COMPLIANCE REPORT
STATISTICAL METHOD FOR GROUNDWATER DATA EVALUATION
COAL COMBUSTION RESIDUALS LANDFILL
INDIAN RIVER GENERATING STATION

Prepared for:

Indian River Power, LLC
Indian River Generating Station
Dagsboro, Delaware

Prepared by:

Michael Baker
INTERNATIONAL

October 17, 2017

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

1.0 Introduction

Title 40 Code of Federal Regulations (40 CRF) §257.91 requires the owner or operator of Coal Combustion Residuals (CCR) landfills and surface impoundments, also known as CCR units, to implement a groundwater monitoring system. These requirements are part of the CCR Rule which was published in the Federal Register on April 17, 2015 and which became effective on October 19, 2015. The groundwater monitoring system for CCR landfills and surface impoundments must consist of a sufficient number of wells (minimum one upgradient and three downgradient) installed at appropriate locations to accurately determine background groundwater quality and to accurately represent the quality of groundwater passing the boundary of the CCR unit.

The Indian River Generating Station, owned by Indian River Power, LLC, a subsidiary of NRG Energy, Inc. (NRG), is a coal-fired power plant located in Dagsboro, Delaware. The CCR Rule applies to this facility due to the management/disposal of CCR resulting from electricity generation. The CCR landfill has a dedicated groundwater monitoring well network that meets the requirements of §257.91 with regard to number and appropriate locations of wells (Michael Baker International, 2017). The station generating capacity was developed between 1957 (Unit 1) and 1980 (Unit 4). The current landfill (Phase I) began operation in 1981 with approval from the State of Delaware and has, with the addition of Phase II, continued operation as a permitted entity to the present. Its current permit to operate was issued by Delaware Department of Natural Resources and Environmental Control (DNREC) as Permit No SW-12/01 (Jan 24, 2007, subsequently amended Feb 27, 2012 and Nov 6, 2015) and includes a rigorous groundwater monitoring program requirement with which the facility is compliant. The US Environmental Protection Agency (USEPA) Part 257 regulations regarding CCR disposal units became effective Oct 19, 2015 and contain substantially equivalent obligations, some of which currently are not fully synchronized with the existing State program. It is anticipated that these differences will be resolved into a combined state/federal program that includes permit conditions similar to those currently in place.

§257.93(a) requires that a groundwater sampling and analysis program be established to include consistent procedures to ensure that the monitoring results accurately represent the quality of groundwater at the upgradient and downgradient wells. This includes selection of a statistical method for use in determining if a significant increase over background concentrations in groundwater has occurred at one or more of the downgradient monitoring well locations. Candidate methods are outlined in §257.93(f)(1-5) and corresponding performance standards (dependent upon the method selected) are specified in §257.93(g)(1-6). Lastly, §257.93(f)(6) requires the owner or operator of the CCR unit to obtain a certification from a professional engineer stating that the selected statistical method is appropriate for evaluating the groundwater monitoring data for the CCR management area.

This report has been prepared to demonstrate compliance with the requirements of §257.93(f)(6), addressing the statistical method selection for the CCR detection monitoring program. The Engineer's Certification will be placed in the Indian River facility's operating record per §257.105(h)(4), noticed to the State Director per §257.106(h)(3), and posted to the publicly accessible internet site per §257.107(h)(3).

1.1 Site Description

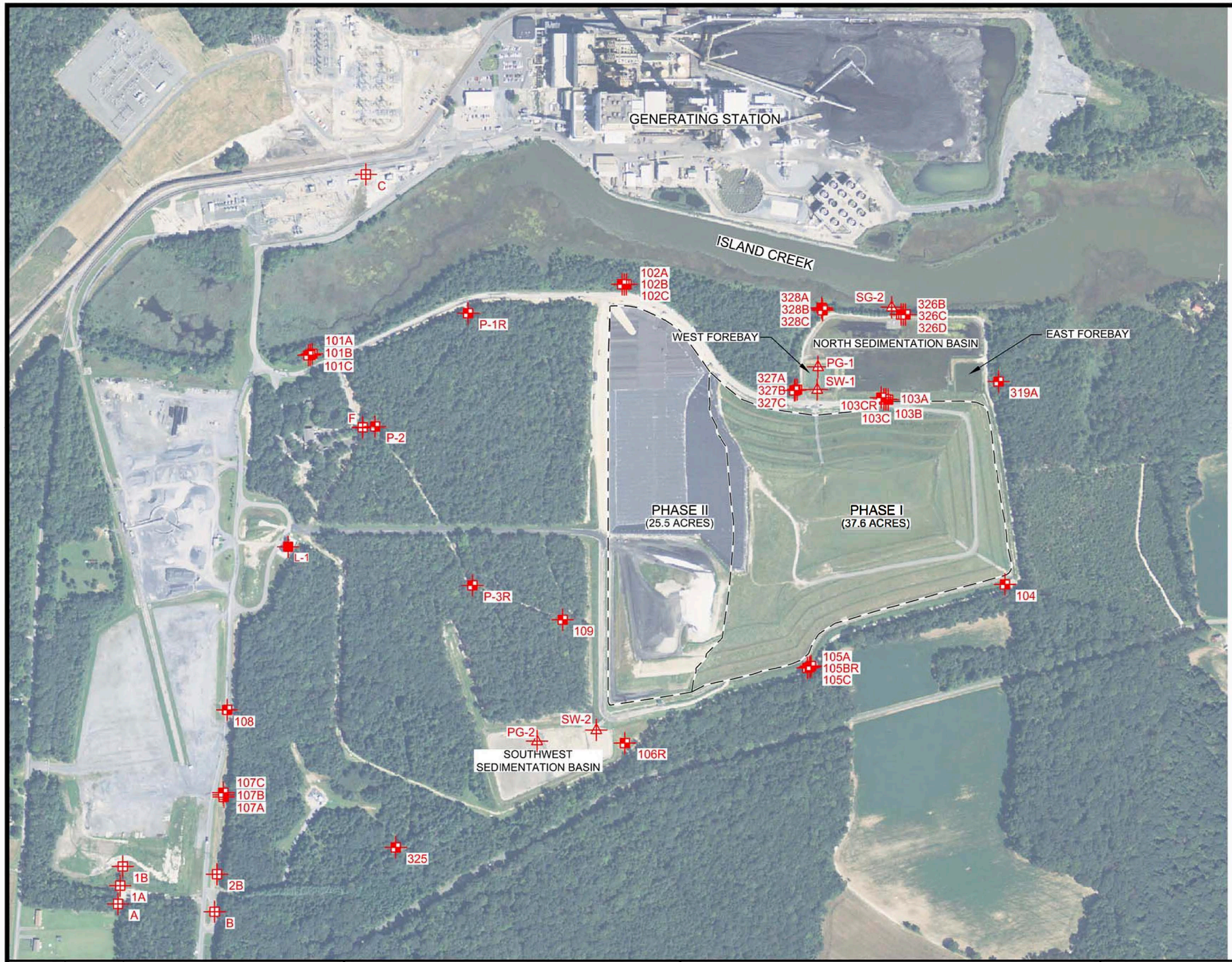
The CCR landfill is located within the 1200-acre plant property at the Indian River Generating Station near the city of Dagsboro, in Sussex County, Delaware. Non-hazardous coal combustion residuals (CCR) that result from burning coal at the station are disposed in the landfill, located about one half of a mile south of the station. The landfill is separated from the generating station area proper by Island Creek as shown on Figure 1.

The station originally operated four generating units with nominal capacities of 90, 90, 165 and 424 megawatts (Units 1 through 4 respectively). Units 1 through 3 have been retired from service and the fourth unit currently operates intermittently. During 2016 it operated at about 13% capacity. It produces fly ash, bottom ash, and a flue gas desulfurization (FGD) byproduct which must be removed from the power plant, hauled to the designated disposal area, or hauled to an off-site utilization project.

The CCR landfill consists of two distinct disposal areas, the original (Phase I) 43.8-acre landfill that is now closed, and the two currently operating cells that comprise the Phase II landfill. The Phase II landfill consists of two, lined cells with a total area of 25.5 acres, immediately west of the closed Phase I cell. The eastern 6.2 acres of the Phase II landfill will be built over, or piggy-back, the western slope of the Phase I landfill with its liner system separating the two phases of disposal. This will raise the overall landfill to a maximum elevation of 100 feet (ft) from the current 65 ft.

Construction of the Phase I cell was initiated in 1979 and disposal commenced in 1980. Waste contains primarily fly ash and bottom ash and, to a lesser extent, wastewater treatment sludge, water treatment sludge, coal pile runoff sump area sludge, coal pyrites, cooling tower sediment sludge, and construction debris produced at the plant. The Phase I Landfill is unlined and was formally closed in 2011 with a cover system that consists of a geosynthetic membrane with a vegetated soil cover. The DNREC approved the Phase I closure October 14, 2014 and this cell is currently in post closure care.

The Phase II units are contiguous to and west of the Phase I landfill, and consist of two lined disposal cells (Cell 1 is to the south and Cell 2 to the north). Only non-hazardous CCR coal fly ash, bottom ash, and Flue Gas Desulfurization (FGD) byproduct, and special wastes consisting of grit blast media used to remove ash and paint from equipment, and soils and sediment contaminated with ash removed during cleanup are permitted to be disposed of in the Phase II landfill in accordance with the current state permit.



N

0 550'

GRAPHIC SCALE

LEGEND

– – – – – – –	APPROXIMATE PHASE BOUNDARY
⌖	GROUNDWATER MONITORING WELL
⌖	PRODUCTION WELL
△	SURFACE WATER MONITORING POINT
■	LEACHATE SAMPLING PORT

NOTES

1. FOR CLARITY, NOT ALL SITE FEATURES MAY BE SHOWN.

REV. NO.	DATE	DESCRIPTION

CB&I Environmental & Infrastructure, Inc.

NRG INDIAN RIVER LANDFILL
SUSSEX COUNTY, DE.

FIGURE 1
CCR LANDFILL GROUNDWATER
MONITORING SYSTEM

DRAWN BY:	APPROVED BY:	PROJ. NO.:	DATE:
NV	RDS	1009684058	JANUARY 2017

2.0 Statistical Method Selection and Background Data Evaluation

The CCR landfill has a dedicated groundwater monitoring system, with multiple upgradient/background wells and at least four downgradient wells that meet the locational requirements of §257.91 (Michael Baker International, 2017).

In accordance with §257.94, NRG has initiated its detection monitoring program by conducting eight rounds of (quarterly) groundwater sampling and analysis for §257 Appendix III parameters (Table 1). The results for the background wells are presented in Tables 2-9 and include 23 independent measurements.

Table 1: Background Groundwater Monitoring Parameters

Part 257 Appendix III Parameters (Quarterly)
Boron
Calcium
Chloride
Fluoride
Sulfate
pH
Total Dissolved Solids

In accordance with §257.93 (f) one of five statistical methods must be selected for the evaluation of each constituent. These methods are drawn from the USEPA Unified Guidance on groundwater monitoring (USEPA, 2009) where their applicability and details of implementation are also provided. In summary the methods are:

Parametric analysis of variance (ANOVA)
Analysis of variance (ANOVA) based on ranks and comparisons of median values
A tolerance or prediction interval procedure
A control chart approach
Other method meeting the specified performance standards

The applicability of each method is dependent on the characteristics of the individual data set and much of the guidance assumes that waste management activities have not yet begun (i.e. there is certainty that ambient groundwater quality has not been affected by the facility at the downgradient waste management boundary). At the Indian River CCR landfill, this presumption cannot be made due to its multi-year history of operation. Accordingly, initial detection monitoring under Part 275 is attempting to establish the presence or absence of increased concentrations of monitored parameters and must, by default, assume that the original downgradient ground water quality profile was similar to that which currently exists in the background wells.

To the extent that normality can be demonstrated in the background analytic results, ANOVA methods are the most appropriate choice to characterize aquifer conditions. Where simple normality is not present, data transformation is attempted. In the following sections, each parameter is evaluated by the following steps:

- Generation of a histogram to enable a visual assessment of the distribution and identify the presence of possible outliers.
- Perform a Shapiro-Wilk normality test.
- If non-normality is indicated, consider removal of outliers and log transformation of the data.
- Repeat Shapiro-Wilk test on transformed data.

The Shapiro-Wilk test is a reliable indicator of normality (USEPA, 2009) and generates a statistic (W) that is compared to tabulated values depending on sample size and probability of error (see Attachment A). If the calculated value exceeds the tabulated value, it is imputed that no evidence of non-normality exists in that data set.

Histograms, data wrangling and statistical testing were performed using the open source R Statistical Programming Language highlighted in the Unified Guidance (USEPA, 2009).

Parameters that are clearly not normally distributed (or which cannot be transformed) are addressed individually below. Results of the statistical testing are summarized in Table 9.

2.1 Boron

Except for a single outlier, Boron concentrations in the background population are all below the reported detection limit of 0.11 mg/l. Given the magnitude of the single outlier (4.6 mg/l) it seems most likely that this sample result is not representative and should be discarded. For purpose of detection monitoring, the reporting limit will be assumed to represent the maximum background value.

Table 2: Analytical Results – Background – Boron

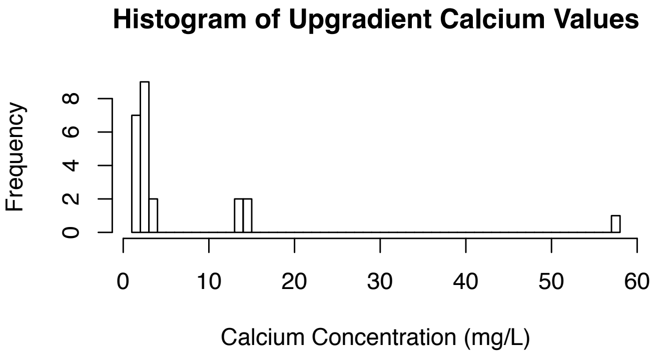
Parameter	**Well ID**	**Sampling Event**							
		2015 4Q	**2016 1Q**	**2016 2Q**	**2016 3Q**	**2016 4Q**	**2017 1Q**	**2017 2Q**	**2017 3Q**
Boron	104	<0.11		<0.11		<0.11		<0.11	
Boron	105A	<0.11		<0.11		<0.11		<0.11	
Boron	106All	<0.11	<0.11		<0.11	4.6	<0.11	<0.11	<0.11
Boron	P-3R	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11

2.2 Calcium

The histogram below Table 3 shows what appears to be either a log normally distributed data set with - possibly - a single outlier, or three distinct distributions. The data as tabulated indicate for non-normality but when log transformed, the W statistic is close to the value that would suggest normality.

Table 3: Analytical Results – Background – Calcium

Parameter	Well ID	Sampling Event							
		2015 4Q	2016 1Q	2016 2Q	2016 3Q	2016 4Q	2017 1Q	2017 2Q	2017 3Q
Calcium	104	13.1		14.7		14.9		13.2	
Calcium	105A	1.4		1.7		1.5		1.5	
Calcium	106All	1.4	1.4		2.7	57.4	2.2	2.2	2
Calcium	P-3R	3.1	2.9	3.2	3	3	3	3	3

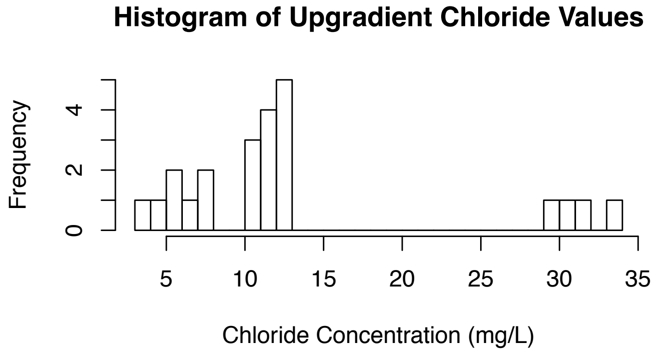


2.3 *Chloride*

The histogram below Table 4 appears to be the left half of a normal distribution with a series of outliers on the right. The W statistic comes close to meeting the tabulated value, but when log transformed exceeds it by a wide margin.

Table 4: Analytical Results – Background – Chloride

Parameter	Well ID	Sampling Event							
		2015 4Q	2016 1Q	2016 2Q	2016 3Q	2016 4Q	2017 1Q	2017 2Q	2017 3Q
Chloride	104	31.2		29.3		30.7		34	
Chloride	105A	12.2		11.8		12.2		12.8	
Chloride	106All	3.3	4.7		5.9	5.6	6.2	7.6	7.6
Chloride	P-3R	11.5	12.6	12.4	10.9	11.9	10.6	10.8	11.5



2.4 Fluoride

All background tests for fluoride were below the detection limit of 0.20 mg/l. For purpose of detection monitoring, the reporting limit will be assumed to represent the maximum background value.

Table 5: Analytical Results – Background – Fluoride

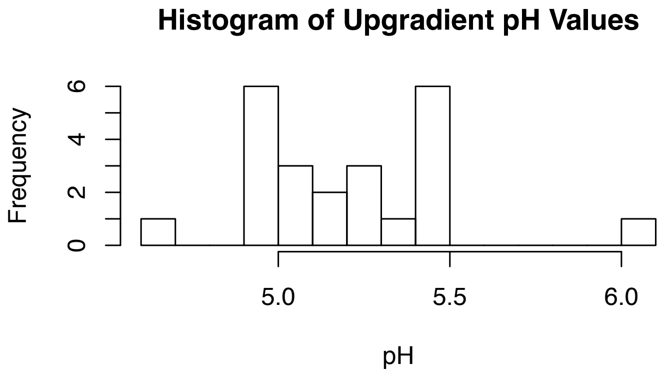
Parameter	**Well ID**	**Sampling Event**							
		2015 4Q	**2016 1Q**	**2016 2Q**	**2016 3Q**	**2016 4Q**	**2017 1Q**	**2017 2Q**	**2017 3Q**
Fluoride	104	<0.20		<0.20		<0.20		<0.20	
Fluoride	105A	<0.20		<0.20		<0.20		<0.20	
Fluoride	106All	<0.20	<0.20		<0.20	<0.20	<0.20	<0.20	<0.20
Fluoride	P-3R	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20

2.5 pH

The pH data set does not indicate for non-normality and transformation is not required.

Table 6: Analytical Results – Background – pH

Parameter	**Well ID**	**Sampling Event**							
		2015 4Q	**2016 1Q**	**2016 2Q**	**2016 3Q**	**2016 4Q**	**2017 1Q**	**2017 2Q**	**2017 3Q**
pH	104	4.93		5.04		4.91		4.94	
pH	105A	5.5		5.42		5.47		5.26	
pH	106All	5.15	4.66		6.04	5.32	5.5	4.99	5
pH	P-3R	5.22	5.06	5.24	5.41	5.12	5.43	4.98	5.03

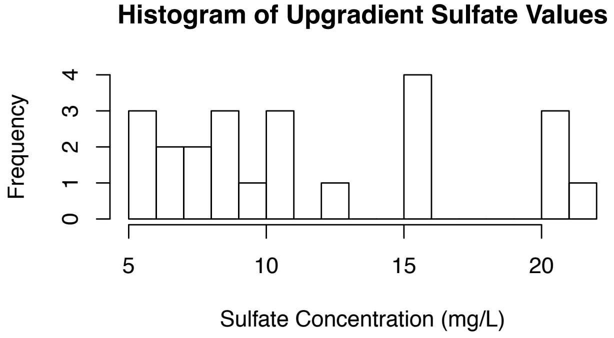


2.6 *Sulfate*

The sulfate data W statistic is close to the tabulated value and when log transformed, exceeds it.

Table 7: Analytical Results – Background – Sulfate

Parameter	**Well ID**	**Sampling Event**							
		2015 4Q	**2016 1Q**	**2016 2Q**	**2016 3Q**	**2016 4Q**	**2017 1Q**	**2017 2Q**	**2017 3Q**
Sulfate	104	10.8		10.7		10.9		12.6	
Sulfate	105A	6.1		6		5.9		5.9	
Sulfate	106All	8.1	8.6		9.4	8.6	8	8	6.9
Sulfate	P-3R	15.7	20.5	20.4	20.2	15.9	21.1	15.5	15.7



2.7 *Total Dissolved Solids*

The TDS results exhibit a distribution similar to that of the chloride data: the left half of a normal distribution and outliers to the right. Without transformation the data indicate as non-normal.

Table 8: Analytical Results – Background – Total Dissolved Solids (TDS)

Parameter	**Well ID**	**Sampling Event**							
		2015 4Q	**2016 1Q**	**2016 2Q**	**2016 3Q**	**2016 4Q**	**2017 1Q**	**2017 2Q**	**2017 3Q**
TDS	104	169		236		204		177	
TDS	105A	45		56		43		27	
TDS	106All	35	73		64	52	72	56	66
TDS	P-3R	57	70	71	63	75	72	63	77

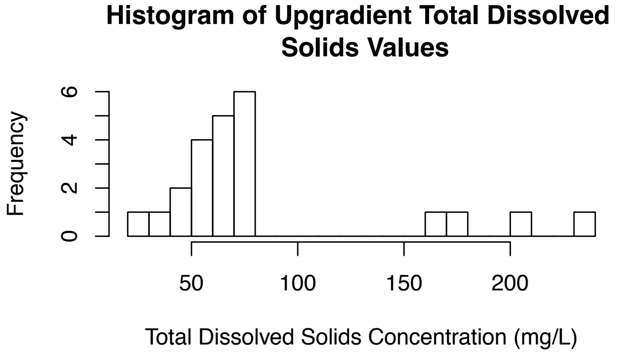


Table 9: Summary of Shapiro-Wilk Statistical Test for Normality

Parameter	W Statistic - raw data	W Statistic - log-transformed data	Comments
	Critical Level of W, α = 0.01, n = 23, 0.881		
Boron	N/A	N/A	Use reporting level as maximum value
Calcium	0.463	0.796	Assume normality for transformed data (marginal) to support parametric ANOVA or use non-parametric test.
Chloride	0.762	0.915	Assume normality for transformed data to support ANOVA
Fluoride	N/A	N/A	Use reporting level as maximum value
pH	0.934	N/A	Assume normality of raw data
Sulfate	0.879	0.917	Assume normality of transformed data to support ANOVA
Total Dissolved Solids	0.715	0.882	Assume normality of transformed data to support ANOVA

2.8 Interpretation of Detection Monitoring Data

In the short term, the multi-year operating history of the facility precludes a monitoring approach that relies on future trends (control charts) or predictive statistics. Rather, this will be an assessment of the status quo - more in the style of a diagnostic assessment - and will be best accomplished through either a parametric or non-parametric one-way ANOVA where individual downgradient wells are compared to the background population as a whole.

The selection of test method will be based on the characteristics of each data set as follows:

- Non-parametric (Kruskal-Wallis): Boron, Calcium, Chloride, Fluoride, Sulfate, Total Dissolved Solids
- Parametric (t-test): pH and Chloride, Sulfate and Total Dissolved Solids when log transformed.

The decision whether to use a parametric test on transformed data should be made on the basis that it might produce more robust results in marginal cases. ANOVA tests will be conducted at a Type 1 error level (false positives) of no less than 0.01 for each testing period.

These analyses will be conducted using the statistical software package ProUCL (v5.1) (USEPA, 2015) that is tailored for groundwater analysis at regulated waste management and disposal sites using the appropriate statistical tools.

3.0 Professional Engineer's Certification

I, Stuart Edwards, hereby certify, based on a review of the information contained herein, and my knowledge and understanding of the principles and accepted practices contained in EPA's Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance, that the statistical methods selected for evaluation of groundwater data associated with the NRG Indian River Generating Station CCR Landfill are adequate and appropriate to meet the performance standards in §257.93(g) and (h).

STUART EDWARDS
No.7341

Signature:

Date: October 17, 2017

Stuart Edwards

Delaware Professional Engineer Registration No. 7341

Michael Baker International

4.0 References

McCurdy, D.E., Garbarino, J.R., and Mullin, A.H., 2008. *Interpreting and Reporting Radiological Water-Quality Data: U.S. Geological Survey Techniques and Methods*, book 5, chap. B6, 33 p.

Michael Baker International, 2017. *Compliance Report Detection Groundwater Monitoring System Coal Combustion Residuals Landfill Indian River Generating Station.* October 2017.

United States Environmental Protection Agency (USEPA). 2009. *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance.* Office of Resource and Recovery Program Implementation and Information Division, US EPA. March 2009. EPA 530-R-09-007.

2015. *ProUCL Version 5.1 Technical Guide*. Office of Research and Development.

Attachment A – Values of Shapiro-Wilk W Statistic

Table 10-3. α-Level Critical Points for Shapiro-Wilk Test, $n = 3(1)50$

n\α	**0.01**	**0.05**	**0.10**
3	0.753	0.767	0.789
4	0.687	0.748	0.792
5	0.686	0.762	0.806
6	0.713	0.788	0.826
7	0.730	0.803	0.838
8	0.749	0.818	0.851
9	0.764	0.829	0.859
10	0.781	0.842	0.869
11	0.792	0.850	0.876
12	0.805	0.859	0.883
13	0.814	0.866	0.889
14	0.825	0.874	0.895
15	0.835	0.881	0.901
16	0.844	0.887	0.906
17	0.851	0.892	0.910
18	0.858	0.897	0.914
19	0.863	0.901	0.917
20	0.868	0.905	0.920
21	0.873	0.908	0.923
22	0.878	0.911	0.926
23	0.881	0.914	0.928
24	0.884	0.916	0.930
25	0.888	0.918	0.931
26	0.891	0.920	0.933
27	0.894	0.923	0.935
28	0.896	0.924	0.936
29	0.898	0.926	0.937
30	0.900	0.927	0.939
31	0.902	0.929	0.940
32	0.904	0.930	0.941
33	0.906	0.931	0.942
34	0.908	0.933	0.943
35	0.910	0.934	0.944
36	0.912	0.935	0.945
37	0.914	0.936	0.946
38	0.916	0.938	0.947
39	0.917	0.939	0.948
40	0.919	0.940	0.949
41	0.920	0.941	0.950
42	0.922	0.942	0.951
43	0.923	0.943	0.951
44	0.924	0.944	0.952
45	0.926	0.945	0.953
46	0.927	0.945	0.953
47	0.928	0.946	0.954
48	0.929	0.947	0.954
49	0.929	0.947	0.955
50	0.930	0.947	0.955

Source: Madansky (1988)
Footnote. The notation $n = 3(1)50$ is shorthand for n from 3 to 50 in unit steps