Upcoming Effluent Guidelines Challenges: Using Constructed Wetland Treatment Systems to your Advantage

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ABSTRACT

The EPA has developed an amendment to the existing effluent guidelines for steam electric generating units. The draft amendment was published in the Federal Register on June 7, 2013. The intent of the amendment is to update current regulations, which have not been updated since 1982. As coal-fired power plants look to implement new technologies for various effluent streams that may be regulated under the new rule, Constructed Wetland Treatment Systems are one technology that can be utilized to successfully remove metals from effluent steams, but constructed wetlands have not been widely utilized thus far in the power industry. Streams that now require additional monitoring or treatment have qualities making them ideal for treatment through a constructed wetland. Wetlands are appealing for their passive operation, and are often lower in capital and O&M costs than other available water treatment technologies. Constructed Wetland Treatment Systems have proven highly successful for removal of key metals, such as mercury and selenium. Wetlands have also successfully removed certain other constituents of interest in the utility sector. This presentation will include a brief review of recent pilot project results with FGD wastewater polishing at Westar Energy's Jeffrey Energy Center, and focus primarily on what these results mean for incorporation of Constructed Wetland Treatment Systems as a proven technology for meeting the future effluent guidelines in the steam electric generating sector.

INTRODUCTION

On June 7th, 2013, the EPA published the proposed rule for Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category. The guidelines aim to revise or establish Best Available Treatment Technology Economically Achievable (BAT), New Source Performance Standards (NSPS), Pretreatment Standards for Existing Sources (PSES), and Pretreatment Standards for New Sources (PSNS) that would apply to various waste streams found within Steam Electric Generating Stations. These waste streams include FGD wastewater, fly ash transport water, bottom ash transport water, combustion residual leachate from landfills and surface impoundments, nonchemical metal cleaning wastes, and wastewater from flue gas mercury control (FGMC) systems. EPA evaluated eight main regulatory options, but have identified four options as the preferred options. Each of these options carries varying degrees of regulation for each of these water streams:

Wastestreams	Technology Basis for the Main BAT/NSPS/PSES/PSNS Regulatory Options			
	3a	3b	3	4a
FGD Wastewater	BPJ Determination	Precipitation+ Biological Treatment for units at a facility with total wet-scrubbed capacity of 2,000MW and more; BPJ determination	Chemical Precipitation+ Biological Treatment	Chemical Precipitation+ Biological Treatment
Fly Ash Transport Water	Dry Handling	Dry Handling	Dry Handling	Dry Handling
Bottom Ash Transport Water	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Dry Handling/Closed loop (for units >400MW); Impoundment (Equal to BPT) (for units ≤400MW)
Combustion Residual	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)	Impoundment (Equal to BPT)
FGMC Wastewater	Dry Handling	Dry Handling	Dry Handling	Dry Handling
Nonchemical Metal Cleaning	Chemical Precipitation	Chemical Precipitation	Chemical Precipitation	Chemical Precipitation

A variety of treatment technologies could be used to meet the proposed guidelines. This paper will focus on the use of Constructed Wetland Treatment Systems (CWTS), and how they can be used to achieve compliance following finalization of the effluent guidelines. Part of this discussion will include an update on the CWTS Pilot and full scale construction that is currently ongoing at Westar Energy's Jeffrey Energy Center. Data gathered from the pilot was implemented in a full scale design. Data gathered is also pertinent in applying this technology to other waste streams within the power sector.

PROJECT BACKGROUND

Westar Energy, Inc.'s (Westar) Jeffrey Energy Center (JEC) is located seven miles northwest of St. Marys, Kansas. Figures 1 and 2 show the JEC site and geographic location, respectively. It is a coal-fired generating facility composed of three separate 800 MW units, each burning Power River Basin (PRB) coal. Each unit operates with a flue gas desulfurization (FGD) scrubber to remove sulfur oxides from the flue gas to meet air emissions regulations. The FGD system produces a slurry mixture by-product high in suspended solids, dissolved solids, nutrients, and metals. The wastewater requires treatment or disposal in accordance with the Kansas Surface Water Quality Standards and Antidegradation policies. In response to these regulations, JEC constructed a wastewater treatment facility to remove suspended solids and mercury. After treatment, the FGD wastewater still contains elevated levels of constituents relative to the Kansas Department of Health and Environment (KDHE) regulations for discharge of industrial wastewater.

Currently, Westar is blending the FGD wastewater and discharging it to Lost Creek, a tributary to the Kansas River. KDHE, however, is only allowing this to occur until June of 2014; therefore a secondary treatment system is required. A pilot scale constructed wetland treatment system (CWTS) was designed by Burns & McDonnell and constructed by JEC in December 2010 to demonstrate the potential for biological treatment of the FGD wastewater treatment stream. The pilot scale system was operated to assist in making an informed decision regarding the final treatment technology chosen for Westar's JEC.

Figure 1: Westar's Jeffrey Energy Center coal-fired generating facility.

Figure 2: Geographic location of Westar's Jeffrey Energy Center coal-fired generating facility.

PILOT CWTS PERFORMANCE

The CWTS pilot project received a 50/50 blend of 18,000 GPD of Kansas River water and 18,000 GPD of FGD effluent. The system exhibited a hydraulic residence time of approximately seven days, and the total wetland area is 2.1 acres. The pilot project was competed in four and a half months, and costs totaled $2.9 million. Kansas State University assisted with the project under a research contract during the operational phase. There are three different cell types operating in the CWTS (Figure 3). These include Free Water Surface (FWS), Vegetated Submerged Bed (VSB), and Vertical Flow Bed (VFB) systems.

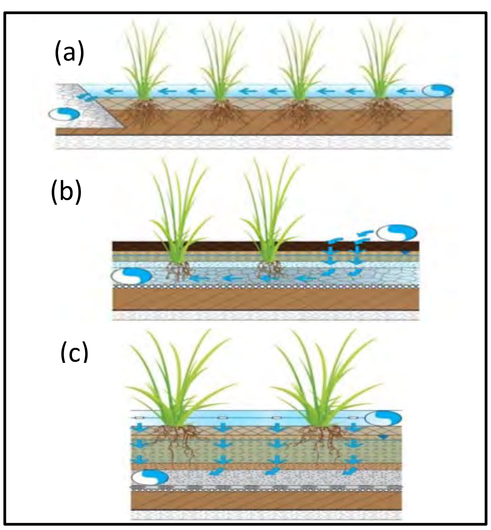

Figure 3: Three wetland cell types used in JEC's wetland system including (a) free water surface (FWS), (b) vegetated submerged bed (VSB), and (c) vertical flow bed (VFB).

After approximately 1.5 years of operation, JEC Pilot CWTS has achieved various levels of performance for treatment of target constituents. The following information concerning results pertains to data collection, validation, and evaluation for the period of May 2011-July 2012.

WATER TREATMENT EFFICIENCY- The removal efficiency of the CWTS was determined for all analytes by comparison of the average concentration in the effluent to the average concentration in the influent. The average influent concentration was calculated from the results of 49 sampling events from May 12, 2011 through July 10, 2012, and average effluent concentration from 51 sampling events between April 12, 2011- July 10, 2012. Note, when calculating averages and in the case of a non-detect result, the detection limit was used to calculate the numerical average. The following criteria were used in the evaluation of removal efficiency:

- Effective constituent removal was categorized by a removal efficiency greater than 20%
- Ineffective constituent removal was categorized by a removal efficiency of 0%
- Percent removal between 0% and 20% indicated little or no removal efficiency and provided inconclusive results

Overall, 19 constituents showed effective removal efficiency, 11 constituents showed ineffective removal efficiency, and 15 constituents showed little or no removal. The following sections summarize these results. Removal efficiencies, influent and effluent concentrations, and KDHE surface water standards are included in Appendix A.

<u>Metals-</u> CWTS influent and effluent were monitored for a total of 22 metals. Nine metals had good removal efficiency: aluminum, barium, boron, chromium, iron, mercury, molybdenum, selenium, and vanadium. Of these metals, aluminum, mercury, and selenium exhibited very good removal efficiencies at 89%, 81%, and 90%, respectively. Additionally, barium and chromium had effluent concentrations below or equal to the minimum KDHE surface water standard.

Six metals had poor removal efficiency: arsenic, cadmium, cobalt, manganese, nickel, and zinc. The concentrations of these analytes increased, thus, it is likely that some of these analytes were involved in ion exchange processes within the system. Arsenic, nickel, and zinc effluent concentrations were below or equal to the minimum KDHE surface water standards. The cadmium effluent concentration was below the Agriculture Irrigation and Domestic Water Supply standards, but not the Aquatic Life standard. Cobalt and manganese do not have available KDHE surface water standards.

The remaining seven metals (Be, Cu, Pb, Ag, Na, Sn, Sb) showed little or no percent removal (0-20%). However, the majority of these metals have effluent concentrations below or equal to the available KDHE surface water standards.

Halogens- Samples for anionic halogens, chloride and fluoride, were analyzed. Chloride showed little to no removal efficiency (3%) and an effluent concentration above the KDHE surface water standard. However, fluoride exhibited very good removal efficiency (83%).

Water Quality Parameters- Twenty-one water quality parameters were monitored. Nine of these parameters experienced good removal efficiency: ammonia, chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), magnesium, nitrate as N, nitrite as N, potassium, total suspended solids (TSS), and total organic carbon (TOC). Nitrate as N showed an effective removal efficiency of 88%. Six water quality parameters showed poor removal efficiency: alkalinity as $CaCO_3$, biological oxygen demand (BOD), calcium, hardness, and phosphorus. The remaining seven water quality parameters had little or no removal. Effluent concentrations of sulfate were above the KDHE surface water standard; however, the effluent concentration of nitrate as N was below the minimum KDHE surface water standards.

WATER MASS LOAD REDUCTION- The mass load reduction estimates for water were calculated by determining the total volume of influent and effluent water in the CWTS and applying the average constituent concentrations of the influent and effluent water samples. With the exception of mercury and selenium, most reported concentrations for elements in water samples were above detection limits. The high detection limit for most mercury and some selenium effluent samples was a factor in most water testing results. However, since detection limits were adjusted with each sample and testing event, they may provide a trend for the concentrations of these elements. The analytical testing results for water provide an accurate estimate of the mass (kg) removed by the CWTS for the major constituents of concern.

Table 1 provides the estimate of the mass removed in water for data collection through May 2012. Generally, both treatment lines performed with similar removal results, and no major trends were observed between individual cells. The total estimated influent mass load minus the total estimated effluent mass load of each major constituent found in the water samples showed a load reduction for all constituents including the following reduction percentages: 93% fluoride; 92% selenium; 83% mercury; 42% boron; 5% sulfate; and 2% chloride. Complete results are included in Appendix A.

Table 1: Constituent mass removal (kg) in water

Analyte	Units	Average Influent Concentration	Average Effluent Concentration	Percent Reduction (%)
Aluminum	mg/L	0.705	0.074	89
Boron	mg/L	3.63	2.177	40
Chromium	mg/L	0.015	0.005	66
Copper	mg/L	0.008	0.007	5
Lead	mg/L	0.004	0.003	18
Magnesium	mg/L	405	307	24
Mercury	mg/L	0.001	0.0002	82
Potassium	mg/L	67.8	30.8	55
Selenium	mg/L	0.153	0.012	92

As the constituent is removed from the water, that mass is attenuated in soil. One concern with the accumulation of constituent mass in soil is that the soil concentration could significantly increase and pose an environmental threat or trigger a regulatory requirement. Soil sample results were compared with risk screening levels specified in the Kansas Department of Health and Environment (KDHE)/ Bureau of Environmental Remediation (BER) risk-based levels for constituents in soil (Kansas Department of Health and Environment, 2010). Mercury and selenium have determined risk levels and are presented in Table 2. Both contaminants are well below the acceptable level for industrial soils.

FULL SCALE DESIGN

With the information gained from the operation of the pilot, the full scale CWTS design was completed. Several design factors were incorporated specifically as a result of the pilot project. The vertical flow bed and vegetative submerged beds in the pilot worked effectively. The free water surface wetland was effectively however this type of wetland represented the greatest ecological risk. The experience gained by the pilot and by Kansas State University column studies indicated that a deep vertical flow bed would most likely be a very successful treatment design in a full scale CWTS. The vertical flow bed design does not go through wetting and drying cycles, thus is anticipated to result in a lower likelihood for constituent releases during these cycles.

The constructed wetland treatment system is designed to have parallel treatment trains or lines so the system can remain operational during maintenance cycles. Each train consists of one Vertical Flow Bed (VFB) and one Vegetated Submerged Bed (VSB).

Considering ecological risk mitigation, the full scale design was developed to minimize ecological exposure by introducing the FGD wastewater in the subsurface within the VFB. This design will greatly reduce constituent levels of concern before the wastewater reaches the surface in the vegetated submerged beds. Each VFB will be further split into four treatment cells. The VFB cells contain a two-tiered system where a shallow tier 1 soil is used for plant growth and the deeper and thicker tier 2 soil provides treatment in an up-flow condition. The tier 1 soil also serves to isolate FGD pollutants from wildlife.

From the VFBs the wastewater will continue to be treated in the VSBs. The VSBs have only one soil layer for plant growth and provide additional polishing treatment through the underlying gravel layer while the surface soil maintains acceptable concentrations of mercury and selenium. Once the wastewater has been treated it may be pumped back to the plant for re-use in the cooling towers or blended with the cooling tower blowdown before being discharged to the Kansas River.

All ponds and treatment beds will be lined with a composite liner. Each VSB and VFB cell will have an effluent distribution manifold, emergency spillway riser, water control structure, and vegetated berms. The design treatment capacity of the system will be 160 gallons per minute (gpm). The maximum design will be 250 gpm plus rainfall. Wetland treatment bed types developed for the system are designed to have little or no standing water to reduce the risk for bioaccumulation of toxic constituents in the food chain.

PROPOSED EFFLUENT GUIDELINES

The proposed effluent guidelines make only a few references to constructed wetlands, but it is our belief that constructed wetlands do have a place in technologies that should be considered in meeting the finalized guidelines. Potential applications for constructed wetland treatment systems, based upon our pilot project results, include, but are not limited to:

- Landfill leachate and coal combustion residual (CCR) pond effluent
- Polishing of FGD wastewater upstream or downstream of other treatment applications

The proposed guidelines are anticipated to be finalized in May 2014, with operation of the Westar full scale CWTS beginning in March 2014. While data from the full scale CWTS will provide more definitive results, the pilot data can be used to determine how constructed wetlands can best be applied following finalization of the proposed effluent guidelines.

TREATMENT OF CCR IMPOUNDMENT EFFLUENT/LANDFILL LEACHATE

CHARACTERIZATION- The EPA conducted extensive research prior to the release of the proposed effluent guidelines for the steam electric generating industry. Part of this research included surveys of power plants to characterize how they were operating. As part of this survey, the EPA has estimated that 100-105 plants discharge an estimated flow of 54,000 gallons per day (per plant) from active and non-active landfills. The survey also indicated that somewhere around 141 plants utilize wet sluicing for fly ash handling, and 335 plants utilize wet sluicing systems as part of their bottom ash handling. Of the plants that ultimately discharge this wastewater, the average plant will discharge 2.4 million gallons per day (MGD) fly ash transport water and 1.8 MGD bottom ash transport water.

As part of this survey, the EPA also characterized the water chemistry of fly ash transport water and landfill and impoundment leachate using the data from many different facilities. Tables 2 and 3 were included within the Technical Development Document for the proposed guidelines.

TREATMENT OPTIONS- Of the four options that the EPA has identified as preferred options, CCR transport systems would have to be converted to dry systems (for fly ash handling) or would require treatment by gravity settling in surface impoundments to remove suspended solids. For Option 4A, bottom ash handling would require conversion to dry handling for some plants. Similar to the bottom ash requirements, landfill and/or impoundment leachate would require treatment by gravity settling in surface impoundments to remove suspended solids. Both bottom ash handling water and leachate effluent would be subject to BPT limits for total suspended solids (TSS), oil, and grease. In some cases, generators may opt to further treat impoundment discharge for use in other applications. Tables 4 and 5 demonstrate expected effluent pollutant concentrations, based off of our pilot project wetland performance, for some primary constituents of concern in combustion residual effluent and landfill leachate. These predicted effluents are based off of the average water chemistries reported in Tables 2 and 3, which were compiled by the EPA's technical supporting document for the proposed effluent guidelines.

POLISHING OF FGD WASTEWATER

CHARACTERIZATION- The EPA steam electric survey indicated that, on average, a steam electric power plant generates 1.2 million gallons per day of flue gas desulfurization (FGD) blowdown slurry. This slurry is generally requires dewatering, where solids will be separated from the wastewater and are treated and/or disposed of in different ways. FGD wastewater is difficult to characterize across the board for all steam electric generators, since the chemistry is heavily dependent on a variety of factors which include but are not limited to:

- Fuel type
- Process additives
- Equipment materials of construction, which may dictate process operations
- Oxidation

EPA's technical document characterized the water chemistry of FGD wastewater from surveys of facilities which utilize forced oxidation, and from some facilities that self-monitored FGD wastewater chemistry. Table 6 was included within the Technical Development Document for the proposed guidelines.

Table 2: Untreated Landfill Leachate Characteristics

Analyte	Units	Untreated Active Landfill	Untreated Inactive Landfill	Untreated Retired Landfill
Classicals				
Chloride	ug/L	542,000	11,100	149,000
Sulfate	ug/L	1,910,000	1,070,000	881,000
TDS	ug/L	3,860,000	1,670,000	1,660,000
TSS	ug/L	41,400	4,210	13,800
Metals				
Aluminum	ug/L	5,030	100	87
Antimony	ug/L	4.6	4.9	1.1
Arsenic	ug/L	46	10	41
Barium	ug/L	57	50	37
Beryllium	ug/L	1.9	0.47	1.1
Boron	ug/L	20,500	3,640	10,100
Cadmium	ug/L	2.7	1.9	0.73
Calcium	ug/L	481,000	386,000	303,000
Chromium	ug/L	4.9	1.6	3.4
Cobalt	ug/L	84	3.8	7.6
Copper	ug/L	10	1.7	2.4
Iron	ug/L	59,000	95	5,700
Lead	ug/L	1.4	0.47	0.83
Magnesium	ug/L	115,000	33,700	21,800
Manganese	ug/L	4,360	355	1,280
Mercury	ug/L	1.4	0.01	13
Molybdenum	ug/L	1,880	995	702
Nickel	ug/L	69	43	16
Selenium	ug/L	74	84	46
Silver	ug/L	0.68	0.42	1.03
Sodium	ug/L	327,000	16,700	66,200
Thallium	ug/L	1.3	0.96	0.92
Tin	ug/L	11	13	33
Titanium	ug/L	17	15	11
Vanadium	ug/L	3,240	6.2	69

Table 3: Untreated Fly Ash Transport Water Characteristics

Analyte	Unit	Average Concentration	
Ammonia As Nitrogen (NH3-N)	mg/L	0.17	
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	2.65	
Total Kjeldahl Nitrogen (TKN)	mg/L	1.01	
Biochemical Oxygen Demand (BOD)	mg/L	ND(2.00)	
Chloride	mg/L	56.8	
Hexane Extractable Material (HEM)	mg/L	7	
Silica Gel Treated HEM (SGT-HEM)	mg/L	6	
Sulfate	mg/L	1,110	
Total Dissolved Solids (TDS)	mg/L	662	
Total Phosphorus	mg/L	4.03	
Total Suspended Solids (TSS)	mg/L	23,400	
Analyte	**Unit**	**Average Total Concentration**	**Average Dissolved Concentration**
Aluminum	µg/L	320000	283
Antimony	µg/L	ND (81.2)	ND (20.0)
Arsenic	µg/L	1520	86.8
Barium	µg/L	5060	164
Beryllium	µg/L	71.5	ND (5.00)
Boron	µg/L	2790	1380
Cadmium	µg/L	39.6	ND (5.00)
Calcium	µg/L	204000	94800
Chromium	µg/L	1300	ND (10.0)
Chromium (VI)	µg/L	NA	5
Cobalt	µg/L	381	ND (50.0)
Copper	µg/L	964	ND (10.0)
Iron	µg/L	298000	ND (100)
Lead	µg/L	786	ND (50.0)
Magnesium	µg/L	35100	15200
Manganese	µg/L	1120	40.3
Mercury	µg/L	2.31	ND (0.200)
Molybdenum	µg/L	333	243
Nickel	µg/L	739	ND (50.0)
Selenium	µg/L	ND (20.3)	16.6
Sodium	µg/L	69900	64400
Thallium	µg/L	ND (40.6)	ND (10.0)
Titanium	µg/L	24900	ND (10.0)
Vanadium	µg/L	2340	70.7
Yttrium	µg/L	521	ND (5.00)
Zinc	µg/L	1220	ND (10.0)
Metals (EPA Method 1638, 1631E)			
Antimony	µg/L	33.1	17.4
Arsenic	µg/L	519	80.7
Cadmium	µg/L	9.51	ND (1.00)
Chromium	µg/L	569	ND (80.0)
Chromium (VI)	µg/L	NA	NA
Copper	µg/L	719	ND (20.0)
Lead	µg/L	260	ND (0.500)
Mercury	µg/L	1.16	0.00055
Nickel	µg/L	291	ND (100)
Selenium	µg/L	ND (200)	21.2
Thallium	µg/L	43.6	3.1
Zinc	µg/L	720	ND (50.0)

Table 4: Predicted Leachate Effluent Concentrations Based on Pilot Project Performance

Analyte	Units	Untreated Active Landfill Concentration	Pilot Project Reduction Percentage	Potential Treated Leachate Concentration
Aluminum	ug/L	5,030	89	553
Boron	ug/L	20,500	40	12,300
Chromium	ug/L	4.9	66	1.7
Copper	ug/L	10	5	9.5
Lead	ug/L	1.4	18	1.1
Magnesium	ug/L	115,000	24	87,400
Mercury	ug/L	1.4	82	0.3
Selenium	ug/L	74	92	6
TSS	ug/L	41,400	50	20,700

Table 5: Predicted Fly Ash Transport Effluent Concentrations Based on Pilot Project Performance

Analyte	Units	Untreated Fly Ash Transport Concentration	Pilot Project Reduction Percentage	Potential Treated Leachate Concentration
Aluminum	ug/L	320,000	89	35,200
Boron	ug/L	2,790	40	1,674
Chromium	ug/L	1300	66	442
Copper	ug/L	964	5	915.8
Lead	ug/L	260	18	213
Magnesium	ug/L	35,100	24	26,676
Mercury	ug/L	2.3	82	0.4
Selenium	ug/L	ND (20.3)	92	ND
TSS	ug/L	23,400	50	11,700

TREATMENT OPTIONS- Of the four options that the EPA has identified as preferred options, the treatment of FGD wastewater range from a BPJ (best practical judgement) determination, to some combination of physical/chemical and biological treatment. In cased where physical/chemical and biological treatment are both required, the EPA has also proposed numeric limits that would apply to mercury, selenium, arsenic, and nitrates/nitrites.

Polishing- Constructed wetlands cannot be used as a stand-alone treatment for FGD wastewater; they can however, be implemented as a polishing treatment upstream or downstream of additional treatment. Should the proposed rule require both physical/chemical and biological treatment, constructed wetlands would be an excellent enhancement to any biological system. In some cases, perhaps a CWTS could be the stand-alone biological treatment. This depends heavily on both the plant operating characteristics, and on the finalization of the EPA's proposed guidelines. Table 7 demonstrates expected FGD wastewater effluent pollutant concentrations, based off of our pilot project wetland performance, assuming there is no other additional treatment. This is a conservative observation of projected effluent concentrations, considering that in almost all cases, a constructed wetland would not be a stand-alone treatment technology for FGD wastewater. These predicted effluents are based off of the average pollutant concentrations in FGD wastewater noted in Table 6. It is also important to note, that concentrations of certain elements found in FGD wastewater (such as Boron and Chloride) may also be limiting factors due to their effects on plant growth. High concentrations of such constituents may also limit the use of the constructed wetlands for FGD wastewater to maintain the health of the ecological system.

Detection Limitations- During pilot project operation, some pollutant concentrations were below detection limits. This is significant to note in the results for mercury, selenium, and nitrates/nitrites. Mercury, selenium, and arsenic all had a significant amount of non-detect concentrations, while nitrates/nitrites had a smaller percentage. Averaging all test results for the CWTS effluent, mercury was 100% non-detect (at 200 ng/L), arsenic was 36% non-detect (at 5 µg/L), selenium was 37% non-detect (at 5 µg/L), nitrates were 8% non-detect (at 0.1 mg/L) and nitrites were 10% non-detect (at 0.1 mg/L). In instances where the concentrations were not detected, the detection limit was used in order to calculate average reduction percentages over the course of the project. This is significant in comparing pilot results with the proposed numeric limits, because it can be inferred that pilot project results may have been more successful than what the calculated results would indicate. Table 6 shows a comparison between pilot project results and the proposed numeric limits in the effluent guidelines.

Table 6: Average Pollutant Concentrations in FGD Wastewater

Analyte	Unit	Average Total Concentration	
Sulfate	mg/L	8,140	
Cyanide, Total	mg/L	0.764	
Total Dissolved Solids	mg/L	28,600	
Total Suspended Solids	mg/L	16,800	
Phosphorus, Total	mg/L	3.19	
Analyte	**Unit**	**Average Total Concentration**	**Average Dissolved**
Metals			
Aluminum	ug/L	332,000	37,200
Antimony	ug/L	22	6
Arsenic	ug/L	489	10
Barium	ug/L	2,850	321
Beryllium	ug/L	17	3
Boron	ug/L	291,000	266,000
Cadmium	ug/L	159	128
Calcium	ug/L	3,250,000	2,100,000
Chromium	ug/L	1,300	380
Chromium (VI)	ug/L	NA	5
Cobalt	ug/L	310	225
Copper	ug/L	784	88
Iron	ug/L	764	52,600
Lead	ug/L	323	6
Magnesium	ug/L	3,630,000	3,400,000
Manganese	ug/L	107,000	106,000
Mercury	ug/L	411	78
Molybdenum	ug/L	313	185
Nickel	ug/L	1,880	1,230
Selenium	ug/L	4,490	1,980
Silver	ug/L	9	1
Sodium	ug/L	275,000	265,000
Thallium	ug/L	27	16
Tin	ug/L	184	130
Titanium	ug/L	4,840	734
Vanadium	ug/L	1,450	18
Zinc	ug/L	5,380	2,290

CONCLUSIONS

The Pilot CWTS at JEC has demonstrated successful results for pollutant reduction in FGD wastewater, especially for selenium and mercury. Innovative design in the full scale CWTS has been completed to reduce ecological exposure to problematic constituents. Since the wastewater is applied to the wetland subsurface, mercury and selenium can be isolated from wildlife, mitigating the ecological risk that can sometimes be associated with constructed wetlands.

CWTS can be a great fit for treatment of combustion residual impoundment effluent and landfill leachate. While the proposed guidelines may only require treatment of these waste streams through the use of impoundments for settling of solids, plants may wish to further polish leachate for re-use or eventual discharge. While Constructed Wetland Treatment Systems may not be an ideal stand-alone treatment technology for FGD wastewater, they may have a place as a polishing technology upstream or downstream of other treatment technologies.

Constructed wetlands show success with removal of metals and suspended solids, which make them an ideal technology for such treatment. Constructed wetlands can also be a good opportunity to implement a green technology that is attractive to stakeholders. CWTS are a passive treatment technology and have low operation and maintenance costs. When used in the right application, CWTS can provide a financially attractive treatment technology.

Table 7: Predicted FGD Wastewater Concentrations Based on Pilot Project Performance

Analyte	Units	Untreated FGD Wastewater Concentration	Pilot Project Reduction Percentage	Potential Treated FGD Wastewater Concentration
Aluminum	ug/L	332,000	89	36,520
Boron	ug/L	291,000	40	174,600
Chromium	ug/L	1,300	66	442.0
Copper	ug/L	784	5	744.8
Lead	ug/L	323	18	264.9
Magnesium	ug/L	3,630,000	24	2,758,800
Mercury	ug/L	411	82	74.0
Selenium	ug/L	4,490	92	359
TSS	ug/L	16,800	50	8,400

Table 8: Pilot Results Compared with Proposed Numeric Limits for FGD Wastewater

Analyte	DRAFT ELG Daily Maximum Limit	DRAFT ELG Monthly Average Limit	Westar Pilot Effluent Averages*
Arsenic	8 µg/L	6 µg/L	8 µg/L
Mercury	242 ng/L	119 ng/L	Non-detect at 200 ng/L
Selenium	16 µg/L	10 µg/L	12 µg/L
Nitrates/Nitrites as N	0.17 mg/L	0.13 mg/L	Nitrate as N: 4.8 mg/L Nitrite as N: 1.1 mg/L

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APPENDIX A

CWTS INFUENT AND EFFLUENT WATER QUALITY DATA
AND
KDHE SURFACE WATER QUALITY STANDARD

Constituent	KDHE Surface Water Standards (mg/L)			Average Influent Concentration[4,6] (mg/L)	Average Effluent Concentration[5,6] (mg/L)	Percent Reduction (%)
	Agriculture Irrigation[1]	Domestic Water Supply[2]	Aquatic Life Chronic[3]			
Alkalinity, as $CaCO_3$	-	-	-	144	309	-114
Aluminum	-	-	-	0.617	0.068	89
Ammonia	-	-	3.51	**1.396**	**0.514**	63
Antimony	-	0.006	0.03	0.007	0.007	4
Arsenic	0.1	0.01	0.15	**0.008**	**0.008**	-6
Barium	-	1	-	**0.102**	**0.067**	35
Beryllium	-	0.004	-	**0.001**	**0.001**	0
BOD	-	-	-	5.125	5.348	-4
Boron	0.75	-	-	3.593	2.424	33
Cadmium	0.01	0.005	0.003	**0.001**	**0.002**	-87
Calcium	-	-	-	341	494	-45
Chemical Oxygen Demand	-	-	-	97	55	44
Chloride	-	250	-	557	541	3
Chromium	0.1	0.1	0.04	**0.017**	**0.005**	70
Cobalt	-	-	-	0.002	0.009	-436
Copper	0.2	1.3	0.1355	**0.008**	**0.007**	13
Fluoride	1	2	-	10.785	1.794	83
Hardness	-	-	-	2257	2291	-2
Iron	-	-	-	1.181	0.617	48
Kjeldahl Nitrogen, as N	-	-	-	4.867	3.461	29
Lead	5	0.015	0.1714	**0.004**	**0.003**	12
Magnesium	-	-	-	374	289	23
Manganese	-	-	-	1.441	3.966	-175
Mercury	-	0.00014	0.00077	0.00108	0.00020	81
Molybdenum	-	-	-	0.035	0.013	62
Nickel	0.2	0.61	0.7378	**0.005**	**0.006**	-22
Nitrate, as N	-	10	-	33.313	**3.883**	88
Nitrite, as N	-	-	-	1.733	0.406	77
pH (std. units)	-	-	6.5 - 8.5	**8.426**	**7.330**	13
Phosphorus	-	-	-	0.204	0.533	-161
Potassium	-	-	-	62.4	31.5	50
Selenium	0.02	0.17	0.005	0.111	0.011	90
Silver	-	0.05	-	**0.001**	**0.001**	0
Sodium	-	-	-	418	410	2
Total Solids	-	-	-	5521	4558	17
Total Dissolved Solids	-	-	-	4645	4201	10
Total Suspended Solids	-	-	-	19.350	6.783	65
Specific Conductance (umhos/cm)	-	-	-	5464	5223	4
Sulfate	-	250	-	2281	2163	5
Sulfide	-	-	-	0.100	0.100	0
Thallium	-	0.002	0.04	0.002	0.002	7
Tin	-	-	-	0.006	0.006	0
Total Organic Carbon	-	-	-	26.712	18.900	29
Vanadium	-	-	-	0.007	0.005	22
Zinc	2	7.4	1.702	**0.022**	**0.022**	-1

Bold numbers indicate that the constituent concentration is less than or equal to the minimum KDHE standard available

[1] KDHE Surface Water Agriculture Irrigation Limit

[2] KDHE Surface Water Domestic Water Supply Limit

[3] KDHE Surface Water Aquatic Life Chronic Limit

[4] Influent calculated as average of available results from 49 sampling events May 12, 2011 – July 10, 2012

[5] Effluent calculated as average of available lift station results from 51 sampling events April 12, 2011 – July 10, 2012

[6] When calculating averages and in the case of a non-detect, the laboratory practical quantitation limit (PQL) was used to calculate the numerical average