

**2018 Annual Groundwater
Monitoring and Corrective
Action Report**



Tennessee Valley Authority
Paradise Fossil Plant Slag Ponds
Area Multi-unit CCR Unit



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January 31, 2019

January 31, 2019

Reference: 2018 Annual Groundwater Monitoring and Corrective Action Report
TVA Paradise Fossil Plant Slag Ponds Area Multi-unit CCR Unit

In accordance with 40 CFR 257.90(e) of the Federal Coal Combustion Residuals (CCR) Rule (CCR Rule), this 2018 Annual Groundwater Monitoring and Corrective Action Report (2018 Annual Report) documents 2018 groundwater monitoring activities at the Slag Ponds Area Multi-unit CCR Unit at the Tennessee Valley Authority (TVA) Paradise Fossil Plant (PAF). In 2017, TVA established a groundwater monitoring network and program at the PAF Slag Ponds Area Multi-unit CCR Unit in accordance with 40 CFR 257.90. The groundwater monitoring network was certified by a qualified Professional Engineer as required by 40 CFR 257.91(f). During 2018, TVA performed the following groundwater monitoring activities:

- Conducted a statistical analysis of the 2017 detection monitoring groundwater sampling data in accordance with 40 CFR 257.93(h), and it was concluded that there were statistically significant increases (SSIs) over background levels for certain Appendix III constituents. The results were included in Table 1 of the 2017 Annual Groundwater Monitoring and Corrective Action Report, which was placed on the CCR Compliance Data and Information website (<https://www.tva.gov/Environment/Environmental-Stewardship/Coal-Combustion-Residuals>).
- Performed an alternate source demonstration for the SSIs over background levels of Appendix III constituents in accordance with 40 CFR 257.94(e)(2).
- Performed error checking and investigated whether the SSIs over background resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality as specified in 40 CFR 257.94(e)(2).
- Established an assessment monitoring program in accordance with 40 CFR 257.94(e)(1) because the Appendix III alternate source demonstration was unable to establish that the SSIs were the result of another source or the result of an error.
- Placed notification of the establishment of the assessment monitoring program in the facility operating record in accordance with 40 CFR 257.94(e)(3) and 257.105(h)(5); provided notification to the State of Kentucky in accordance with 40 CFR 257.106(h)(4); and placed notification on the CCR Compliance Data and Information website <https://www.tva.gov/Environment/Environmental-Stewardship/Coal-Combustion-Residuals> in accordance with 40 CFR 257.107(h)(4).
- Sampled and analyzed groundwater in the certified monitoring network for Appendix IV constituents in accordance with 40 CFR 257.95(b).
- Sampled wells in the certified monitoring network and analyzed samples for CCR constituents (Appendix III and Appendix IV constituents) in accordance with 40 CFR 257.95(d)(1). The sampling results were placed in the operating record as required by 40 CFR 257.95(d)(1) and 257.105(h)(6). Additionally, these results are included in Table 1 of this 2018 Annual Report in accordance with 257.95(d)(3).
- Established groundwater protection standards in accordance with 40 CFR 257.95(d)(2) and included the standards in this 2018 Annual Report in accordance with 257.95(d)(3).

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- Performed field and desktop site characterization investigations to improve the PAF Conceptual Site Model (CSM).
- Continued TVA's third-party Quality Assurance Program to evaluate and improve groundwater analytical data using best practices concerning field methods and validation techniques, as well as the application of the most appropriate statistical methods.
- Reviewed new data as it became available to maintain compliance with 40 CFR 257.90 through 257.98.
- Complied with recordkeeping requirements as specified in 40 CFR 257.105(h), notification requirements specified in 40 CFR 257.106(h) and internet requirements specified in 40 CFR 257.107(h).

No problems were encountered during the second year of the TVA Groundwater Quality Monitoring Program and therefore, no further action has been recommended, except for the planned key activities for 2019 that are outlined below.

The projected key activities for 2019 are:

- Complete an evaluation of whether one or more Appendix IV constituents are detected at statistically significant levels (SSLs) above the established groundwater protection standards in accordance with 40 CFR 257.95(g).
- Perform an alternate source demonstration for the SSLs over groundwater protection standards (Appendix IV constituents) in accordance with 40 CFR 257.95(g)(3)(ii).
- Initiate characterization of the nature and extent of the release in accordance with 40 CFR 257.95(g)(1) if the Appendix IV alternate source demonstration performed under 40 CFR 257.95(g)(3)(ii) is not successful.
- Notification of the exceedances of established groundwater protection standards will be placed in the facility operating record in accordance with 40 CFR 257.95(g) and 257.105(h)(8); will be provided to the State of Kentucky in accordance with 40 CFR 257.106(h)(6); and will be placed on the CCR Compliance Data and Information website (<https://www.tva.gov/Environment/Environmental-Stewardship/Coal-Combustion-Residuals>) in accordance with 40 CFR 257.107(h)(6).
- All persons who own the land or reside on the land that directly overlies any part of the plume of contamination if contaminants have migrated off-site will be notified in accordance with 40 CFR 257.95(g)(2) if the Appendix IV alternate source demonstration performed under 40 CFR 257.95(g)(3)(ii) is not successful.
- Initiate Assessment of Corrective Measures in accordance with 40 CFR 257.95(g)(3)(i) and 40 CFR 257.96.
- Perform further field and desktop site characterization investigations to improve the PAF CSM.
- Continue semi-annual assessment monitoring at the certified groundwater monitoring network consistent with 40 CFR 257.95.
- Continue TVA's third-party Quality Assurance Program to evaluate groundwater analytical data using best practices concerning field methods and validation techniques, as well as the application of the most appropriate statistical methods.
- Review new data as it becomes available and implement changes to the groundwater monitoring program as necessary to maintain compliance with 40 CFR 257.90 through 257.98.

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- Comply with recordkeeping requirements as specified in 40 CFR 257.105(h), notification requirements specified in 40 CFR 257.106(h) and internet requirements specified in 40 CFR 257.107(h).

GROUNDWATER MONITORING WELL NETWORK

Slag Ponds 2A and 2B and Slag Stilling Pond 2C are located in the northeast corner of PAF. The slag ponds are located directly east of the coal storage yard, west of the Green River, south of Red Water Pond 2, and north of the plant. Slag Ponds 2A and 2B and Slag Stilling Pond 2C serve as an ash pond management facility for the storage and settling of boiler slag. Influent to this impoundment consists of sluiced boiler slag, which flows into the southeastern portion of Slag Pond 2A via a series of ash inlets. Slag Ponds 2A and 2B also receive process water from many areas surrounding the ponds such as the Red Water Ponds and Coal Yard Runoff Ponds. Water flows from Slag Pond 2A to Slag Pond 2B to Slag Stilling Pond 2C. Slag Stilling Pond 2C discharges to the Green River.

The monitoring well network for the PAF Slag Ponds Area Multi-unit CCR Unit consists of three background wells (95-48A, PAF-108, and PAF-109) and four downgradient wells (95-47C, PAF-110, PAF-112, and PAF-113). The downgradient wells are installed at the waste boundary. Figure 1 is an aerial photograph that shows Slag Ponds Area and the groundwater monitoring well locations. The monitoring well network was designed for a multi-unit CCR unit (Slag Ponds 2A and 2B and Slag Stilling Pond 2C).

No monitoring wells in the CCR network were installed or decommissioned during the 2018 reporting period. The certification of the groundwater monitoring system required under 40 CFR 257.91(f) is included in the facility operating record and on the CCR Compliance Data and Information website (<https://www.tva.gov/Environment/Environmental-Stewardship/Coal-Combustion-Residuals>).

GROUNDWATER SAMPLING AND LABORATORY ANALYTICAL TESTING

A groundwater sampling and analysis program was developed in 2016-2017 and includes procedures and techniques for: sample collection; sample preservation and shipment; analytical procedures; chain-of-custody control; and, quality assurance and quality control (QA/QC) required by 40 CFR 257.93(a). The groundwater monitoring program includes sampling and analysis procedures designed to provide monitoring results that are an accurate representation of groundwater quality at background and downgradient wells.

Assessment monitoring groundwater sampling was conducted between May and August 2018 and the results are summarized in Table 1. A summary of groundwater sample locations, well designations, analytes sampled, sampling dates and monitoring program status is provided in Table 2.

Groundwater elevations were measured in each monitoring well immediately prior to purging during each sampling event as required by 40 CFR 257.93(c). Groundwater elevations and Green River surface water elevations are summarized in Table 3. Groundwater flow directions were determined for each sampling event, and a generalized depiction of groundwater flow direction is illustrated on Figure 2. In general, groundwater flow at PAF is influenced by Green River to the northeast. The primary groundwater flow direction from the Slag Ponds Area Multi-unit CCR unit is to the northeast toward the Green River.

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Testing for hydraulic conductivity at the background or downgradient groundwater monitoring wells, as summarized in Table 4, was determined by a 2018 hydrogeologic evaluation (Terracon, 2018). Testing data indicates the uppermost saturated zone has a geometric mean hydraulic conductivity of 8.96×10^{-5} centimeters per second (cm/sec). Linear groundwater flow velocity was calculated for the uppermost aquifer using:

- the geometric mean hydraulic conductivity calculated from hydraulic testing (8.96×10^{-5} cm/sec);
- horizontal hydraulic gradients measured during the implementation of the groundwater sampling and analysis program, ranging from 0.0127 to 0.028 feet per foot (ft/ft); and,
- an effective porosity of 30% (TVA, 1998).

The average linear flow velocity in the uppermost aquifer ranges from approximately 4 to 9 feet per year.

STATISTICAL ANALYSIS OF GROUNDWATER DATA

The groundwater monitoring data for the assessment monitoring events were evaluated using statistical procedures as required by 40 CFR 257.93(f) through 257.93(h). The statistical method certification is included in the facility operating record and the CCR Compliance Data and Information website. Groundwater protection standards were established in accordance with 40 CFR 257.95(h), as the larger of published regulatory limits or screening criteria (e.g., maximum contaminant levels [MCLs]) and upper tolerance limits (UTLs) derived from background. Maximum contaminant levels may or may not be considered the appropriate groundwater protection standard depending on background well concentrations for each Appendix IV¹ constituent². The 2018 Statistical Analysis Report is included in Appendix A and covers the three CCR Units at PAF.

The sampling results used to identify potential groundwater protection standards exceedances were obtained during five distinct monitoring events that were performed between May and August of 2018³. Comparisons were made against a fixed groundwater protection standard via a confidence interval or confidence interval band. No retesting was conducted and none of the individual compliance point measurements were directly compared against the groundwater protection standard. All of the Appendix IV monitoring data collected both in Year-One and

¹ Appendix IV CCR Constituents: antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, radium 226 and radium 228 combined

² USEPA has published MCLs or alternate regulatory limits for each of the Appendix IV constituents. Consequently, in most cases the groundwater protection standard is equal to the MCL. However, there may be cases where background levels of a constituent exceed the MCL. In these instances, an alternate groundwater protection standard must be derived from on-site background levels. On July 30, 2018, EPA provided alternate regulatory limits (i.e., that could be used as potential groundwater protection standards) for four of the Appendix IV chemical Constituents of Interest (COIs) for which the agency has not assigned MCLs to date. If site-specific background levels are lower, these may be used in place of background levels under 257.95(h)(2). Specifically, those alternate COIs include threshold values at the following health-based levels: 1.) Cobalt - 6 µg/L; 2.) Lithium - 40 µg/L; 3.) Molybdenum - 100 µg/L; and, 4.) Lead - 15 µg/L.

³ The CCR rule requires a minimum of two semi-annual sampling events per well once the required background data has been obtained. Groundwater aquifers can be quite complex, with significant changes and heterogeneity over both time and space. Two events per well per year is sometimes inadequate to reasonably characterize groundwater quality. Much greater flexibility in statistical approach, as well critical information about groundwater variability, can be gained from more frequent sampling.

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Year-Two were used to construct the confidence interval bands. Cross-sections of each confidence interval band were then compared to the groundwater protection standard for the most recent assessment monitoring event in each case for the purpose of identifying any SSLs. A well-constituent pair is considered out of compliance only if its average constituent levels, as estimated via the confidence interval cross-section, currently exceed the groundwater protection standard. During Assessment Monitoring, one arsenic-related SSL was recorded at well PAF-113.

NARRATIVE DISCUSSION OF ANY TRANSITION BETWEEN MONITORING PROGRAMS

In January 2018, TVA evaluated the groundwater monitoring data for SSLs over background levels for the constituents listed in Appendix III⁴ as required by 40 CFR 257.93(h). The groundwater analytical results from the initial round of detection monitoring indicated SSLs of Appendix III CCR constituents at the downgradient monitoring wells. TVA performed error checking and investigated whether the SSL over background resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality as specified in 40 CFR 257.94(e)(2). TVA also performed investigations to determine whether a source other than the CCR materials contained within the PAF Slag Ponds Area was the cause of the SSL. The alternate source demonstration study did not demonstrate that the SSL was a result of error or another source. An Assessment Monitoring Program was established and implemented as specified in 40 CFR 257.95. Notification of the assessment monitoring program was provided to the State of Kentucky and placed on the CCR Compliance Data and Information website (<https://www.tva.gov/Environment/Environmental-Stewardship/Coal-Combustion-Residuals>) in accordance with 40 CFR 257.106(h)(4) and 40 CFR 257.107(h)(4), respectively.

In accordance with assessment monitoring program requirements, groundwater in wells in the certified monitoring network was sampled and analyzed for Appendix IV constituents in accordance with 40 CFR 257.95(b) within 90 days of triggering assessment monitoring. Subsequent sampling and analysis of all wells in the certified monitoring network for Appendix III and IV constituents occurred in accordance with 40 CFR 257.95(d)(1). Appendix III and IV constituent concentrations were placed in the facility operating record in accordance with 40 CFR 257.105(h)(6) and are summarized in Table 1. Groundwater protection standards were established in accordance with 40 CFR 257.95(d)(2) and are summarized in Table 5. In January 2019, an evaluation of whether there are SSLs over established groundwater protection standards for one or more Appendix IV constituents was completed in accordance with 40 CFR 257.95(g). Although not required to be included in this 2018 Annual Report, during Assessment Monitoring, one arsenic-related SSL was recorded at monitoring well PAF-113. TVA will continue to review new data as it becomes available and implement changes to the groundwater monitoring program as necessary to maintain compliance with 40 CFR 257.90 through 257.98.

⁴ Appendix III CCR Constituents: boron, calcium, chloride, fluoride, pH, sulfate and total dissolved solids (TDS).

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LIMITATIONS

This document entitled 2018 Annual Groundwater Monitoring and Corrective Action Report was prepared by Stantec Consulting Services Inc. ("Stantec") for the Tennessee Valley Authority (the "Client"). The material in it reflects Stantec's professional judgment in light of the scope, schedule and other limitations stated in the document. The opinions in the document are based on conditions and information existing at the time the document was published and do not take into account any subsequent changes. In preparing the document, Stantec relied upon data and information supplied to it by the client.

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References:

TVA, 1998. Paradise Fossil Plant Groundwater Assessment WR98-1-64-124. October 1998.

Terracon, 2018. Aquifer Testing and Equipment Blank Results. TVA CCR Rule – Paradise Fossil Plant (PAF). Terracon Consultants, Inc. December 12, 2018.

Attachments:

Figure 1 – Map with CCR Unit Background and Downgradient Wells

Figure 2 – Generalized Groundwater Flow Direction Map

Table 1 – Assessment Monitoring Groundwater Sampling Results

Table 2 – Groundwater Sampling Summary

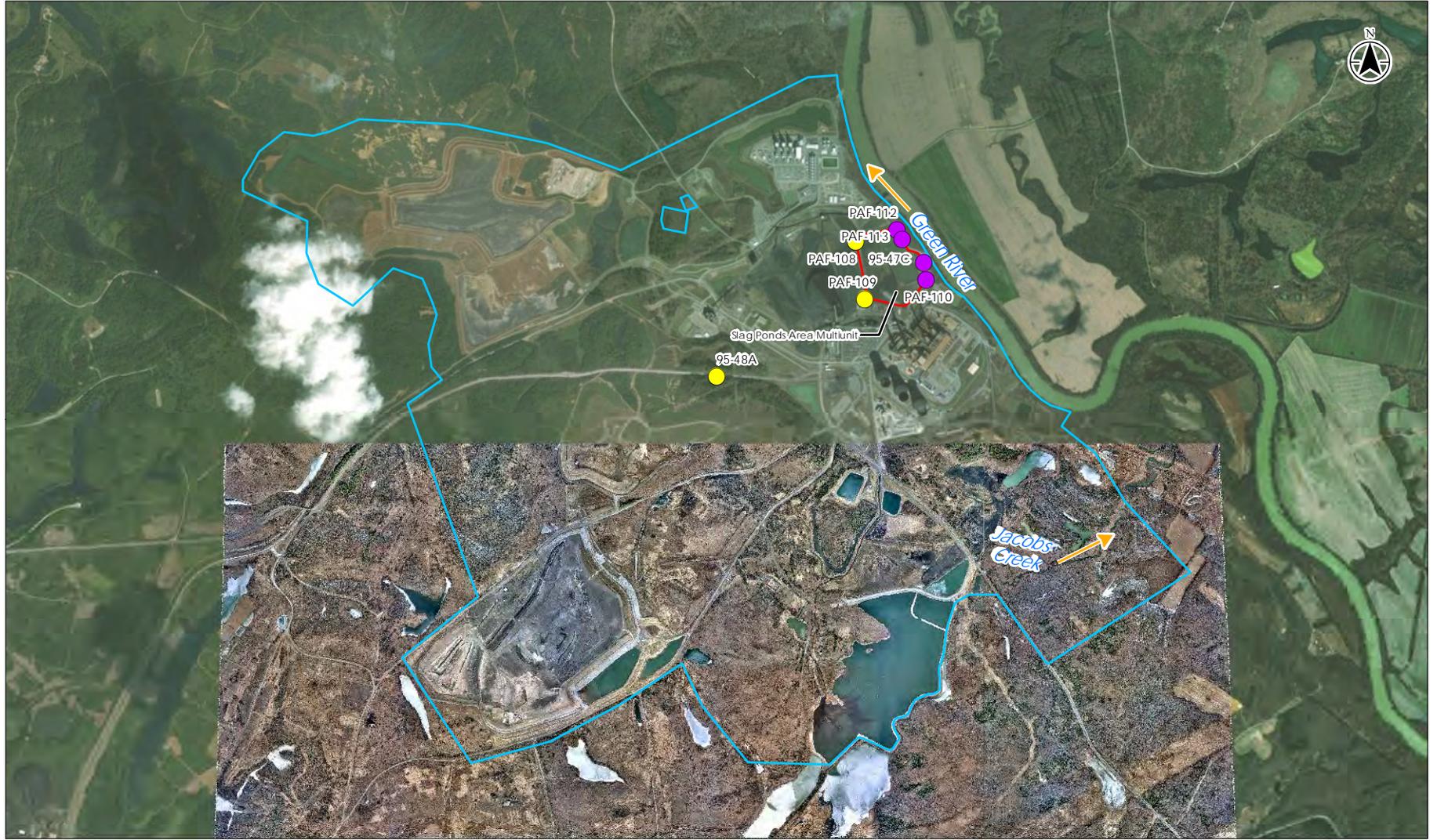
Table 3 – Groundwater and Surface Water Elevation Summary

Table 4 – Hydraulic Conductivity Data Summary

Table 5 – Groundwater Protection Standards

Appendix A – 2018 Statistical Analysis Report

FIGURES



- Background Well
- Downgradient Well
- CCR Unit Subject to CCR Rule
- TVA Property Boundary



Notes
 1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet
 2. Aerial Image provided by AECOM (Dated 2014), and Additional Imagery Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

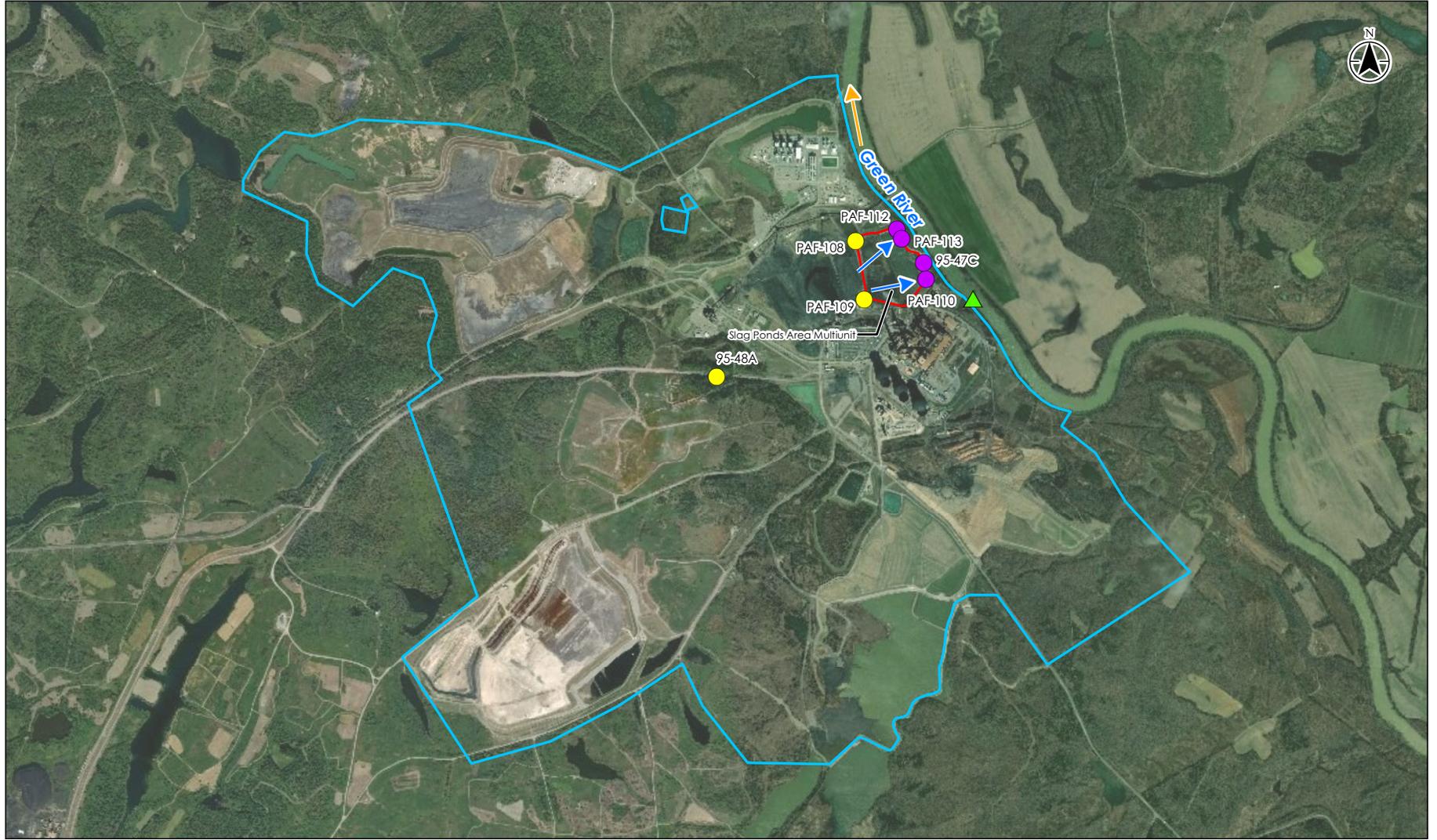


Project Location 182603174
 Drakesboro Prepared by WSW on 2018-01-30
 Muhlenberg County, Kentucky Technical Review by MD on 2018-01-30
 Independent Review by JK on 2018-01-30

Client/Project
 Tennessee Valley Authority
 Paradise Fossil Plant
 CCR Rule

Figure No. 1

Title
 Map with CCR Unit Background and Downgradient Wells



- ▲ Staff Gauge
- Background or Upgradient Well
- Downgradient Well
- Groundwater Flow Direction
- CCR Unit Subject to CCR Rule
- TVA Property Boundary



Notes
 1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet
 2. Aerial Image provided by AECOM (Dated 2014), and Additional Imagery Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Project Location: 182603419
 Drakeboro, Muhlenberg County, Kentucky
 Prepared by CMB on 2019-01-08
 Technical Review by WSW on 2019-01-08
 Independent Review by MD on 2019-01-08

Client/Project: Tennessee Valley Authority
 Paradise Fossil Plant
 CCR Rule

Figure No. **2**

Title: **Generalized Groundwater Flow Direction Map**

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U:\182603419\182603419_PAF2_FIG_GeneralizedGroundwaterFlowDirectionMap.mxd - Revised: 2019-01-08 by cchblack

TABLES

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
Action Report - TVA Paradise Fossil Plant**

Monitoring Well		95-47C									
Sample Date		24-May-18		20-Jun-18		10-Jul-18		31-Jul-18		21-Aug-18	
Sample Round		1		2		3		4		5	
Well Designation		Downgradient		Downgradient		Downgradient		Downgradient		Downgradient	
Analyte	Units	Result	Q								
Total Metals											
Antimony	mg/L	< 0.00112	U								
Arsenic	mg/L	< 0.000624	U*	0.000628	J	< 0.000932	U*	< 0.000577	U*	< 0.000700	U*
Barium	mg/L	0.0194		0.0213		0.0233		0.0198		0.0177	
Beryllium	mg/L	< 0.000258	U*	0.000174	J	0.000249	J	0.000129	J	0.000157	J
Boron	mg/L	1.14		1.09		0.964		0.954		1.06	
Cadmium	mg/L	< 0.000125	U								
Calcium	mg/L	113		113		120		106		105	
Chromium	mg/L	< 0.000631	U	< 0.00142	U*	< 0.00188	U*	< 0.000961	U*	< 0.00201	U*
Cobalt	mg/L	0.0341		0.0361		0.0340		0.0368		0.0327	
Lead	mg/L	< 0.0000940	U								
Lithium	mg/L	0.123		0.172		0.146		0.168		0.160	
Mercury	mg/L	< 0.0000653	U								
Molybdenum	mg/L	< 0.000474	U								
Selenium	mg/L	< 0.000813	U								
Thallium	mg/L	< 0.0000630	U								
Radium 226 + Radium 228	pCi/L	1.99		2.04		1.87	J	1.81	J	1.70	J
Anions											
Chloride	mg/L	12.4		17.0		12.8		15.6		16.1	
Fluoride	mg/L	0.264		0.302		0.293		0.244		0.414	J
Sulfate	mg/L	381		459		381		418		406	
General Chemistry											
Total Dissolved Solids	mg/L	853		789		838		815		800	
Field pH											
pH (field)	SU	6.17		6.32		6.24		6.23		6.16	

Notes:

NA - Not Available

Q - Data Qualifier

U* - This result should be considered not detected because it was detected in an associated field or laboratory blank at a similar concentration

UJ - Analyte not detected, but the reporting limit may or may not be higher due to a bias identified during data validation

J - Quantitation is approximate due to limitations identified during data validation

U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
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Monitoring Well		95-48A									
Sample Date		21-May-18		18-Jun-18		09-Jul-18		30-Jul-18		20-Aug-18	
Sample Round		1		2		3		4		5	
Well Designation		Background		Background		Background		Background		Background	
Analyte	Units	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Total Metals											
Antimony	mg/L	< 0.00112	U	< 0.00112	U	< 0.00112	U	< 0.00112	U	< 0.00112	U
Arsenic	mg/L	0.00377		0.00522		0.00716		0.00680		0.00598	
Barium	mg/L	0.00461	J	0.00556	J	0.00618	J	0.00597	J	< 0.00536	U*
Beryllium	mg/L	0.000998	J	0.000749	J	0.000897	J	0.000623	J	0.000600	J
Boron	mg/L	0.271		0.281		0.251		0.292		0.284	
Cadmium	mg/L	< 0.000125	U	< 0.000125	U	< 0.000125	U	< 0.000125	U	< 0.000125	U
Calcium	mg/L	454		431		413		431		392	
Chromium	mg/L	< 0.000631	U	< 0.00189	U*	< 0.00196	U*	< 0.00132	U*	< 0.00212	U*
Cobalt	mg/L	0.0834		0.0897		0.0857		0.0836		0.0632	
Lead	mg/L	< 0.0000940	U	< 0.0000940	U	< 0.0000940	U	0.0000950	J	0.000108	J
Lithium	mg/L	0.154		0.149		0.170		0.156		0.150	
Mercury	mg/L	< 0.0000653	U	< 0.0000653	U	< 0.0000653	U	< 0.0000653	U	< 0.0000653	U
Molybdenum	mg/L	< 0.000474	U	< 0.000474	U	< 0.000474	U	< 0.000474	U	< 0.000474	U
Selenium	mg/L	< 0.000813	U	< 0.000813	U	< 0.000813	U	< 0.000813	U	< 0.000813	U
Thallium	mg/L	< 0.0000630	U	< 0.0000630	U	< 0.0000630	U	< 0.0000630	U	< 0.0000630	U
Radium 226 + Radium 228	pCi/L	1.77		2.11		2.02		2.38		2.11	
Anions											
Chloride	mg/L	25.5		39.7		26.6		42.4		38.1	
Fluoride	mg/L	0.653		0.460		0.557		0.262	J	< 0.395	U*
Sulfate	mg/L	2920		3520		2890		3230		3010	
General Chemistry											
Total Dissolved Solids	mg/L	4680		4800		4620		4580		4770	
Field pH											
pH (field)	SU	5.90		5.97		5.91		5.83		5.85	

Notes:

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UJ - Analyte not detected, but the reporting limit may or may not be higher due to a bias identified during data validation

J - Quantitation is approximate due to limitations identified during data validation

U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
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Monitoring Well		PAF-108									
Sample Date		24-May-18		20-Jun-18		09-Jul-18		30-Jul-18		20-Aug-18	
Sample Round		1		2		3		4		5	
Well Designation		Upgradient		Upgradient		Upgradient		Upgradient		Upgradient	
Analyte	Units	Result	Q								
Total Metals											
Antimony	mg/L	< 0.00112	U								
Arsenic	mg/L	< 0.000323	U	0.000769	J	< 0.000746	U*	< 0.000800	U*	< 0.00109	U*
Barium	mg/L	0.0215		0.0608		0.0627		0.0591		0.0492	
Beryllium	mg/L	< 0.0000570	U								
Boron	mg/L	< 0.101	U*	0.239		0.203		0.244		0.232	
Cadmium	mg/L	< 0.000125	U								
Calcium	mg/L	79.9		133		131		145		136	
Chromium	mg/L	< 0.000631	U	< 0.00187	U*	< 0.00229	U*	< 0.00148	U*	< 0.00218	U*
Cobalt	mg/L	0.000524		0.00782		0.00815		0.0105		0.00809	
Lead	mg/L	< 0.0000940	U								
Lithium	mg/L	0.0251		0.0418		0.0489		0.0479		0.0466	
Mercury	mg/L	< 0.0000653	U								
Molybdenum	mg/L	< 0.00133	U*	0.00115	J	0.00117	J	0.00118	J	0.00129	J
Selenium	mg/L	< 0.000813	U								
Thallium	mg/L	< 0.0000630	U								
Radium 226 + Radium 228	pCi/L	0.423	J	0.756	J	0.855	U*	1.44	J	1.02	J
Anions											
Chloride	mg/L	9.61		14.2		9.47		16.4		13.7	
Fluoride	mg/L	0.165		0.185		0.128		0.134		< 0.205	U*
Sulfate	mg/L	133		239		248		393		220	
General Chemistry											
Total Dissolved Solids	mg/L	537		657		704		831		595	
Field pH											
pH (field)	SU	6.78		6.46		6.51		6.49		6.45	

Notes:

NA - Not Available

Q - Data Qualifier

U* - This result should be considered not detected because it was detected in an associated field or laboratory blank at a similar concentration

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J - Quantitation is approximate due to limitations identified during data validation

U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
Action Report - TVA Paradise Fossil Plant**

Monitoring Well		PAF-109									
Sample Date		24-May-18		20-Jun-18		10-Jul-18		30-Jul-18		20-Aug-18	
Sample Round		1		2		3		4		5	
Well Designation		Upgradient		Upgradient		Upgradient		Upgradient		Upgradient	
Analyte	Units	Result	Q								
Total Metals											
Antimony	mg/L	< 0.00112	U								
Arsenic	mg/L	< 0.00232	U*	0.00273		0.00309		0.00301		0.00292	
Barium	mg/L	0.0412		0.0393		0.0395		0.0380		0.0335	
Beryllium	mg/L	< 0.0000570	U								
Boron	mg/L	0.0489	J	0.0624	J	0.0388	J	0.0635	J	0.0444	J
Cadmium	mg/L	< 0.000125	U								
Calcium	mg/L	93.0		90.3		87.1		90.6		85.5	
Chromium	mg/L	< 0.00171	U*	< 0.00184	U*	< 0.00213	U*	< 0.00126	U*	< 0.00172	U*
Cobalt	mg/L	0.000436	J	0.00165		0.00199		0.00152		0.00101	
Lead	mg/L	< 0.0000940	U	0.000611	J	< 0.0000940	U	< 0.0000940	U	0.0000970	J
Lithium	mg/L	0.0482		0.0476		0.0513		0.0456		0.0465	
Mercury	mg/L	< 0.0000653	U								
Molybdenum	mg/L	< 0.000474	U	0.000673	J	0.000640	J	0.000737	J	0.000642	J
Selenium	mg/L	< 0.000813	U								
Thallium	mg/L	< 0.0000630	U								
Radium 226 + Radium 228	pCi/L	0.533	U*	0.700	U	0.951	U*	1.04	U*	0.678	U*
Anions											
Chloride	mg/L	5.66		8.22		5.59		7.86		7.61	
Fluoride	mg/L	0.207		0.254		0.219		0.194		< 0.213	U*
Sulfate	mg/L	209		247		202		222		199	
General Chemistry											
Total Dissolved Solids	mg/L	594		628		557		535		534	
Field pH											
pH (field)	SU	7.29		6.82		6.86		6.84		6.83	

Notes:

NA - Not Available

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J - Quantitation is approximate due to limitations identified during data validation

U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
Action Report - TVA Paradise Fossil Plant**

Monitoring Well		PAF-110									
Sample Date		24-May-18		20-Jun-18		10-Jul-18		31-Jul-18		21-Aug-18	
Sample Round		1		2		3		4		5	
Well Designation		Downgradient		Downgradient		Downgradient		Downgradient		Downgradient	
Analyte	Units	Result	Q								
Total Metals											
Antimony	mg/L	< 0.00112	U								
Arsenic	mg/L	< 0.000705	U*	0.000474	J	< 0.000520	U*	< 0.000463	U*	< 0.000535	U*
Barium	mg/L	0.0262		0.0279		0.0275		0.0249		0.0218	
Beryllium	mg/L	< 0.0000570	U								
Boron	mg/L	0.676		0.774		0.616		0.675		0.703	
Cadmium	mg/L	< 0.000125	U								
Calcium	mg/L	142		146		138		138		139	
Chromium	mg/L	< 0.00161	U*	< 0.00162	U*	< 0.00169	U*	< 0.00145	U*	< 0.00196	U*
Cobalt	mg/L	0.000124	J	0.000171	J	0.000193	J	0.000151	J	0.000109	J
Lead	mg/L	< 0.0000940	U								
Lithium	mg/L	0.0466		0.0521		0.0477		0.0423		0.0424	
Mercury	mg/L	< 0.0000653	U								
Molybdenum	mg/L	0.000639	J	0.00112	J	0.000965	J	0.000834	J	0.000702	J
Selenium	mg/L	< 0.000813	U								
Thallium	mg/L	< 0.0000630	U								
Radium 226 + Radium 228	pCi/L	0.498	U*	0.386	U*	0.960	U*	0.839	U*	0.420	U*
Anions											
Chloride	mg/L	8.03		11.3		8.51		11.0		11.6	
Fluoride	mg/L	0.131		0.145		0.135		0.114		0.480	
Sulfate	mg/L	357		433		359		409		387	
General Chemistry											
Total Dissolved Solids	mg/L	883		842		876		880		904	
Field pH											
pH (field)	SU	6.99		6.92		6.81		6.74		6.59	

Notes:

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J - Quantitation is approximate due to limitations identified during data validation

U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
Action Report - TVA Paradise Fossil Plant**

Monitoring Well		PAF-112									
Sample Date		24-May-18		21-Jun-18		11-Jul-18		31-Jul-18		21-Aug-18	
Sample Round		1		2		3		4		5	
Well Designation		Downgradient		Downgradient		Downgradient		Downgradient		Downgradient	
Analyte	Units	Result	Q								
Total Metals											
Antimony	mg/L	< 0.00112	U								
Arsenic	mg/L	0.0239		0.00875	J	0.0108		0.0115		0.0114	
Barium	mg/L	0.223		0.199		0.206		0.200		0.165	
Beryllium	mg/L	< 0.0000570	U								
Boron	mg/L	0.277		0.488		0.387		0.481		0.470	
Cadmium	mg/L	< 0.000125	U								
Calcium	mg/L	55.9		60.5		56.9		53.6		45.7	
Chromium	mg/L	< 0.000631	U	< 0.00163	U*	< 0.00146	U*	< 0.00131	U*	< 0.00173	U*
Cobalt	mg/L	0.000277	J	0.00329		0.00174		0.000965		0.000549	
Lead	mg/L	< 0.0000940	U								
Lithium	mg/L	< 0.00413	U*	< 0.00256	U	< 0.00317	U*	< 0.00256	U	< 0.00256	U
Mercury	mg/L	< 0.0000653	U								
Molybdenum	mg/L	< 0.000649	U*	0.000957	J	0.000657	J	0.000739	J	0.000814	J
Selenium	mg/L	< 0.000813	U								
Thallium	mg/L	< 0.0000630	U								
Radium 226 + Radium 228	pCi/L	0.790	J	0.960	J	0.639	U*	1.06	U*	0.945	J
Anions											
Chloride	mg/L	6.76		11.4		8.15		11.4		11.1	
Fluoride	mg/L	0.205		0.182		0.170		0.153		< 0.146	U*
Sulfate	mg/L	83.6		145		97.4		116		99.2	
General Chemistry											
Total Dissolved Solids	mg/L	391		449		385		402		394	
Field pH											
pH (field)	SU	6.26		5.93		6.17		5.97		5.90	

Notes:

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J - Quantitation is approximate due to limitations identified during data validation

U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

**Table 1 - Assessment
Monitoring Groundwater
Sampling Results**

**CCR Annual Groundwater Monitoring and Corrective
Action Report - TVA Paradise Fossil Plant**

Monitoring Well		PAF-113							
Sample Date		21-Jun-18		12-Jul-18		31-Jul-18		21-Aug-18	
Sample Round		2		3		4		5	
Well Designation		Downgradient		Downgradient		Downgradient		Downgradient	
Analyte	Units	Result	Q	Result	Q	Result	Q	Result	Q
Total Metals									
Antimony	mg/L	< 0.00112	U						
Arsenic	mg/L	0.0727		0.0770		0.0917		0.0855	
Barium	mg/L	0.191		0.185		0.195		0.155	
Beryllium	mg/L	< 0.0000570	U						
Boron	mg/L	< 0.0765	U*	0.0400	J	0.0422	J	0.0403	J
Cadmium	mg/L	< 0.000125	U						
Calcium	mg/L	56.2		55.1		56.7		50.9	
Chromium	mg/L	< 0.00274	U*	< 0.00165	U*	< 0.00150	U*	< 0.00218	U*
Cobalt	mg/L	0.00174		0.00197		0.00182		0.00140	
Lead	mg/L	0.000321	J	< 0.0000940	U	< 0.0000940	U	0.000114	J
Lithium	mg/L	< 0.00256	U						
Mercury	mg/L	< 0.0000653	U						
Molybdenum	mg/L	0.00437	J	0.00464	J	0.00484	J	0.00441	J
Selenium	mg/L	< 0.000813	U						
Thallium	mg/L	< 0.0000630	U						
Radium 226 + Radium 228	pCi/L	0.689	U*	0.706	U*	1.06	U*	0.898	J
Anions									
Chloride	mg/L	22.4		15.8		21.5		20.6	
Fluoride	mg/L	0.346		0.308		0.282		0.441	
Sulfate	mg/L	4.92		4.31		5.46		4.13	
General Chemistry									
Total Dissolved Solids	mg/L	293		296		284		289	
Field pH									
pH (field)	SU	6.78		6.79		6.71		6.67	

Notes:

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U - Concentration not detected

mg/L - milligrams per liter

pCi/L - picoCurie per liter

SU - Standard Unit

**ASSESSMENT
MONITORING**

Table 2 - Groundwater Sampling Summary

CCR Annual Groundwater Monitoring and Corrective Action Report - TVA Paradise Fossil Plant

Well ID	Well Designation	Number of Samples Collected	May 21-24, 2018	June 18-21, 2018	July 9-12, 2018	July 30-31, 2018	August 20-21, 2018	Assessment Monitoring Program
95-47C	Downgradient	5	X	X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents
95-48A	Background	5	X	X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents
PAF-108	Background	5	X	X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents
PAF-109	Background	5	X	X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents
PAF-110	Downgradient	5	X	X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents
PAF-112	Downgradient	5	X	X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents
PAF-113	Downgradient	4		X	X	X	X	Assessment Monitoring - 257.95(a); 257.95(b); 257.95(d)(1) - Appendix III and Appendix IV Constituents

Notes:

Appendix III Constituents - boron, calcium, chloride, fluoride, pH, sulfate, total dissolved solids (TDS)

Appendix IV Constituents - antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, radium 226 and radium 228

**Table 3
Groundwater and Surface Water Elevation
Summary**

**CCR Annual Groundwater Monitoring and
Corrective Action Report - TVA Paradise
Fossil Plant**

Groundwater Elevation Collection Date		21-May-18	18-Jun-18	09-Jul-18	30-Jul-18	20-Aug-18
Monitoring Well	Units					
95-47C	ft-MSL	374.51	374.16	373.97	372.96	373.65
95-48A	ft-MSL	444.09	443.86	443.82	443.81	443.95
PAF-108	ft-MSL	408.68	408.74	408.87	409.04	408.68
PAF-109	ft-MSL	410.59	410.58	410.53	410.52	410.39
PAF-110	ft-MSL	380.86	379.59	380.01	378.92	379.24
PAF-112	ft-MSL	388.62	386.84	387.74	386.17	386.06
PAF-113	ft-MSL	397.08	395.57	396.01	395.26	395.06
Green River	ft-MSL	368.98	365.39	366.50	364.32	365.77

**Table 4 - Hydraulic Conductivity
Data Summary**

**CCR Annual Groundwater Monitoring and
Corrective Action Report - TVA Paradise
Fossil Plant**

Well ID	Well Designation	Slug Test Hydraulic Conductivity (cm/sec)
95-47C	Downgradient	1.044E-03
95-48A	Background	1.248E-03
PAF-108	Background	4.397E-05
PAF-109	Background	1.269E-04
PAF-110	Downgradient	5.513E-05
PAF-112	Downgradient	2.316E-05
PAF-113	Downgradient	5.013E-06
Geometric Mean of Hydraulic Conductivity (cm/sec)		8.96E-05

Notes:

cm/sec - centimeters per second

Table 5 - Groundwater Protection Standards

CCR Annual Groundwater Monitoring and Corrective Action Report - TVA Paradise Fossil Plant

Chemical Name	Unit	GWPS / BTV*
Antimony	mg/L	0.006
Arsenic	mg/L	0.0134
Barium	mg/L	2
Beryllium	mg/L	0.004
Boron	mg/L	0.433*
Cadmium	mg/L	0.005
Calcium	mg/L	479*
Chloride	mg/L	43.7*
Chromium	mg/L	0.1
Cobalt	mg/L	0.0897
Fluoride	mg/L	4
Lead	mg/L	0.015
Lithium	mg/L	0.17
Mercury	mg/L	0.002
Molybdenum	mg/L	0.1
pH (field)	SU	5.79 – 6.37*
Radium 226 + Radium 228	pCi/L	5
Selenium	mg/L	0.05
Sulfate	mg/L	3496*
Thallium	mg/L	0.002
Total Dissolved Solids	mg/L	5094*

Notes:

GWPS - groundwater protection standard

* - BTV - Background Threshold Values for Appendix III Constituents (2017)

mg/L - milligrams per liter

SU - standard units

pCi/L - picocuries per liter

N/A - not applicable

APPENDIX A
STATISTICAL ANALYSIS REPORT

**STATISTICAL ANALYSIS REPORT
PARADISE FOSSIL PLANT**

2018



1/15/2019

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1 Introduction

This report summarizes the statistical analysis performed on groundwater quality constituents monitored during the Coal Combustion Residuals (CCR) Rule’s 2018 Annual Groundwater Monitoring (GWM) Program for the Tennessee Valley Authority (TVA) Paradise Fossil Plant (PAF). The 2018 Annual GWM Program is the second year of the program. Statistically significant increases (SSIs) were identified for one or more parameters based on the 2017 annual groundwater sampling results; therefore, the CCR Units transitioned to the Assessment Monitoring phase of the monitoring program.

Baseline datasets collected during the first year of monitoring were combined with data collected in 2018 and were used to establish statistically-derived Groundwater Protection Standards (GWPS) for each Unit located at PAF. Consistent with methods presented in USEPA’s Unified Guidance document on the statistical analysis of groundwater monitoring data (2009), confidence-interval (CI) bands were compared against relevant GWPS. A statistically significant level (SSL) is found if and only if the lower limit of the CI band exceeds the GWPS for the most recent Assessment Monitoring sampling event.

At the PAF plant’s CCR Units, the sampling results used to identify potential GWPS exceedances were obtained during a minimum of five distinct monitoring events that were performed between May of 2018 and August of 2018 by Terracon, with laboratory analysis performed by Test America Laboratories (located at Pittsburg, PA, and St Louis, MO), and Quality Assurance Controls by Environmental Standards, Inc., all under direct contracts to TVA.

The current CCR Rule groundwater monitoring networks — one for the Gypsum Stack area, one for the Peabody area, and one for the Slag Pond area — as Certified by a Professional Engineer at the firm of AECOM or other, are presented in **Table 1**.

Table 1. CCR Rule Monitoring Well Networks

Site	Background		Downgradient	
Gypsum Stack	95-48A PAF-101 PAF-104		94-35A PAF-114 PAF-103	PAF-115 PAF-116
Peabody Ash Pond	95-48A 10-5	PAF-105 PAF-106	PAF-119 10-6 PAF-118	PAF-117 PAF-107 10-4
Slag Ponds Area	95-48A PAF-108	PAF-109	PAF-110 95-47C	PAF-113 PAF-112

The ‘R’ Statistical Analysis package (www.r-project.org) in conjunction with R-Studio (www.rstudio.com) (both popular public domain software products) and other analytical tools were used in the production of the statistical values and graphs. ProUCL data dumps from

TVA's EQUIS Professional and Enterprise Database were used to populate the R-based statistical analyses.

Groundwater samples collected as part of the CCR Rule monitoring program were analyzed for constituents listed in Appendix IV of the CCR Rule. Only non-filtered sample results were utilized for the statistical analysis of Appendix IV constituents. As high turbidity measurements during the purging of wells (e.g., values above 5 NTUs) have the propensity to increase the concentrations of Appendix IV constituents, filtered samples were also collected to better understand and/or dispel the potential source(s) of falsely-named GWPS exceedances. A summary of constituents included in the data analysis is provided in the second column of **Table 2**.

Table 2. CCR Rule Monitored Constituents

Appendix III Constituents (Detection Monitoring)	Appendix IV Constituents (Assessment Monitoring)
Boron Calcium Chloride Fluoride pH (field) Sulfate Total Dissolved Solids (TDS)	Antimony Arsenic Barium Beryllium Cadmium Chromium Cobalt Fluoride Lead Lithium Mercury Molybdenum Radium 226 + 228 Selenium Thallium

2 Statistical Analysis

The Assessment Monitoring analysis includes the following steps:

- 1) Developing groundwater protection standards (GWPS) for each Appendix IV constituent. The GWPS is the published MCL/water quality limit or the background concentration (95% UTL with 95% coverage), whichever is larger;
- 2) Computing trends and associated confidence interval (CI) bands for each downgradient well location and Appendix IV constituent (i.e., each well-constituent pair); and
- 3) Comparing each CI band against its respective GWPS to assess whether an exceedance occurred.

2.1 Developing Groundwater Protection Standards (GWPS)

According to the promulgated CCR Rule (80 Federal Register 21302, 21405, April 17, 2015):

“For each appendix IV constituent that is detected, a groundwater protection standard must be set. The groundwater protection standards must be the MCL or the background concentration level for the detected constituent, whichever is higher. If there is no MCL promulgated for a detected constituent, then the groundwater protection standard must be set at background.”

On July 17, 2018, EPA unofficially promulgated alternate regulatory limits (i.e., potential GWPS) for four of the Appendix IV chemical Constituents of Interest (COIs) for which the agency has not assigned MCLs to date. In the absence of MCLs or site-specific GWPS, those may be used in place of background levels under 257.95(h)(2). Specifically, those alternate COIs include threshold values at the following health-based levels:

1. Cobalt - 6 µg/L
2. Lithium - 40 µg/L
3. Molybdenum – 100 µg/L
4. Lead - 15 µg/L.

An Upper Tolerance Limit (UTL) with 95% confidence and 95% coverage was calculated using pooled site-specific background data for each Appendix IV parameter. Then these UTLs were compared against the promulgated regulatory limits to determine the site-specific GWPS.

To handle any non-detects in these calculations, non-detect values were treated as statistically ‘left-censored,’ with the censoring limit equal to the reporting limit (RL). Then the Kaplan-Meier adjustment method (USEPA, 2009) was employed to derive estimated summary statistics that account for the presence of non-detects.

For PAF, **Table 3, included below**, lists the calculated UTLs and final GWPS established for CCR Units.

Table 3A. PAF, Gypsum Stack, Groundwater Protection Standards (GWPS)

COI	N	ND.PCT	MODEL	COV	CONF	UTL	UNITS	MCL	GWPS
Antimony	48	95.8	NP	0.95	0.9147	0.0024	mg/L	0.006	0.006
Arsenic	48	0	NP	0.95	0.9147	0.0154	mg/L	0.01	0.0154
Barium	48	6.2	Square Root	0.95	0.9500	0.0292	mg/L	2	2
Beryllium	48	68.8	Cube Root	0.95	0.9500	0.0011	mg/L	0.004	0.004
Cadmium	48	100	NP	0.95	0.9147	0.0010	mg/L	0.005	0.005
Chromium	48	91.7	NP	0.95	0.9147	0.0045	mg/L	0.1	0.1
Cobalt*	48	4.2	NP	0.95	0.9147	0.0897	mg/L	0.006	0.0897
Fluoride	51	5.9	Square Root	0.95	0.9500	0.6193	mg/L	4	4
Lead	48	85.4	NP	0.95	0.9147	0.0023	mg/L	0.015	0.015
Lithium*	48	0	NP	0.95	0.9147	0.1700	mg/L	0.04	0.17
Mercury	48	100	NP	0.95	0.9147	0.0002	mg/L	0.002	0.002
Molybdenum*	48	37.5	NP	0.95	0.9147	0.0092	mg/L	0.1	0.1
Rad226+228	45	0	Cube Root	0.95	0.9500	4.1010	pCi/L	5	5
Selenium	48	89.6	NP	0.95	0.9147	0.0050	mg/L	0.05	0.05
Thallium	48	95.8	NP	0.95	0.9147	0.0010	mg/L	0.002	0.002

* No potential Health Effects provided for these Constituents of Interests (COI)

Table 4B. PAF, Peabody, Groundwater Protection Standards (GWPS)

COI	N	ND.PCT	MODEL	COV	CONF	UTL	UNITS	MCL	GWPS
Antimony	64	100	NP	0.95	0.9625	0.0049	mg/L	0.006	0.006
Arsenic	64	15.6	NP	0.95	0.9625	0.0154	mg/L	0.01	0.0154
Barium	64	9.4	Square	0.95	0.9500	0.0157	mg/L	2	2
Beryllium	64	76.6	Square Root	0.95	0.9500	0.0011	mg/L	0.004	0.004
Cadmium	64	98.4	NP	0.95	0.9625	0.0010	mg/L	0.005	0.005
Chromium	64	96.9	NP	0.95	0.9625	0.0029	mg/L	0.1	0.1
Cobalt*	64	3.1	NP	0.95	0.9625	0.0897	mg/L	0.006	0.0897
Fluoride	68	8.8	Log	0.95	0.9500	0.5409	mg/L	4	4
Lead	64	89.1	NP	0.95	0.9625	0.0010	mg/L	0.015	0.015
Lithium*	64	0	NP	0.95	0.9625	0.1700	mg/L	0.04	0.17
Mercury	64	100	NP	0.95	0.9625	0.0002	mg/L	0.002	0.002
Molybdenum*	64	37.5	NP	0.95	0.9625	0.0050	mg/L	0.1	0.1
Rad226+228	60	0	Sixth Root	0.95	0.9500	3.7717	pCi/L	5	5
Selenium	64	93.8	NP	0.95	0.9625	0.0050	mg/L	0.05	0.05
Thallium	64	89.1	NP	0.95	0.9625	0.0010	mg/L	0.002	0.002

Table 5C. PAF, Slag Pond, Groundwater Protection Standards (GWPS)

COI	N	ND.PCT	MODEL	COV	CONF	UTL	UNITS	MCL	GWPS
Antimony	48	97.9	NP	0.95	0.9147	0.0026	mg/L	0.006	0.006
Arsenic	48	18.8	Log	0.95	0.9500	0.0134	mg/L	0.01	0.0134
Barium	48	6.2	NP	0.95	0.9147	0.0627	mg/L	2	2
Beryllium	48	68.8	Cube Root	0.95	0.9500	0.0011	mg/L	0.004	0.004
Cadmium	48	100	NP	0.95	0.9147	0.0010	mg/L	0.005	0.005
Chromium	48	97.9	NP	0.95	0.9147	0.0023	mg/L	0.1	0.1
Cobalt*	48	2.1	NP	0.95	0.9147	0.0897	mg/L	0.006	0.0897
Fluoride	51	5.9	Log	0.95	0.9500	0.7117	mg/L	4	4
Lead	48	85.4	NP	0.95	0.9147	0.0010	mg/L	0.015	0.015
Lithium*	48	0	NP	0.95	0.9147	0.1700	mg/L	0.04	0.17
Mercury	48	100	NP	0.95	0.9147	0.0002	mg/L	0.002	0.002
Molybdenum*	48	37.5	Log	0.95	0.9500	0.0021	mg/L	0.1	0.1
Rad226+228	45	0	Square Root	0.95	0.9500	3.8529	pCi/L	5	5
Selenium	48	91.7	NP	0.95	0.9147	0.0050	mg/L	0.05	0.05
Thallium	48	93.8	NP	0.95	0.9147	0.0010	mg/L	0.002	0.002

To compute each upper tolerance limit (UTL), the following steps were taken:

- 1) All baseline data - those from designated up-gradient or background wells collected up through from the Program's first sampling event through August of 2018 were grouped and checked for possible outliers.

At PAF, no likely outliers among the background data were flagged at any of the CCR units.

- 2) The grouped baseline data were also analyzed to determine whether they could be fit to a known statistical model. If so, a parametric UTL was computed; if not, a nonparametric UTL was constructed.

To fit potential statistical models, a series of normalizing mathematical transformations was applied to each baseline dataset. These transformations are known as power transformations, since they raise each observation to a mathematical power. The goal is to find, if possible, a transformation that normalizes the data on the transformed scale.

Datasets which could not be sufficiently normalized were analyzed using nonparametric methods. Nonparametric UTLs do not assume a known statistical model and require larger sample sizes to achieve the target confidence level of 95%.

- 3) The final statistical model for each COI was used to compute an upper tolerance limit (UTL) with 95% coverage and 95% confidence.

When a parametric model is appropriate, on the normalized scale, a UTL is computed using the standard normal theory equation:

$$UTL = \bar{x} + \kappa s$$

where \bar{x} and s represent the mean and standard deviation of the (transformed) observations, and κ is a multiplier which depends on the number of baseline measurements, as well as the desired coverage and confidence levels. If the data have been transformed, the final UTL is derived by back-transforming the scaled UTL.

For nonparametric models, the normal theory equation does not apply. Instead, the UTL is selected as one of the largest of the sample values, typically the maximum. Because there is no multiplier as in the parametric case, the confidence level associated with a nonparametric UTL is computed 'after the fact,' based on the sample size and desired coverage level: the smaller the sample size, the lower the confidence; the bigger the sample size, the higher the confidence level.

Table 6A. Descriptive Summary Statistics of Background Data, Gypsum Stack

Constituent	Units	N	No. of NDs	Minimum	Maximum	Mean	Median
Antimony	mg/L	32	31	0.0006	0.0020	0.0006	0.0013
Arsenic	mg/L	32	14	0.0003	0.0031	0.0012	0.0010
Barium	mg/L	32	0	0.0206	0.0852	0.0471	0.0422
Beryllium	mg/L	32	32	0.0010	0.0010	0.0005	0.0010
Cadmium	mg/L	32	16	0.0001	0.0010	0.0003	0.0003
Chromium	mg/L	32	19	0.0005	0.0025	0.0007	0.0006
Cobalt	mg/L	32	13	0.0001	0.0011	0.0003	0.0003
Lead	mg/L	32	4	0.0306	0.2880	0.1295	0.0880
Lithium	mg/L	32	25	0.0001	0.0010	0.0002	0.0002
Mercury	mg/L	32	20	0.0022	0.0099	0.0040	0.0038
Molybdenum	mg/L	32	32	0.0002	0.0002	0.0001	0.0002
Radium 226 + 228	pCi/L	32	3	0.0006	0.0955	0.0413	0.0379
Selenium	mg/L	30	0	0.0190	2.5300	0.8943	0.8175
Thallium	mg/L	32	31	0.0024	0.0050	0.0024	0.0037

Notes:

1. ND = not detected above the laboratory reporting limit.
2. All computations involving non-detects handled using the Kaplan-Meier adjustment. In the case of 100% NDs, mean is computed by substituting half the reporting limit for each ND.

Table 7B. Descriptive Summary Statistics of Background Data, Peabody

Constituent	Units	N	No. of NDs	Minimum	Maximum	Mean	Median
Antimony	mg/L	32	31	0.0006	0.0020	0.0006	0.0013
Arsenic	mg/L	32	14	0.0003	0.0031	0.0012	0.0010
Barium	mg/L	32	0	0.0206	0.0852	0.0471	0.0422
Beryllium	mg/L	32	32	0.0010	0.0010	0.0005	0.0010
Cadmium	mg/L	32	16	0.0001	0.0010	0.0003	0.0003
Chromium	mg/L	32	19	0.0005	0.0025	0.0007	0.0006
Cobalt	mg/L	32	13	0.0001	0.0011	0.0003	0.0003
Lead	mg/L	32	4	0.0306	0.2880	0.1295	0.0880
Lithium	mg/L	32	25	0.0001	0.0010	0.0002	0.0002
Mercury	mg/L	32	20	0.0022	0.0099	0.0040	0.0038
Molybdenum	mg/L	32	32	0.0002	0.0002	0.0001	0.0002
Radium 226 + 228	pCi/L	32	3	0.0006	0.0955	0.0413	0.0379
Selenium	mg/L	30	0	0.0190	2.5300	0.8943	0.8175
Thallium	mg/L	32	31	0.0024	0.0050	0.0024	0.0037

Table 8C. Descriptive Summary Statistics of Background Data, Slag Pond

Constituent	Units	N	No. of NDs	Minimum	Maximum	Mean	Median
Antimony	mg/L	32	31	0.0006	0.0020	0.0006	0.0013
Arsenic	mg/L	32	14	0.0003	0.0031	0.0012	0.0010
Barium	mg/L	32	0	0.0206	0.0852	0.0471	0.0422
Beryllium	mg/L	32	32	0.0010	0.0010	0.0005	0.0010
Cadmium	mg/L	32	16	0.0001	0.0010	0.0003	0.0003
Chromium	mg/L	32	19	0.0005	0.0025	0.0007	0.0006
Cobalt	mg/L	32	13	0.0001	0.0011	0.0003	0.0003
Lead	mg/L	32	4	0.0306	0.2880	0.1295	0.0880
Lithium	mg/L	32	25	0.0001	0.0010	0.0002	0.0002
Mercury	mg/L	32	20	0.0022	0.0099	0.0040	0.0038
Molybdenum	mg/L	32	32	0.0002	0.0002	0.0001	0.0002
Radium 226 + 228	pCi/L	32	3	0.0006	0.0955	0.0413	0.0379
Selenium	mg/L	30	0	0.0190	2.5300	0.8943	0.8175
Thallium	mg/L	32	31	0.0024	0.0050	0.0024	0.0037

2.2 Computing Trend Lines and Confidence Interval Bands

The USEPA's Unified Guidance recommends comparing some type of confidence interval (CI) against a groundwater protection standard (GWPS) in order to assess whether or not the limit has been exceeded with statistical significance. If the entire interval exceeds the GWPS, an SSL is identified. If none of the interval, or only part, exceeds the GWPS, no SSL is recorded.

Since groundwater data are collected over time, variation in the measurements may be due to a trend. To account for this possibility, USEPA also recommends a variation on the confidence interval method known as a confidence interval band around a trend line. In this case, a (linear) trend line is first fit to the data, then a confidence band is constructed around the trend line. The

confidence interval band can be compared against a GWPS in much the same fashion as a confidence interval, only now a comparison can be made at different points in time by comparing the 'cross-section' of the band for a given sampling date. If the interval represented by the confidence band cross-section fully exceeds the GWPS, an SSL is identified for that sampling event.

At PAF, CI bands were constructed using equations [21.24] and [21.25] of Section 21.3 in the Unified Guidance for each well-constituent pair using all data collected through September of 2018. Cross-sections of each band were then compared to the GWPS for the most recent Assessment Monitoring event in each case for the purpose of identifying any SSLs.

For well-constituent pairs with no non-detects, linear regression and the formula above were used to construct each confidence band with 98% overall confidence, corresponding to a lower confidence limit with 99% confidence. When non-detects are present, the same formulas apply but an adjustment must be made for the censored measurements. The strategy adopted for TVA's CCR sites involves the following steps:

- 1) Each non-detect is assumed to follow a triangle distribution centered at half the (sample-specific) reporting limit, and with limits extending from zero to the reporting limit. Then an imputation for each non-detect is randomly drawn from this distribution;
- 2) The combined set of detected values and imputed non-detects are used to estimate a linear regression trend line and associated confidence band with 98% statistical confidence;
- 3) Steps (1) and (2) are repeated 500 times, each time with a different set of random imputations, leading to 500 potentially different trend lines and confidence bands;
- 4) The 500 sets of trends lines and bands are averaged point-wise (i.e., at each time along a sequence of dates spanning the time range of the data) to compute the final trend and confidence band estimates.

By repeating this sequence of steps a large number of times (500), the uncertainty associated with the non-detects can be reasonably captured within the final CI band estimate.

2.2.1 Outliers

Prior to constructing any of the CI bands, the data at each well-constituent pair were examined for possible outliers. Any possible outliers were then tested using Rosner's outlier test. For the PAF CCR units, no observations were confirmed as outliers in the Gypsum Stack network, four outliers were identified in the Peabody area network, and seven outliers were confirmed in the Slag Pond network. All of these observations were excluded from subsequent statistical calculations. Table 5 lists the outliers confirmed using Rosner's test.

Table 5. Confirmed Statistical Outliers at PAF CCR Sites

Site	Constituent	Units	Outlier Value	Well Location	Sampling Date
Peabody	Arsenic	mg/L	0.0506	10-4	06-29-2017
	Barium	mg/L	0.184	PAF-118	01-19-2017
	Barium	mg/L	0.384	PAF-107	11-30-2016
	Fluoride	mg/L	1.51	10-4	03-09-2017
Slag Pond	Barium	mg/L	0.191	PAF-113	06-21-2018
	Barium	mg/L	0.195	PAF-113	07-31-2018
	Fluoride	mg/L	1.1	PAF-109	03-09-2017
	Fluoride	mg/L	0.48	PAF-110	08-21-2018
	Fluoride	mg/L	0.153	95-47C	03-09-2017
	Fluoride	mg/L	0.414	95-47C	08-21-2018
	Fluoride	mg/L	1.66	PAF-113	02-10-2017

2.3 Comparing Confidence Interval Bands Against GWPS

To assess whether any SSLs occurred during the 2018 Assessment Monitoring at PAF, the CI bands were compared against the constituent-specific GWPS. An SSL was identified if and only if the CI band fully exceeded the GWPS at the *most recent* sampling event.

3 Summary of Statistical Analysis

To facilitate an 'at-a-glance' summary of the statistical comparison results, **Table 6** is a set of 'traffic light' matrices, showing for each CCR network a compact representation of each well location matched against each constituent in Appendix IV. This summary is useful in planning for mitigation actions. Green cells indicate that no statistically significant level (SSL) was observed in 2018. Red cells indicate that an SSL was flagged during the most recent sampling events. Yellow cells are warnings which indicate that a well-constituent pair should be closely watched. These cases have increasing trends and a CI band whose lower limit is at least 65% of the GWPS. Often, the CI band cross-section straddles the GWPS in yellow cells.

At the PAF Gypsum Stack CCR Unit (Table 6A), no SSLs were recorded during the Assessment Monitoring. Warning flags (yellow) were raised for cobalt and lithium at well 93-48A and for beryllium at well PAF-114. In summary, a total of zero SSLs and three warnings were identified across the network wells that are located near the PAF plant's Gypsum Stack CCR Unit during the Assessment Monitoring.

At the PAF Peabody Ash Pond CCR Unit (Table 6B), one arsenic-related SSL was recorded at well PAF-113 during Assessment Monitoring. Warning flags (yellow) were raised for cobalt and lithium at well 95-48A, lithium at well 95-47C and arsenic at well PAF-112. In summary, a total of one SSL and four warnings were identified across the network wells that are located near the PAF plant's Peabody Ash Pond CCR Unit during the Assessment Monitoring.

At the PAF Slag Ponds CCR Unit (Table 6C), one arsenic-related SSL was recorded at well PAF-119 during Assessment Monitoring. Warning flags (yellow) were raised for cobalt and lithium at well 95-48A. In summary, a total of one SSL and two warnings were identified across the network wells that are located near the PAF plant's Slag Ponds CCR Unit during the Assessment Monitoring.

Table 6A. PAF Gypsum Stack - Traffic Light Matrix Based on Comparative Analysis of Statistical Analysis Results versus Groundwater Protection Standards (GWPS)

ITEM No.	Constituent of Interest	TRAFFIC LIGHT MATRIX							
		GROUNDWATER QUALITY MONITORING WELL LOCATIONS							
		95-48A	PAF-101	PAF-104	94-35A	PAF-114	PAF-103	PAF-115	PAF-116
1.	Antimony	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
2.	Arsenic	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
3.	Barium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
4.	Beryllium	GREEN	GREEN	GREEN	GREEN	YELLOW	GREEN	GREEN	GREEN
5.	Cadmium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
6.	Chromium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
7.	Cobalt	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
8.	Fluoride	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
9.	Lead	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
10.	Lithium	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
11.	Mercury	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
12.	Molybdenum	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
13.	Rad226+228	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
14.	Selenium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
15.	Thallium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN

COLOR-CODING KEY:	
	Monitored data for the specific COI are deemed to fall below GWPS
	Monitored data are deemed to fall below GWPS, but an internal warning is issued to TVA staff that CI band lower limit is at least 65% of the GWPS.
	Monitored data for the specific COI are deemed to exceed GWPS

Table 6B. PAF Peabody Ash Pond - Traffic Light Matrix Based on Comparative Analysis of Statistical Analysis Results versus Groundwater Protection Standards (GWPS)

ITEM No.	Constituent of Interest	TRAFFIC LIGHT MATRIX									
		GROUNDWATER QUALITY MONITORING WELL LOCATIONS									
		95-48A	10-5	PAF-105	PAF-106	PAF-119	10-6	PAF-118	PAF-117	PAF-107	10-4
16.	Antimony	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
17.	Arsenic	GREEN	GREEN	GREEN	GREEN	RED	GREEN	GREEN	GREEN	GREEN	GREEN
18.	Barium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
19.	Beryllium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
20.	Cadmium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
21.	Chromium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
22.	Cobalt	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
23.	Fluoride	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
24.	Lead	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
25.	Lithium	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
26.	Mercury	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
27.	Molybdenum	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
28.	Rad226+228	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
29.	Selenium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
30.	Thallium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN

COLOR-CODING KEY:	
	Monitored data for the specific COI are deemed to fall below GWPS
	Monitored data are deemed to fall below GWPS, but an internal warning is issued to TVA staff that CI band lower limit is at least 65% of the GWPS.
	Monitored data for the specific COI are deemed to exceed GWPS

Table 6C. PAF Slag Pond - Traffic Light Matrix Based on Comparative Analysis of Statistical Analysis Results versus Groundwater Protection Standards (GWPS)

ITEM No.	Constituent of Interest	TRAFFIC LIGHT MATRIX						
		GROUNDWATER QUALITY MONITORING WELL LOCATIONS						
		95-48A	PAF-108	PAF-109	PAF-110	95-47C	PAF-113	PAF-112
31.	Antimony	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
32.	Arsenic	GREEN	GREEN	GREEN	GREEN	GREEN	RED	YELLOW
33.	Barium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
34.	Beryllium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
35.	Cadmium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
36.	Chromium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
37.	Cobalt	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
38.	Fluoride	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
39.	Lead	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
40.	Lithium	YELLOW	GREEN	GREEN	GREEN	YELLOW	GREEN	GREEN
41.	Mercury	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
42.	Molybdenum	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
43.	Rad226+228	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
44.	Selenium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN
45.	Thallium	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN

COLOR-CODING KEY:	
	Monitored data for the specific COI are deemed to fall below GWPS
	Monitored data are deemed to fall below GWPS, but an internal warning is issued to TVA staff that CI band lower limit is at least 65% of the GWPS.
	Monitored data for the specific COI are deemed to exceed GWPS

4 References

1) US Environmental Protection Agency (2009) *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance* - Office of Resource Conservation and Recovery EPA 530/R-09-007

2) US Environmental Protection Agency (2007) *Framework for Metals Risk Assessment* EPA 120/R-07/001 Office of the Science Advisor Risk Assessment Forum, Washington, DC 20460