	9.53	15.88	8.54
6/2/2011	-59.01	5.68	11.75	-11.96	-5.78
6/3/2011	-60.34	4.77	13.58	-14.53	-5.11
6/4/2011	-27.58	4.42	13.21	-7.17	-2.40
6/5/2011	-2.74	4.11	13.98	-0.77	-0.23
6/6/2011	6.73	4.40	14.79	1.76	0.52
6/7/2011	8.40	4.36	12.96	2.21	0.74
6/8/2011	12.43	4.29	16.26	3.32	0.87
6/9/2011	9.52	4.51	16.33	2.34	0.65
6/10/2011	5.29	4.45	11.14	1.37	0.55
6/11/2011	3.76	3.82	10.77	1.13	0.40
6/12/2011	6.07	4.68	9.98	1.46	0.68
6/13/2011	7.63	4.81	15.32	1.81	0.57
6/14/2011	7.50	5.48	13.84	1.57	0.62
6/15/2011	4.31	5.21	14.83	0.95	0.33
6/16/2011	7.56	5.08	10.87	1.49	0.70
6/17/2011	1.86	6.35	14.16	0.31	0.14
6/18/2011	4.32	5.15	12.44	0.25	0.11
6/19/2011	-1.14	6.01	13.98	-0.22	-0.09
6/20/2011	10.16	7.05	15.20	1.58	0.73
6/21/2011	4.06	5.53	9.52	0.84	0.49
6/22/2011	10.31	5.87	12.80	2.02	0.93
6/23/2011	6.04	4.90	13.20	1.42	0.53

6/24/2011	7.50	5.41	13.08	1.59	0.66
6/25/2011	9.21	5.22	13.05	1.79	0.72
6/26/2011	5.10	6.45	14.32	0.91	0.41
6/27/2011	-5.74	5.67	12.80	-1.23	-0.55
6/28/2011	6.62	4.99	12.52	1.53	0.61
6/29/2011	6.81	6.35	15.35	1.23	0.51
6/30/2011	6.67	8.44	17.01	0.91	0.45
7/1/2011	5.05	8.23	16.07	0.71	0.36
7/2/2011	11.09	5.39	12.85	2.37	0.99
7/3/2011	1.72	5.23	10.59	0.38	0.19
7/4/2011	3.33	5.58	13.01	0.69	0.29
7/5/2011	6.86	6.31	14.45	1.25	0.55
7/6/2011	2.24	5.66	12.57	0.43	0.20
7/7/2011	-10.76	5.28	10.59	-2.38	-1.19
7/8/2011	1.00	5.62	12.64	0.19	0.09
7/9/2011	6.02	6.16	13.83	1.12	0.50
7/10/2011	7.39	7.11	15.86	1.20	0.54
7/11/2011	8.83	6.07	15.83	1.67	0.64
7/12/2011	12.43	6.41	16.31	2.17	0.85
7/13/2011	3.06	5.43	12.69	0.62	0.27
7/14/2011	8.88	6.62	14.07	1.54	0.73
7/15/2011	10.59	7.48	15.23	1.63	0.80
7/16/2011	11.26	7.16	15.61	1.80	0.83
7/17/2011	11.03	7.03	15.68	1.80	0.81
7/18/2011	10.53	6.53	15.03	1.85	0.81
7/19/2011	-2.07	6.99	15.73	-0.34	-0.15
7/20/2011	-0.02	7.91	16.76	0.00	0.00
7/21/2011	-0.03	7.35	15.04	0.00	0.00
7/22/2011	-0.02	7.57	16.29	0.00	0.00
7/23/2011	-0.01	7.55	16.72	0.00	0.00
7/24/2011	1.01	6.94	17.52	0.15	0.06
7/25/2011	11.43	5.61	14.70	2.04	0.78
7/26/2011	0.00	6.32	14.78	0.00	0.00
7/27/2011	0.00	9.55	16.83	0.00	0.00
7/28/2011	0.00	5.96	15.56	0.00	0.00
7/29/2011	18.29	5.65	10.55	3.24	1.73
7/30/2011	2.54	6.63	13.75	0.38	0.18
7/31/2011	0.51	7.15	14.86	0.07	0.03
8/1/2011	0.25	7.51	16.93	0.03	0.02
8/2/2011	0.00	7.32	15.68	0.00	0.00
8/3/2011	8.49	6.06	10.96	1.61	0.89
8/4/2011	21.47	5.52	11.78	4.45	2.09

8/5/2011	27.32	5.70	12.48	5.33	2.44
8/6/2011	12.19	6.07	13.02	2.30	1.07
8/7/2011	-6.94	5.80	13.09	-1.38	-0.61
8/8/2011	-0.51	5.62	11.84	-0.12	-0.06
8/9/2011	6.86	5.13	12.61	1.53	0.62
8/10/2011	2.83	4.75	10.36	0.68	0.31
8/11/2011	4.21	5.14	12.87	0.94	0.38
8/12/2011	-5.10	4.60	11.86	-1.31	-0.51
8/13/2011	-8.29	5.59	13.28	-1.71	-0.72
8/14/2011	5.13	5.57	14.06	1.06	0.42
8/15/2011	2.54	6.05	12.71	0.19	0.09
8/16/2011	1.33	6.56	14.95	0.23	0.10
8/17/2011	0.49	5.65	9.82	0.10	0.06
8/18/2011	2.59	6.26	13.34	0.46	0.22
8/19/2011	-18.62	5.60	11.09	-3.83	-1.93
8/20/2011	-40.55	5.44	9.50	-8.59	-4.92
8/21/2011	4.14	5.75	11.58	0.81	0.40
8/22/2011	1.88	6.53	11.65	0.31	0.18
8/23/2011	9.46	6.71	14.12	1.61	0.77
8/24/2011	5.74	6.35	12.50	1.03	0.53
8/25/2011	8.93	4.61	10.54	2.22	0.97
8/26/2011	7.16	5.64	12.78	1.45	0.64
8/27/2011	10.36	5.47	11.96	2.18	1.00
8/28/2011	3.54	5.47	10.91	0.74	0.37
8/29/2011	8.41	4.94	10.54	1.96	0.92
8/30/2011	3.64	6.06	11.54	0.65	0.34
8/31/2011	0.26	6.33	12.84	0.05	0.02
9/1/2011	9.46	9.34	13.69	1.16	0.79
9/2/2011	12.21	7.28	12.81	1.93	1.10
9/3/2011	10.34	5.11	10.16	2.25	1.13
9/4/2011	4.19	4.74	8.55	1.02	0.56
9/5/2011	5.38	3.37	8.82	1.84	0.70
9/6/2011	8.16	3.55	8.59	2.65	1.09
9/7/2011	5.01	3.49	9.32	1.65	0.62
9/8/2011	-2.53	3.76	8.77	-0.77	-0.33
9/9/2011	-3.49	4.33	9.55	-1.05	-0.48
9/10/2011	-6.89	4.29	9.24	-1.95	-0.91
9/11/2011	-2.86	4.01	10.49	-0.82	-0.31
9/12/2011	-1.73	6.39	12.02	-0.31	-0.17
9/13/2011	-0.22	5.14	8.48	-0.05	-0.03
9/14/2011	-5.13	3.54	6.80	-1.66	-0.87
9/15/2011	-3.33	2.66	4.69	-1.44	-0.82

9/16/2011	-3.59	2.98	4.78	-1.61	-1.01
9/17/2011	-7.44	3.26	5.14	-2.68	-1.69
9/18/2011	-33.68	4.25	5.90	-9.40	-6.77
9/19/2011	-12.33	4.44	9.83	-3.25	-1.47
9/20/2011	-3.24	4.89	9.02	-0.79	-0.43
9/21/2011	-2.52	3.48	6.99	-0.84	-0.42
9/22/2011	-3.19	3.22	8.21	-1.15	-0.45
9/23/2011	-11.83	3.60	7.63	-3.79	-1.79
9/24/2011	-7.99	3.85	6.95	-2.38	-1.32
9/25/2011	-9.18	2.89	6.81	-3.65	-1.55
9/26/2011	-4.93	2.88	8.41	-1.98	-0.68
9/27/2011	-0.78	3.62	8.99	-0.25	-0.10
9/28/2011	0.87	2.81	10.10	0.36	0.10
9/29/2011	6.90	5.15	7.88	1.54	1.01
9/30/2011	6.39	3.30	7.62	2.23	0.96
10/1/2011	0.10	3.87	7.26	0.03	0.02
10/2/2011	-3.13	4.46	7.91	-0.81	-0.46
10/3/2011	-0.30	6.04	8.78	-0.06	-0.04
10/4/2011	6.08	6.72	9.51	1.04	0.74
10/5/2011	-0.57	5.80	8.11	-0.11	-0.08
10/6/2011	12.39	6.85	7.95	2.08	1.79
10/7/2011	5.95	6.26	6.63	1.09	1.03
10/8/2011	7.03	4.25	6.19	1.90	1.31
10/9/2011	7.86	4.60	6.88	1.96	1.31
10/10/2011	-7.36	3.12	5.23	-2.81	-1.68
10/11/2011	2.01	3.82	6.58	0.59	0.35
10/12/2011	-3.51	3.60	5.96	-1.14	-0.69
10/13/2011	6.65	3.94	6.70	1.93	1.14
10/14/2011	2.72	2.88	4.91	1.07	0.63
10/15/2011	1.14	3.67	7.00	0.36	0.19
10/16/2011	3.07	3.50	5.46	1.01	0.65
10/17/2011	3.01	2.61	3.81	1.30	0.89
10/18/2011	2.86	2.81	3.67	1.17	0.89
10/19/2011	0.82	2.65	3.68	0.35	0.26
10/20/2011	2.03	1.88	4.31	1.24	0.54
10/21/2011	0.96	2.62	6.26	0.42	0.18
10/22/2011	2.21	2.63	5.95	0.96	0.43
10/23/2011	4.32	3.26	7.01	1.52	0.71
10/24/2011	0.79	4.96	7.77	0.18	0.12
10/25/2011	0.81	5.69	6.54	0.16	0.14
10/26/2011	3.28	2.61	3.63	1.43	1.03
10/27/2011	7.90	2.07	3.91	4.40	2.33

10/28/2011	1.69	2.26	4.59	0.86	0.42
10/29/2011	3.34	4.02	5.43	0.96	0.71
10/30/2011	2.61	3.29	3.79	0.91	0.79
10/31/2011	1.35	2.38	5.51	0.65	0.28
11/1/2011	2.23	3.57	5.56	0.72	0.46
11/2/2011	2.44	2.53	4.53	1.06	0.59
11/3/2011	2.43	2.46	3.08	1.10	0.88
11/4/2011	1.27	2.17	4.08	0.67	0.36
11/5/2011	1.43	2.45	3.62	0.67	0.45
11/6/2011	1.01	2.93	3.86	0.40	0.30
11/7/2011	2.10	2.42	3.20	0.59	0.44
11/8/2011	-8.72	0.88	2.47	-13.39	-4.77
11/9/2011	-8.83	2.00	2.86	-5.46	-3.82
11/10/2011	26.49	1.38	3.15	19.04	8.36
11/11/2011	0.92	2.32	4.05	0.44	0.25
11/12/2011	1.11	3.12	4.02	0.41	0.32
11/13/2011	0.92	2.94	3.81	0.36	0.28
11/14/2011	-22.67	1.92	2.98	-13.56	-8.76
11/15/2011	-18.74	2.44	3.84	-8.84	-5.61
11/16/2011	-1.80	1.28	2.02	-1.61	-1.02
11/17/2011	-0.24	1.76	2.79	-0.18	-0.11
11/18/2011	0.00	2.66	3.36	0.00	0.00
11/19/2011	6.55	2.72	4.09	2.77	1.84
11/20/2011	11.89	0.77	1.17	17.82	11.71
11/21/2011	2.04	0.56	1.45	4.19	1.61
11/22/2011	4.82	0.58	1.44	7.89	3.17
11/23/2011	-1.51	1.54	3.71	-1.15	-0.48
11/24/2011	0.93	3.13	3.96	0.34	0.27
11/25/2011	3.31	1.72	3.20	2.01	1.08
11/26/2011	0.85	1.81	2.86	-0.28	-0.18
11/27/2011	1.38	1.31	1.81	1.21	0.88
11/28/2011	2.63	0.80	2.35	3.77	1.28
11/29/2011	0.51	1.78	2.11	0.33	0.28
11/30/2011	0.97	2.20	2.79	0.51	0.40
12/1/2011	4.35	1.37	2.09	3.65	2.39
12/2/2011	3.96	0.62	1.77	7.25	2.56
12/3/2011	-21.61	0.45	2.18	-55.56	-11.62
12/4/2011	76.35	0.64	1.46	-14.43	-6.34
12/5/2011	1.13	0.45	0.79	2.88	1.64
12/6/2011	2.85	0.58	0.97	5.67	3.37
12/7/2011	2.86	0.81	1.79	3.97	1.80
12/8/2011	1.09	0.62	1.69	1.96	0.72

12/9/2011	2.12	0.53	1.25	4.43	1.86
12/10/2011	2.41	0.87	2.07	2.83	1.19
12/11/2011	-0.61	1.01	2.10	-0.73	-0.35
12/12/2011	-1.12	1.15	1.52	-1.12	-0.85
12/13/2011	10.64	0.60	1.39	16.41	7.14
12/14/2011	-17.04	0.98	3.09	-22.78	-7.21
12/15/2011	-2.17	0.98	1.75	-2.54	-1.42
12/16/2011	0.44	0.52	1.83	0.98	0.28
12/17/2011	2.02	0.71	2.49	3.26	0.93
12/18/2011	0.16	1.85	3.08	0.10	0.06
12/19/2011	-2.00	0.81	2.01	-4.24	-1.71
12/20/2011	-33.18	0.26	0.58	-144.65	-65.54
12/21/2011	-8.00	0.44	1.94	-21.81	-5.00
12/22/2011	-3.57	0.67	1.41	-6.21	-2.93
12/23/2011	-2.12	0.70	1.53	-3.47	-1.59
12/24/2011	2.97	0.87	2.19	3.90	1.54
12/25/2011	1.11	0.85	2.50	1.50	0.51
12/26/2011	1.38	0.64	2.05	2.49	0.77
12/27/2011	-4.90	1.31	1.88	-4.29	-3.00
12/28/2011	2.96	1.19	2.24	2.85	1.52
12/29/2011	0.78	1.03	2.54	0.87	0.35
12/30/2011	-0.38	2.38	2.58	-0.19	-0.17
12/31/2011	-0.18	2.59	3.07	-0.12	-0.10
1/1/2012	4.46	2.14	2.07	2.40	2.48
1/2/2012	3.28	1.20	1.61	3.15	2.34
1/3/2012	1.66	1.22	2.00	1.57	0.95
1/4/2012	-0.07	2.04	2.77	-0.04	-0.03
1/5/2012	0.84	2.08	3.70	0.47	0.26
1/6/2012	0.97	2.19	2.84	0.51	0.39
1/7/2012	1.87	1.03	2.19	2.08	0.98
1/8/2012	-0.46	0.81	1.80	-0.66	-0.30
1/9/2012	6.50	0.97	2.83	7.71	2.64
1/10/2012	-0.01	1.15	3.26	-0.01	0.00
1/11/2012	4.72	0.63	2.05	8.66	2.65
1/12/2012	4.80	1.02	0.94	5.39	5.88
1/13/2012	5.18	1.66	1.69	3.59	3.52
1/14/2012	-1.30	1.09	2.20	-1.37	-0.68
1/15/2012	-0.47	3.43	4.04	-0.16	-0.13
1/16/2012	-1.80	1.51	2.73	-1.37	-0.76
1/17/2012	3.89	0.76	1.12	5.85	3.98
1/18/2012	4.90	1.47	2.26	3.84	2.50
1/19/2012	1.87	0.94	1.34	2.30	1.61

1/20/2012	7.14	0.63	0.93	13.14	8.79
1/21/2012	3.38	0.52	1.25	7.40	3.12
1/22/2012	0.42	2.28	3.86	0.18	0.11
1/23/2012	-1.79	1.11	1.91	-1.85	-1.08
1/24/2012	2.40	1.70	2.91	1.63	0.95
1/25/2012	-3.12	1.29	2.82	-2.78	-1.27
1/26/2012	-1.52	1.95	3.23	-0.90	-0.54
1/27/2012	-0.09	1.32	2.49	-0.08	-0.04
1/28/2012	2.92	2.04	2.84	1.65	1.18
1/29/2012	0.77	1.58	3.64	0.56	0.24
1/30/2012	0.73	4.04	4.71	0.21	0.18
1/31/2012	-1.06	2.14	3.31	-0.57	-0.37
2/1/2012	6.35	1.36	4.27	5.37	1.71
2/2/2012	8.76	2.03	3.68	4.97	2.74
2/3/2012	8.69	1.89	2.48	3.50	2.66
2/4/2012	-7.98	0.71	1.76	-13.81	-5.54
2/5/2012	-2.30	1.23	2.77	-2.15	-0.95
2/6/2012	1.84	1.16	3.50	1.78	0.59
2/7/2012	0.16	1.01	2.35	0.18	0.08
2/8/2012	2.06	0.65	1.11	3.68	2.15
2/9/2012	-6.55	0.89	1.94	-8.44	-3.88
2/10/2012	-2.72	1.30	2.23	-2.41	-1.40
2/11/2012	3.44	1.01	1.19	3.90	3.31
2/12/2012	4.38	1.28	2.22	3.92	2.27
2/13/2012	3.68	0.82	1.64	5.09	2.55
2/14/2012	-4.88	1.09	3.54	-5.20	-1.61
2/15/2012	-6.72	0.93	2.06	-8.43	-3.79
2/16/2012	-7.42	1.12	3.68	-7.65	-2.32
2/17/2012	-1.64	2.00	4.18	-0.94	-0.45
2/18/2012	0.69	1.46	2.85	0.54	0.28
2/19/2012	-0.34	1.90	3.79	-0.21	-0.10
2/20/2012	4.41	1.58	2.80	2.75	1.55
2/21/2012	-4.63	2.34	4.15	-2.29	-1.29
2/22/2012	-6.99	2.26	5.19	-3.61	-1.57
2/23/2012	-1.07	2.46	4.22	-0.50	-0.29
2/24/2012	3.20	2.22	3.63	1.66	1.02
2/25/2012	1.76	1.68	3.92	1.20	0.52
2/26/2012	2.56	4.12	5.11	0.71	0.57
2/27/2012	3.32	1.91	3.81	2.00	1.00
2/28/2012	1.63	2.77	5.22	0.55	0.29
2/29/2012	-0.91	3.44	4.44	-0.30	-0.24
3/1/2012	1.50	3.69	6.51	0.47	0.26

3/2/2012	5.10	2.69	4.22	2.09	1.34
3/3/2012	4.68	1.93	3.93	2.79	1.37
3/4/2012	1.05	3.52	6.01	0.34	0.20
3/5/2012	3.66	3.25	6.15	1.30	0.68
3/6/2012	-0.08	5.41	6.07	-0.02	-0.02
3/7/2012	-0.09	3.77	7.15	-0.03	-0.01
3/8/2012	8.68	2.28	4.53	4.31	2.17
3/9/2012	2.14	2.49	6.66	0.99	0.37
3/10/2012	3.34	3.77	6.86	1.02	0.56
3/11/2012	3.47	2.28	3.36	1.22	0.82
3/12/2012	-0.78	4.26	7.76	-0.30	-0.17
3/13/2012	0.68	4.34	8.86	0.18	0.09
3/14/2012	3.47	4.94	8.33	0.81	0.48
3/15/2012	2.18	4.00	8.11	0.63	0.31
3/16/2012	3.05	3.96	7.71	0.89	0.46
3/17/2012	-0.08	4.48	7.25	-0.02	-0.01
3/18/2012	-0.86	4.36	5.32	-0.23	-0.19
3/19/2012	10.13	3.15	5.88	3.01	1.61
3/20/2012	-0.10	2.33	2.50	-0.43	-0.40
3/21/2012	-3.14	2.22	5.14	-1.93	-0.84
3/22/2012	-14.07	2.64	5.86	-6.39	-2.88
3/23/2012	-7.06	2.57	6.44	-3.33	-1.33
3/24/2012	1.47	2.88	9.53	0.51	0.15
3/25/2012	2.97	3.30	9.46	1.00	0.35
3/26/2012	0.44	5.37	9.17	0.09	0.05
3/27/2012	-12.29	4.71	8.37	-3.00	-1.69
3/28/2012	-5.14	4.19	9.40	-1.42	-0.63
3/29/2012	-2.55	4.72	9.02	-0.63	-0.33
3/30/2012	-1.07	3.83	9.73	-0.32	-0.13
3/31/2012	7.87	4.75	11.23	1.90	0.81
4/1/2012	8.40	6.21	11.76	1.55	0.82
4/2/2012	11.44	7.10	10.39	1.85	1.27
4/3/2012	6.53	3.47	8.24	2.17	0.91
4/4/2012	6.63	2.67	4.71	2.60	1.47
4/5/2012	0.08	2.81	6.22	-0.02	-0.01
4/6/2012	-0.51	3.31	8.25	-0.18	-0.07
4/7/2012	8.26	3.45	6.63	2.45	1.27
4/8/2012	2.02	2.97	9.13	0.78	0.25
4/9/2012	3.01	3.04	9.15	1.14	0.38
4/10/2012	6.46	2.98	8.07	2.49	0.92
4/11/2012	4.80	2.51	7.11	2.20	0.78
4/12/2012	5.37	3.15	5.19	1.87	1.13

4/13/2012	2.92	4.42	10.69	0.76	0.31
4/14/2012	0.94	3.90	8.04	0.13	0.06
4/15/2012	0.07	5.76	9.63	-0.06	-0.03
4/16/2012	3.78	3.69	7.89	1.18	0.55
4/17/2012	4.48	4.18	9.67	1.23	0.53
4/18/2012	6.74	4.54	10.18	1.71	0.76
4/19/2012	6.21	4.60	10.82	1.55	0.66
4/20/2012	3.69	3.44	7.23	1.23	0.59
4/21/2012	2.15	3.67	10.72	0.67	0.23
4/22/2012	9.66	3.95	8.21	2.82	1.35
4/23/2012	4.88	2.48	10.57	2.26	0.53
4/24/2012	7.80	5.90	15.06	1.52	0.60
4/25/2012	6.76	6.27	15.34	1.24	0.51
4/26/2012	2.42	5.18	10.02	0.54	0.28
4/27/2012	5.71	3.86	6.91	1.70	0.95
4/28/2012	9.32	4.12	9.09	2.58	1.17
4/29/2012	-16.39	3.43	5.06	-5.49	-3.73
4/30/2012	-1.02	4.14	8.19	-0.28	-0.14
5/1/2012	4.72	5.50	12.23	0.99	0.44
5/2/2012	5.74	5.95	10.12	1.10	0.64
5/3/2012	4.40	5.50	12.38	0.91	0.41
5/4/2012	5.33	6.21	12.54	0.99	0.49
5/5/2012	5.75	5.94	12.33	1.11	0.54
5/6/2012	-0.57	4.77	10.23	-0.14	-0.06
5/7/2012	5.47	5.03	9.55	1.25	0.66
5/8/2012	7.50	4.06	11.03	2.12	0.78
5/9/2012	5.83	3.53	10.92	1.90	0.61
5/10/2012	4.37	5.22	13.87	0.96	0.36
5/11/2012	9.25	4.13	10.37	2.58	1.03
5/12/2012	0.10	3.85	8.60	0.03	0.01
5/13/2012	-0.79	3.78	10.94	-0.24	-0.08
5/14/2012	8.65	3.66	12.32	2.72	0.81
5/15/2012	3.81	4.85	14.80	0.90	0.30
5/16/2012	9.31	4.86	13.32	2.20	0.80
5/17/2012	10.19	6.66	14.58	1.76	0.80
5/18/2012	8.39	6.70	13.36	1.44	0.72
5/19/2012	9.77	7.60	11.83	1.48	0.95
5/20/2012	5.75	4.27	11.46	1.55	0.58
5/21/2012	8.37	3.89	12.35	2.48	0.78
5/22/2012	12.02	2.80	7.15	4.93	1.93

Appendix I - The Mass Balance

A Microsoft Excel spreadsheet, titled Weekly_Water_Budget.xlsx, was created and used to develop a mass balance for the seven main constituents discussed above. Within the spreadsheet, there were worksheets for each of the seven constituents as well as a Daily Flow and Weekly Flow worksheets. The Daily Flow worksheet is similar to the water budget spreadsheet discussed earlier, in which it contains a daily value of all the water inputs and outputs of the CWTS. The RAW, FGDWW, and LS (effluent) were input into this spreadsheet in US gallons, which are converted to liters by multiplying the US gallons value by 3.785, because there are 3.785 US gallons in 1 Liter. The precipitation daily values were input into the spreadsheet as millimeters, so no conversion was needed. These daily values were then converted to weekly values within the Weekly Flow worksheet.

In the Weekly Flow worksheet, the date is broken down into a 7 day period, representing a week, in which the first week starts on January 4th, 2011, which was a Tuesday. All the weeks begin on a Tuesday, because all water quality measurements, weather data, effluent flow data, and water samples were conducted on a Tuesday. All the RAW, FGDWW, and LS (effluent) data was summed up to acquire a weekly value, while the precipitation was also summed up to a weekly value and converted from millimeters to liters by dividing by 1000, because there is 1000 mm in 1 L. All of these weekly values, RAW, FGDWW, LS, and Precipitation, were linked to their own columns in each of the seven worksheets for each constituent.

The water samples taken each week and tested through CAS determined the concentration of each concentration for influent, RAW and FGDWW, as well as concentrations for effluent, LS; therefore, a mass balance could be completed to determine how much the CWTS is removing from the FGD waters. For each constituent and the corresponding worksheet, the mass of the pollutant entering and leaving the CWTS was determined to find the total amount of the pollutant removed. A weekly percentage of pollutant removal, as well as a weekly running total of the input and output pollutant totals, were also determined within each worksheet for each constituent.

Boron was the first worksheet in the spreadsheet. Boron concentrations were given from CAS in micrograms per liter ($\mu\text{g/L}$), but were converted to milligrams per liter (mg/L) by dividing the concentrations by 1000, because there are 1000 $\mu\text{g/L}$ in 1 mg/L . Both RAW and FGDWW boron concentrations were multiplied by RAW and FGDWW flow, respectively, in order to determine the incoming mass concentration of boron. Boron concentrations leaving from LS were multiplied by LS flow to determine the outgoing mass concentration of boron; therefore, the total boron mass removed from the water by the CWTS was determined by subtracting the incoming mass concentration from the outgoing mass concentration of boron, given in milligrams (mg) and converted to grams (g). The weekly percentage of boron removal was determined by subtracting incoming mass concentration from outgoing mass concentration of boron, then dividing the number by the incoming mass concentration of boron and multiplying by 100 to get rid of the metric units and create a percentage value. Running totals for both incoming and outgoing mass concentrations were also determined by adding the previous week's incoming and outgoing mass concentration to the current weeks incoming and outgoing mass concentration amounts, respectively. By creating a running total for both incoming and outgoing mass concentrations, how much boron entered and left the CWTS could be determined over the entire study time of the project.

Manganese, mercury, selenium, chloride, fluoride, and sulfate all had their own worksheet inside the spreadsheet, in which the incoming and outgoing mass concentrations, total mass concentration removed, weekly percentage of constituent removal, and running totals for incoming and outgoing mass concentration amounts were determined for each constituent. Manganese, mercury, and selenium concentrations were given from CAS in $\mu\text{g/L}$, which were converted, like the boron concentrations, to mg/L ; however, chloride, fluoride, and sulfate were all given in mg/L from CAS and were not converted.

The following tables (Table I.1 to I.14) all represent one of the seven main pollutants with incoming and outgoing concentrations of each to determine the ability of the CWTS at JEC to remove each one of these pollutants. Each of the seven main pollutants will have two tables, one for the mass removal for 2011 and one for 2012 until May 22nd. The tables are all weekly mass balances.

Table I.1. Boron mass balance for 2011 for the CWTs showing influent and effluent boron concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration. (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/11-1/17	2	74928	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/18-1/24	3	244787	2458		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/25-1/31	4	1404975	8063		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/1-2/7	5	1727647	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/15-2/21	7	345354	206869		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/22-2/28	8	804425	439798		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
3/1-3/7	9	555354	453771		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
3/8-3/14	10	477039	448934		0.0E+00	0	676930	0.0E+00	0	0	#DIV/0!
3/15-3/21	11	449862	403326		0.0E+00	0	794629	0.0E+00	0	0	#DIV/0!
3/22-3/28	12	477041	477041		0.0E+00	0	851842	0.0E+00	0	0	#DIV/0!
3/29-4/4	13	477036	442801		0.0E+00	0	924108	0.0E+00	0	0	#DIV/0!
4/5-4/11	14	403712	333618		0.0E+00	0	4437	0.0E+00	0	0	#DIV/0!
4/12-4/18	15	475294	429557		5.7E+00	2461363	618617	1.2E+00	717596	1744	71%
4/19-4/25	16	429744	397270		5.7E+00	2276360	798544	1.2E+00	926311	1350	59%
4/26-5/2	17	445556	444342		1.7E+00	746495	556057	1.4E+00	750677	-4	-1%
5/3-5/9	18	476990	476986		1.7E+00	801337	592120	1.4E+00	799362	2	0%
5/10-5/16	19	436706	436367		1.7E+00	733096	541199	1.4E+00	730618	2	0%
5/17-5/23	20	473027	472512	0.0E+00	6.2E+00	2948476	1182311	2.0E+00	2376445	572	19%
5/24-5/30	21	476988	476985	0.0E+00	6.2E+00	2976384	2312454	2.0E+00	4648032	-1672	-56%
5/31-6/6	22	465465	461665	0.0E+00	5.3E+00	2442208	2511595	1.3E+00	3365538	-923	-38%
6/7-6/13	23	476988	454262	0.0E+00	6.4E+00	2902732	452238	1.5E+00	678357	2224	77%
6/14-6/20	24	476992	476988	0.0E+00	6.4E+00	3047956	973860	1.5E+00	1460791	1587	52%
6/21-6/27	25	476994	476996	0.0E+00	6.4E+00	3048004	699257	1.5E+00	1048886	1999	66%

6/28-7/4	26	476994	385648	0.0E+00	6.4E+00	2464293	455161	1.5E+00	682741	1782	72%
7/5-7/11	27	476992	477011	0.0E+00	6.9E+00	3300917	766080	2.1E+00	1570464	1730	52%
7/12-7/18	28	472442	463020	0.0E+00	6.9E+00	3204100	303972	2.0E+00	607945	2596	81%
7/19-7/25	29	0	0	0.0E+00	8.1E+00	0	21343	2.1E+00	43966	-44	#DIV/0!
7/26-8/1	30	0	0	0.0E+00	8.1E+00	0	1	2.1E+00	2	0	#DIV/0!
8/2-8/8	31	542690	374177	0.0E+00	9.5E+00	3550936	392520	1.8E+00	706535	2844	80%
8/9-8/15	32	463401	459443	0.0E+00	7.9E+00	3625005	972470	2.5E+00	2470073	1155	32%
8/16-8/22	33	477002	461941	0.0E+00	8.8E+00	4078942	1450070	2.6E+00	3784683	294	7%
8/23-8/29	34	476933	476237	0.0E+00	1.0E+01	4762370	434178	2.7E+00	1167939	3594	75%
8/30-9/5	35	468958	468777	0.0E+00	1.0E+01	4875280	533899	2.8E+00	1516273	3359	69%
9/6-9/12	36	476994	209004	0.0E+00	6.8E+00	1427497	793925	2.7E+00	2167415	-740	-52%
9/13-9/19	37	477000	0	0.0E+00	6.5E+00	0	1278692	2.6E+00	3299026	-3299	#DIV/0!
9/20-9/26	38	204427	0	0.0E+00	5.4E+00	0	645253	2.4E+00	1542155	-1542	#DIV/0!
9/27-10/3	39	351840	0	0.0E+00	5.4E+00	0	252640	2.8E+00	709917	-710	#DIV/0!
10/4-10/10	40	415896	458005	0.0E+00	5.4E+00	2477805	584152	2.8E+00	1641468	836	34%
10/11-10/17	41	427888	509456	0.0E+00	5.4E+00	2756156	805933	2.8E+00	2264672	491	18%
10/18-10/24	42	469921	514948	0.0E+00	6.0E+00	3105139	846823	2.9E+00	2481193	624	20%
10/25-10/31	43	476988	586837	0.0E+00	5.3E+00	3092632	859377	2.6E+00	2234381	858	28%
11/1-11/7	44	476988	658862	0.0E+00	4.1E+00	2714513	1086266	2.5E+00	2693940	21	1%
11/8-11/14	45	416467	585490	0.0E+00	4.6E+00	2669833	1549620	1.9E+00	2944278	-274	-10%
11/15-11/21	46	177812	213217	0.0E+00	4.6E+00	972270	396601	2.0E+00	773372	199	20%
11/22-11/28	47	476988	551103	0.0E+00	2.9E+00	1581665	1093661	2.0E+00	2132639	-551	-35%
11/29-12/5	48	725716	1398505	0.0E+00	3.1E+00	4279426	1566433	2.0E+00	3148530	1131	26%
12/6-12/12	49	951929	606484	0.0E+00	4.0E+00	2413804	1501363	1.6E+00	2447222	-33	-1%
12/13-12/19	50	950135	557701	0.0E+00	4.0E+00	2219650	1989910	1.6E+00	3263452	-1044	-47%
12/20-12/26	51	824622	451198	0.0E+00	5.0E+00	2246968	1724703	1.6E+00	2776771	-530	-24%
12/27-1/2/2012	52	679947	280442	0.0E+00	4.6E+00	1298448	984962	1.5E+00	1516842	-218	-17%

Table I.2. Boron mass balance for 2012 until week 20 or May 22 for the CWTS showing influent and effluent boron concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration. (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	0.0E+00	4.6E+00	2619189	1406015	1.5E+00	2165264	454	17%
1/10-1/16	2	951921	590914	0.0E+00	4.3E+00	2535022	1433115	1.5E+00	2121011	414	16%
1/17-1/23	3	951172	641502	0.0E+00	5.2E+00	3310152	1402139	1.6E+00	2173316	1137	34%
1/24-1/30	4	951740	500291	0.0E+00	4.1E+00	2031183	1431457	1.5E+00	2132871	-102	-5%
1/31-2/6	5	949756	488753	0.0E+00	6.5E+00	3152460	1563137	1.7E+00	2719858	433	14%
2/7-2/13	6	653867	397596	0.0E+00	6.5E+00	2564494	1010046	1.7E+00	1757481	807	31%
2/14-2/20	7	475934	369277	0.0E+00	8.3E+00	3076076	1059859	1.5E+00	1621584	1454	47%
2/21-2/27	8	475936	432515	0.0E+00	8.3E+00	3602854	936829	1.5E+00	1433348	2170	60%
2/28-3/5	9	475942	353005	0.0E+00	1.1E+01	3706550	701668	2.2E+00	1508586	2198	59%
3/6-3/12	10	473283	283189	0.0E+00	1.1E+01	2973480	707119	2.2E+00	1520305	1453	49%
3/13-3/19	11	443980	434017	0.0E+00	8.6E+00	3715187	837526	3.0E+00	2504203	1211	33%
3/20-3/26	12	471946	512541	0.0E+00	8.6E+00	4387351	1380029	3.0E+00	4126286	261	6%
3/27-4/2	13	155169	155666	0.0E+00	5.7E+00	881071	250117	3.9E+00	980460	-99	-11%
4/3-4/9	14	447109	446173	0.0E+00	5.7E+00	2525341	761708	3.9E+00	2985896	-461	-18%
4/10-4/16	15	446434	446132	0.0E+00	6.9E+00	3064924	737546	7.2E+00	5295579	-2231	-73%
4/17-4/23	16	439360	438674	0.0E+00	6.9E+00	3013693	504785	7.2E+00	3624354	-611	-20%
4/24-4/30	17	367001	364210	0.0E+00	8.3E+00	3030224	592054	7.4E+00	4357514	-1327	-44%
5/1-5/7	18	420572	419357	0.0E+00	8.3E+00	3489053	542968	7.4E+00	3996245	-507	-15%
5/8-5/14	19	394169	390456	0.0E+00	8.1E+00	3154883	440115	8.6E+00	3771783	-617	-20%
5/15-5/21	20	381848	380327	0.0E+00	8.1E+00	3073042	213482	8.6E+00	1829541	1244	40%

Table I.3. Manganese mass balance for 2011 for the CWTs showing influent and effluent manganese concentrations, total mass removed weekly, and percent removed weekly. The bold red values show extreme percent removed weekly values.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		3.9E-02	0	0	1.8E-02	0	0	#DIV/0!
1/11-1/17	2	74928	0		3.9E-02	0	0	1.8E-02	0	0	#DIV/0!
1/18-1/24	3	244787	2458		3.9E-02	96	0	1.8E-02	0	0	100%
1/25-1/31	4	1404975	8063		3.9E-02	314	0	1.8E-02	0	0	100%
2/1-2/7	5	1727647	0		3.9E-02	0	0	1.8E-02	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		3.9E-02	1641	0	1.8E-02	0	2	100%
2/15-2/21	7	345354	206869		3.9E-02	8068	0	1.8E-02	0	8	100%
2/22-2/28	8	804425	439798		3.9E-02	17152	0	1.8E-02	0	17	100%
3/1-3/7	9	555354	453771		3.9E-02	17697	0	1.8E-02	0	18	100%
3/8-3/14	10	477039	448934		3.9E-02	17508	676930	1.8E-02	12185	5	30%
3/15-3/21	11	449862	403326		3.9E-02	15730	794629	1.8E-02	14303	1	9%
3/22-3/28	12	477041	477041		3.9E-02	18605	851842	1.8E-02	15333	3	18%
3/29-4/4	13	477036	442801		3.9E-02	17269	924108	1.8E-02	16634	1	4%
4/5-4/11	14	403712	333618		3.9E-02	13011	4437	1.8E-02	80	13	99%
4/12-4/18	15	475294	429557		7.0E+00	2998309	618617	2.3E-01	142282	2856	95%
4/19-4/25	16	429744	397270		7.0E+00	2772948	798544	2.3E-01	183665	2589	93%
4/26-5/2	17	445556	444342		8.7E-02	38658	556057	5.2E-01	289150	-250	-648%
5/3-5/9	18	476990	476986		8.7E-02	41498	592120	5.2E-01	307902	-266	-642%
5/10-5/16	19	436706	436367		8.7E-02	37964	541199	5.2E-01	281423	-243	-641%
5/17-5/23	20	473027	472512	1.1E-01	1.1E+01	5153272	1182311	5.5E-01	646724	4507	87%
5/24-5/30	21	476988	476985	1.1E-01	1.1E+01	5201994	2312454	5.5E-01	1264912	3937	76%
5/31-6/6	22	465465	461665	1.1E-01	2.0E+00	954203	2511595	1.8E+00	4621335	-3667	-384%
6/7-6/13	23	476988	454262	2.5E+00	7.5E-01	1530214	452238	2.0E+00	899954	630	41%
6/14-6/20	24	476992	476988	2.5E+00	7.5E-01	1547360	973860	2.0E+00	1937982	-391	-25%
6/21-6/27	25	476994	476996	2.5E+00	7.5E-01	1547370	699257	2.0E+00	1391522	156	10%

6/28-7/4	26	476994	385648	2.5E+00	7.5E-01	1478494	455161	2.0E+00	905770	573	39%
7/5-7/11	27	476992	477011	1.5E-01	8.5E-01	475100	766080	8.1E+00	6189926	-5715	-1203%
7/12-7/18	28	472442	463020	2.2E-01	6.0E-03	105770	303972	8.8E+00	2681036	-2575	-2435%
7/19-7/25	29	0	0	4.8E-01	9.1E-02	0	21343	1.0E+01	215563	-216	#DIV/0!
7/26-8/1	30	0	0	2.1E+00	4.7E-01	0	1	1.1E+01	8	0	#DIV/0!
8/2-8/8	31	542690	374177	1.4E+00	4.9E-02	756393	392520	7.9E+00	3112680	-2356	-312%
8/9-8/15	32	463401	459443	1.5E-01	2.0E-01	162314	972470	7.4E+00	7176826	-7015	-4322%
8/16-8/22	33	477002	461941	7.5E-01	1.1E-01	408565	1450070	5.2E+00	7598367	-7190	-1760%
8/23-8/29	34	476933	476237	2.9E-01	3.8E-01	317852	434178	7.1E+00	3100031	-2782	-875%
8/30-9/5	35	468958	468777	1.0E-01	3.5E+00	1678708	533899	6.3E+00	3384920	-1706	-102%
9/6-9/12	36	476994	209004	9.7E-02	2.4E+00	543698	793925	7.8E+00	6168797	-5625	-1035%
9/13-9/19	37	477000	0	2.3E-01	5.1E-01	109233	1278692	7.0E+00	8976421	-8867	-8118%
9/20-9/26	38	204427	0	8.0E-02	2.1E+00	16354	645253	5.2E+00	3355317	-3339	-20417%
9/27-10/3	39	351840	0	4.9E-01	2.1E+00	172402	252640	6.9E+00	1735633	-1563	-907%
10/4-10/10	40	415896	458005	4.9E-01	2.1E+00	1165598	584152	6.9E+00	4013126	-2848	-244%
10/11-10/17	41	427888	509456	4.9E-01	9.9E-01	711479	805933	6.2E+00	4972607	-4261	-599%
10/18-10/24	42	469921	514948	9.0E-02	1.5E+00	788968	846823	4.1E+00	3463508	-2675	-339%
10/25-10/31	43	476988	586837	6.9E-02	1.9E+00	1124429	859377	3.3E+00	2870321	-1746	-155%
11/1-11/7	44	476988	658862	6.7E-02	2.2E+00	1461689	1086266	2.8E+00	3084996	-1623	-111%
11/8-11/14	45	416467	585490	9.5E-02	3.7E+00	2188311	1549620	6.3E+00	9685125	-7497	-343%
11/15-11/21	46	177812	213217	4.8E-01	3.7E+00	868390	396601	7.7E+00	3061760	-2193	-253%
11/22-11/28	47	476988	551103	4.6E-02	1.2E+00	661221	1093661	7.7E+00	8443064	-7782	-1177%
11/29-12/5	48	725716	1398505	7.3E-02	2.7E-01	427777	1566433	2.6E+00	4135383	-3708	-867%
12/6-12/12	49	951929	606484	1.2E-01	2.4E+00	1560871	1501363	2.0E+00	2942672	-1382	-89%
12/13-12/19	50	950135	557701	7.3E-02	2.4E+00	1402265	1989910	1.3E+00	2487387	-1085	-77%
12/20-12/26	51	824622	451198	2.6E-01	4.0E+00	2017982	1724703	1.3E+00	2276607	-259	-13%
12/27-1/2/2012	52	679947	280442	2.0E-01	9.8E+00	2894861	984962	9.7E-01	959353	1936	67%

Table I.4. Manganese mass balance for 2012 until week 20 for the CWTs showing influent and effluent manganese concentrations, total mass removed weekly, and percent removed weekly. The bold red values show extreme percent removed weekly values.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	2.0E-01	9.8E+00	5755917	1406015	9.7E-01	1369459	4386	76%
1/10-1/16	2	951921	590914	3.6E-02	3.1E+00	1842466	1433115	7.9E-01	1135027	707	38%
1/17-1/23	3	951172	641502	1.1E-01	8.4E+00	5495859	1402139	7.4E-01	1033377	4462	81%
1/24-1/30	4	951740	500291	1.2E-01	6.5E+00	3372057	1431457	7.7E-01	1105085	2267	67%
1/31-2/6	5	949756	488753	3.4E-01	1.2E+01	6235884	1563137	5.4E-01	844094	5392	86%
2/7-2/13	6	653867	397596	3.4E-01	1.2E+01	5032573	1010046	5.4E-01	545425	4487	89%
2/14-2/20	7	475934	369277	4.1E-01	5.2E+00	2108463	1059859	8.3E-01	877563	1231	58%
2/21-2/27	8	475936	432515	4.1E-01	5.2E+00	2436040	936829	8.3E-01	775694	1660	68%
2/28-3/5	9	475942	353005	1.7E-01	1.5E+00	613471	701668	1.0E+00	715701	-102	-17%
3/6-3/12	10	473283	283189	1.7E-01	1.5E+00	507599	707119	1.0E+00	721261	-214	-42%
3/13-3/19	11	443980	434017	7.7E-02	9.2E-02	74116	837526	1.1E+00	946405	-872	-1177%
3/20-3/26	12	471946	512541	7.7E-02	9.2E-02	83494	1380029	1.1E+00	1559432	-1476	-1768%
3/27-4/2	13	155169	155666	7.7E-02	9.2E-02	26269	250117	1.1E+00	282633	-256	-976%
4/3-4/9	14	447109	446173	7.7E-02	9.2E-02	75475	761708	1.1E+00	860730	-785	-1040%
4/10-4/16	15	446434	446132	1.5E+00	9.4E-02	689266	737546	3.9E+00	2861678	-2172	-315%
4/17-4/23	16	439360	438674	1.5E+00	9.4E-02	678308	504785	3.9E+00	1958564	-1280	-189%
4/24-4/30	17	367001	364210	1.5E+00	9.4E-02	566388	592054	3.9E+00	2297168	-1731	-306%
5/1-5/7	18	420572	419357	1.5E+00	9.4E-02	649250	542968	3.9E+00	2106716	-1457	-224%
5/8-5/14	19	394169	390456	2.2E-01	1.6E-01	150373	440115	6.0E+00	2649490	-2499	-1662%
5/15-5/21	20	381848	380327	2.2E-01	1.6E-01	146004	213482	6.0E+00	1285162	-1139	-780%

Table I.5. Mercury mass balance for 2011 for the CWTs showing influent and effluent mercury concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/11-1/17	2	74928	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/18-1/24	3	244787	2458		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/25-1/31	4	1404975	8063		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/1-2/7	5	1727647	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/15-2/21	7	345354	206869		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/22-2/28	8	804425	439798		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
3/1-3/7	9	555354	453771		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
3/8-3/14	10	477039	448934		0.0E+00	0	676930	0.0E+00	0	0	#DIV/0!
3/15-3/21	11	449862	403326		0.0E+00	0	794629	0.0E+00	0	0	#DIV/0!
3/22-3/28	12	477041	477041		0.0E+00	0	851842	0.0E+00	0	0	#DIV/0!
3/29-4/4	13	477036	442801		0.0E+00	0	924108	0.0E+00	0	0	#DIV/0!
4/5-4/11	14	403712	333618		0.0E+00	0	4437	0.0E+00	0	0	#DIV/0!
4/12-4/18	15	475294	429557		6.6E-03	2835	618617	0.0E+00	0	3	100%
4/19-4/25	16	429744	397270		6.6E-03	2622	798544	0.0E+00	0	3	100%
4/26-5/2	17	445556	444342		0.0E+00	0	556057	0.0E+00	0	0	#DIV/0!
5/3-5/9	18	476990	476986		0.0E+00	0	592120	0.0E+00	0	0	#DIV/0!
5/10-5/16	19	436706	436367	0.0E+00	0.0E+00	0	541199	0.0E+00	0	0	#DIV/0!
5/17-5/23	20	473027	472512	0.0E+00	6.0E-04	284	1182311	0.0E+00	0	0	100%
5/24-5/30	21	476988	476985	0.0E+00	6.0E-04	286	2312454	0.0E+00	0	0	100%
5/31-6/6	22	465465	461665	0.0E+00	2.1E-03	969	2511595	0.0E+00	0	1	100%
6/7-6/13	23	476988	454262	0.0E+00	2.4E-03	1090	452238	0.0E+00	0	1	100%
6/14-6/20	24	476992	476988	0.0E+00	2.4E-03	1145	973860	0.0E+00	0	1	100%
6/21-6/27	25	476994	476996	0.0E+00	2.4E-03	1145	699257	0.0E+00	0	1	100%

6/28-7/4	26	476994	385648	0.0E+00	2.4E-03	926	455161	0.0E+00	0	1	100%
7/5-7/11	27	476992	477011	0.0E+00	2.0E-03	954	766080	0.0E+00	0	1	100%
7/12-7/18	28	472442	463020	0.0E+00	1.2E-03	556	303972	0.0E+00	0	1	100%
7/19-7/25	29	0	0	0.0E+00	1.5E-03	0	21343	0.0E+00	0	0	#DIV/0!
7/26-8/1	30	0	0	0.0E+00	0.0E+00	0	1	0.0E+00	0	0	#DIV/0!
8/2-8/8	31	542690	374177	0.0E+00	0.0E+00	0	392520	0.0E+00	0	0	#DIV/0!
8/9-8/15	32	463401	459443	0.0E+00	0.0E+00	0	972470	0.0E+00	0	0	#DIV/0!
8/16-8/22	33	477002	461941	0.0E+00	1.3E-03	601	1450070	0.0E+00	0	1	100%
8/23-8/29	34	476933	476237	0.0E+00	1.2E-03	571	434178	0.0E+00	0	1	100%
8/30-9/5	35	468958	468777	0.0E+00	6.0E-04	281	533899	0.0E+00	0	0	100%
9/6-9/12	36	476994	209004	0.0E+00	1.1E-03	230	793925	0.0E+00	0	0	100%
9/13-9/19	37	477000	0	0.0E+00	8.0E-04	0	1278692	0.0E+00	0	0	#DIV/0!
9/20-9/26	38	204427	0	0.0E+00	3.6E-03	0	645253	0.0E+00	0	0	#DIV/0!
9/27-10/3	39	351840	0	0.0E+00	3.6E-03	0	252640	0.0E+00	0	0	#DIV/0!
10/4-10/10	40	415896	458005	0.0E+00	3.6E-03	1649	584152	0.0E+00	0	2	100%
10/11-10/17	41	427888	509456	0.0E+00	4.5E-03	2293	805933	0.0E+00	0	2	100%
10/18-10/24	42	469921	514948	0.0E+00	4.4E-03	2266	846823	0.0E+00	0	2	100%
10/25-10/31	43	476988	586837	0.0E+00	3.6E-03	2113	859377	0.0E+00	0	2	100%
11/1-11/7	44	476988	658862	0.0E+00	3.4E-04	224	1086266	2.0E-04	217	0	3%
11/8-11/14	45	416467	585490	0.0E+00	3.8E-03	2225	1549620	0.0E+00	0	2	100%
11/15-11/21	46	177812	213217	0.0E+00	3.8E-03	810	396601	0.0E+00	0	1	100%
11/22-11/28	47	476988	551103	0.0E+00	2.4E-03	1323	1093661	0.0E+00	0	1	100%
11/29-12/5	48	725716	1398505	0.0E+00	5.0E-04	699	1566433	0.0E+00	0	1	100%
12/6-12/12	49	951929	606484	0.0E+00	2.0E-03	1213	1501363	0.0E+00	0	1	100%
12/13-12/19	50	950135	557701	0.0E+00	2.0E-03	1115	1989910	0.0E+00	0	1	100%
12/20-12/26	51	824622	451198	0.0E+00	5.4E-03	2436	1724703	0.0E+00	0	2	100%
12/27-1/2/2012	52	679947	280442	0.0E+00	7.2E-03	2019	984962	0.0E+00	0	2	100%

Table I.6. Mercury mass balance for 2012 until week 20 for the CWTs showing influent and effluent mercury concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	0.0E+00	7.2E-03	4073	1406015	0.0E+00	0	4	100%
1/10-1/16	2	951921	590914	0.0E+00	3.0E-03	1773	1433115	0.0E+00	0	2	100%
1/17-1/23	3	951172	641502	0.0E+00	3.3E-03	2117	1402139	3.0E-04	421	2	80%
1/24-1/30	4	951740	500291	0.0E+00	1.1E-03	550	1431457	0.0E+00	0	1	100%
1/31-2/6	5	949756	488753	0.0E+00	2.2E-03	1075	1563137	0.0E+00	0	1	100%
2/7-2/13	6	653867	397596	0.0E+00	2.2E-03	875	1010046	0.0E+00	0	1	100%
2/14-2/20	7	475934	369277	0.0E+00	2.3E-03	849	1059859	0.0E+00	0	1	100%
2/21-2/27	8	475936	432515	0.0E+00	2.3E-03	995	936829	0.0E+00	0	1	100%
2/28-3/5	9	475942	353005	0.0E+00	1.8E-03	635	701668	0.0E+00	0	1	100%
3/6-3/12	10	473283	283189	0.0E+00	1.8E-03	510	707119	0.0E+00	0	1	100%
3/13-3/19	11	443980	434017	0.0E+00	1.2E-03	521	837526	0.0E+00	0	1	100%
3/20-3/26	12	471946	512541	0.0E+00	1.2E-03	615	1380029	0.0E+00	0	1	100%
3/27-4/2	13	155169	155666	0.0E+00	0.0E+00	0	250117	0.0E+00	0	0	#DIV/0!
4/3-4/9	14	447109	446173	0.0E+00	0.0E+00	0	761708	0.0E+00	0	0	#DIV/0!
4/10-4/16	15	446434	446132	5.0E-04	4.0E-04	402	737546	0.0E+00	0	0	100%
4/17-4/23	16	439360	438674	5.0E-04	4.0E-04	395	504785	0.0E+00	0	0	100%
4/24-4/30	17	367001	364210	0.0E+00	1.0E-03	364	592054	0.0E+00	0	0	100%
5/1-5/7	18	420572	419357	0.0E+00	1.0E-03	419	542968	0.0E+00	0	0	100%
5/8-5/14	19	394169	390456	0.0E+00	3.0E-04	117	440115	0.0E+00	0	0	100%
5/15-5/21	20	381848	380327	0.0E+00	3.0E-04	114	213482	0.0E+00	0	0	100%

Table I.7. Selenium mass balance for 2011 for the CWTs showing influent and effluent selenium concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/11-1/17	2	74928	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/18-1/24	3	244787	2458		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
1/25-1/31	4	1404975	8063		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/1-2/7	5	1727647	0		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/15-2/21	7	345354	206869		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
2/22-2/28	8	804425	439798		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
3/1-3/7	9	555354	453771		0.0E+00	0	0	0.0E+00	0	0	#DIV/0!
3/8-3/14	10	477039	448934		0.0E+00	0	676930	0.0E+00	0	0	#DIV/0!
3/15-3/21	11	449862	403326		0.0E+00	0	794629	0.0E+00	0	0	#DIV/0!
3/22-3/28	12	477041	477041		0.0E+00	0	851842	0.0E+00	0	0	#DIV/0!
3/29-4/4	13	477036	442801		0.0E+00	0	924108	0.0E+00	0	0	#DIV/0!
4/5-4/11	14	403712	333618		0.0E+00	0	4437	0.0E+00	0	0	#DIV/0!
4/12-4/18	15	475294	429557		1.2E-01	51547	618617	2.7E-02	16703	35	68%
4/19-4/25	16	429744	397270		1.2E-01	47672	798544	2.7E-02	21561	26	55%
4/26-5/2	17	445556	444342		1.1E-01	50211	556057	1.0E-02	5561	45	89%
5/3-5/9	18	476990	476986		1.1E-01	53899	592120	1.0E-02	5921	48	89%
5/10-5/16	19	436706	436367		1.1E-01	49309	541199	1.0E-02	5412	44	89%
5/17-5/23	20	473027	472512	0.0E+00	2.7E-01	126633	1182311	2.4E-02	28375	98	78%
5/24-5/30	21	476988	476985	0.0E+00	2.7E-01	127832	2312454	2.4E-02	55499	72	57%
5/31-6/6	22	465465	461665	0.0E+00	2.7E-01	124650	2511595	0.0E+00	0	125	100%
6/7-6/13	23	476988	454262	0.0E+00	3.4E-01	154449	452238	0.0E+00	0	154	100%
6/14-6/20	24	476992	476988	0.0E+00	3.4E-01	162176	973860	0.0E+00	0	162	100%
6/21-6/27	25	476994	476996	0.0E+00	3.4E-01	162179	699257	0.0E+00	0	162	100%

6/28-7/4	26	476994	385648	0.0E+00	3.4E-01	131120	455161	0.0E+00	0	131	100%
7/5-7/11	27	476992	477011	0.0E+00	3.7E-01	174109	766080	0.0E+00	0	174	100%
7/12-7/18	28	472442	463020	0.0E+00	5.2E-01	242160	303972	0.0E+00	0	242	100%
7/19-7/25	29	0	0	0.0E+00	6.0E-01	0	21343	0.0E+00	0	0	#DIV/0!
7/26-8/1	30	0	0	0.0E+00	6.2E-01	0	1	0.0E+00	0	0	#DIV/0!
8/2-8/8	31	542690	374177	0.0E+00	5.7E-01	214403	392520	0.0E+00	0	214	100%
8/9-8/15	32	463401	459443	0.0E+00	5.3E-01	242126	972470	0.0E+00	0	242	100%
8/16-8/22	33	477002	461941	0.0E+00	4.4E-01	203254	1450070	4.4E-02	63803	139	69%
8/23-8/29	34	476933	476237	0.0E+00	4.6E-01	220021	434178	1.0E-02	4342	216	98%
8/30-9/5	35	468958	468777	0.0E+00	3.5E-01	164072	533899	2.5E-02	13347	151	92%
9/6-9/12	36	476994	209004	0.0E+00	2.1E-01	43473	793925	2.3E-02	18260	25	58%
9/13-9/19	37	477000	0	0.0E+00	1.9E-01	0	1278692	2.2E-02	28131	-28	#DIV/0!
9/20-9/26	38	204427	0	0.0E+00	1.1E-01	0	645253	1.8E-02	11615	-12	#DIV/0!
9/27-10/3	39	351840	0	0.0E+00	1.1E-01	0	252640	1.0E-02	2526	-3	#DIV/0!
10/4-10/10	40	415896	458005	0.0E+00	1.1E-01	50380	584152	1.0E-02	5842	45	88%
10/11-10/17	41	427888	509456	0.0E+00	8.4E-02	42794	805933	7.0E-03	5642	37	87%
10/18-10/24	42	469921	514948	0.0E+00	7.7E-02	39651	846823	1.2E-02	10162	29	74%
10/25-10/31	43	476988	586837	0.0E+00	9.5E-02	55750	859377	1.3E-02	11172	45	80%
11/1-11/7	44	476988	658862	0.0E+00	7.5E-02	49415	1086266	1.2E-02	13035	36	74%
11/8-11/14	45	416467	585490	0.0E+00	7.2E-02	42155	1549620	9.0E-03	13947	28	67%
11/15-11/21	46	177812	213217	0.0E+00	7.2E-02	15352	396601	0.0E+00	0	15	100%
11/22-11/28	47	476988	551103	0.0E+00	6.3E-02	34719	1093661	0.0E+00	0	35	100%
11/29-12/5	48	725716	1398505	0.0E+00	4.2E-02	58737	1566433	0.0E+00	0	59	100%
12/6-12/12	49	951929	606484	0.0E+00	4.3E-02	26079	1501363	8.0E-03	12011	14	54%
12/13-12/19	50	950135	557701	0.0E+00	4.3E-02	23981	1989910	8.0E-03	15919	8	34%
12/20-12/26	51	824622	451198	0.0E+00	7.3E-02	32937	1724703	9.0E-03	15522	17	53%
12/27-1/2/2012	52	679947	280442	0.0E+00	7.0E-02	19631	984962	1.0E-02	9850	10	50%

Table I.8. Selenium mass balance for 2012 until week 20 for the CWTs showing influent and effluent selenium concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	0.0E+00	7.0E-02	39599	1406015	1.0E-02	14060	26	64%
1/10-1/16	2	951921	590914	0.0E+00	6.1E-02	36046	1433115	1.3E-02	18630	17	48%
1/17-1/23	3	951172	641502	0.0E+00	7.8E-02	50037	1402139	1.4E-02	19630	30	61%
1/24-1/30	4	951740	500291	0.0E+00	6.0E-02	30017	1431457	1.8E-02	25766	4	14%
1/31-2/6	5	949756	488753	0.0E+00	6.5E-02	31769	1563137	1.3E-02	20321	11	36%
2/7-2/13	6	653867	397596	0.0E+00	6.5E-02	25844	1010046	1.3E-02	13131	13	49%
2/14-2/20	7	475934	369277	0.0E+00	1.3E-01	49114	1059859	1.1E-02	11658	37	76%
2/21-2/27	8	475936	432515	0.0E+00	1.3E-01	57525	936829	1.1E-02	10305	47	82%
2/28-3/5	9	475942	353005	0.0E+00	1.9E-01	65306	701668	2.2E-02	15437	50	76%
3/6-3/12	10	473283	283189	0.0E+00	1.9E-01	52390	707119	2.2E-02	15557	37	70%
3/13-3/19	11	443980	434017	0.0E+00	1.2E-01	49912	837526	2.3E-02	19263	31	61%
3/20-3/26	12	471946	512541	0.0E+00	1.2E-01	58942	1380029	2.3E-02	31741	27	46%
3/27-4/2	13	155169	155666	0.0E+00	7.2E-02	11208	250117	7.0E-03	1751	9	84%
4/3-4/9	14	447109	446173	0.0E+00	7.2E-02	32124	761708	7.0E-03	5332	27	83%
4/10-4/16	15	446434	446132	0.0E+00	8.7E-02	38813	737546	0.0E+00	0	39	100%
4/17-4/23	16	439360	438674	0.0E+00	8.7E-02	38165	504785	0.0E+00	0	38	100%
4/24-4/30	17	367001	364210	0.0E+00	6.9E-02	25130	592054	0.0E+00	0	25	100%
5/1-5/7	18	420572	419357	0.0E+00	6.9E-02	28936	542968	0.0E+00	0	29	100%
5/8-5/14	19	394169	390456	0.0E+00	1.2E-01	46464	440115	0.0E+00	0	46	100%
5/15-5/21	20	381848	380327	0.0E+00	1.2E-01	45259	213482	0.0E+00	0	45	100%

Table I.9. Chloride mass balance for 2011 for the CWTs showing influent and effluent chloride concentrations, total mass removed weekly, and percent removed weekly. The bold red values show extreme percent removed weekly values.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		1.1E+02	0	0	1.4E+02	0	0	#DIV/0!
1/11-1/17	2	74928	0		1.1E+02	0	0	1.4E+02	0	0	#DIV/0!
1/18-1/24	3	244787	2458		1.1E+02	260545	0	1.4E+02	0	261	100%
1/25-1/31	4	1404975	8063		1.1E+02	854720	0	1.4E+02	0	855	100%
2/1-2/7	5	1727647	0		1.1E+02	0	0	1.4E+02	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		1.1E+02	4459571	0	1.4E+02	0	4460	100%
2/15-2/21	7	345354	206869		1.1E+02	21928165	0	1.4E+02	0	21928	100%
2/22-2/28	8	804425	439798		1.1E+02	46618552	0	1.4E+02	0	46619	100%
3/1-3/7	9	555354	453771		1.1E+02	48099679	0	1.4E+02	0	48100	100%
3/8-3/14	10	477039	448934		1.1E+02	47586995	676930	1.4E+02	94770138	-47183	-99%
3/15-3/21	11	449862	403326		1.1E+02	42752573	794629	1.4E+02	111248015	-68495	-160%
3/22-3/28	12	477041	477041		1.1E+02	50566386	851842	1.4E+02	119257928	-68692	-136%
3/29-4/4	13	477036	442801		1.1E+02	46936946	924108	1.4E+02	129375180	-82438	-176%
4/5-4/11	14	403712	333618		1.1E+02	35363550	4437	1.4E+02	621179	34742	98%
4/12-4/18	15	475294	429557		1.1E+03	455330603	618617	4.8E+02	296936300	158394	35%
4/19-4/25	16	429744	397270		1.1E+03	421106676	798544	4.8E+02	383300924	37806	9%
4/26-5/2	17	445556	444342		3.8E+02	168849977	556057	4.5E+02	248557616	-79708	-47%
5/3-5/9	18	476990	476986		3.8E+02	181254866	592120	4.5E+02	264677715	-83423	-46%
5/10-5/16	19	436706	436367		3.8E+02	165819329	541199	4.5E+02	241915867	-76097	-46%
5/17-5/23	20	473027	472512	8.7E+01	1.2E+03	589267419	1182311	5.0E+02	586426211	2841	0%
5/24-5/30	21	476988	476985	8.7E+01	1.2E+03	594800121	2312454	5.0E+02	1146977147	-552177	-93%
5/31-6/6	22	465465	461665	8.6E+01	1.1E+03	566328099	2511595	3.4E+02	863988802	-297661	-53%
6/7-6/13	23	476988	454262	8.1E+01	1.3E+03	642804141	452238	2.6E+02	116225224	526579	82%
6/14-6/20	24	476992	476988	8.1E+01	1.3E+03	673030914	973860	2.6E+02	250282122	422749	63%
6/21-6/27	25	476994	476996	8.1E+01	1.3E+03	673041136	699257	2.6E+02	179709091	493332	73%

6/28-7/4	26	476994	385648	8.1E+01	1.3E+03	551548743	455161	2.6E+02	116976264	434572	79%
7/5-7/11	27	476992	477011	6.4E+01	1.1E+03	536159259	766080	7.0E+02	536255931	-97	0%
7/12-7/18	28	472442	463020	7.7E+01	1.2E+03	605892904	303972	7.4E+02	224939540	380953	63%
7/19-7/25	29	0	0	6.6E+01	1.3E+03	0	21343	6.9E+02	14726607	-14727	#DIV/0!
7/26-8/1	30	0	0	7.0E+01	1.3E+03	0	1	7.4E+02	560	-1	#DIV/0!
8/2-8/8	31	542690	374177	7.0E+01	1.5E+03	584286125	392520	6.1E+02	239436937	344849	59%
8/9-8/15	32	463401	459443	7.1E+01	1.3E+03	616394054	972470	7.7E+02	748801620	-132408	-21%
8/16-8/22	33	477002	461941	6.8E+01	1.3E+03	609862824	1450070	6.8E+02	986047681	-376185	-62%
8/23-8/29	34	476933	476237	6.6E+01	1.5E+03	755357817	434178	6.3E+02	273532156	481826	64%
8/30-9/5	35	468958	468777	6.7E+01	1.3E+03	622079027	533899	6.2E+02	331017392	291062	47%
9/6-9/12	36	476994	209004	7.1E+01	1.0E+03	249140637	793925	7.3E+02	579565259	-330425	-133%
9/13-9/19	37	477000	0	7.0E+01	9.9E+02	33389982	1278692	6.7E+02	856723918	-823334	-2466%
9/20-9/26	38	204427	0	6.3E+01	9.4E+02	12878925	645253	6.3E+02	406509606	-393631	-3056%
9/27-10/3	39	351840	0	6.6E+01	9.4E+02	23221444	252640	6.4E+02	161689291	-138468	-596%
10/4-10/10	40	415896	458005	6.6E+01	9.4E+02	457973381	584152	6.4E+02	373857443	84116	18%
10/11-10/17	41	427888	509456	6.6E+01	9.0E+02	486750868	805933	7.4E+02	596390490	-109640	-23%
10/18-10/24	42	469921	514948	7.1E+01	9.1E+02	501967520	846823	6.2E+02	525030565	-23063	-5%
10/25-10/31	43	476988	586837	8.8E+01	9.4E+02	593601989	859377	5.9E+02	507032684	86569	15%
11/1-11/7	44	476988	658862	9.4E+01	7.4E+02	532394993	1086266	5.2E+02	564858480	-32463	-6%
11/8-11/14	45	416467	585490	1.1E+02	1.0E+03	635490062	1549620	6.6E+02	1022749209	-387259	-61%
11/15-11/21	46	177812	213217	1.0E+02	8.8E+02	205412266	396601	6.9E+02	273654689	-68242	-33%
11/22-11/28	47	476988	551103	9.5E+01	7.7E+02	469663175	1093661	6.9E+02	754626165	-284963	-61%
11/29-12/5	48	725716	1398505	1.1E+02	7.3E+02	1097834768	1566433	5.8E+02	908531094	189304	17%
12/6-12/12	49	951929	606484	1.0E+02	8.8E+02	629850324	1501363	4.7E+02	705640707	-75790	-12%
12/13-12/19	50	950135	557701	8.1E+01	8.8E+02	567737721	1989910	4.6E+02	915358584	-347621	-61%
12/20-12/26	51	824622	451198	7.5E+01	9.2E+02	476949127	1724703	3.9E+02	665735166	-188786	-40%
12/27-1/2/2012	52	679947	280442	7.2E+01	9.8E+02	323789573	984962	3.9E+02	386105203	-62316	-19%

Table I.10. Chloride mass balance for 2012 until May 22 for the CWTS showing influent and effluent chloride concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	7.2E+01	9.8E+02	622924394.8	1406015	3.9E+02	551158075	71766	12%
1/10-1/16	2	951921	590914	7.2E+01	8.8E+02	588542771.5	1433115	3.5E+02	501590341.1	86952	15%
1/17-1/23	3	951172	641502	7.2E+01	8.1E+02	588101294	1402139	3.9E+02	541225745	46876	8%
1/24-1/30	4	951740	500291	7.4E+01	6.8E+02	410626865.8	1431457	4.0E+02	571151442.8	-160525	-39%
1/31-2/6	5	949756	488753	7.5E+01	8.7E+02	496447196.8	1563137	3.3E+02	517398209.4	-20951	-4%
2/7-2/13	6	653867	397596	7.5E+01	8.7E+02	394948572.2	1010046	3.3E+02	334325319.9	60623	15%
2/14-2/20	7	475934	369277	6.6E+01	1.1E+03	441308963.6	1059859	3.7E+02	386848358.8	54461	12%
2/21-2/27	8	475936	432515	6.6E+01	1.1E+03	511503952.3	936829	3.7E+02	341942529.9	169561	33%
2/28-3/5	9	475942	353005	6.6E+01	1.2E+03	444427757.7	701668	4.6E+02	319258809.4	125169	28%
3/6-3/12	10	473283	283189	6.6E+01	1.2E+03	362567262.8	707119	4.6E+02	321739011.2	40828	11%
3/13-3/19	11	443980	434017	6.7E+01	1.1E+03	511505736.2	837526	5.0E+02	418763070.9	92743	18%
3/20-3/26	12	471946	512541	6.7E+01	1.1E+03	600540872.6	1380029	5.0E+02	690014322.8	-89473	-15%
3/27-4/2	13	155169	155666	6.7E+01	1.1E+03	183185834.7	250117	5.0E+02	125058649	58127	32%
4/3-4/9	14	447109	446173	6.7E+01	1.1E+03	525208608.8	761708	5.0E+02	380854064.6	144355	27%
4/10-4/16	15	446434	446132	7.0E+01	8.8E+02	423846216.4	737546	9.4E+02	693293095.1	-269447	-64%
4/17-4/23	16	439360	438674	7.0E+01	8.8E+02	416788647.4	504785	9.4E+02	474497581.2	-57709	-14%
4/24-4/30	17	367001	364210	7.0E+01	8.8E+02	346194550.4	592054	9.4E+02	556530331.4	-210336	-61%
5/1-5/7	18	420572	419357	7.0E+01	8.8E+02	398474569.7	542968	9.4E+02	510390022.9	-111915	-28%
5/8-5/14	19	394169	390456	5.6E+01	9.3E+02	385197336.3	440115	1.1E+03	475323860.9	-90127	-23%
5/15-5/21	20	381848	380327	5.6E+01	9.3E+02	375087533	213482	1.1E+03	230560649.4	144527	39%

Table I.11. Fluoride mass balance for 2011 for the CWTS showing influent and effluent fluoride concentrations, total mass removed weekly, and percent removed weekly. The bold red values show extreme percent removed weekly values.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		3.0E-01	0	0	2.0E-01	0	0	#DIV/0!
1/11-1/17	2	74928	0		3.0E-01	0	0	2.0E-01	0	0	#DIV/0!
1/18-1/24	3	244787	2458		3.0E-01	737	0	2.0E-01	0	1	100%
1/25-1/31	4	1404975	8063		3.0E-01	2419	0	2.0E-01	0	2	100%
2/1-2/7	5	1727647	0		3.0E-01	0	0	2.0E-01	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		3.0E-01	12621	0	2.0E-01	0	13	100%
2/15-2/21	7	345354	206869		3.0E-01	62061	0	2.0E-01	0	62	100%
2/22-2/28	8	804425	439798		3.0E-01	131939	0	2.0E-01	0	132	100%
3/1-3/7	9	555354	453771		3.0E-01	136131	0	2.0E-01	0	136	100%
3/8-3/14	10	477039	448934		3.0E-01	134680	676930	2.0E-01	135386	-1	-1%
3/15-3/21	11	449862	403326		3.0E-01	120998	794629	2.0E-01	158926	-38	-31%
3/22-3/28	12	477041	477041		3.0E-01	143112	851842	2.0E-01	170368	-27	-19%
3/29-4/4	13	477036	442801		3.0E-01	132840	924108	2.0E-01	184822	-52	-39%
4/5-4/11	14	403712	333618		3.0E-01	100086	4437	2.0E-01	887	99	99%
4/12-4/18	15	475294	429557		2.1E+01	9020701	618617	3.0E-01	185585	8835	98%
4/19-4/25	16	429744	397270		2.1E+01	8342679	798544	3.0E-01	239563	8103	97%
4/26-5/2	17	445556	444342		9.1E+00	4043513	556057	4.0E-01	222423	3821	94%
5/3-5/9	18	476990	476986		9.1E+00	4340577	592120	4.0E-01	236848	4104	95%
5/10-5/16	19	436706	436367		2.5E+01	10909166	541199	4.0E-01	216480	10693	98%
5/17-5/23	20	473027	472512	3.0E-01	2.5E+01	11954711	1182311	4.0E-01	472924	11482	96%
5/24-5/30	21	476988	476985	3.0E-01	2.5E+01	12067711	2312454	4.0E-01	924982	11143	92%
5/31-6/6	22	465465	461665	3.0E-01	2.9E+01	13527925	2511595	4.0E-01	1004638	12523	93%
6/7-6/13	23	476988	454262	3.0E-01	3.1E+01	14225210	452238	4.0E-01	180895	14044	99%
6/14-6/20	24	476992	476988	3.0E-01	3.1E+01	14929737	973860	4.0E-01	389544	14540	97%
6/21-6/27	25	476994	476996	3.0E-01	3.1E+01	14929973	699257	4.0E-01	279703	14650	98%

6/28-7/4	26	476994	385648	3.0E-01	3.1E+01	12098195	455161	4.0E-01	182064	11916	98%
7/5-7/11	27	476992	477011	3.0E-01	2.8E+01	13499408	766080	3.0E-01	229824	13270	98%
7/12-7/18	28	472442	463020	4.0E-01	3.6E+01	16857704	303972	4.0E-01	121589	16736	99%
7/19-7/25	29	0	0	3.0E-01	4.0E+01	0	21343	3.0E-01	6403	-6	#DIV/0!
7/26-8/1	30	0	0	3.0E-01	2.1E+01	0	1	2.0E-01	0	0	#DIV/0!
8/2-8/8	31	542690	374177	3.0E-01	3.6E+01	13633165	392520	3.0E-01	117756	13515	99%
8/9-8/15	32	463401	459443	3.0E-01	3.6E+01	16678968	972470	5.0E-01	486235	16193	97%
8/16-8/22	33	477002	461941	4.0E-01	2.8E+01	13125159	1450070	7.0E-01	1015049	12110	92%
8/23-8/29	34	476933	476237	4.0E-01	3.3E+01	15906594	434178	5.0E-01	217089	15690	99%
8/30-9/5	35	468958	468777	3.0E-01	3.1E+01	14672770	533899	1.0E+00	533899	14139	96%
9/6-9/12	36	476994	209004	3.0E-01	2.4E+01	5242794	793925	4.0E-01	317570	4925	94%
9/13-9/19	37	477000	0	2.0E-01	1.2E+01	95400	1278692	9.0E-01	1150823	-1055	-1106%
9/20-9/26	38	204427	0	2.0E-01	9.0E+00	40885	645253	8.0E-01	516203	-475	-1163%
9/27-10/3	39	351840	0	2.0E-01	9.0E+00	70368	252640	1.2E+00	303167	-233	-331%
10/4-10/10	40	415896	458005	2.0E-01	9.0E+00	4205220	584152	1.2E+00	700983	3504	83%
10/11-10/17	41	427888	509456	2.0E-01	2.1E+01	10580368	805933	1.7E+00	1370086	9210	87%
10/18-10/24	42	469921	514948	3.0E-01	2.0E+01	10542936	846823	2.2E+00	1863012	8680	82%
10/25-10/31	43	476988	586837	4.0E-01	2.3E+01	13688052	859377	2.4E+00	2062506	11626	85%
11/1-11/7	44	476988	658862	2.0E-01	1.4E+01	9517128	1086266	1.9E+00	2063906	7453	78%
11/8-11/14	45	416467	585490	2.0E-01	1.7E+01	10036617	1549620	1.2E+00	1859544	8177	81%
11/15-11/21	46	177812	213217	0.0E+00	1.4E+01	2985039	396601	3.0E-01	118980	2866	96%
11/22-11/28	47	476988	551103	1.0E-01	8.6E+00	4787184	1093661	3.0E-01	328098	4459	93%
11/29-12/5	48	725716	1398505	3.0E-01	1.1E+01	14902020	1566433	1.6E+00	2506293	12396	83%
12/6-12/12	49	951929	606484	1.0E-01	1.4E+01	8585962	1501363	1.1E+00	1651500	6934	81%
12/13-12/19	50	950135	557701	0.0E+00	1.4E+01	7807813	1989910	1.4E+00	2785874	5022	64%
12/20-12/26	51	824622	451198	3.0E-01	2.0E+01	9271354	1724703	2.2E+00	3794346	5477	59%
12/27-1/2/2012	52	679947	280442	3.0E-01	1.3E+01	3877777	984962	2.6E+00	2560902	1317	34%

Table I.12. Fluoride mass balance for 2012 until week 20 for the CWTS showing influent and effluent fluoride concentrations, total mass removed weekly, and percent removed weekly.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	3.0E-01	1.3E+01	7696242	1406015	2.6E+00	3655640	4041	53%
1/10-1/16	2	951921	590914	2.0E-01	1.7E+01	10354107	1433115	3.1E+00	4442657	5911	57%
1/17-1/23	3	951172	641502	2.0E-01	1.8E+01	11737277	1402139	3.2E+00	4486846	7250	62%
1/24-1/30	4	951740	500291	3.0E-01	1.9E+01	9791058	1431457	3.1E+00	4437517	5354	55%
1/31-2/6	5	949756	488753	3.0E-01	2.0E+01	10059996	1563137	3.6E+00	5627292	4433	44%
2/7-2/13	6	653867	397596	3.0E-01	2.0E+01	8148080	1010046	3.6E+00	3636167	4512	55%
2/14-2/20	7	475934	369277	2.0E-01	2.4E+01	8957831	1059859	3.1E+00	3285561	5672	63%
2/21-2/27	8	475936	432515	2.0E-01	2.4E+01	10475559	936829	3.1E+00	2904169	7571	72%
2/28-3/5	9	475942	353005	3.0E-01	2.8E+01	10026917	701668	3.7E+00	2596171	7431	74%
3/6-3/12	10	473283	283189	3.0E-01	2.8E+01	8071264	707119	3.7E+00	2616339	5455	68%
3/13-3/19	11	443980	434017	3.0E-01	1.9E+01	8466324	837526	3.8E+00	3182599	5284	62%
3/20-3/26	12	471946	512541	3.0E-01	1.9E+01	9982370	1380029	3.8E+00	5244109	4738	47%
3/27-4/2	13	155169	155666	3.0E-01	1.5E+01	2381544	250117	4.4E+00	1100516	1281	54%
4/3-4/9	14	447109	446173	3.0E-01	1.5E+01	6826731	761708	4.4E+00	3351516	3475	51%
4/10-4/16	15	446434	446132	3.0E-01	1.6E+01	7272036	737546	7.6E+00	5605348	1667	23%
4/17-4/23	16	439360	438674	3.0E-01	1.6E+01	7150598	504785	7.6E+00	3836363	3314	46%
4/24-4/30	17	367001	364210	2.0E-01	1.6E+01	5900754	592054	7.2E+00	4262786	1638	28%
5/1-5/7	18	420572	419357	2.0E-01	1.6E+01	6793833	542968	7.2E+00	3909370	2884	42%
5/8-5/14	19	394169	390456	2.0E-01	1.3E+01	5154759	440115	9.8E+00	4313124	842	16%
5/15-5/21	20	381848	380327	2.0E-01	1.3E+01	5020620	213482	9.8E+00	2092124	2928	58%

Table I.13. Sulfate mass balance for 2011 for the CWTS showing influent and effluent sulfate concentrations, total mass removed weekly, and percent removed weekly. The bold red values show extreme percent removed weekly values.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/4-1/10	1	3838	0		1.5E+02	0	0	5.7E+02	0	0	#DIV/0!
1/11-1/17	2	74928	0		1.5E+02	0	0	5.7E+02	0	0	#DIV/0!
1/18-1/24	3	244787	2458		1.5E+02	363780	0	5.7E+02	0	364	100%
1/25-1/31	4	1404975	8063		1.5E+02	1193383	0	5.7E+02	0	1193	100%
2/1-2/7	5	1727647	0		1.5E+02	0	0	5.7E+02	0	0	#DIV/0!
2/8-2/14	6	1018071	42071		1.5E+02	6226570	0	5.7E+02	0	6227	100%
2/15-2/21	7	345354	206869		1.5E+02	30616683	0	5.7E+02	0	30617	100%
2/22-2/28	8	804425	439798		1.5E+02	65090053	0	5.7E+02	0	65090	100%
3/1-3/7	9	555354	453771		1.5E+02	67158043	0	5.7E+02	0	67158	100%
3/8-3/14	10	477039	448934		1.5E+02	66442219	676930	5.7E+02	388557564	-322115	-485%
3/15-3/21	11	449862	403326		1.5E+02	59692272	794629	5.7E+02	456116863	-396425	-664%
3/22-3/28	12	477041	477041		1.5E+02	70602124	851842	5.7E+02	488957504	-418355	-593%
3/29-4/4	13	477036	442801		1.5E+02	65534605	924108	5.7E+02	530438237	-464904	-709%
4/5-4/11	14	403712	333618		1.5E+02	49375522	4437	5.7E+02	2546835	46829	95%
4/12-4/18	15	475294	429557		4.3E+03	1864278129	618617	1.9E+03	1156814337	707464	38%
4/19-4/25	16	429744	397270		4.3E+03	1724153749	798544	1.9E+03	1493276518	230877	13%
4/26-5/2	17	445556	444342		1.5E+03	684286749	556057	1.8E+03	995342578	-311056	-45%
5/3-5/9	18	476990	476986		1.5E+03	734559194	592120	1.8E+03	1059895099	-325336	-44%
5/10-5/16	19	436706	436367		1.5E+03	672004649	541199	1.8E+03	968745866	-296741	-44%
5/17-5/23	20	473027	472512		4.7E+03	2216081903	1182311	1.9E+03	2210921402	5161	0%
5/24-5/30	21	476988	476985		4.7E+03	2237057759	2312454	1.9E+03	4324288840	-2087231	-93%
5/31-6/6	22	465465	461665	1.3E+02	4.3E+03	2035505825	2511595	1.5E+03	3666929217	-1631423	-80%
6/7-6/13	23	476988	454262	1.2E+02	5.0E+03	2329024175	452238	1.2E+03	520073958	1808950	78%
6/14-6/20	24	476992	476988	1.2E+02	5.0E+03	2442657963	973860	1.2E+03	1119939456	1322719	54%
6/21-6/27	25	476994	476996	1.2E+02	5.0E+03	2442696046	699257	1.2E+03	804145737	1638550	67%

6/28-7/4	26	476994	385648	1.2E+02	5.0E+03	1985957724	455161	1.2E+03	523434647	1462523	74%
7/5-7/11	27	476992	477011	1.2E+02	4.6E+03	2252921072	766080	2.8E+03	2129702126	123219	5%
7/12-7/18	28	472442	463020	1.4E+02	5.0E+03	2390503362	303972	2.8E+03	860241754	1530262	64%
7/19-7/25	29	0	0	1.3E+02	5.1E+03	0	21343	2.8E+03	60400432	-60400	#DIV/0!
7/26-8/1	30	0	0	1.2E+02	5.2E+03	0	1	2.8E+03	2120	-2	#DIV/0!
8/2-8/8	31	542690	374177	1.2E+02	6.1E+03	2347600035	392520	2.6E+03	1012700486	1334900	57%
8/9-8/15	32	463401	459443	1.2E+02	5.6E+03	2647329990	972470	3.0E+03	2868785428	-221455	-8%
8/16-8/22	33	477002	461941	1.1E+02	4.9E+03	2336368555	1450070	2.8E+03	4016694232	-1680326	-72%
8/23-8/29	34	476933	476237	1.2E+02	6.1E+03	2960846784	434178	2.6E+03	1115837524	1845009	62%
8/30-9/5	35	468958	468777	1.2E+02	5.6E+03	2691269926	533899	2.6E+03	1409493413	1281777	48%
9/6-9/12	36	476994	209004	1.3E+02	4.8E+03	1058958025	793925	3.1E+03	2469106787	-1410149	-133%
9/13-9/19	37	477000	0	1.2E+02	4.2E+03	57716968	1278692	2.9E+03	3657060307	-3599343	-6236%
9/20-9/26	38	204427	0	1.1E+02	3.9E+03	22078157	645253	2.6E+03	1703468825	-1681391	-7616%
9/27-10/3	39	351840	0	1.2E+02	3.9E+03	41517128	252640	2.7E+03	682126698	-640610	-1543%
10/4-10/10	40	415896	458005	1.2E+02	3.9E+03	1830713352	584152	2.7E+03	1577211086	253502	14%
10/11-10/17	41	427888	509456	1.2E+02	4.0E+03	2062841404	805933	3.0E+03	2393621292	-330780	-16%
10/18-10/24	42	469921	514948	1.0E+02	4.1E+03	2148451868	846823	2.6E+03	2235614018	-87162	-4%
10/25-10/31	43	476988	586837	1.1E+02	4.1E+03	2441373304	859377	2.5E+03	2122662255	318711	13%
11/1-11/7	44	476988	658862	1.1E+02	3.3E+03	2199882755	1086266	2.2E+03	2433236527	-233354	-11%
11/8-11/14	45	416467	585490	1.1E+02	3.8E+03	2260211635	1549620	2.4E+03	3719088034	-1458876	-65%
11/15-11/21	46	177812	213217	1.1E+02	3.2E+03	703808428	396601	2.5E+03	1007366538	-303558	-43%
11/22-11/28	47	476988	551103	1.1E+02	3.2E+03	1798511127	1093661	2.5E+03	2777899216	-979388	-54%
11/29-12/5	48	725716	1398505	1.1E+02	3.0E+03	4273893096	1566433	2.0E+03	3054544196	1219349	29%
12/6-12/12	49	951929	606484	1.0E+02	3.3E+03	2118590768	1501363	1.7E+03	2522290187	-403699	-19%
12/13-12/19	50	950135	557701	9.8E+01	3.3E+03	1950257292	1989910	1.6E+03	3104259545	-1154002	-59%
12/20-12/26	51	824622	451198	1.0E+02	3.7E+03	1768730580	1724703	1.4E+03	2380089452	-611359	-35%
12/27-1/2/2012	52	679947	280442	9.6E+01	4.0E+03	1181163017	984962	1.4E+03	1408496021	-227333	-19%

Table I.14. Sulfate mass balance for 2012 until May 22 for the CWTS showing influent and effluent sulfate concentrations, total mass removed weekly, and percent removed weekly. The bold red values show extreme percent removed weekly values.

Date	Week	RAW (L)	FGDWW (L)	RAW Concentration (mg/L)	FGDWW Concentration (mg/L)	Mass Pollutant (mg)	LS (L)	LS Concentration (mg/L)	Mass Pollutant (mg)	Total Mass Removed Weekly (g)	Percent Removed Weekly (%)
1/3-1/9	1	951929	565700	9.6E+01	4.0E+03	2342488437	1406015	1.4E+03	2010602161	331886	14%
1/10-1/16	2	951921	590914	1.1E+02	3.8E+03	2351334590	1433115	1.4E+03	1949036754	402298	17%
1/17-1/23	3	951172	641502	1.0E+02	3.5E+03	2368889111	1402139	1.5E+03	2159294423	209595	9%
1/24-1/30	4	951740	500291	1.1E+02	3.2E+03	1700620847	1431457	1.6E+03	2247387883	-546767	-32%
1/31-2/6	5	949756	488753	1.1E+02	3.9E+03	2015499121	1563137	1.4E+03	2219653950	-204155	-10%
2/7-2/13	6	653867	397596	1.1E+02	3.9E+03	1626525756	1010046	1.4E+03	1434265723	192260	12%
2/14-2/20	7	475934	369277	1.1E+02	4.8E+03	1818809225	1059859	1.5E+03	1589787776	229021	13%
2/21-2/27	8	475936	432515	1.1E+02	4.8E+03	2121722394	936829	1.5E+03	1405243273	716479	34%
2/28-3/5	9	475942	353005	1.1E+02	4.7E+03	1727500061	701668	1.9E+03	1361235363	366265	21%
3/6-3/12	10	473283	283189	1.1E+02	4.7E+03	1396267951	707119	1.9E+03	1371810289	24458	2%
3/13-3/19	11	443980	434017	1.2E+02	4.6E+03	2027611879	837526	2.1E+03	1775555420	252056	12%
3/20-3/26	12	471946	512541	1.2E+02	4.6E+03	2388223011	1380029	2.1E+03	2925660729	-537438	-23%
3/27-4/2	13	155169	155666	1.2E+02	4.6E+03	726746366	250117	2.1E+03	530248671.7	196498	27%
4/3-4/9	14	447109	446173	1.2E+02	4.6E+03	2083294223	761708	2.1E+03	1614821234	468473	22%
4/10-4/16	15	446434	446132	1.4E+02	8.7E+01	101760704	737546	4.1E+03	3053439802	-2951679	-2901%
4/17-4/23	16	439360	438674	1.4E+02	8.7E+01	100114490	504785	4.1E+03	2089808496	-1989694	-1987%
4/24-4/30	17	367001	364210	1.4E+02	8.7E+01	83433426	592054	4.1E+03	2451101672	-2367668	-2838%
5/1-5/7	18	420572	419357	1.4E+02	8.7E+01	95784814	542968	4.1E+03	2247887973	-2152103	-2247%
5/8-5/14	19	394169	390456	1.2E+02	4.1E+03	1655189709	440115	5.1E+03	2222579164	-567389	-34%
5/15-5/21	20	381848	380327	1.2E+02	4.1E+03	1612005050	213482	5.1E+03	1078084518	533921	33%

Boron

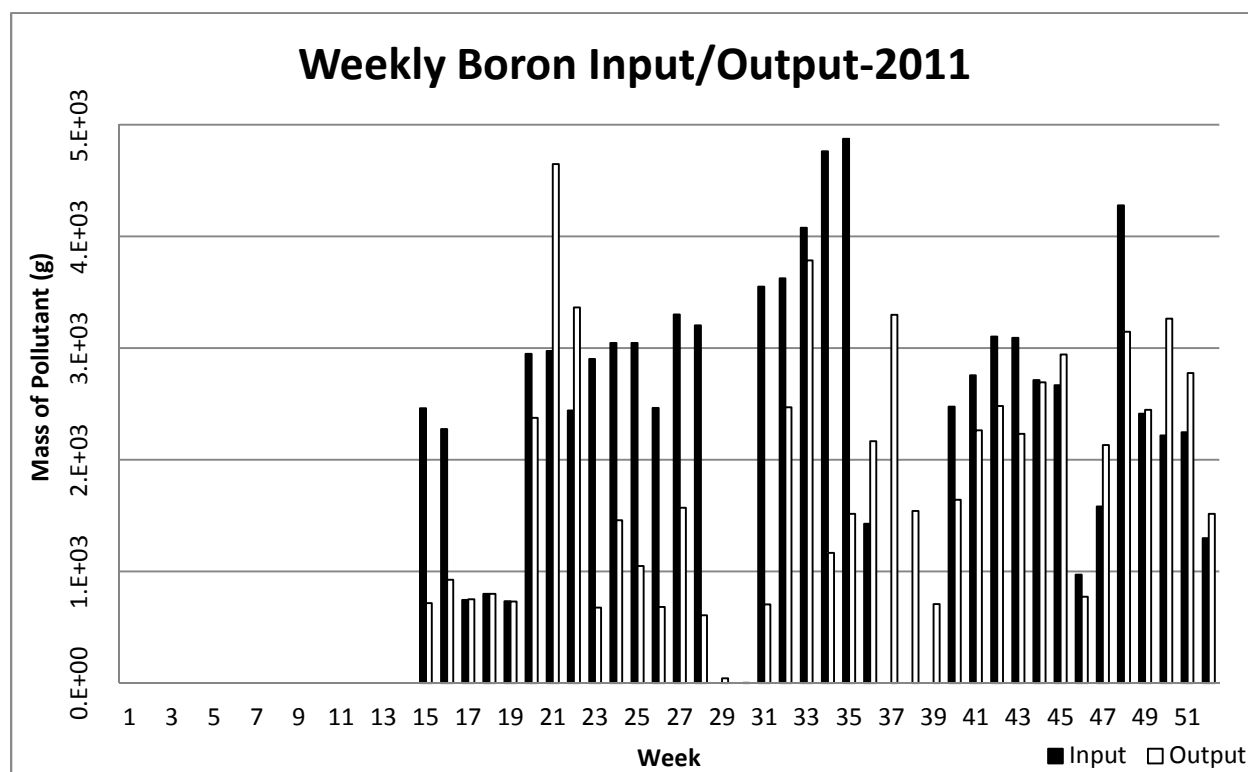


Figure I.1. Weekly input and output mass of boron, in grams, for 2011.

Figure I.1 displays the weekly input and output mass of boron, in grams, for 2011, in which the darker purple represents the mass of boron entering the CWTS and the light purple represents the mass of boron leaving the CWTS. This figure is a better representation of how much boron entered each week compared to how much was released each week, as well as determine how much was removed each week, which was discussed earlier in Figure 4.65 for 2011. The average weekly input of boron for 2011 was about 1,700 g [3.75 lb}, while the average weekly output of boron also 2011 was about 1,300 g [2.87 lb]; therefore, in 2011, the percent of boron removed weekly was only 23.5%. Some weeks show the same amount of boron added into the CWTS as released by the CWTS, such as week's 17-19. From this data, 21 weeks out of the 37 weeks the CWTS was in use the amount of boron entering the CWTS was greater than the amount of boron leaving the CWTS, which is a positive outcome for the CWTS, showing its ability to uptake and hold boron within the cells of the wetland system. On the other hand, the remaining 13 weeks allowed more boron to be released by the CWTS instead of being

captured within the cells. There are two possibilities on why this occurred including maintenance to the wastewater treatment building discussed earlier, as well as large rain events which might have added extra boron into the system and had to be released to maintain a specific water capacity in each of the wetland cells.

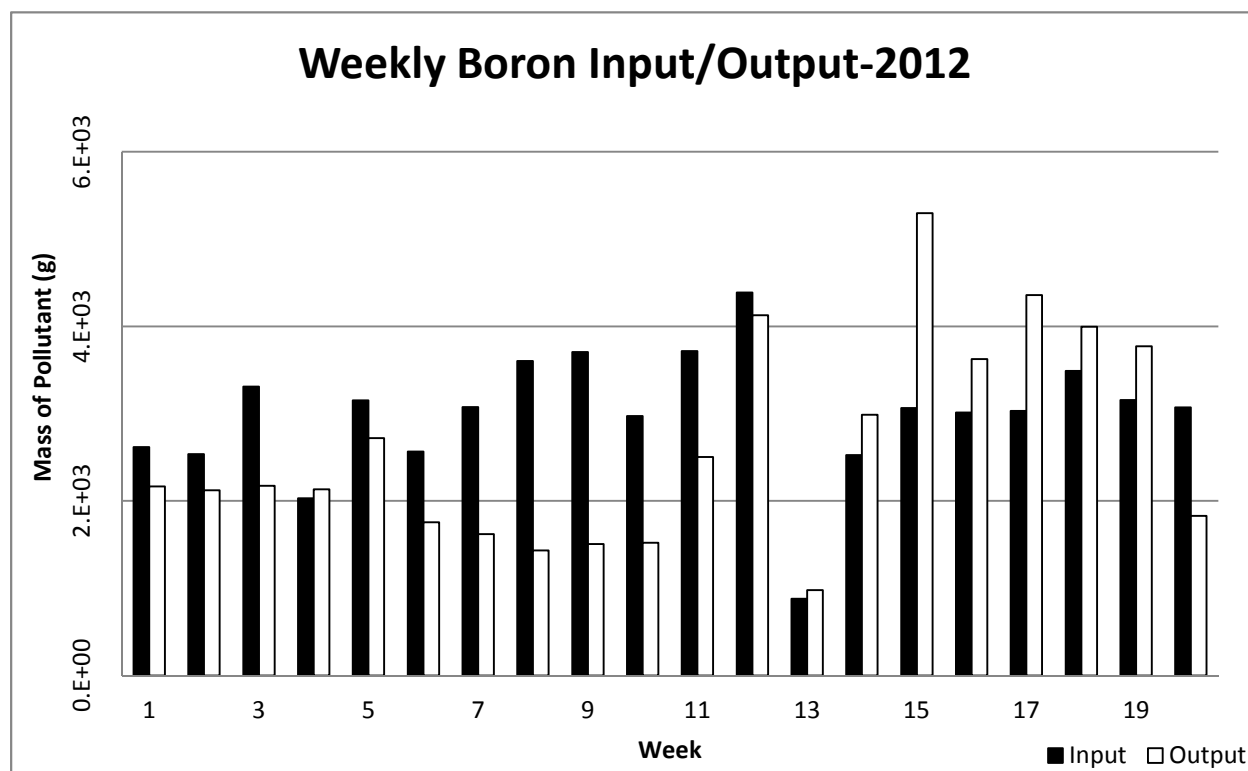


Figure I.2. Weekly input and output mass of boron, in grams, for 2012 until May 22nd.

For 2012, Figure I.2 represents the weekly input and output mass of boron, in grams, until May 22nd when research was completed at JEC CWTS. The average weekly input of boron in 2012 was 3,000 g [6.61 lb], which was 43% increase in weekly boron input, while the average weekly output of boron in 2012 was about 2,600 g [5.73 lb], a 50% increase in weekly boron output from the CWTS to Lost Creek. With the larger amount of boron entering and leaving the CWTS, the weekly percentage removed for the 20 weeks was only 13%. Even though 12 weeks out of the 20 resulted in more boron input than output, the results show a decreasing ability to remove boron from the wastewater through the CWTS.

Manganese

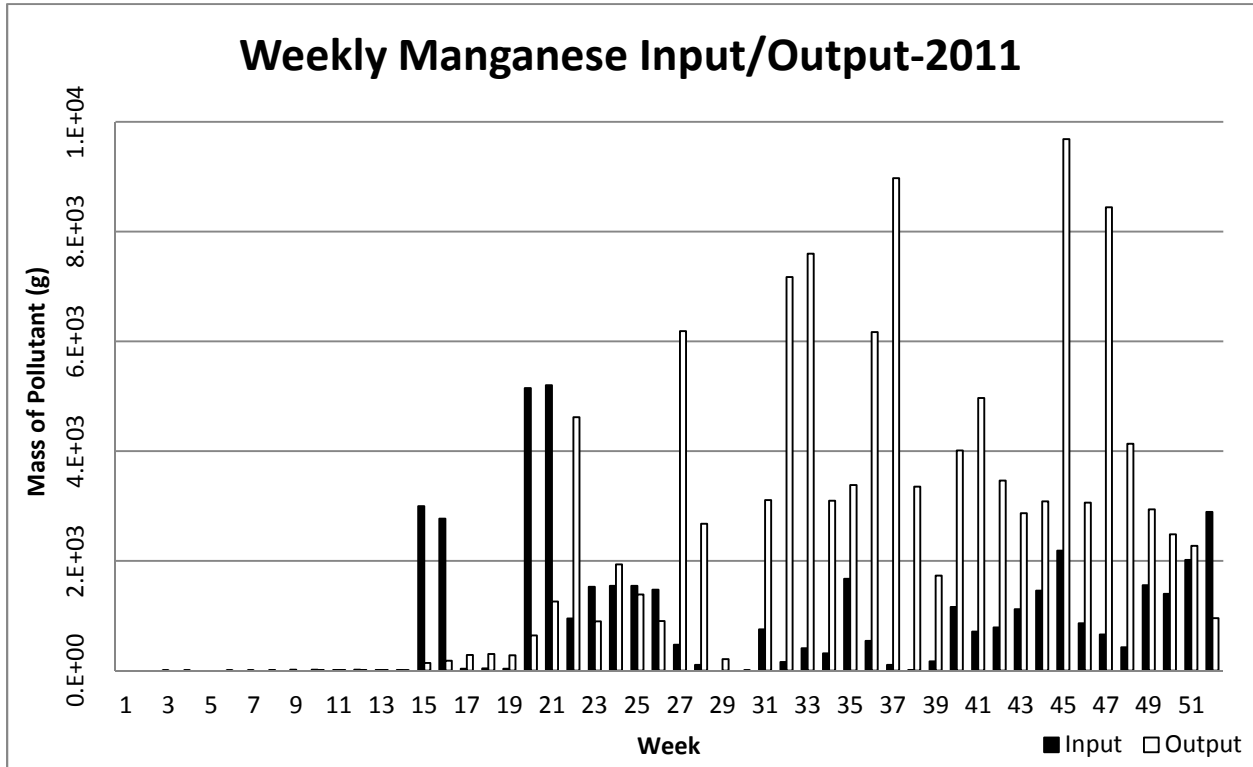


Figure I.3. Weekly input and output for the mass of manganese, in grams, for 2011.

Figure I.3 represents the weekly input and output for the mass of manganese, in grams, for 2011. This figure shows a better representation of exactly how much manganese was released by the CWTS into Lost Creek. The average weekly input of manganese into the CWTS was about 875 g [1.93 lb], while the average weekly output of manganese by the CWTS was about 2,300 g [5.07 lb]; therefore, in 2011, the percent of manganese removed weekly was - 163%, showing 100% of the manganese entering the CWTS also exited the CWTS, along with an extra 63% of manganese.

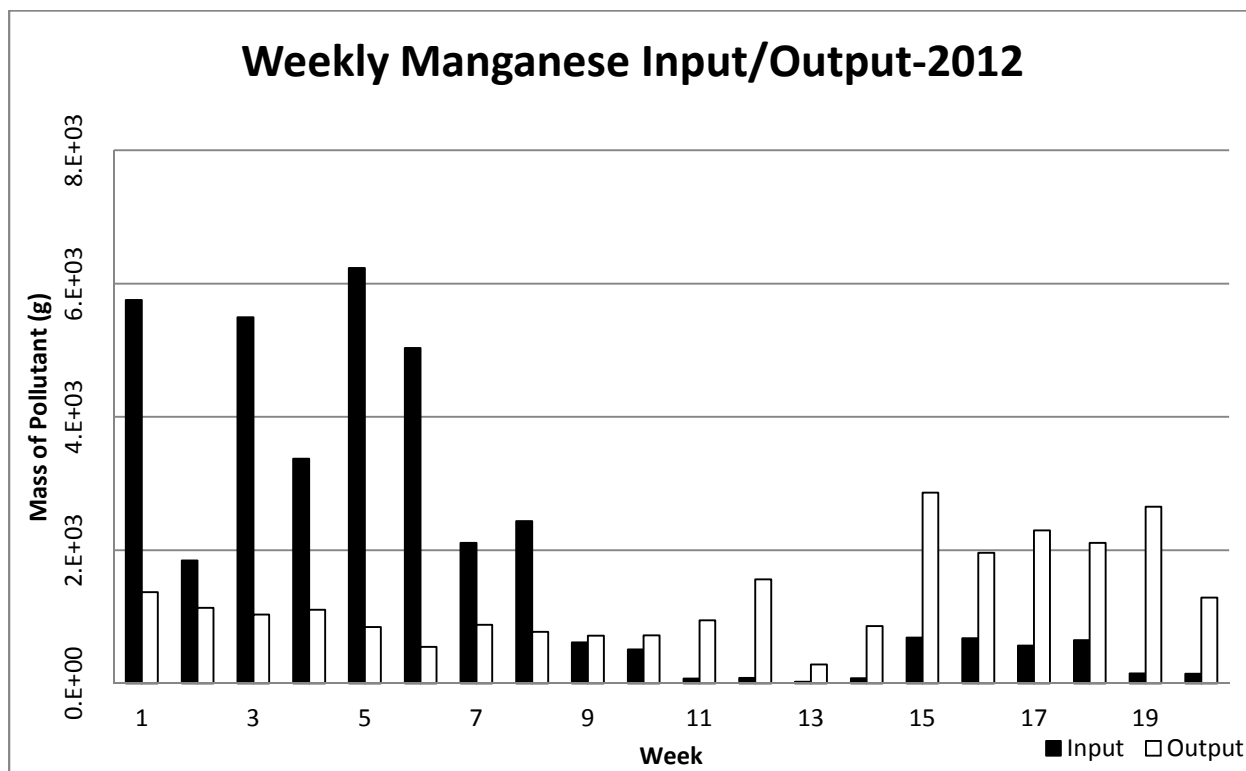


Figure I.4. Weekly input and output for the mass of manganese, in grams, for 2012 until May 22nd.

For 2012, Figure I.4 represents the weekly input and output for the mass of manganese, in grams, until May 22nd or week 20. Out of the 20 weeks the CWTS was still being researched, only 8 of the weeks resulted in a higher input of manganese than output, allowing more manganese to be released in the remaining 12 weeks. The average weekly input of manganese over these 20 weeks was about 1,800 g[3.97 lb], while the average weekly output of manganese was 1,300 g[2.87 lb]; therefore, in 2012, the percent of manganese removed by the CWTS was about 28% weekly manganese removal. Compared to 2011, the first 20 weeks in 2012 showed a greater percent manganese removal, but the remaining 12 weeks within the 20 show a higher release of manganese than input, showing the possibility of the 28% weekly manganese removal to decrease dramatically if research was still being conducted at the CWTS.

Mercury

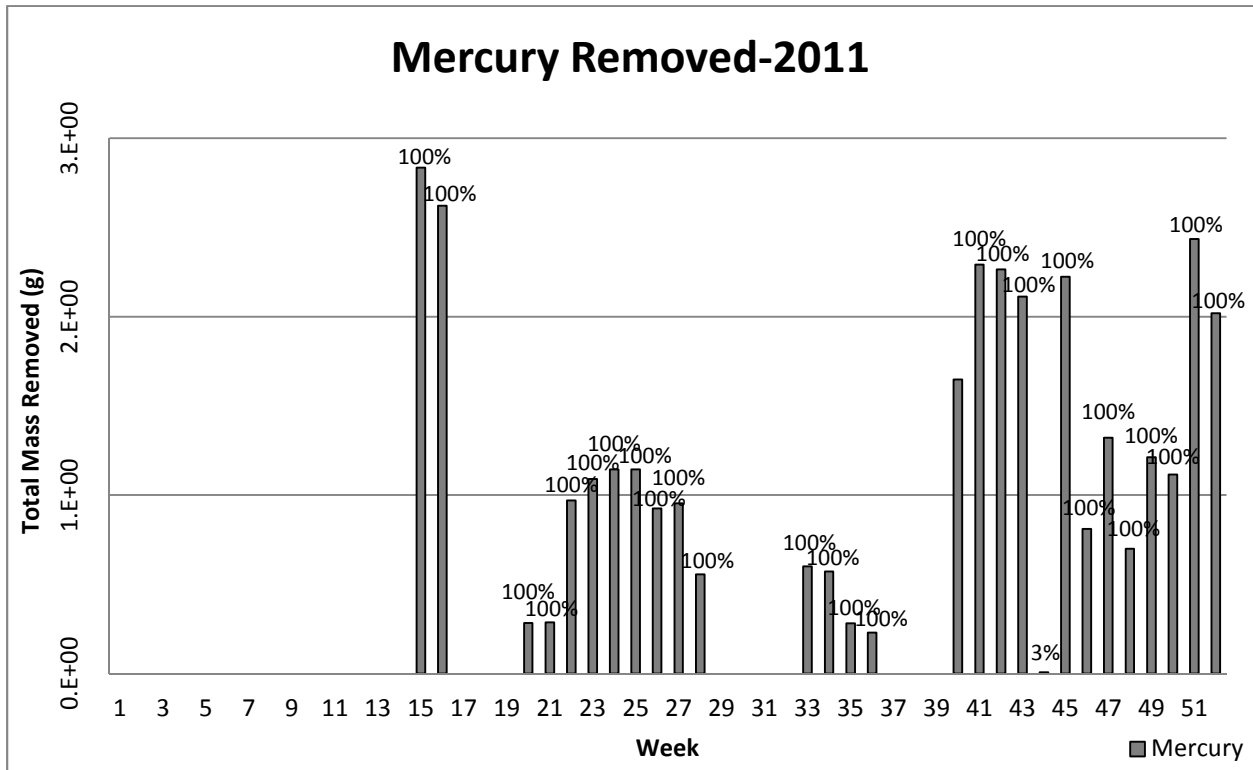


Figure I.5. Weekly total mercury mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Figure I.5 shows the weekly total mercury mass removal, in grams, for 2011, with the percentage removal for each week above each bar. With this figure, some of the bars are missing on the bar graph, which is due to no mercury entering or leaving the CWTS for that specific week. There are 10 weeks out of the year where no mercury entered or left the CWTS. Besides these 10 weeks, only one week (week 44) during 2011 resulted in a weekly removal of 3%, while all the other weeks resulted in a 100% weekly mercury removal.

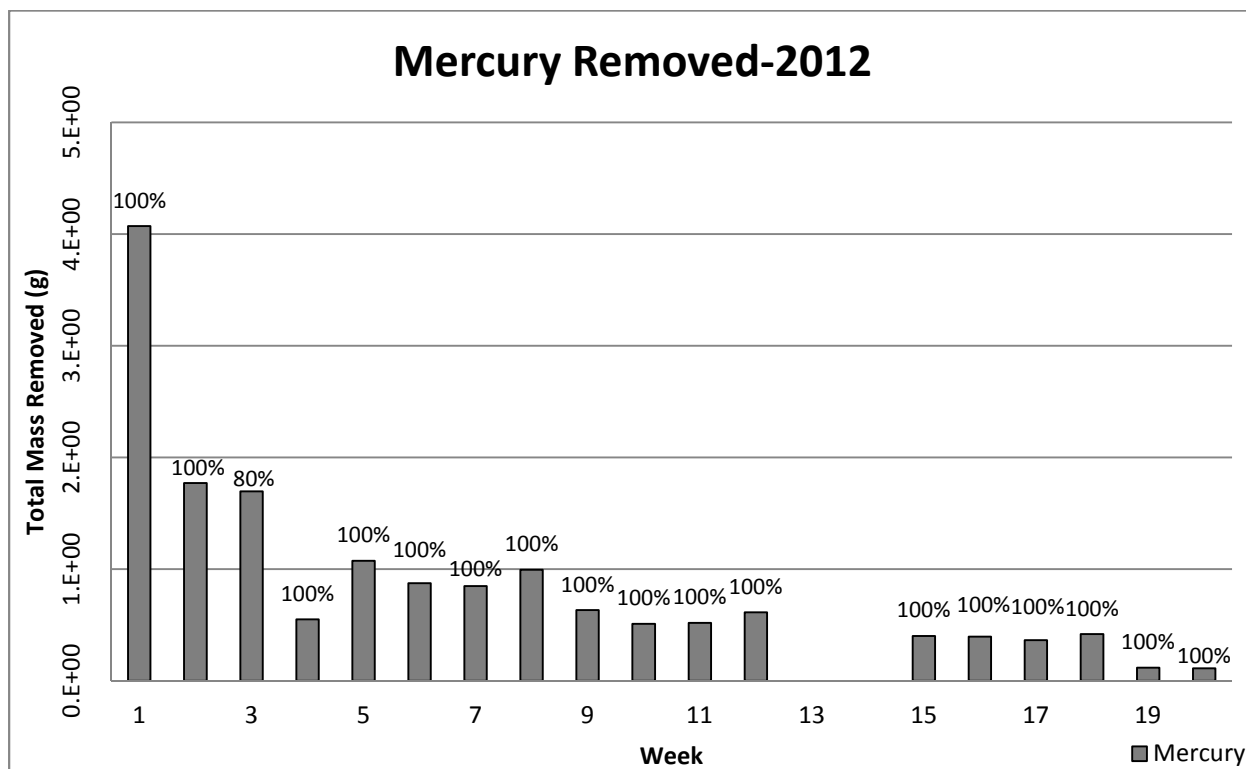


Figure I.6. Weekly total mercury mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Figure I.6 shows the weekly total mercury mass removal, in grams, for 2012 until May 22nd. In 2012, only 2 weeks out of the 20 weeks the CWTS was being researched resulted in no mercury entering or leaving the wetland. The remaining 18 weeks almost all resulted in a weekly mercury removal of 100% minus one week, week 3, which had a weekly mercury removal of 80%.

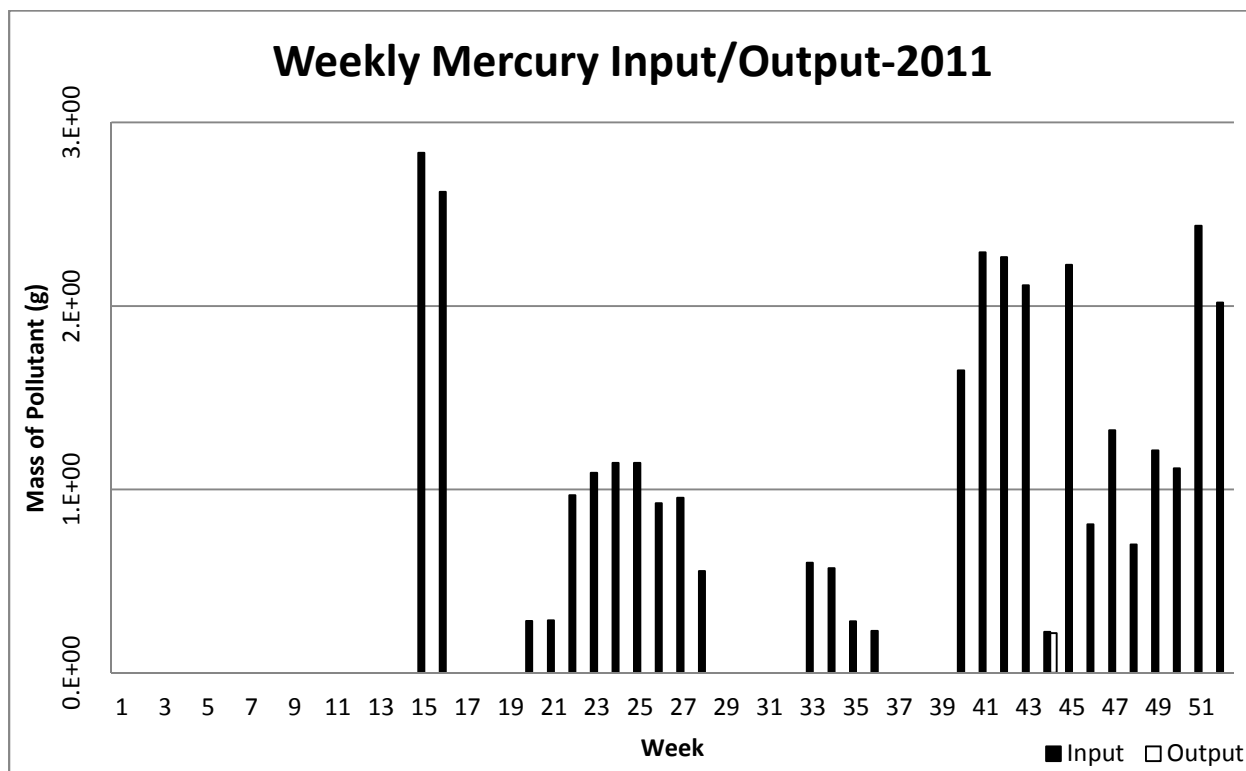


Figure I.7. Weekly input and output for 2011 for the mass of mercury in grams.

Figure I.7 shows the weekly input and output for 2011 for the mass of mercury in grams. The average weekly input of mercury for 2011 was about 670 mg[0.0236 oz], while the average weekly output of mercury was 4 mg [1.4×10^{-4} oz]; therefore, the overall average weekly removal of mercury for 2011 was 99%. The mercury percentage removal is the highest of all the pollutants tested for, showing the CWTS has the ability to remove such a harmful pollutant from the water stream before it is released into Lost Creek and eventually to the Kansas River.

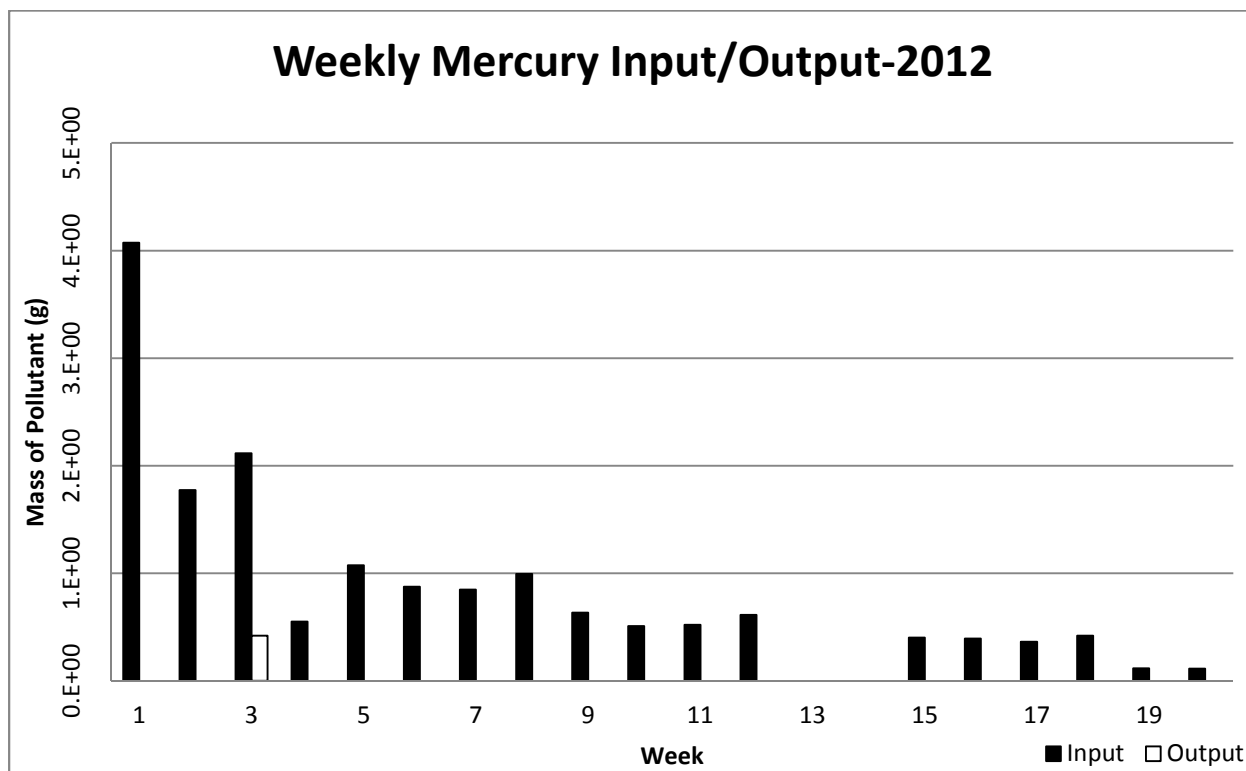


Figure I.8. Weekly input and output for 2012 until May 22nd for the mass of mercury in grams.

Figure I.8 shows the weekly input and output for 2012 until May 22nd for the mass of mercury in grams. Similar to 2011, most of the mercury input each week is removed by the CWTs and little to no mercury is released. The average weekly input of mercury for the 20 weeks in 2012 was 780 mg[0.0275 oz], while the average weekly output of mercury was 20 mg[7.05 x 10⁻⁴ oz] ; therefore, for 2012, the average weekly percent removal of mercury was 97%, decreasing by 2% from 2011.

Selenium

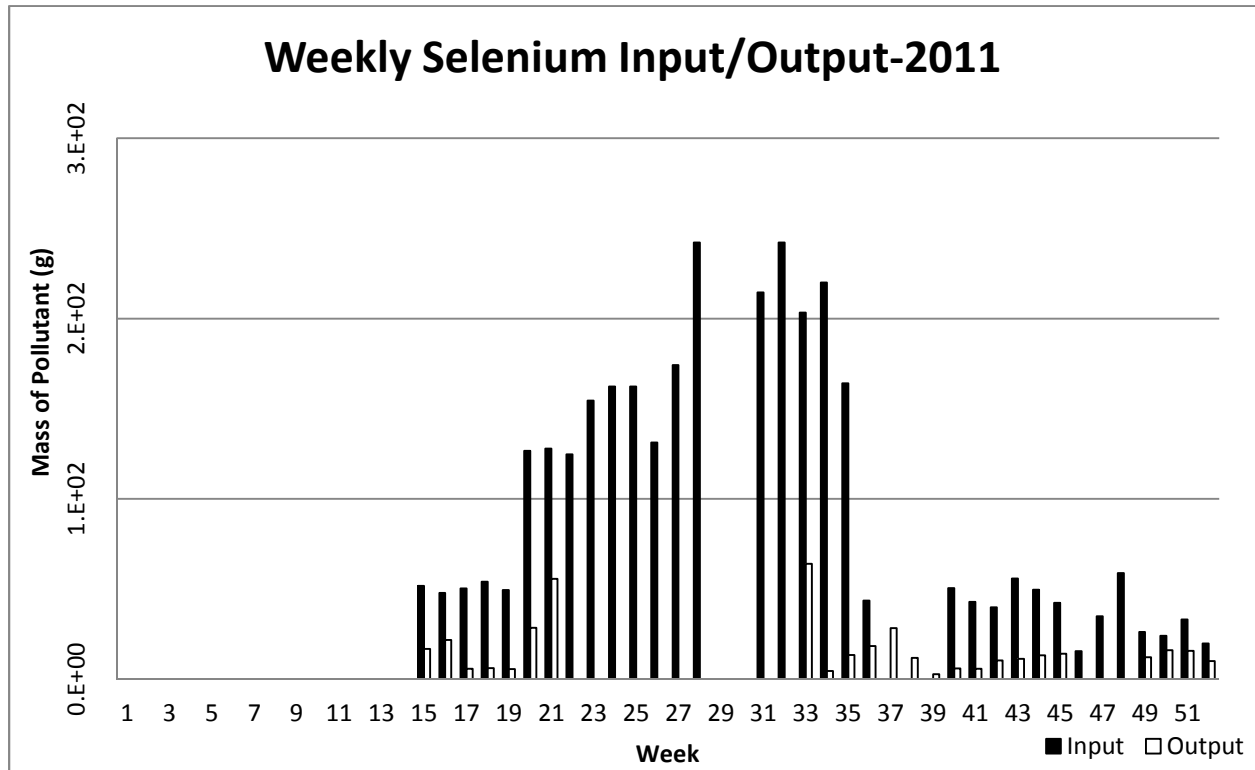


Figure I.9. Weekly input and output for 2011 for the mass of selenium in grams.

Figure 4.85 shows the weekly input and output for 2011 for the mass of selenium in grams. This figure shows there was a lot of selenium to enter the CWTS in 2011, but only a minimal amount of selenium left the CWTS, which is a plus for this system. Out of the 38 weeks the CWTS was under research in 2011, only 3 weeks had more selenium leave the CWTS than enter. The average weekly input of selenium into the CWTS in 2011 was about 62 g[0.137 lb], while the average weekly output of selenium was about 8 g[0.018 lb]; therefore, the average weekly percent removal of selenium for 2011 was around 87%.

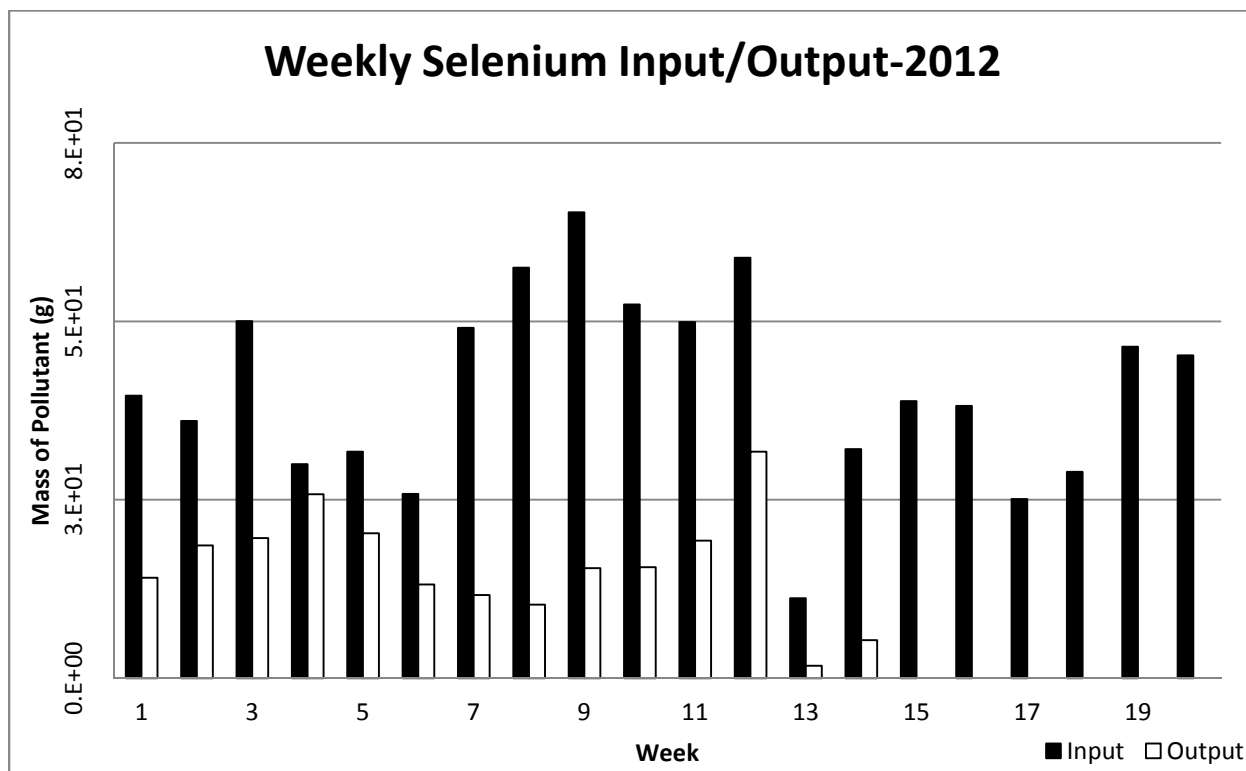


Figure I.10. Weekly input and output for 2012 until May 22nd for the mass of selenium in grams.

Figure 4.86 shows the weekly input and output for 2012 until May 22nd for the mass of selenium in grams. In 2012, there were no weeks where selenium output exceeds selenium input unlike 2011 which had 3 weeks of more selenium output than input. The average weekly selenium input for the 20 weeks in 2012 was about 39 g[0.086 lb], while the average weekly selenium output was around 11 g[0.024 lb]; therefore, the average weekly selenium removal was about 72%.

Chloride

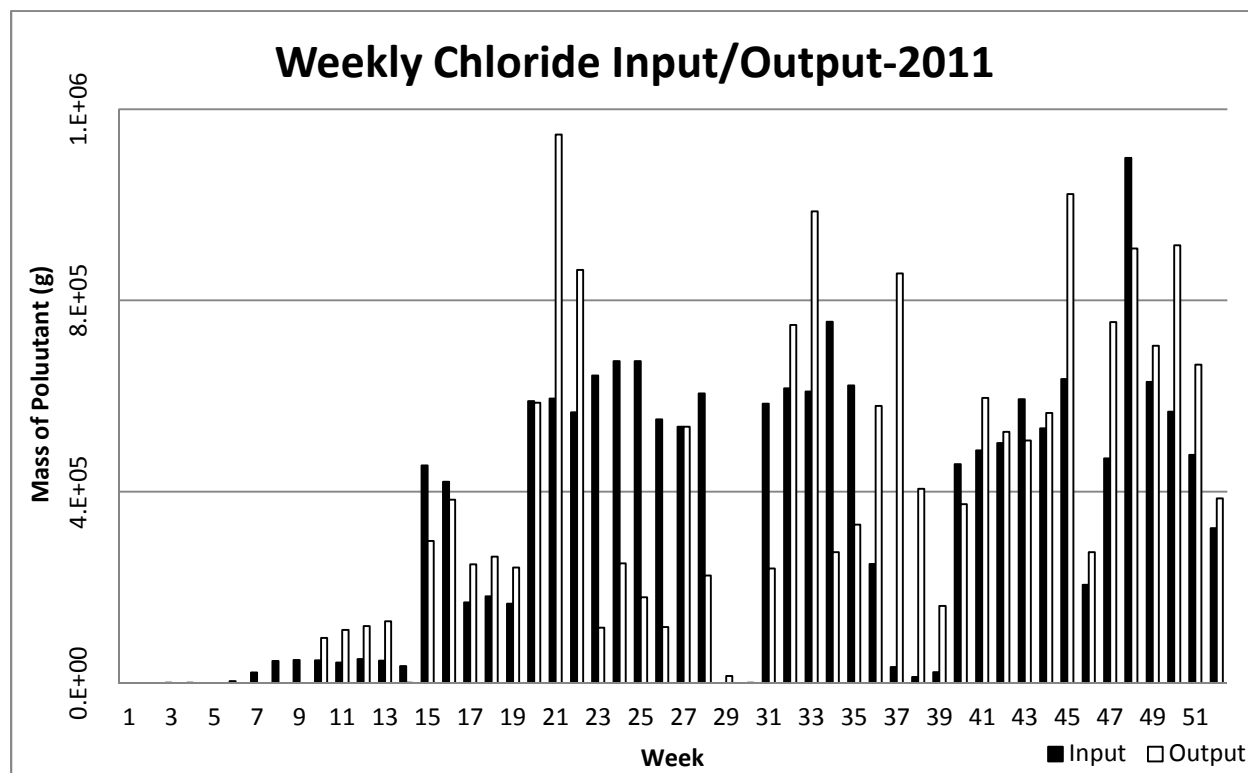


Figure I.11. Weekly input and output for 2011 for the mass of chloride in grams.

Figure I.11 shows the weekly input and output for 2011 for the mass of chloride in grams. For the year, about half the weeks have more chloride leaving the CWTS than entering, while the other half have more chloride entering than leaving the CWTS. The average weekly input of chloride into the CWTS was about 340,000 g[750 lb], while the average weekly output of chloride from the CWTS was about 360,000 g[794 lb]; therefore, the average weekly removal of chloride for 2011 was about -1%.

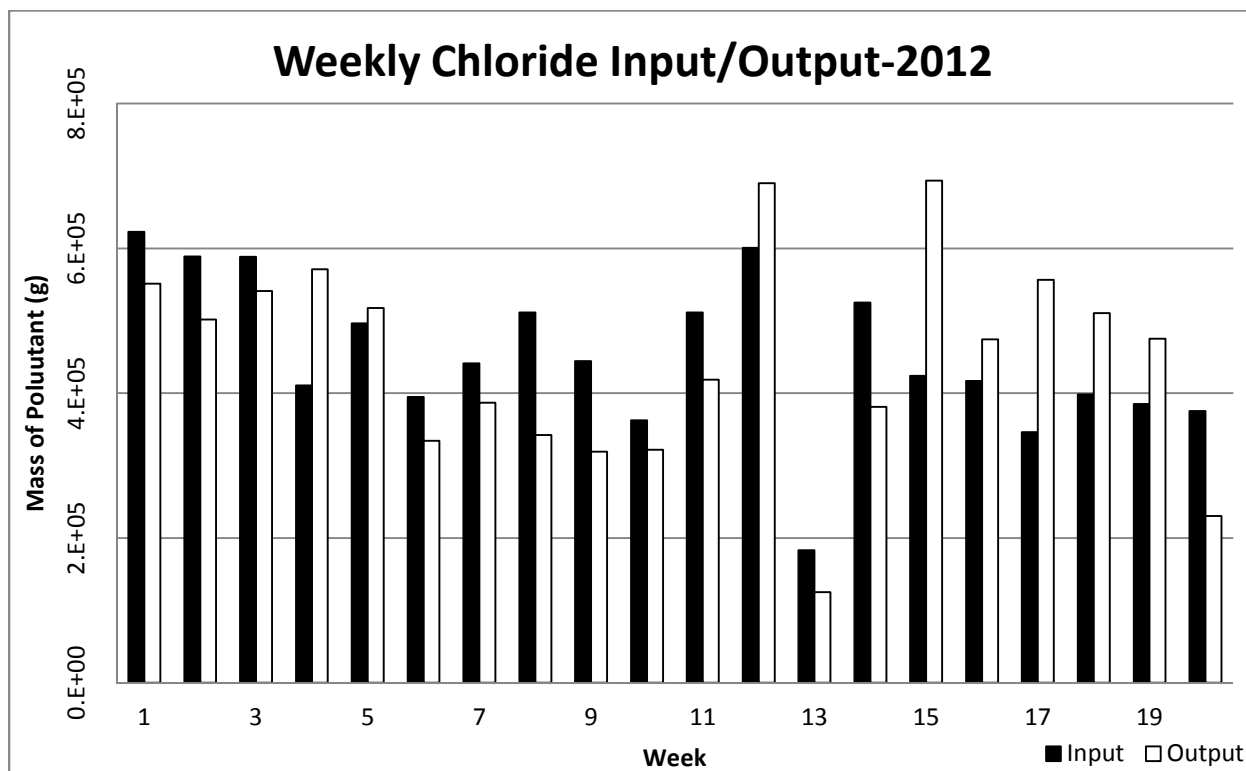


Figure I.12. Weekly input and output for 2012 until May 22nd for the mass of chloride in grams.

Figure I.12 represents the weekly input and output for 2012 until May 22nd for the mass of chloride in grams. Out of the 20 weeks the CWTS was being researched in 2012, eight out of the twenty week's output more chloride weekly than what is input. The average weekly chloride input into the CWTS was around 451,500 g[995 lb], while the average weekly chloride output was about 447,000 g[985.5 lb]; therefore, the average weekly removal of chloride for the first 20 weeks in 2012 was about 1%.

Fluoride

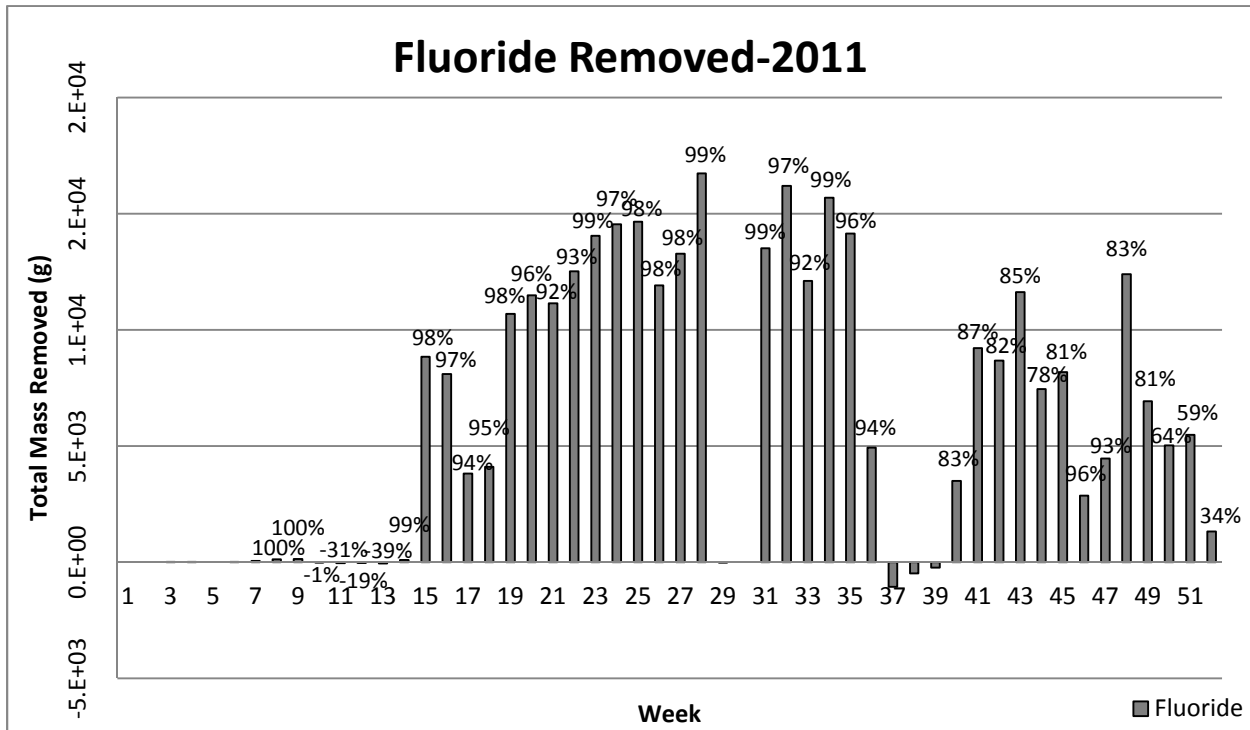


Figure I.13. Weekly total fluoride mass removal, in grams, for 2011. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Figure I.13 displays the weekly total fluoride mass removal, in grams, for 2011, in which each bar shows the percentage of fluoride removed for each specific week. Fluoride removal began early in the year, with 100% weekly removal of fluoride, because only water was entering the CWTS to fill up all the cells with water and therefore, no water was leaving, resulting in 100% removal. When water began to be released from the CWTS, which was week 10, the fluoride weekly removal was -1%, -31%, -19%, and -39% for the next four weeks. The excess fluoride leaving the CWTS was more than likely a build-up of fluoride that was not retained within the cells well when the CWTS was being filled; therefore, once the water was being output, the fluoride not taken up by the plants escaped, showing negative weekly removal percentages. After these four weeks of negative weekly removal percentages, fluoride was removed by the CWTS at an average weekly removal of 97% for the next fifteen weeks, until weeks 29 and 30 where no water was entering the CWTS due to maintenance issues. After the

maintenance issues were fixed, fluoride continued to be removed at high weekly removal percentages with an average weekly fluoride removal of 96% for the next six weeks.

Despite the high weekly fluoride removal percentages, weeks 37-39 show an output of fluoride, because of no water entering the CWTS due to more maintenance issues; however, water was still leaving the CWTS, allowing fluoride to leave. After these three weeks, fluoride removal continued at positive weekly removal percentages until the end of the year. The average weekly fluoride removal for the remaining 13 weeks of 2011 was around 77%, which was about a 20% decrease from earlier in the year.

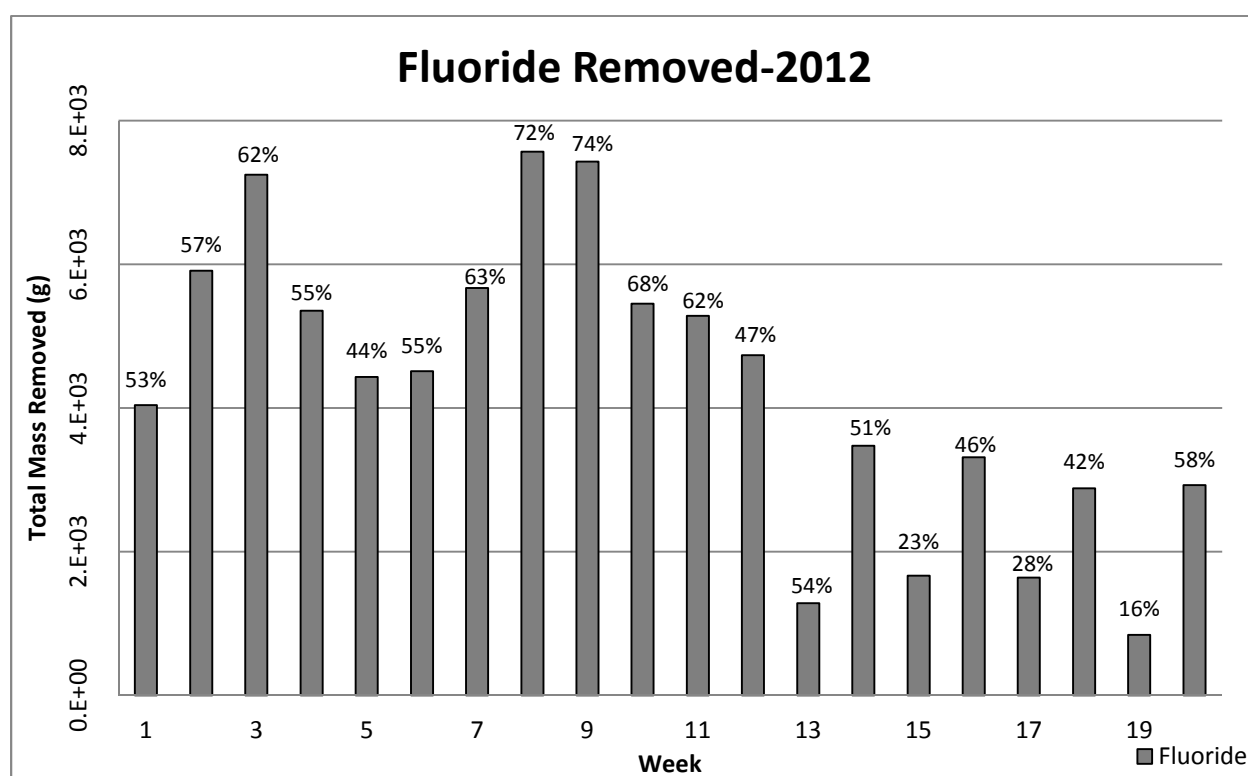


Figure I.14. Weekly total fluoride mass removal, in grams, for 2012 until May 22nd. Above each bar shows the percentage removed for the specific week. NOTE: If there is no percentage, this means the percentage is above a one-hundred value, either positive or negative, unless stated otherwise.

Figure I.14 shows the weekly total fluoride mass removal, in grams, for 2012 until May 22nd with weekly fluoride removal percentages above each bar. Compared to 2011, every week in 2012 shows a positive weekly fluoride removal; however, the percentage values are not as

high as seen in 2011. The highest weekly fluoride removal percentage occurred on week 10, with a 74% removal, which is 3% below the lowest weekly average removal for 2011. For 2012, the average weekly removal for fluoride was about 52%.

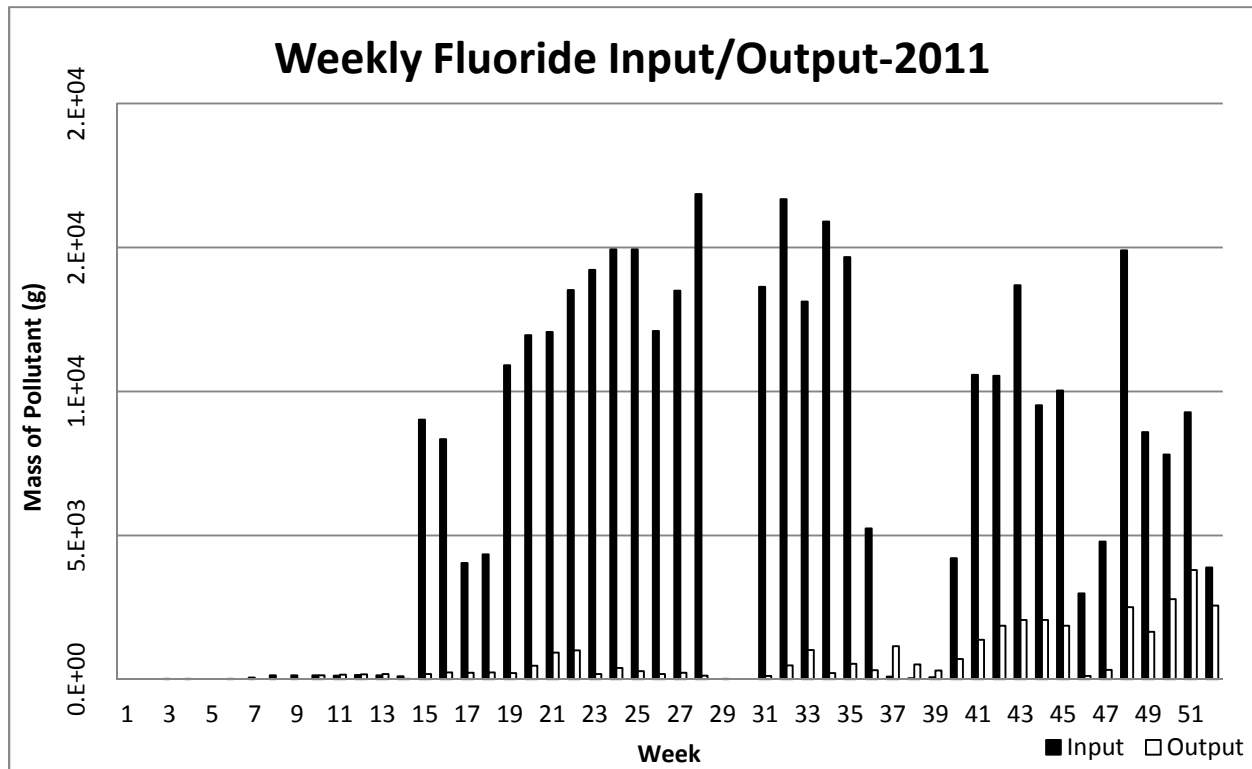


Figure I.15. Weekly input and output for 2011 for the mass of fluoride in grams.

Figure I.15 shows the weekly input and output for 2011 for the mass of fluoride in grams. During 2011, only about 8 weeks out of the year have more fluoride leaving the CWTS than fluoride entering. The average weekly input of fluoride into the CWTS was about 6770 g[15 lb], while the average weekly output of fluoride was about 650 g[1.43 lb]; therefore, in 2011, the average weekly fluoride removal by the CWTS was about 90%.

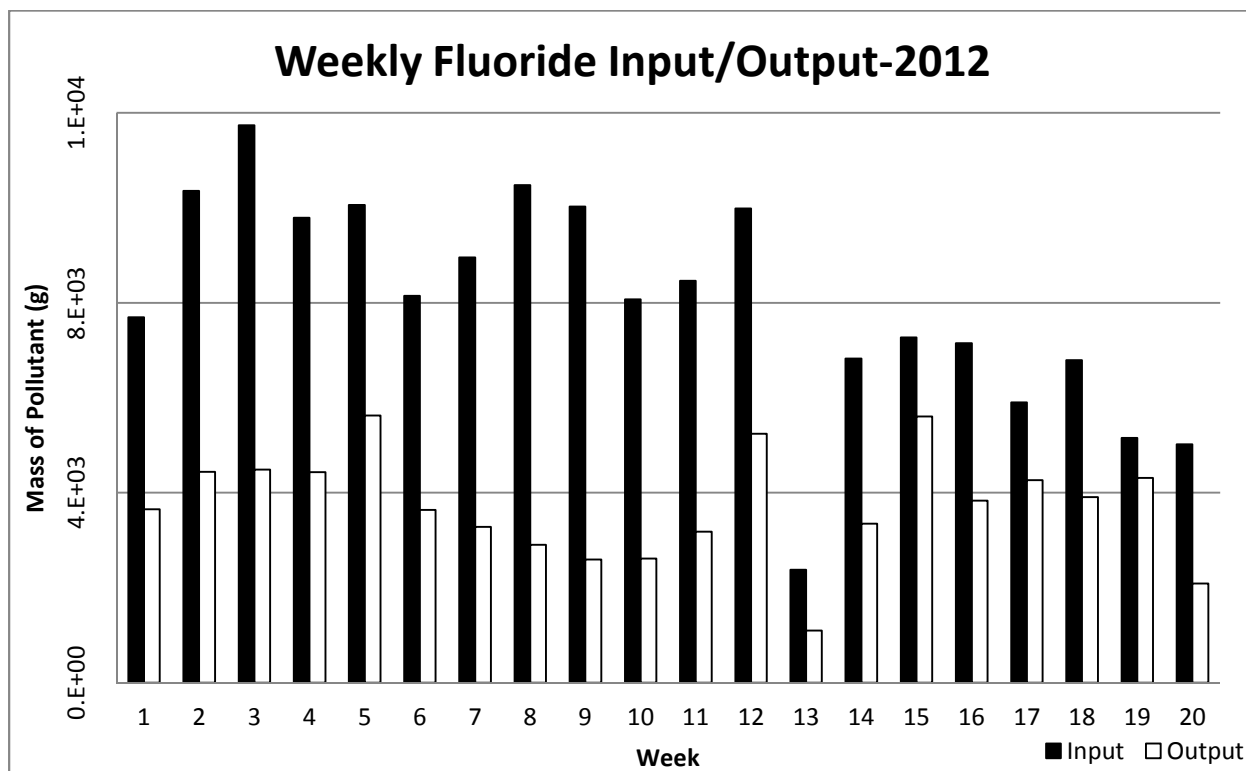


Figure I.16. Weekly input and output for 2012 until May 22nd for the mass of fluoride in grams.

Figure I.16 represents the weekly input and output for 2012 until May 22nd for the mass of fluoride in grams. Unlike 2011, every week in 2012 show more fluoride entering the CWTS than the amount of fluoride leaving. The average weekly input of fluoride into the CWTS was about 8015 g[17.7 lb], while the average weekly output of fluoride from the CWTS was around 3730 g[8.22 lb]; therefore, in 2012, the average weekly removal of fluoride was about 53%, a 37% decrease from 2011.

Sulfate

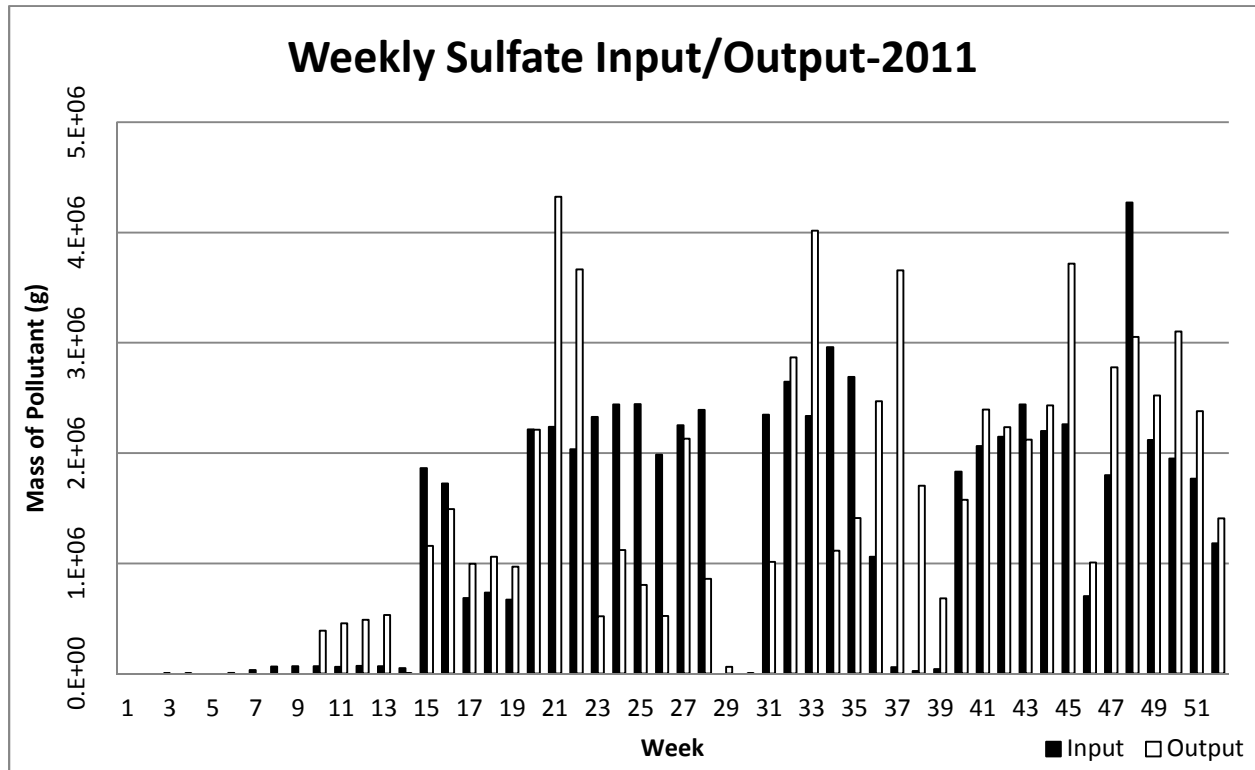


Figure I.17. Weekly input and output for 2011 for the mass of sulfate in grams.

Figure I.17 shows the weekly input and output for 2011 for the mass of sulfate in grams. Over half of the weeks in 2011 have more sulfates leaving the CWTS than what entered the wetland. The average weekly input of sulfate into the CWTS was about 1,300,000 g[2,866 lb], while the average weekly output of sulfate was about 1,413,000 g[3,115 lb]; therefore, the average weekly removal of sulfate in 2011 was about -9%.

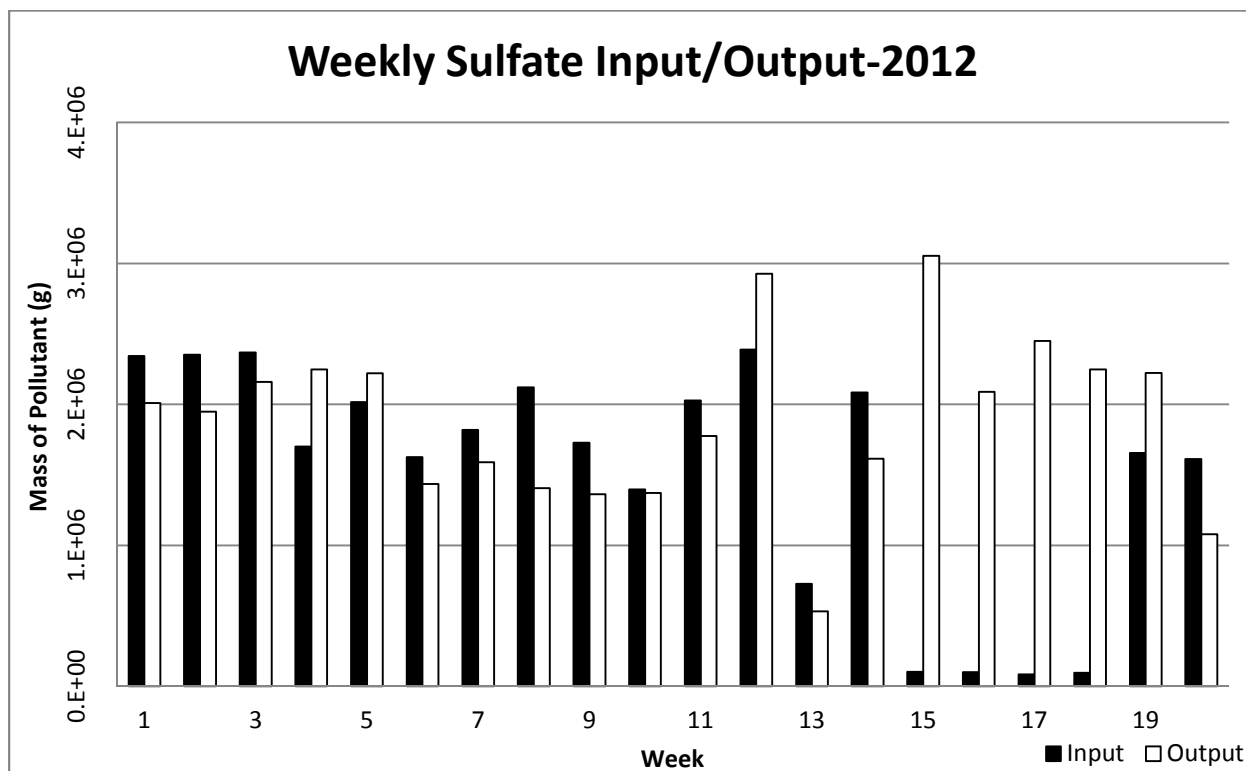


Figure I.18. Weekly input and output for 2012 until May 22nd for the mass of sulfate in grams.

Figure I.18 represents the weekly input and output for 2012 until May 22nd for the mass of sulfate in grams. Unlike 2011, only eight weeks out of the twenty weeks of operation in 2012 resulted in more sulfate being released by the CWTS than the amount of sulfate entering the wetland. The average weekly input of sulfate for 2012 was about 1,518,000 g[3,347 lb], while the average weekly output of sulfate was about 1,890,000 g[4,167 lb]; therefore, in 2012, the average weekly removal of sulfate was about -25%.