



October 1, 2024

Daniela Ortiz de Montellano, Project Manager  
Industrial and Hazardous Waste Permits Section  
Waste Permits Division  
Texas Commission on Environmental Quality

RE: New Coal Combustion Residuals (CCR) Registration No. CCR1  
Technical NOD 3 Addendum  
Lower Colorado River Authority – La Grange, Fayette County  
Industrial Solid Waste Registration No. 31575  
EPA Identification No. TXD083566547  
Tracking No. 27214088; RN100226844/CN600253637

Dear Ms. Ortiz de Montellano,

The Lower Colorado River Authority (LCRA) received your email dated August 15, 2024 in which TCEQ stated that the Alternate Source Demonstration (ASD) dated July 17, 2024 satisfies TCEQ requirements. The ASD was prepared in response to a Statistically Significant Increase (SSI) for boron at the Combustion Byproducts Landfill (CBL) groundwater monitoring well CBL-302I at Fayette Power Project that was initially reported to the TCEQ on April 30, 2024. During a meeting on July 31, 2024 with the Texas Commission on Environmental Quality (TCEQ), LCRA agreed to provide this addendum to the September 14, 2023 notice of deficiency response (NOD3) to update the Background Evaluation Report (BER) and Statistical Analysis Plan (SAP) to document the updated Dixon test analysis presented in the ASD.


The SSI was flagged in the first semi-annual sampling event (January 2024) in monitoring well CBL-302I for boron. However, the data for CBL-302I have too few detections to test whether the dataset is normally or lognormally distributed. Accordingly, the use of Dixon's Test to determine outliers was not in accordance with EPA's *Unified Guidance*. Therefore, two previously identified outliers for CBL-302I have been reinstated in the background dataset resulting in an Intrawell Control Limits (ICL) for boron of 0.2970 mg/L. Both the January and April 2024 sampling data results for boron are below the updated ICL for boron. Based on these findings, the initially identified SSI is no longer applicable and there is no evidence of a release from the CBL.

The attached BER and SAP have been updated to reflect the inclusion of the background data that had previously been excluded for CBL-302I. Attached are the updated BER and SAP which were previously submitted with the September 14, 2023 notice of deficiency response. In addition, a redline/strike out version of the replacement pages of the BER and SAP has been included, where necessary.

Furthermore, the cover letter of the Technical NOD Response letter dated September 14, 2023 has been modified to reflect these changes and is included as an attachment.

If you have any questions or would like additional information, please feel free to contact me at 512-578-3205.

Sincerely,

A handwritten signature in black ink that reads "Kate McCarthy". The signature is written in a cursive, flowing style.

Kate McCarthy, P.G.  
Senior Environmental Coordinator

Enclosures:

- Updated NOD 3 Letter
  - Redline/Strikeout Pages
  - Revised NOD 3 Letter
- Updated Attachment 13 – Statistical Analysis Plan
  - Redline/Strikeout SAP Pages
  - Revised SAP
- Updated Attachment 14 – Background Evaluation Report
  - Redline/Strikeout BER Pages
  - Revised BER

**Updated NOD 3 Letter**  
Redline/Strikeout Pages  
Revised NOD 3 Letter



September 14, 2023

Updated October 1, 2024

Daniela Ortiz de Montellano, Project Manager  
Industrial and Hazardous Waste Permits Section  
Waste Permits Division  
Texas Commission on Environmental Quality

RE: New Coal Combustion Residuals (CCR) Registration No. CCR1  
Technical NOD Response – Request for Clarification (Supersedes information submitted September 14, 2023).  
Lower Colorado River Authority – La Grange, Fayette County  
Industrial Solid Waste Registration No. 31575  
EPA Identification No. TXD083566547  
Tracking No. 27214088; RN100226844/CN600253637

Dear Ms. Ortiz de Montellano,

The Lower Colorado River Authority is in receipt of your email dated June 16, 2023, outlining TCEQ's request for additional information and clarification of previously submitted information regarding the Coal Combustion Residuals registration application for the above referenced facility (dated January 24, 2022, revised October 28, 2022). The below information replaces the previously submitted response information (September 14, 2023). Our responses are outlined below, corresponding to the numbering in your letter. Furthermore, TCEQ has requested that LCRA prepare two stand-alone documents (Background Evaluation Report and the Statistical Analysis Plan) that consolidate information contained in the original registration application. These documents were not contemplated in the original application form prepared by TCEQ and are included as new attachments to the application. In addition, we have included a redline/strike out version of the application changes as well as replacement pages, where necessary.

#### 15. Application Section VI.28

Revise the statistical analysis plan to include narratives to explain the following items listed below. It is recommended that the statistical analysis plan be a unique attachment, instead of within a one-time groundwater monitoring report, to facilitate future updates and revisions.

**The statistical analysis plan has been updated and is included as “Attachment 13” of the application.**

- a. Justification to replace the initial interwell statistical analysis with the intrawell statistical analysis.

**See the attached Statistical Analysis Plan – Section 3.1.**

- b. How the analytical method selected meets the requirements in 40 CFR 257.93(d), (e), and (g).

**See the attached Statistical Analysis Plan – Sections 1.1 and 3.1.**

- c. The statistical method selected for detection evaluation, including, but not limited to:
  - i. Definition of nonparametric prediction limit, normal control limits, prediction limits, baseline threshold values, and CUSUM values.

**See the attached Statistical Analysis Plan – Section 3.1.**

- ii. Establishment of normal control limit, nonparametric prediction limits, baseline threshold values, and CUSUM values.

**See the attached Statistical Analysis Plan – Section 3.1.**

- iii. Statistical Assumptions.

**See the attached Statistical Analysis Plan – Section 3.1.**

- iv. Handling of duplicates, outliers, and non-detects.

**See the attached Statistical Analysis Plan – Section 3.1.**

- v. Assumptions and justification used for methodology implementation and removal of anomalous data.

**See the attached Statistical Analysis Plan – Section 3.2.**

- vi. How the statistically significant increase (SSIs) will be determined and resampling procedures.

**See the attached Statistical Analysis Plan – Section 3.2.**

- vii. How the control limits will be used to evaluate and determine SSIs.

**See the attached Statistical Analysis Plan – Sections 4.1, 4.2, 5.1, and 5.2.**

16. Application Section VI.29.B

Ensure the background evaluation report includes a statistical evaluation of background data for the following: assumptions, the statistical method selected, spatial or temporal stationarity, trends and/or seasonal variation, homogeneity of variance, outliers, non-detects, and normality. It is recommended that the background evaluation report be a unique attachment to facilitate future updates and revisions. Please also include at a minimum, the following items listed below.

The **B**background **E**evaluation **R**report **has been** updated and is included as “Attachment 14” of the application.

- a. A narrative explaining how the eight background samples (baseline observations) collected between 2016 and 2017 meet independent sample requirements.

**See the attached Background Evaluation Report – Section 1.1.**

- b. Include the most recent Table 3 – *Groundwater Monitoring Result Summary for Appendices III and IV including background/upgradient well CBL340I*, see pdf pages 2011 - 2012 of the initial registration application submittal, in the background evaluation report attachment.

**See attached revised Table 3.**

- c. Provide a table that includes a summary of the statistical results for constituents in Appendix III for all monitoring. Explain if the background concentrations are the normal control limits, nonparametric prediction limits, baseline threshold values, and groundwater protection standards.

**See Attachment A, Table 1 in the Background Evaluation Report.**

- d. A narrative explaining how and why background concentrations/statistical limits will be updated and how often.

**See the attached Background Evaluation Report – Section 2.1.**

- e. A narrative discussing whether the background concentrations/statistical limits for Appendix III constituents accurately represent the quality of background that has not been affected by leakage from any CCR unit. In addition, provide site-specific evidence to demonstrate and support your discussion.

**See the attached Background Evaluation Report – Section 1.1 and 16(f)(iii)**

- f. A narrative explaining how the intrawell control charts statistical limits were generated including management of non-detect, outliers, procedures, and assumptions for all the monitoring wells and constituents, for example:

**See the attached Background Evaluation Report and the following specific response as requested.**

16 (f)(i)(a) – Boron: Explain how non-detects were used to generate the statistical limits if more than 50% of the sample data was non-detect at CBL301I, CBL302I, and CBL341I what do these limits mean.

**Some groundwater monitoring parameters are not detected at a frequency great enough to generate the combined Shewhart-CUSUM control charts. For constituents that are detected less than 25% of the time at a particular well, the data are plotted as a time series until a sufficient number of data points are available to provide a 99% confidence nonparametric prediction limit. Thirteen**

independent measurements (with 1 resample) are necessary to achieve a 99% confidence (1% false positive rate) nonparametric prediction limit. Eight independent measurements (for pass 1 of 2 resamples) are necessary to achieve a 99% confidence nonparametric prediction limit. The nonparametric prediction limit is the largest determination out of the dataset collected for that well and parameter. If the detection frequency is 0% after thirteen samples have been collected, the reporting limit (practical quantitation limit) becomes the nonparametric prediction limit.

The boron data points at CBL-301I (0.0707 mg/L and 0.0801 mg/L) may meet the Dixon criteria for exclusion but are not extreme enough (>3x median background value) to be excluded using the DUMPStat protocol, where every other result is <0.05 mg/L boron. For this test, a value of 0.05 mg/L is substituted for each non-detect. The resulting highest value in the background is 0.0801 mg/L boron, which becomes the 99% nonparametric prediction limit.

The boron data points at CBL-302I (0.156 mg/L and 0.297 mg/L) may meet the Dixon criteria for exclusion, however, meet the DUMPStat outlier criteria, as discussed in the Unified Guidance sections §6.3.3 and §12.3, Dixon's Test should not be used to identify potential outliers if more than 50% of the data set are non-detect observations. Use of Dixon's Test assumes the data are normally distributed. The low detection frequency to date "makes it difficult to implement parametric statistical tests, since it may not be possible to determine if the underlying population is normal or can be nrmalized." These data were also not previously excluded by ProUCL and were thus retained as valid data by DUMPStat. ~~Future comparisons will not include these concentrations in the background if they are determined to be outliers. With these outliers removed, the 99% nonparametric prediction limit is now 0.0743 mg/L boron at CBL-302I.~~

With 5 boron detections out of 13 monitoring events at CBL-341I (38% detections), a normal control limit was computed after checking for outliers. The highest boron concentrations at CBL-341I (0.1020 mg/L, 0.0896 mg/L, or 0.0668 mg/L) did not meet the outlier criteria for both Dixon and extremeness. The control limit is simply defined as:

$$\begin{aligned}\text{control limit} &= (\text{control chart factor})(\text{standard deviation}) + \text{mean} \\ &= (5)(0.0172) + 0.0591 \\ &= 0.1452 \text{ mg/L B}\end{aligned}$$

Where each ND result is substituted with 0.05 mg/L for the mean concentration and standard deviation calculations.

16 (f)(i)(b) – Boron: Explain how potential outliers reported in the BOX Plots at CBL301I, CBL302I, CBL308, and CBL341I were used in the statistical analysis and why these outliers were not detected with Dixon's test for outliers.

BOX plots were initially used in the January 2018 report (Amec Foster Wheeler, January 2018) as a qualitative tool to screen for spatial heterogeneity among the wells. Some of the BOX plots showed potential outliers. Based on an update to the Background Evaluation Report using DUMPStat, the boron data points at

**CBL-302I from October 2016 and March 2017 (0.156 mg/L and 0.297 mg/L, respectively) ~~would meet the established outlier criteria under DUMPStat~~ be excluded using Dixon's Test, however, as described in the response for 16 (f)(1)(a), as discussed in the Unified Guidance, use of Dixon's Test assumes the data are normally distributed. The low detection frequency to date "makes it difficult to implement parametric statistical tests, since it may not be possible to determine if the underlying population is normal or can be nrmalized." These data were not previously excluded by the ProUCL background evaluation, and given the not-applicability of using Dixon's Test for the CBL-302I Boron dataset (>50% non-detects), were thus these data were not identified as outliers, and were thus retained as valid data by DUMPStat. Future comparisons will treat these datapoints as outliers and not include these concentrations in background.**

Using a background period of 2016 through 2020, the following samples would be excluded from background if only the Dixon outlier test was applied to the data.

Well	Parameter	Result	Date
CBL-301I	Boron	0.0707	5/18/2017
	Boron	0.0801	9/17/2020
CBL-341I	Boron	0.0668	6/20/2017
	Boron	0.0896	5/16/2017
	Boron	0.1020	9/17/2020

These data exemplify why Dr. Gibbons found it necessary to include an additional layer of scrutiny before excluding certain background data. One limitation of the Dixon test is that it assumes normality. The boron results at CBL-301I and CBL-341I listed above would not pass the Dixon test. With these two detections at CBL-301I and the remaining 13 data points being <0.05 mg/L, the Dixon test, standing alone, would call these extreme. Obviously, they are not extreme. The DUMPStat software tests only extreme concentrations that are at least 3x the median background concentration.

16 (f)(ii)(a) – pH: Explain how potential outliers reported in the BOX Plots for wells CBL302I, CBL308, and CBL306I were used in the statistical analysis and why these outliers were not detected with Dixon's test for outliers.

Using a background period of 2016 through 2020, the following samples would be excluded from background if only the Dixon outlier test was applied to the data.

Well	Parameter	Result	Date
CBL-301I	pH	7.16	1/17/2019
CBL-306I	pH	4.41	3/22/2017
	pH	5.61	5/18/2017
CBL-308I	pH	5.54	5/16/2017
	pH	6.83	1/19/2017



**These data exemplify why Dr. Gibbons found it necessary to include an additional layer of scrutiny before excluding certain background data. The pH results listed above would not pass the Dixon test. The DUMPStat software tests only extreme concentrations that are at least 3x the median (or 1/3x the median) background concentration.**

**An option to identify a data point as an outlier manually is available. This may be due to a resample not confirming the original result, known errors in the lab or sampling, or other causes. Unified Guidance §5.3.2 cautions against removing data unless a discrepancy is identified.**

**Outliers are identified using unique symbols, whether detected statistically or designated manually. Those data points are not included in the determination of statistical limits.**

16 (f)(ii)(b) – pH: Explain why wells CBL302I and CBL306 reported a wider range between lower and upper control statistical limits than at the rest of the downgradient wells. Their statistical limits range between 2.55 to 9.48 and 3.03 to 10.25 respectively.

**The statistical limits are a function of the mean and standard deviation of the background data. Since these disputed points are not true statistical outliers, they are included in the background and contribute to the control limits.**

16 (f)(iii) – Total Dissolved Solids: Explain why the TDS background concentration at CBL308I is between 1.5 and 4 times greater than at the rest of the downgradient wells.

**Significant spatial heterogeneity exists across the site. As described in Section 2.1 of the Geology Summary Report included as Attachment 4 to the original CCR Registration Application, subsurface sediments at the CBL site were deposited in a fluvio-deltaic depositional environment. Sand lenses, channel fills, and sheet splays are common subsurface features and are limited in lateral extent. This creates the spatial heterogeneity that we see in the boring logs of the wells, as well as their geochemistry, including CBL 308I. The Geology Summary Report describes the results of numerous hydrogeology studies conducted at FPP, including those conducted specifically in the CBL area (Amec 2013, 2014). Several noteworthy observations were described in these reports regarding the presence of dissolved anions and cations in groundwater, as follows:**

- **Prior to construction of the Lake Fayette Reservoir (serving as the FPP cooling pond), early geotechnical studies identified the shallowest groundwater bearing unit extending across the majority of the FPP site as what is now referenced as the “Middle Sand.” It was in the process of completing an Affected Property Assessment in the CBL area (Amec 2014), and a focused hydrogeologic assessment of the CBL area (Amec 2013), that a shallower unit was identified beneath the CBL area. The relatively late**

identification of this GWBU suggests the unit may not have been a GWBU of note until completion and filling of the Lake Fayette Reservoir in the 1970s.

- The two shallowest GWBUs beneath the CBL are the Intermediate Sand and the Middle Sand. These GWBUs are relatively thin sand-dominant transmissive units within the Miocene-age Oakville Sandstone, deposited in a fluvio-deltaic system. These GWBUs are overlain and underlain by thick low permeability clay units. Both GWBUs are limited in lateral extent, both by original depositional limits, and by post-depositional erosion along the flanks of Baylor Creek west of the CBL.
- As described in Section 4.2 of the Geology Summary Report and as documented in the soil boring and monitoring well logs contained in Appendices L and N of the report, dozens of geotechnical and environmental borings throughout the CBL area document the presence of nodular calcium carbonates (calcareous nodules), “calcareous horizons,” calcite seams, pyrite, gypsum, gypsum seams, and both reduced and oxidized iron-rich layers. The attached Table 1 provides a summary of observations of macrocrystalline carbonates, sulfates, pyrite, and oxidized iron recorded in lithologic logs developed from multiple geotechnical and environmental drilling programs occurring in the CBL area dating back to 1983. The attached Figure 1 shows the locations of the borings in Table 1. These types of deposits, when subjected to partial dissolution by surface water and/or groundwater, commonly lead to the transport of cations and anions and re-precipitation elsewhere within the stratigraphic unit. As such, the occurrence of mineralized calcium carbonate (calcite), calcium sulfate (gypsum), halite (sodium chloride), pyrite (iron sulfide formed under reducing conditions), hematite, and limonite (iron oxides in various states of hydration) is expected, and these minerals are also expected to be present in various localized abundances based on transport, and localized or widespread redox conditions controlled by the presence or absence of air, water, and/or organic matter.
- As discussed in a 1995 geology and groundwater study conducted at FPP (Radian, 1995), gypsum is observed in veins in soils overlying the shallow groundwater units, suggesting a post-depositional precipitation of the mineral from solution. Precipitation of gypsum indicates that calcium and sulfate ions contributed by calcite dissolution and pyrite oxidation are, or have been at, saturation with respect to gypsum. Re-exposed to groundwater dissolution, these minerals may again serve as sources for the dissolution and transport of these ions, and other evaporite ions such as sodium and chloride in groundwater.
- This report (Radian, 1995) concluded that the groundwater geochemical environment in the shallow lithologies at FPP suggests natural cations and anions may contribute significant concentrations of several chemical

**species which are also in common with coal combustion byproducts, in particular calcium, chloride, sodium, and sulfate.**

**Given this geochemical backdrop, total dissolved solids (TDS), calcium, chloride, and sulfates, all of which are Appendix III analytes in the CCR program, are anticipated to be present in a range of concentrations in groundwater based on past and present mineral hydration conditions, groundwater saturation, and past and present redox conditions. The attached Table 2, as an example, summarizes the average concentrations of TDS and sulfates in the CBL GWMS wells, in addition to a monitoring well immediately upgradient of the CBL (CBL-401M) screened in the deeper Middle Sand.**

**With respect to TDS, the values among all of the wells are generally consistent, with one exception: CBL-306I. CBL-306I is a unique well in the CCR GWMS, as it has the shallowest potentiometric surface below the ground surface, which is at times less than four feet below ground surface). This well is also located in the topographically lowest area proximal to the CBL (see geologic cross section in Appendix G, Figure 3 of the Geology Summary Report). Our conclusion is that groundwater in the CBL-306I is subject to greater diffusion from surface water/shallow groundwater infiltration, and, as such, major anions and cations, such as calcium, chloride, sulfate, and TDS, will have concentrations that are expected to be significantly lower than the upgradient wells.**

**Regarding groundwater geochemistry in general, a significant observation among all wells in the CBL GWMS is that CBL-308I is the only well screened through the Intermediate Sand, where the Intermediate Sand is not fully saturated. As much as one to three feet of an unconsolidated transmissive Intermediate Sand is present above the fluctuating groundwater surface. This condition results in expected repeated instances of dissolution and remineralization of naturally-occurring evaporite minerals, corresponding with a flux of their associated major ions naturally (calcium, chloride, sulfates, and TDS) and the state of hydration. As such, the higher observed concentrations of these major ions in the vicinity of CBL-308I is not unexpected.**

**16 (f)(iv) – Sulfate: Explain the presence of greater sulfate concentrations at downgradient monitoring wells CBL302I and CBL308I, which are also the ones closest to the landfill unit footprint, than at the other downgradient wells. The concentration (ranges between 993 to 1390 mg/l at CBL302I, and 1310 to 1580 mg/l at CBL308I) of sulfate at these wells are 3 to 4 times greater than at the rest of the other downgradient wells.**

**As described in response to comment ID 16(f)(iii) above, sulfate is naturally occurring in the subsurface throughout the CBL. The boring logs for CBL302I and CBL 308I, among other borings/wells, show evaporate minerals present in the borehole (Table 1). Groundwater monitoring data obtained by analysis of groundwater samples collected during the Affected Property Assessment study for Middle Sand monitoring well CBL-401M, located upgradient of the CBL, and unaffected by CBL operation (see attached Figure 2), show even higher average sulfate concentrations (averaging 1780 mg/L), as shown in comparison to the CCR GWMS wells (see attached Table 2).**

Semi-annual statistical reports prepared by LCRA have acknowledged a slight upward trend in sulfate at CBL 302I. However, this was a generalized statement about the data. When examining the data, the slight upward trend occurred in the 2016-2018 time-period. During the time-period following 2018-2022, there is not an upward trend and sulfate values appear to be relatively stable. In addition, analytical data trends observed during the CCR monitoring period 2016-2022 timeframe show declining trends in CBL-302I data for the major ions calcium, chloride, and TDS (discussed further below in response to comment ID 17) and as shown in Figure 3.

- No obvious trends in analyte concentrations over time were observed in CBL-308I data (2016-2022).
- Neither CBL 302I or 308I have a documented SSI for sulfate.

Based on observations of multiple lines of evidence (prior geochemical studies and review of the major cation-anion trends) the trend data observed in CBL-302I and CBL-308I suggest the levels in these two wells are naturally occurring. In addition, higher concentrations of sulfate in upgradient well (CBL-401M) screened in the Middle Sand groundwater bearing unit indicate the sulfate concentrations observed in CBL-302I and CBL-308I may be representative of background conditions, given the lack of data suggesting otherwise. Again, as described in response to comment ID 16 (f) (iii), the presence of these ions is expected, given the Oakville Sandstone mineralogy, and the distribution of these ions (with in the mineralized state or the dissolve state) is expected to be quite variable over the CBL area.

16 (f)(v) – CBL306I: Clarify what sample constituents from Appendix III from the July 31, 2019, sampling event were used to conduct combined Shewhart-CUSUM Control Charts statistical analysis and explain why. Attachment 10, pdf page 1907 of the registration application, suggests that the sampling results from July 31, 2019, are anomalous across many constituents and should not be included in future statistical analysis.

**See Attachment C in the Background Evaluation Report. All data from the July 31, 2019 CBL-306I sampling event were excluded from statistical background evaluation based on review of the initial sampling, which showed anomalous results. The well was resampled and all analytes re-evaluated. This is reflected in the updated Attachment C.**

16 (f)(vi)(a) – Attachment 4 of 2 NOD response and Table 4 -Dixon's Test Outliers provide: A narrative explaining the discrepancy in the number of observations used for the input data shown in Appendices E and D, and listed in Table 4: Dixon's Test Outliers, and assumptions used to evaluate the outlier data, as requested 16.f

**See Attachments A and C in the Background Evaluation Report. The number of observations identified in the summary table and the graphs have been updated and are now in agreement.**

- g. Explain what the CUSUM value represents in the control charts for each well and constituents.

**In addition to comparing the compliance data to background concentrations using a control chart, the Shewhart-CUSUM control chart used provides additional information. The CUSUM portion identifies cumulative increases over time, as described in Chapter 20 of the *Unified Guidance*.**

**Compute the standardized concentration  $Z_i$  for each  $x_i$  after background:**

**$Z_i = (x_i - \text{mean})/\text{standard deviation}$**

**use  $Z_i$  to compute the standardized CUSUM  $S_i$ . Set  $S_0 = 0$**

**$S_i^* = \max [0, Z_i - k + S_{i-1}]$**

**where in this case,  $k = 0.75$ .**

**The cumulative sum is expressed as:**

**$S_i = S_i^*(\text{standard deviation}) + \text{mean}$**

**The CUSUM portion of the control chart is compared to the same control limit as was established for the data concentration. The cumulative sum sequentially analyzes each new measurement with prior compliance data.**

**The CUSUM value is listed in column  $S_i$  of the statistical summary table and plotted as a blue circle on the graphs. The CUSUM value is computed on non-background data. The current BER assembled includes only background events so the  $S_i$  column is empty and there are no CUSUM data points plotted. Previous reports show the data concentrations as red squares and the CUSUM as blue circles, both being compared to a common control limit.**

- h. Provide the source for this statement: "NE = Not established, EPA considers these compounds are not a concern from a human health standpoint," see the statement in the notes for Table 3, pdf pages 2011-2012 of the original registration application submittal.

**The table note has been updated to say, "NE= Not established." The amended Table 3 is attached.**

**No maximum contaminant level (MCL) has been established by the EPA for boron, calcium, chloride, fluoride, pH, sulfate, or total dissolved solids (TDS). While secondary MCLs have been established for chloride, fluoride, pH, sulfate, and TDS those guidelines are for managing aesthetic considerations such as and taste, color, and odor; no human health concern is associated with these constituents. Neither an MCL nor a secondary MCL has been established for boron or calcium.**

#### 17. Application Section VI.29

Provide a narrative explaining the cause of an increased trend of sulfate background concentration at CBL302L. In your discussion include site-specific information and other information to demonstrate that this trend accurately represents the quality of background

groundwater that has not been affected by leakage from any CCR unit. This trend was reported in the groundwater reports without further analysis appendix C, pdf page 4 of 2022 groundwater detection monitoring report.

**See The Background Evaluation Report and response 16(f)(iv).**

18. Application Section VI.29

Address the following:

- a. Response to NOD item ID # 8 (received on October 28, 2022): Revise the title of the table to replace " Table VI.D.2" with "Table VI.C-1".
- b. Include a footnote in Table VI.C.1 to reference where the narrative of the statistical analysis method explanation to determine concentration limits is in the application.

**Table VI.D.2 title has been changed to Table VI.C-1 and a footnote has been added to reference the narrative of the statistical analysis method explanation. A redline version is also attached.**

Additional Applications updates

**Application Section 8- Primary Contact Information has been updated and the red line and replacement page is attached.**

**The Groundwater Sampling and Analysis Plan has been updated to reflect the new Attachments 13 and 14.**

If you have any questions or would like additional information, please feel free to contact me at 512-578-2939.

Sincerely,



Kate McCarthy, P.G.  
Senior Environmental Coordinator

Enclosures:

The following enclosures apply to responses in this letter:

- Table 1 – Soil Boring/Monitor Well Lithologic Log Descriptions Indicating Presence of Macrocrystalline Calcium, Iron, and/or Sulfate Mineralogy
- Table 2 – Average Sulfate Concentrations
- Figure 1 – Boring Locations Where Observations of Macrocrystalline Calcium, Iron, and/or Sulfate Mineralogy Recorded
- Figure 2 – Monitor Well Location CBL-401M
- Figure 3 – Major Ion Trends in CBL-302I

The following enclosures apply to CCR Registration Application:

CCR Registration Application – red line and replacement pages and attachments:

Change of Primary Contact #8

Table 3 – Updated

Table VI.C-1 – Updated (Replaces Table VI.D.2)

Revised Attachment 10 Groundwater Sampling and Analysis Plan

New Attachment 13 – Statistical Analysis Plan

New Attachment 14 Background Evaluation Report





September 14, 2023  
*Updated October 1, 2024*

Daniela Ortiz de Montellano, Project Manager  
Industrial and Hazardous Waste Permits Section  
Waste Permits Division  
Texas Commission on Environmental Quality

RE: New Coal Combustion Residuals (CCR) Registration No. CCR1  
Technical NOD Response – Request for Clarification (Supersedes information  
submitted September 14, 2023).  
Lower Colorado River Authority – La Grange, Fayette County  
Industrial Solid Waste Registration No. 31575  
EPA Identification No. TXD083566547  
Tracking No. 27214088; RN100226844/CN600253637

Dear Ms. Ortiz de Montellano,

The Lower Colorado River Authority is in receipt of your email dated June 16, 2023, outlining TCEQ's request for additional information and clarification of previously submitted information regarding the Coal Combustion Residuals registration application for the above referenced facility (dated January 24, 2022, revised October 28, 2022). The below information replaces the previously submitted response information (September 14, 2023). Our responses are outlined below, corresponding to the numbering in your letter. Furthermore, TCEQ has requested that LCRA prepare two stand-alone documents (Background Evaluation Report and the Statistical Analysis Plan) that consolidate information contained in the original registration application. These documents were not contemplated in the original application form prepared by TCEQ and are included as new attachments to the application. In addition, we have included a redline/strike out version of the application changes as well as replacement pages, where necessary.

#### 15. Application Section VI.28

Revise the statistical analysis plan to include narratives to explain the following items listed below. It is recommended that the statistical analysis plan be a unique attachment, instead of within a one-time groundwater monitoring report, to facilitate future updates and revisions.

**The statistical analysis plan has been updated and is included as “Attachment 13” of the application.**

- a. Justification to replace the initial interwell statistical analysis with the intrawell statistical analysis.

**See the attached Statistical Analysis Plan – Section 3.1.**

- b. How the analytical method selected meets the requirements in 40 CFR 257.93(d), (e), and (g).



**See the attached Statistical Analysis Plan – Sections 1.1 and 3.1.**

- c. The statistical method selected for detection evaluation, including, but not limited to:
  - i. Definition of nonparametric prediction limit, normal control limits, prediction limits, baseline threshold values, and CUSUM values.

**See the attached Statistical Analysis Plan – Section 3.1.**

- ii. Establishment of normal control limit, nonparametric prediction limits, baseline threshold values, and CUSUM values.

**See the attached Statistical Analysis Plan – Section 3.1.**

- iii. Statistical Assumptions.

**See the attached Statistical Analysis Plan – Section 3.1.**

- iv. Handling of duplicates, outliers, and non-detects.

**See the attached Statistical Analysis Plan – Section 3.1.**

- v. Assumptions and justification used for methodology implementation and removal of anomalous data.

**See the attached Statistical Analysis Plan – Section 3.2.**

- vi. How the statistically significant increase (SSIs) will be determined and resampling procedures.

**See the attached Statistical Analysis Plan – Section 3.2.**

- vii. How the control limits will be used to evaluate and determine SSIs.

**See the attached Statistical Analysis Plan – Sections 4.1, 4.2, 5.1, and 5.2.**

**16. Application Section VI.29.B**

Ensure the background evaluation report includes a statistical evaluation of background data for the following: assumptions, the statistical method selected, spatial or temporal stationarity, trends and/or seasonal variation, homogeneity of variance, outliers, non-detects, and normality. It is recommended that the background evaluation report be a unique attachment to facilitate future updates and revisions. Please also include at a minimum, the following items listed below.

**The Background Evaluation Report has been updated and is included as “Attachment 14” of the application.**

- a. A narrative explaining how the eight background samples (baseline observations) collected between 2016 and 2017 meet independent sample requirements.

**See the attached Background Evaluation Report – Section 1.1.**

- b. Include the most recent Table 3 – *Groundwater Monitoring Result Summary for Appendices III and IV including background/upgradient well CBL340I*, see pdf pages 2011 - 2012 of the initial registration application submittal, in the background evaluation report attachment.

**See attached revised Table 3.**

- c. Provide a table that includes a summary of the statistical results for constituents in Appendix III for all monitoring. Explain if the background concentrations are the normal control limits, nonparametric prediction limits, baseline threshold values, and groundwater protection standards.

**See Attachment A, Table 1 in the Background Evaluation Report.**

- d. A narrative explaining how and why background concentrations/statistical limits will be updated and how often.

**See the attached Background Evaluation Report – Section 2.1.**

- e. A narrative discussing whether the background concentrations/statistical limits for Appendix III constituents accurately represent the quality of background that has not been affected by leakage from any CCR unit. In addition, provide site-specific evidence to demonstrate and support your discussion.

**See the attached Background Evaluation Report – Section 1.1 and 16(f)(iii)**

- f. A narrative explaining how the intrawell control charts statistical limits were generated including management of non-detect, outliers, procedures, and assumptions for all the monitoring wells and constituents, for example:

**See the attached Background Evaluation Report and the following specific response as requested.**

16 (f)(i)(a) – Boron: Explain how non-detects were used to generate the statistical limits if more than 50% of the sample data was non-detect at CBL301I, CBL302I, and CBL341I what do these limits mean.

**Some groundwater monitoring parameters are not detected at a frequency great enough to generate the combined Shewhart-CUSUM control charts. For constituents that are detected less than 25% of the time at a particular well, the data are plotted as a time series until a sufficient number of data points are available to provide a 99% confidence nonparametric prediction limit. Thirteen**

independent measurements (with 1 resample) are necessary to achieve a 99% confidence (1% false positive rate) nonparametric prediction limit. Eight independent measurements (for pass 1 of 2 resamples) are necessary to achieve a 99% confidence nonparametric prediction limit. The nonparametric prediction limit is the largest determination out of the dataset collected for that well and parameter. If the detection frequency is 0% after thirteen samples have been collected, the reporting limit (practical quantitation limit) becomes the nonparametric prediction limit.

The boron data points at CBL-301I (0.0707 mg/L and 0.0801 mg/L) may meet the Dixon criteria for exclusion but are not extreme enough ( $>3\times$  median background value) to be excluded using the DUMPStat protocol, where every other result is  $<0.05$  mg/L boron. For this test, a value of 0.05 mg/L is substituted for each non-detect. The resulting highest value in the background is 0.0801 mg/L boron, which becomes the 99% nonparametric prediction limit.

The boron data points at CBL-302I (0.156 mg/L and 0.297 mg/L) may meet the Dixon criteria for exclusion, however, as discussed in the Unified Guidance sections §6.3.3 and §12.3, Dixon's Test should not be used to identify potential outliers if more than 50% of the data set are non-detect observations. Use of Dixon's Test assumes the data are normally distributed. The low detection frequency to date "makes it difficult to implement parametric statistical tests, since it may not be possible to determine if the underlying population is normal or can be normalized." These data were also not previously excluded by ProUCL and were thus retained as valid data by DUMPStat.

With 5 boron detections out of 13 monitoring events at CBL-341I (38% detections), a normal control limit was computed after checking for outliers. The highest boron concentrations at CBL-341I (0.1020 mg/L, 0.0896 mg/L, or 0.0668 mg/L) did not meet the outlier criteria for both Dixon and extremeness. The control limit is simply defined as:

$$\begin{aligned}\text{control limit} &= (\text{control chart factor})(\text{standard deviation}) + \text{mean} \\ &= (5)(0.0172) + 0.0591 \\ &= 0.1452 \text{ mg/L B}\end{aligned}$$

Where each ND result is substituted with 0.05 mg/L for the mean concentration and standard deviation calculations.

16 (f)(i)(b) – Boron: Explain how potential outliers reported in the BOX Plots at CBL301I, CBL302I, CBL308, and CBL341I were used in the statistical analysis and why these outliers were not detected with Dixon's test for outliers.

BOX plots were initially used in the January 2018 report (Amec Foster Wheeler, January 2018) as a qualitative tool to screen for spatial heterogeneity among the wells. Some of the BOX plots showed potential outliers. Based on an update to the Background Evaluation Report using DUMPStat, the boron data points at CBL-302I from October 2016 and March 2017 (0.156 mg/L and 0.297 mg/L, respectively) would be excluded using Dixon's Test, however, as described in the response for 16 (f)(1)(a), as discussed in the Unified Guidance, use of

**Dixon's Test** assumes the data are normally distributed. The low detection frequency to date "makes it difficult to implement parametric statistical tests, since it may not be possible to determine if the underlying population is normal or can be normalized." These data were not previously excluded by the ProUCL background evaluation, and given the not-applicability of using Dixon's Test for the CBL-302I Boron dataset (>50% non-detects), these data were not identified as outliers, and were thus retained by DUMPStat. Using a background period of 2016 through 2020, the following samples would be excluded from background if only the Dixon outlier test was applied to the data.

Well	Parameter	Result	Date
CBL-301I	Boron	0.0707	5/18/2017
	Boron	0.0801	9/17/2020
CBL-341I	Boron	0.0668	6/20/2017
	Boron	0.0896	5/16/2017
	Boron	0.1020	9/17/2020

These data exemplify why Dr. Gibbons found it necessary to include an additional layer of scrutiny before excluding certain background data. One limitation of the Dixon test is that it assumes normality. The boron results at CBL-301I and CBL-341I listed above would not pass the Dixon test. With these two detections at CBL-301I and the remaining 13 data points being <0.05 mg/L, the Dixon test, standing alone, would call these extreme. Obviously, they are not extreme. The DUMPStat software tests only extreme concentrations that are at least 3x the median background concentration.

16 (f)(ii)(a) – pH: Explain how potential outliers reported in the BOX Plots for wells CBL302I, CBL308, and CBL306I were used in the statistical analysis and why these outliers were not detected with Dixon's test for outliers.

Using a background period of 2016 through 2020, the following samples would be excluded from background if only the Dixon outlier test was applied to the data.

Well	Parameter	Result	Date
CBL-301I	pH	7.16	1/17/2019
CBL-306I	pH	4.41	3/22/2017
	pH	5.61	5/18/2017
CBL-308I	pH	5.54	5/16/2017
	pH	6.83	1/19/2017

These data exemplify why Dr. Gibbons found it necessary to include an additional layer of scrutiny before excluding certain background data. The pH results listed above would not pass the Dixon test. The DUMPStat software tests only extreme concentrations that are at least 3x the median (or 1/3x the median) background concentration.

**An option to identify a data point as an outlier manually is available. This may be due to a resample not confirming the original result, known errors in the lab or sampling, or other causes. Unified Guidance §5.3.2 cautions against removing data unless a discrepancy is identified.**

**Outliers are identified using unique symbols, whether detected statistically or designated manually. Those data points are not included in the determination of statistical limits.**

16 (f)(ii)(b) – pH: Explain why wells CBL302I and CBL306 reported a wider range between lower and upper control statistical limits than at the rest of the downgradient wells. Their statistical limits range between 2.55 to 9.48 and 3.03 to 10.25 respectively.

**The statistical limits are a function of the mean and standard deviation of the background data. Since these disputed points are not true statistical outliers, they are included in the background and contribute to the control limits.**

16 (f)(iii) – Total Dissolved Solids: Explain why the TDS background concentration at CBL308I is between 1.5 and 4 times greater than at the rest of the downgradient wells.

**Significant spatial heterogeneity exists across the site. As described in Section 2.1 of the Geology Summary Report included as Attachment 4 to the original CCR Registration Application, subsurface sediments at the CBL site were deposited in a fluvio-deltaic depositional environment. Sand lenses, channel fills, and sheet splays are common subsurface features and are limited in lateral extent. This creates the spatial heterogeneity that we see in the boring logs of the wells, as well as their geochemistry, including CBL 308I. The Geology Summary Report describes the results of numerous hydrogeology studies conducted at FPP, including those conducted specifically in the CBL area (Amec 2013, 2014). Several noteworthy observations were described in these reports regarding the presence of dissolved anions and cations in groundwater, as follows:**

- **Prior to construction of the Lake Fayette Reservoir (serving as the FPP cooling pond), early geotechnical studies identified the shallowest groundwater bearing unit extending across the majority of the FPP site as what is now referenced as the “Middle Sand.” It was in the process of completing an Affected Property Assessment in the CBL area (Amec 2014), and a focused hydrogeologic assessment of the CBL area (Amec 2013), that a shallower unit was identified beneath the CBL area. The relatively late identification of this GWBU suggests the unit may not have been a GWBU of note until completion and filling of the Lake Fayette Reservoir in the 1970s.**
- **The two shallowest GWBUs beneath the CBL are the Intermediate Sand and the Middle Sand. These GWBUs are relatively thin sand-dominant transmissive units within the Miocene-age Oakville Sandstone, deposited in a fluvio-deltaic system. These GWBUs are overlain and underlain by thick**

low permeability clay units. Both GWBUs are limited in lateral extent, both by original depositional limits, and by post-depositional erosion along the flanks of Baylor Creek west of the CBL.

- As described in Section 4.2 of the Geology Summary Report and as documented in the soil boring and monitoring well logs contained in Appendices L and N of the report, dozens of geotechnical and environmental borings throughout the CBL area document the presence of nodular calcium carbonates (calcareous nodules), “calcareous horizons,” calcite seams, pyrite, gypsum, gypsum seams, and both reduced and oxidized iron-rich layers. The attached Table 1 provides a summary of observations of macrocrystalline carbonates, sulfates, pyrite, and oxidized iron recorded in lithologic logs developed from multiple geotechnical and environmental drilling programs occurring in the CBL area dating back to 1983. The attached Figure 1 shows the locations of the borings in Table 1. These types of deposits, when subjected to partial dissolution by surface water and/or groundwater, commonly lead to the transport of cations and anions and re-precipitation elsewhere within the stratigraphic unit. As such, the occurrence of mineralized calcium carbonate (calcite), calcium sulfate (gypsum), halite (sodium chloride), pyrite (iron sulfide formed under reducing conditions), hematite, and limonite (iron oxides in various states of hydration) is expected, and these minerals are also expected to be present in various localized abundances based on transport, and localized or widespread redox conditions controlled by the presence or absence of air, water, and/or organic matter.
- As discussed in a 1995 geology and groundwater study conducted at FPP (Radian, 1995), gypsum is observed in veins in soils overlying the shallow groundwater units, suggesting a post-depositional precipitation of the mineral from solution. Precipitation of gypsum indicates that calcium and sulfate ions contributed by calcite dissolution and pyrite oxidation are, or have been at, saturation with respect to gypsum. Re-exposed to groundwater dissolution, these minerals may again serve as sources for the dissolution and transport of these ions, and other evaporite ions such as sodium and chloride in groundwater.
- This report (Radian, 1995) concluded that the groundwater geochemical environment in the shallow lithologies at FPP suggests natural cations and anions may contribute significant concentrations of several chemical species which are also in common with coal combustion byproducts, in particular calcium, chloride, sodium, and sulfate.

Given this geochemical backdrop, total dissolved solids (TDS), calcium, chloride, and sulfates, all of which are Appendix III analytes in the CCR program, are anticipated to be present in a range of concentrations in groundwater based on past and present mineral hydration conditions, groundwater saturation, and



past and present redox conditions. The attached Table 2, as an example, summarizes the average concentrations of TDS and sulfates in the CBL GWMS wells, in addition to a monitoring well immediately upgradient of the CBL (CBL-401M) screened in the deeper Middle Sand.

With respect to TDS, the values among all of the wells are generally consistent, with one exception: CBL-306I. CBL-306I is a unique well in the CCR GWMS, as it has the shallowest potentiometric surface below the ground surface, which is at times less than four feet below ground surface). This well is also located in the topographically lowest area proximal to the CBL (see geologic cross section in Appendix G, Figure 3 of the Geology Summary Report). Our conclusion is that groundwater in the CBL-306I is subject to greater diffusion from surface water/shallow groundwater infiltration, and, as such, major anions and cations, such as calcium, chloride, sulfate, and TDS, will have concentrations that are expected to be significantly lower than the upgradient wells.

Regarding groundwater geochemistry in general, a significant observation among all wells in the CBL GWMS is that CBL-308I is the only well screened through the Intermediate Sand, where the Intermediate Sand is not fully saturated. As much as one to three feet of an unconsolidated transmissive Intermediate Sand is present above the fluctuating groundwater surface. This condition results in expected repeated instances of dissolution and remineralization of naturally-occurring evaporite minerals, corresponding with a flux of their associated major ions naturally (calcium, chloride, sulfates, and TDS) and the state of hydration. As such, the higher observed concentrations of these major ions in the vicinity of CBL-308I is not unexpected.

16 (f)(iv) – Sulfate: Explain the presence of greater sulfate concentrations at downgradient monitoring wells CBL302I and CBL308I, which are also the ones closest to the landfill unit footprint, than at the other downgradient wells. The concentration (ranges between 993 to 1390 mg/l at CBL302I, and 1310 to 1580 mg/l at CBL308I) of sulfate at these wells are 3 to 4 times greater than at the rest of the other downgradient wells.

As described in response to comment ID 16(f)(iii) above, sulfate is naturally occurring in the subsurface throughout the CBL. The boring logs for CBL302I and CBL 308I, among other borings/wells, show evaporate minerals present in the borehole (Table 1). Groundwater monitoring data obtained by analysis of groundwater samples collected during the Affected Property Assessment study for Middle Sand monitoring well CBL-401M, located upgradient of the CBL, and unaffected by CBL operation (see attached Figure 2), show even higher average sulfate concentrations (averaging 1780 mg/L), as shown in comparison to the CCR GWMS wells (see attached Table 2).

Semi-annual statistical reports prepared by LCRA have acknowledged a slight upward trend in sulfate at CBL 302I. However, this was a generalized statement about the data. When examining the data, the slight upward trend occurred in the 2016-2018 time-period. During the time-period following 2018-2022, there is not an upward trend and sulfate values appear to be relatively stable. In addition, analytical data trends observed during the CCR monitoring period 2016-2022 timeframe show declining trends in CBL-302I data for the major ions

calcium, chloride, and TDS (discussed further below in response to comment ID 17) and as shown in Figure 3.

- No obvious trends in analyte concentrations over time were observed in CBL-308I data (2016-2022).
- Neither CBL 302I or 308I have a documented SSI for sulfate.

Based on observations of multiple lines of evidence (prior geochemical studies and review of the major cation-anion trends) the trend data observed in CBL-302I and CBL-308I suggest the levels in these two wells are naturally occurring. In addition, higher concentrations of sulfate in upgradient well (CBL-401M) screened in the Middle Sand groundwater bearing unit indicate the sulfate concentrations observed in CBL-302I and CBL-308I may be representative of background conditions, given the lack of data suggesting otherwise. Again, as described in response to comment ID 16 (f) (iii), the presence of these ions is expected, given the Oakville Sandstone mineralogy, and the distribution of these ions (with in the mineralized state or the dissolve state) is expected to be quite variable over the CBL area.

16 (f)(v) – CBL306I: Clarify what sample constituents from Appendix III from the July 31, 2019, sampling event were used to conduct combined Shewhart-CUSUM Control Charts statistical analysis and explain why. Attachment 10, pdf page 1907 of the registration application, suggests that the sampling results from July 31, 2019, are anomalous across many constituents and should not be included in future statistical analysis.

**See Attachment C in the Background Evaluation Report. All data from the July 31, 2019 CBL-306I sampling event were excluded from statistical background evaluation based on review of the initial sampling, which showed anomalous results. The well was resampled and all analytes re-evaluated. This is reflected in the updated Attachment C.**

16 (f)(vi)(a) – Attachment 4 of 2 NOD response and Table 4 -Dixon's Test Outliers provide: A narrative explaining the discrepancy in the number of observations used for the input data shown in Appendices E and D, and listed in Table 4: Dixon's Test Outliers, and assumptions used to evaluate the outlier data, as requested 16.f

**See Attachments A and C in the Background Evaluation Report. The number of observations identified in the summary table and the graphs have been updated and are now in agreement.**

- g. Explain what the CUSUM value represents in the control charts for each well and constituents.

**In addition to comparing the compliance data to background concentrations using a control chart, the Shewhart-CUSUM control chart used provides additional information. The CUSUM portion identifies cumulative increases over time, as described in Chapter 20 of the *Unified Guidance*.**



**Compute the standardized concentration  $Z_i$  for each  $x_i$  after background:**

**$Z_i = (x_i - \text{mean})/\text{standard deviation}$**

**use  $Z_i$  to compute the standardized CUSUM  $S_i$ . Set  $S_0 = 0$**

**$S_i^* = \max [0, Z_i - k + S_{i-1}]$**

**where in this case,  $k = 0.75$ .**

**The cumulative sum is expressed as:**

**$S_i = S_i^*(\text{standard deviation}) + \text{mean}$**

**The CUSUM portion of the control chart is compared to the same control limit as was established for the data concentration. The cumulative sum sequentially analyzes each new measurement with prior compliance data.**

**The CUSUM value is listed in column  $S_i$  of the statistical summary table and plotted as a blue circle on the graphs. The CUSUM value is computed on non-background data. The current BER assembled includes only background events so the  $S_i$  column is empty and there are no CUSUM data points plotted.**

**Previous reports show the data concentrations as red squares and the CUSUM as blue circles, both being compared to a common control limit.**

- h. Provide the source for this statement: "NE = Not established, EPA considers these compounds are not a concern from a human health standpoint," see the statement in the notes for Table 3, pdf pages 2011-2012 of the original registration application submittal.

**The table note has been updated to say, "NE= Not established." The amended Table 3 is attached.**

**No maximum contaminant level (MCL) has been established by the EPA for boron, calcium, chloride, fluoride, pH, sulfate, or total dissolved solids (TDS). While secondary MCLs have been established for chloride, fluoride, pH, sulfate, and TDS those guidelines are for managing aesthetic considerations such as taste, color, and odor; no human health concern is associated with these constituents. Neither an MCL nor a secondary MCL has been established for boron or calcium.**

#### 17. Application Section VI.29

Provide a narrative explaining the cause of an increased trend of sulfate background concentration at CBL302L. In your discussion include site-specific information and other information to demonstrate that this trend accurately represents the quality of background groundwater that has not been affected by leakage from any CCR unit. This trend was reported in the groundwater reports without further analysis appendix C, pdf page 4 of 2022 groundwater detection monitoring report.

**See The Background Evaluation Report and response 16(f)(iv).**

18. Application Section VI.29

Address the following:

- a. Response to NOD item ID # 8 (received on October 28, 2022): Revise the title of the table to replace " Table VI.D.2" with "Table VI.C-1".
- b. Include a footnote in Table VI.C.1 to reference where the narrative of the statistical analysis method explanation to determine concentration limits is in the application.

**Table VI.D.2 title has been changed to Table VI.C-1 and a footnote has been added to reference the narrative of the statistical analysis method explanation. A redline version is also attached.**

Additional Applications updates

**Application Section 8- Primary Contact Information has been updated and the red line and replacement page is attached.**

**The Groundwater Sampling and Analysis Plan has been updated to reflect the new Attachments 13 and 14.**

If you have any questions or would like additional information, please feel free to contact me at 512-578-2939.

Sincerely,



Kate McCarthy, P.G.  
Senior Environmental Coordinator

Enclosures:

The following enclosures apply to responses in this letter:

- Table 1 – Soil Boring/Monitor Well Lithologic Log Descriptions Indicating Presence of Macrocrystalline Calcium, Iron, and/or Sulfate Mineralogy
- Table 2 – Average Sulfate Concentrations
- Figure 1 – Boring Locations Where Observations of Macrocrystalline Calcium, Iron, and/or Sulfate Mineralogy Recorded
- Figure 2 – Monitor Well Location CBL-401M
- Figure 3 – Major Ion Trends in CBL-302I

The following enclosures apply to CCR Registration Application:

- CCR Registration Application – red line and replacement pages and attachments:
  - Change of Primary Contact #8
- Table 3 – Updated
- Table VI.C-1 – Updated (Replaces Table VI.D.2)

Revised Attachment 10 Groundwater Sampling and Analysis Plan  
New Attachment 13 – Statistical Analysis Plan  
New Attachment 14 Background Evaluation Report

**Updated Attachment 13 – Statistical Analysis Plan**  
Redline/Strikeout SAP Pages  
Revised SAP

LOWER COLORADO RIVER AUTHORITY  
Austin, Texas

---

**STATISTICAL ANALYSIS PLAN  
COMBUSTION BYPRODUCTS LANDFILL  
FAYETTE POWER PROJECT  
LA GRANGE, TEXAS**

October 1, 2024

**REDLINE/STRIKETHROUGH PAGES**

---

Bullock, Bennett & Associates, LLC  
Engineering and Geoscience  
Registrations: Engineering F-8542, Geoscience 50127  
[www.bbaengineering.com](http://www.bbaengineering.com)



## Table of Contents

1.	INTRODUCTION .....	1
1.1	CBL Groundwater Monitoring System .....	1
2.	DATA MANAGEMENT .....	3
2.1	Management of Duplicate Data .....	3
2.2	Management of Non-Detect Data.....	3
2.3	Management of Anomalous Detections.....	3
3.	STATISTICAL PROCEDURE.....	4
3.1	Intrawell Analysis Using Control Charts .....	4
3.2	Intrawell Analysis Using DUMPStat Statistical Program.....	5
4.	DETECTION MONITORING DATA EVALUATION .....	<u>98</u>
4.1	No Statistically Significant Increase over Background Values .....	<u>98</u>
4.2	Statistically Significant Increase over Background Values .....	<u>109</u>
5.	ASSESSMENT MONITORING DATA EVALUATION .....	<u>1110</u>
6.	REPORTING REQUIREMENTS .....	<u>1312</u>
7.	REFERENCES .....	<u>1413</u>

## Attachments

Attachment A: DUMPStat 2.1.8 Statistical Guide

Attachment B: DUMPStat 2.3 Release Notes

## Control Chart Procedure

A minimum of eight rounds of data is recommended to establish an initial background concentration for each well and parameter. In cases where the detection frequency is  $\geq 25\%$ , a control limit can be calculated to which future data is compared. The control limit is simply defined as:

$$\text{control limit} = (\text{control chart factor})(\text{standard deviation}) + \text{mean}$$

The control chart factor typically ranges from 4.5 to 6.5 for  $N < 12$  and from 4.0 to 6.5 for  $N \geq 12$ . A statistical power curve indicates the expected false assessments for the site as a whole. The statistical power is a function of the number of wells included, the number of constituents compared, the detection frequencies, and the data distributions involved. For intrawell comparisons, the recommended site-wide false positive rate is 5%. Evaluating and adjusting the factor to achieve false assessment objectives is done each time the background is established. Generally, the factor is lowered as background is updated to include more data points.

In addition to comparing the compliance data to background concentrations using a control chart, the Shewhart-CUSUM control chart used provides additional information. The CUSUM portions identifies cumulative increases over time as described in Chapter 20 of the *Unified Guidance*.

Compute the standardized concentration  $Z_i$  for each  $x_i$  after background:

$$Z_i = (x_i - \text{mean}) / \text{standard deviation}$$

use  $Z_i$  to compute the standardized CUSUM  $S_i$ . Set  $S_0 = 0$

$$S_i^* = \max [ 0, Z_i - k + S_{i-1} ]$$

where in this case,  $k = 0.75$ .

The cumulative sum is expressed as:

$$S_i = S_i^* (\text{standard deviation}) + \text{mean}$$

The CUSUM portion of the control chart is compared to the same control limit as was established for the data concentration. The cumulative sum sequentially analyzes each new measurement with prior compliance data.

## Outliers

In developing the statistical background, the historical data must be thoroughly screened for anomalous data which may be due to sampling error, lab error, transcription error, shipping error, or chance alone. An erroneous data point, if not removed prior to the mean and variance computations, would yield a larger control limit thus increasing the false negative rate.

The DUMPStat® program evaluates extreme background values for data sets with at least 25% detections screens for outliers using the Dixon's test. A detected background concentration is defined as an extreme value when a concentration is at least three times (or less than one-third) the median background concentration. DUMPStat® labels a detected background concentration

as an outlier when it is defined as an extreme value and it fails the Dixon's test. Note, the DUMPStat® program is equipped to handle much larger data sets than what is referenced in the Unified Guidance. (Verma and Quiroz-Ruiz, 2006). For normally distributed data (Parametric), if the Dixon test indicates an outlier, the value is compared to three times the median value for intrawell analyses. If the value fails both criteria of the two-stage screening, the Such an outlier value is may be considered a statistical outlier and may will not be used in the mean and variance determinations. Anomalous detected data identified by DUMPStat® as described above will still be plotted on the graphs (with a unique symbol) but will not be included in the calculations. In the care of non-parametric data the Dixon's test should not be used

The DUMPStat program's default approach for data sets with less than 25 datapoints is to first run Dixon's Test. If the results are flagged as potential outliers, then the suspect outlier results are compared to three times the median value. However, as stated in the USEPA document *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (EPA, 2009), the Dixon's "test performance can suffer when more than 50% of the data are non-detects" and "the guidance generally recommends non-parametric options when non-detect data exceed 50%" (Unified Guidance Section 15.6).

Additionally, data can be manually designated as an outlier if the statistician has a justifiable reason. The outlier data, either statistically detected or manually selected, will be graphically displayed (with a unique symbol) but not included in background calculations.

Note, as the Unified Guidance (EPA, 2009) document suggests indicates, the Dixon's test should not be utilized for nonparametric data.

## **Resample Verification**

The verification resample plan is an integral function of the statistical plan to reduce the probability that anomalous data obtained after the background has been established are indicative of a landfill release. Should a control limit exceedance be identified, the resampling plan is implemented by the operator to collect a verification sample. If the resample data obtained confirm the control limit exceedance, the exceedance is considered statistically significant for parametric data. For non-parametric data, two sampling events are necessary to confirm the SSI.

The CBL resampling/retesting strategy is to allow for one resample for constituents evaluated using a parametric method, which applies to all wells and constituents, except for boron in monitoring well CBL-302I. Two resample events may be conducted for constituents evaluated using a nonparametric method, which applies to boron in CBL-302I. If the retesting strategy involves one resample, the initial exceedance is disconfirmed if the constituent concentration in the resample does not exceed the control limit/prediction limit. If the retesting strategy involves two resamples, the initial exceedance is disconfirmed if the constituent concentration in the first or second resample does not exceed the prediction limit (pass one of two resamples); if the first resample passes, the second resample does not need to be taken.

The resampling strategy will be periodically reevaluated and changed as necessary during a background update, which would include new sample results since the previous background evaluation and may include new wells or changes to the list of constituents monitored.

If an initial exceedance over a background limit is determined, the owner or operator may conduct verification resampling. The verification resampling results will confirm or disprove the initial



## 7. REFERENCES

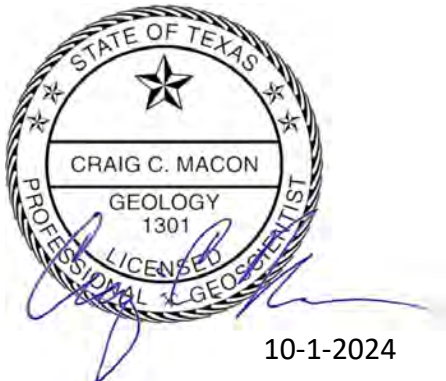
- Amec Foster Wheeler (October 2017): *Groundwater Sampling and Analysis Program, Selection of Statistical Method Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- Amec Foster Wheeler (April 2018a): *Groundwater Geochemical Evaluation at the Lower Colorado River Authority, Fayette Power Project, La Grange, Texas.*
- Amec Foster Wheeler (April 2018b): *Groundwater Monitoring System, Certification of Alternate Source Demonstration, Lower Colorado River Authority, Coal Combustion Residuals Unit: Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- Amec Foster Wheeler (April 2018c): *Groundwater Monitoring System Addendum Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- Bullock, Bennett & Associates (May 2021): *Groundwater Monitoring System Addendum Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- DUMPStat (2003) DUMPStat Statistical Guide, version 2.1.8., by Robert D. Gibbons Ltd., with accompanying DUMPStat 2.3 Release Notes.
- EPA (2009): *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (EPA 530/R-09-007).
- Gibbons, Bhaumik, and Aryal (2009): *Statistical Methods for Groundwater Monitoring, 2<sup>nd</sup> Edition*, 400 pages.
- [Verma and Quiroz-Ruiz \(2006\): Critical Values for Six Dixon's Tests for Outliers in Normal Samples up to Sizes 100, and Applications in Science and Engineering, Revista Mexicana de Ciencias Geologicas, v. 23, num. 2, p. 133-161.](#)

**LOWER COLORADO RIVER AUTHORITY**  
**Austin, Texas**

---

**STATISTICAL ANALYSIS PLAN**  
**COMBUSTION BYPRODUCTS LANDFILL**  
**FAYETTE POWER PROJECT**  
**LA GRANGE, TEXAS**

October 1, 2024



**Bullock, Bennett & Associates, LLC**  
**Engineering and Geoscience**  
**Registrations: Engineering F-8542, Geoscience 50127**  
**[www.bbaengineering.com](http://www.bbaengineering.com)**



## Table of Contents

1.	INTRODUCTION.....	1
1.1	CBL Groundwater Monitoring System .....	1
2.	DATA MANAGEMENT .....	3
2.1	Management of Duplicate Data .....	3
2.2	Management of Non-Detect Data.....	3
2.3	Management of Anomalous Detections.....	3
3.	STATISTICAL PROCEDURE.....	4
3.1	Intrawell Analysis Using Control Charts .....	4
3.2	Intrawell Analysis Using DUMPStat Statistical Program.....	5
4.	DETECTION MONITORING DATA EVALUATION .....	9
4.1	No Statistically Significant Increase over Background Values .....	9
4.2	Statistically Significant Increase over Background Values .....	10
5.	ASSESSMENT MONITORING DATA EVALUATION .....	11
6.	REPORTING REQUIREMENTS .....	13
7.	REFERENCES .....	14

## Attachments

Attachment A: DUMPStat 2.1.8 Statistical Guide

Attachment B: DUMPStat 2.3 Release Notes

# 1. INTRODUCTION

The Lower Colorado River Authority's (LCRA's) Fayette Power Project (FPP) is a coal-fired power plant located east of La Grange in Fayette County, Texas. The coal combustion residuals (CCR) that are generated at FPP (e.g., fly ash, bottom ash, and synthetic gypsum), and certain other solid waste residuals associated with electric power generation, are managed in the on-site Combustion Byproduct Landfill (CBL). The CBL is a CCR unit subject to the U.S. Environmental Protection Agency's (EPA's) CCR regulations and the Texas Commission on Environmental Quality's (TCEQ's) CCR registration program.

EPA's CCR regulations, also referred to as the "CCR Rule," are codified in 40 CFR Part 257, Subpart D, and have been adopted by TCEQ under Chapter 352 of Title 30 of the Texas Administrative Code (30 TAC Chapter 352). These federal and state CCR regulations require facilities to design and install a groundwater monitoring system (GWMS) to evaluate the uppermost groundwater bearing unit (GWBU) beneath CCR units (landfills and impoundments) for potential effects on groundwater quality. The GWBU beneath the CBL is referred to as the "Intermediate Sand."

The CCR Rule requires statistical analysis of analytical data obtained by periodic collection and analysis of groundwater samples from the GWMS. The objective of the statistical analysis is to identify releases from CCR units, based on data comparisons and trend analyses, should they occur. The CCR Rule allows for use of interwell or intrawell analysis. Interwell analysis is conducted where groundwater data from GWMS wells downgradient of the CCR unit are compared to data from GWMS wells unaffected by the CCR unit (preferably at nearby locations upgradient or sidegradient of the CCR unit). Intrawell analysis is conducted on each independent GWMS well in comparison to previous results, in the absence of having a valid background well for comparison.

The CCR Rule provides several options for statistically evaluating groundwater data, as specified in 40 CFR §257.93(f)(1)-(5) and 30 TAC §352.931. EPA's *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (EPA 530/R-09-007), referred herein as the *Unified Guidance*, presents acceptable statistical approaches for such evaluations and analyses.

This Statistical Analysis Plan (SAP) describes the current statistical evaluation approach utilized by LCRA to analyze groundwater chemical data obtained from the CBL GWMS in determining if a statistically significant increase (SSI) is present. This statistical evaluation is conducted in compliance with 40 CFR §§257.93 (30 TAC §352.931), 257.94 (30 TAC §352.941), and 257.95 (30 TAC §352.951) regarding detection and assessment monitoring. This SAP conforms with the *Unified Guidance*. Presently, the CBL is in the detection monitoring program.

## 1.1 CBL Groundwater Monitoring System

The CBL GWMS consists of six groundwater monitoring wells (CBL-301I, CBL-302I, CBL-306I, CBL-308I, CBL-340I, and CBL-341I) screened within the Intermediate Sand and installed at locations downgradient of the current CBL footprint. The Intermediate Sand has not been encountered upgradient of the CBL. As such, additional well CBL-340I is installed at a sidegradient location relative to the CBL to evaluate Intermediate Sand groundwater that is unaffected by the CBL. This addresses the 40 CFR § 257.93(d) requirement for establishment of background groundwater quality in a hydraulically upgradient or sidegradient well.

In the course of completing an Alternate Source Demonstration (ASD) in 2018, it was concluded that monitoring well CBL-340I is not a viable background monitoring well for use in statistical comparisons due to the observed geochemical heterogeneity within the Intermediate Sand, in major anion and cation signatures [Amec Foster Wheeler, April 2018a, April 2018b)]. The identification of natural aquifer heterogeneity resulted in the determination that CBL-340I could not reliably be used to characterize the background geochemistry of the groundwater flowing beneath the CCR unit. As described in the *Unified Guidance*, such spatially variable natural conditions indicate a need to use intrawell statistical analytical procedures rather than more traditional upgradient/sidegradient-to-downgradient interwell procedures.

Based on the CBL geochemistry findings and EPA's *Unified Guidance*, the GWMS was recertified in April 2018 to indicate that CBL-340I would not be included in future statistical evaluations. Furthermore, the statistical analytical method was changed to an Intrawell Prediction Interval Procedure with a new statistical method certification being completed in April 2018. The use of the Intrawell Prediction Interval Procedure eliminated the need for CBL-340I in the statistical analysis and, accordingly, CBL-340I is still sampled but only used for potentiometric surface gauging. Documentation of the ASD, and the revision to the intrawell statistical method, was certified by a Texas Professional Engineer and a Texas Professional Geoscientist [Amec Foster Wheeler (April 2018b, and April 2018c)].

## **2. DATA MANAGEMENT**

### **2.1 Management of Duplicate Data**

If multiple results are obtained for a select parameter at a well on the same sample date, the results will be averaged and appear as one result in the data summary table. The mean data will be noted with an asterisk. The averaged result would then be compared to background. Field duplicates are typically assigned a unique sample identification and would not be combined and averaged.

Field duplicates and data rejected after data validations are removed from the data set.

### **2.2 Management of Non-Detect Data**

Laboratory reporting limits have been established for each of the parameters monitored. The reporting limit, or practical quantitation limit (PQL), reflects a level of confidence that the parameter is detectable, and the analytical result is reliable at that concentration. If a parameter is not detected above the reporting limit or PQL, it can be reasonably assumed that the constituent is not present. Concentrations above the method detection limit but below the reporting limits or PQLs (J-values) are not considered in the statistical evaluations since there is a higher degree of uncertainty in those values.

### **2.3 Management of Anomalous Detections**

In cases when an anomalously high or low detection cannot be confirmed after resampling a well, the anomalous detection should be considered for removal from the dataset and should be replaced by the resampled concentration so that current conditions are not over- or under-estimated. This is an important step when estimating a baseline or background value to use to compare to future analyte concentrations from the GWMS. An anomalous detection may be identified at any point after analytical laboratory results are available, based on professional judgment or based on the outlier evaluation (see Section 3.4 for more details about testing for outliers). If an analytical result is removed, documentation will be provided in the annual report stating which analytical result was removed and justifying its removal.

### 3. STATISTICAL PROCEDURE

#### 3.1 Intrawell Analysis Using Control Charts

The CCR Rule provides several options for evaluating groundwater data [40 CFR §257.93(f) and 30 TAC §352.931]. Per the *Unified Guidance*, the preferred methods for comparing groundwater data are using either prediction limits or using control charts.

As discussed in Section 1.1, CBL-340I was initially utilized as a background monitoring well intended to provide a basis for comparison of each groundwater monitoring well's analyte concentrations using Interwell Prediction Limit Method statistical analysis (Amec Foster Wheeler, October 2017). As described in Section 1.2, subsequent evaluation of groundwater conditions following completion of the initial background assessment and initiation of detection monitoring led to the recognition of multiple geochemical facies within the Intermediate Sand groundwater, as documented (Amec Foster Wheeler, April 2018a). As such, CBL-340I is no longer considered appropriate as a background well, and the initial CBL SAP utilizing the Interwell Prediction Limit approach was revised to instead utilize the Intrawell Prediction Limit approach (Amec Foster Wheeler, April 2018b and April 2018c).

The Intrawell Prediction Limit statistical method is considered appropriate when natural spatial variation in groundwater conditions prevents a representative background well designation(s) for groundwater conditions downgradient of the CCR Unit. Intrawell analysis establishes background concentrations at each downgradient groundwater well location using a subset of sample data that reflects a baseline groundwater condition. Future sample data collected from the groundwater well are then compared to its respective baseline groundwater condition to assess if there is an SSI at that location.

Intrawell statistical evaluations assume that: (1) current groundwater conditions (e.g., baseline conditions) at the site are void of constituents leaking from a CCR unit and (2) baseline conditions are representative of natural temporal variations in groundwater quality. At this time, there is no substantial geologic, site operation, or hydrogeologic evidence to suggest these assumptions are invalid with respect to the CBL. It is recognized, however, that two years of sampling are likely inadequate to characterize natural seasonal variations and regional temporal trends in groundwater quality reliably. As such, baseline conditions require updating as sufficient data become available.

Initial baseline conditions were established using the eight initial groundwater samples from each downgradient monitoring well for each constituent in 40 CFR Part 257, Appendix III (detection monitoring parameters) and Appendix IV (assessment monitoring parameters).

In 2021, the SAP was revised to replace the Intrawell Prediction Limit with use of Intrawell Control Charts. The control chart procedure offers an advantage over the prediction limit procedure as more data are generated over time, because the control chart procedure generates a graph of compliance data over time and allows for better identification of long-term trends. This method revision to the GWMS has been certified (Bullock, Bennett & Associates, 2021).

The currently used semiannual groundwater monitoring program and use of the Intrawell Control Charts evaluation procedure meets the requirements of 40 CFR §§ 257.94(e) and (g).

### 3.2 Intrawell Analysis Using DUMPStat Statistical Program

The intrawell control chart method is now applied to the CBL groundwater analytical data using the DUMPStat® statistical program (DUMPStat, 2003). DUMPStat® is a program for the statistical analysis of groundwater monitoring data using methods described in *Statistical Methods for Groundwater Monitoring* (Gibbons, Bhaumik, and Aryal, 2009). Groundwater statistical analysis is presently conducted on the Appendix III detection monitoring parameters.

Intrawell statistics compare new measurements to the historical data at each groundwater monitoring well independently. The *Unified Guidance*-recommended technique for intrawell comparisons is the combined Shewhart-CUSUM control chart. This control chart procedure detects changes in analyte concentrations both in terms of constituent concentration and cumulative concentration increases. This method is also extremely sensitive to sudden and gradual releases. A requirement for constructing these control charts is that the parameter is detected at a frequency greater than or equal to 25%, otherwise the data variance is not properly defined (ASTM D 6312-98 *Standard Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs*). For this method, nondetects can be replaced with the reporting limit without serious consequence. Since reporting limits may vary over time due to the laboratory performing the testing or methodology changes, or sample matrix interferences, the median reporting limit is substituted for non-detects.

The combined Shewhart-CUSUM control chart assumes that the data are independent and normally distributed with a fixed mean and a constant variance. Independent data are much more critical than the normality assumption. To achieve independence, it is recommended that data are collected no more frequently than quarterly to account for seasonal variation. The combined Shewhart-CUSUM control chart is robust to deviations from normality. Because the control charts do not use a specific multiplier based on a normal distribution, it is more conservative to assume normality.

#### Non-detects

Some groundwater monitoring parameters are not detected at a frequency great enough to generate the combined Shewhart-CUSUM control charts. For constituents that are detected less than 25% of the time at a particular well, the data are plotted as a time series until a sufficient number of data points are available to provide a 99% confidence nonparametric prediction limit. Thirteen independent measurements (with 1 resample) are necessary to achieve a 99% confidence (1% false positive rate) nonparametric prediction limit. The nonparametric prediction limit is the largest determination out of the dataset collected for that well and parameter. If the detection frequency is 0% after thirteen samples have been collected, the reporting limit (PQL) becomes the nonparametric prediction limit. Based on the background evaluation conducted using 2016-2022 data, the one nonparametric prediction limit presently used is for the analyte boron, in monitoring well CBL-302I.

#### Control Chart Procedure

A minimum of eight rounds of data is recommended to establish an initial background concentration for each well and parameter. In cases where the detection frequency is  $\geq 25\%$ , a control limit can be calculated to which future data is compared. The control limit is simply



defined as:

$$\text{control limit} = (\text{control chart factor})(\text{standard deviation}) + \text{mean}$$

The control chart factor typically ranges from 4.5 to 6.5 for  $N < 12$  and from 4.0 to 6.5 for  $N \geq 12$ . A statistical power curve indicates the expected false assessments for the site as a whole. The statistical power is a function of the number of wells included, the number of constituents compared, the detection frequencies, and the data distributions involved. For intrawell comparisons, the recommended site-wide false positive rate is 5%. Evaluating and adjusting the factor to achieve false assessment objectives is done each time the background is established. Generally, the factor is lowered as background is updated to include more data points.

In addition to comparing the compliance data to background concentrations using a control chart, the Shewhart-CUSUM control chart used provides additional information. The CUSUM portions identifies cumulative increases over time as described in Chapter 20 of the *Unified Guidance*.

Compute the standardized concentration  $Z_i$  for each  $x_i$  after background:

$$Z_i = (x_i - \text{mean}) / \text{standard deviation}$$

use  $Z_i$  to compute the standardized CUSUM  $S_i$ . Set  $S_0 = 0$

$$S_i^* = \max [0, Z_i - k + S_{i-1}]$$

where in this case,  $k = 0.75$ .

The cumulative sum is expressed as:

$$S_i = S_i^* (\text{standard deviation}) + \text{mean}$$

The CUSUM portion of the control chart is compared to the same control limit as was established for the data concentration. The cumulative sum sequentially analyzes each new measurement with prior compliance data.

## Outliers

In developing the statistical background, the historical data must be thoroughly screened for anomalous data which may be due to sampling error, lab error, transcription error, shipping error, or chance alone. An erroneous data point, if not removed prior to the mean and variance computations, would yield a larger control limit thus increasing the false negative rate.

The DUMPStat® program evaluates extreme background values for data sets with at least 25% detections using Dixon's test. A detected background concentration is defined as an extreme value when a concentration is at least three times (or less than one-third) the median background concentration. DUMPStat® labels a detected background concentration as an outlier when it is defined as an extreme value and it fails Dixon's test. Note, the DUMPStat® program is equipped to handle much larger data sets than what is referenced in the Unified Guidance (Verma and Quiroz-Ruiz, 2006). Anomalous detected data identified by DUMPStat® as described above will still be plotted on the graphs (with a unique symbol) but will not be included in the background calculations. Additionally, data can be manually designated as an outlier if the statistician has a

justifiable reason. The outlier data, either statistically detected or manually selected, will be graphically displayed (with a unique symbol) but not included in background calculations.

Note, as the Unified Guidance (EPA, 2009) document indicates, Dixon's test should not be utilized for nonparametric data.

### **Resample Verification**

The verification resample plan is an integral function of the statistical plan to reduce the probability that anomalous data obtained after the background has been established are indicative of a landfill release. Should a control limit exceedance be identified, the resampling plan is implemented by the operator to collect a verification sample. If the resample data obtained confirm the control limit exceedance, the exceedance is considered statistically significant for parametric data. For non-parametric data, two sampling events are necessary to confirm the SSI.

The CBL resampling/retesting strategy is to allow for one resample for constituents evaluated using a parametric method, which applies to all wells and constituents, except for boron in monitoring well CBL-302I. Two resample events may be conducted for constituents evaluated using a nonparametric method, which applies to boron in CBL-302I. If the retesting strategy involves one resample, the initial exceedance is disconfirmed if the constituent concentration in the resample does not exceed the control limit/prediction limit. If the retesting strategy involves two resamples, the initial exceedance is disconfirmed if the constituent concentration in the first or second resample does not exceed the prediction limit (pass one of two resamples); if the first resample passes, the second resample does not need to be taken.

The resampling strategy will be periodically reevaluated and changed as necessary during a background update, which would include new sample results since the previous background evaluation and may include new wells or changes to the list of constituents monitored.

If an initial exceedance over a background limit is determined, the owner or operator may conduct verification resampling. The verification resampling results will confirm or disprove the initial exceedance. If an initial exceedance is verified, an SSI is declared, and assessment monitoring is triggered unless a successful ASD completed within 90 days of the determination of an SSI. If a verification resample does not confirm an exceedance, routine detection monitoring may continue.

Statistical background includes all data collected for that well and parameter during the background time period indicated. Resample verification data are an integral component of the statistical plan and are considered valid data points. In some cases, an errant data point is replaced with the resample data. In other situations, the resample data confirm the semi-annual data obtained. Unified Guidance §5.3.3 and the TCEQ guidance document, Guidelines for Updating Background Data Sets for Municipal Solid Waste Groundwater Monitoring, allow for inclusion of both routine monitoring data and resample verification data in future background sets.

### **Trend Testing**

The background data for each well and analyte are assessed for existing trends using Sen's nonparametric estimate of trend.

A significant trend is one in which the 99% lower confidence bound is greater than zero. In this way, even pre-existing trends in the background dataset will be detected. In large databases, very

gradual trends can be statistically significant; however, such trends should not preclude the use of intrawell comparisons.

### **Background Update**

Background will be updated periodically with data that are representative of background groundwater quality. The frequency that background should be updated is generally considered to be every four events (if semiannual) or every two years (*Unified Guidance*, Chapter 5.3). As groundwater monitoring at a facility proceeds, it is recommended to update background datasets periodically with valid detection monitoring results that are representative of background groundwater quality not affected by leakage from a monitored unit. The procedures used for a background update must be protective of human health and the environment and must comply with the statistical performance standards specified in 30 TAC §330.233(f) and (g). Failure to update background will exclude factors such as natural temporal variation, changes in field or laboratory methodologies, and changes in the water table due to meteorological conditions or other influences. Ongoing operations at a facility such as excavations or drainage control may affect the groundwater flow direction and water quality. An increase in the number of statistical failures, unrelated to the facility, is routinely observed for sites neglecting to update the statistical background with valid data points.

## 4. DETECTION MONITORING DATA EVALUATION

Detection monitoring will be performed using the CBL GWMS on a semiannual basis during the active life of the CBL unit and during the post-closure period. Each GWMS well will be sampled for the Appendix III analytes as part of the detection monitoring program. The Appendix III analytes are as follows:

- Boron
- Calcium
- Chloride
- Fluoride
- field-measured pH
- Sulfate
- Total Dissolved Solids (TDS)
- 

After every detection monitoring event, the analyte concentrations from each well will be compared to their respective Normal Control Limit or Nonparametric Prediction Limit, as applicable, to ascertain if an SSI exists. Possible outcomes from comparing the detection monitoring constituent concentrations in each well to their respective background values are as follows:

- All detection monitoring analyte concentrations in a GWMS well are less than or equal to their respective background Normal Control Limit or Nonparametric Prediction Limit; or
- One or more detection monitoring analyte concentrations in a GWMS well are above their respective background Normal Control Limit or Nonparametric Prediction Limit.

### 4.1 No Statistically Significant Increase over Background Values

Background values (Normal Control Limits and Nonparametric Prediction Limits) are based on a 1-of-2 resampling approach, meaning that if zero or one analyte concentration measurements from a series of two independent samples collected from a well do not exceed the appropriate background, then an SSI over background has not occurred. This conclusion will be reached if the data indicate either of the following:

- All detection monitoring analyte concentrations in a GWMS well are less than or equal to their respective background values; or
- At least one detection monitoring analyte concentration in a well is above its respective background value. If this occurs, the well or wells with analyte concentration(s) above the background value(s) will be resampled and analyzed for the detection monitoring analyte(s) with exceedances. If the resample indicates that the target detection monitoring analyte concentration(s) in the well or wells is/are less than or equal to their respective background value(s), then it can be concluded that an SSI over background for all detection monitoring analytes has not occurred, since concentrations in one sample of the two independent samples do not exceed the appropriate background value(s).

If the groundwater monitoring data indicate that an SSI over background has not occurred at the CCR wells, then detection monitoring at all CCR wells will continue on a semi-annual basis.

#### **4.2 Statistically Significant Increase over Background Values**

If one or more detection monitoring analyte concentration(s) in any well is/are above their respective background value in both the original detection monitoring sample and the resample, then an SSI over background for the target detection monitoring analyte can be concluded. If an SSI is indicated, within 90 days LCRA will:

- Establish an assessment monitoring program as described in this plan, or
- Demonstrate that a source other than the CCR unit caused the SSI over the background value for an analyte, or that the SSI resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. If a successful ASD is completed within the 90-day period, LCRA will continue with the detection monitoring program.

## 5. ASSESSMENT MONITORING DATA EVALUATION

Assessment monitoring will be conducted using the CBL GWMS should an SSI over background values be confirmed for one or more Appendix III constituent(s), assuming an ASD was unsuccessful in identifying a source other than a release from the CBL. Within 90 days of triggering the assessment monitoring program, and annually thereafter, each CCR monitoring well will be sampled for the Appendix IV analytes as part of the assessment monitoring program. The Appendix IV analytes are as follows:

- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Fluoride
- Lead
- Lithium
- Mercury
- Molybdenum
- Selenium
- Thallium
- Radium 226 and 228 combined

Within 90 days of obtaining the results from the initial assessment monitoring sampling event, all wells in the CBL GWMS will be resampled and analyzed for:

- All Appendix III detection monitoring parameters; and
- The Appendix IV assessment monitoring parameters that were detected as part of the assessment monitoring event.

This assessment monitoring will be performed on at least an annual basis thereafter, unless LCRA can demonstrate the need for an alternative monitoring frequency for repeated sampling and analysis for these analytes during the active life and the post-closure care period based on the availability of groundwater.

Within 90 days of obtaining the results from the initial assessment monitoring sampling event, a GWPS will be established for each of the Appendix IV assessment monitoring analyte that were detected in the groundwater monitoring system wells as follows:

- For constituents for which a Maximum Contaminant Level (MCL) has been established, the highest of the MCL, Upper Prediction Limit (UPL), and reporting limit for that constituent; or
- For constituents for which an MCL has not been established, the higher of the UPL, reporting limit, or levels that are equivalent to specified regional screening level (RSL) for that analyte (note: future revisions to the CCR Rule may allow additional flexibility in

establishing GWPS for states with EPA-approved CCR permit programs for Appendix IV analytes that do not have an MCL).

Each assessment monitoring analyte will be evaluated to ascertain if an SSI above the GWPS exists. Possible outcomes are as follows:

- All averages from assessment monitoring analyte concentrations at a well are not statistically greater than to their respective GWPS; or
- One or more averages from assessment monitoring constituent concentrations at a well are statistically greater than their respective GWPS.

## 6. REPORTING REQUIREMENTS

The results of the CBL groundwater monitoring program performed will be reported yearly in an Annual Groundwater Monitoring and Corrective Action Report. The annual report will document the status of the groundwater monitoring and corrective action programs, summarize key actions completed, describe any problems encountered, discuss actions to resolve the problems, and will project key activities for the upcoming year. At a minimum, the Annual Groundwater Monitoring and Corrective Action Report will contain the following information:

- A map, aerial image, or diagram showing the CCR unit and all background (or upgradient) and downgradient monitoring wells, to include the well identification numbers, that are part of the groundwater monitoring program for the CCR unit;
- Identification of any monitoring wells that were installed or decommissioned during the preceding year, along with a narrative description of why those actions were taken;
- In addition to all the monitoring data obtained under the CCR Rule (40 CFR §§ 257.90 through 257.98), a summary including the number of groundwater samples that were collected for analysis for each background and downgradient well, the dates the samples were collected, and whether the sample was required by the detection monitoring or assessment monitoring program, as well as the basis for the background values and the statistical methods employed to establish the background values;
- A narrative discussion of any transition between monitoring programs (e.g., the date and circumstances for transitioning from detection monitoring to assessment monitoring in addition to identifying the constituent(s) detected at a SSI over background levels); and
- Other information required to be included in the annual report as specified in CCR Rule (40 CFR §§257.90 through 257.98).

The Groundwater Monitoring and Corrective Action Report for the previous calendar year's monitoring program must be placed in the facility operating record no later than January 31. The reports must also be posted to the owner or operator's CCR Rule Compliance Data and Information internet site within 30 days of placing the reports in the operating record.



## 7. REFERENCES

- Amec Foster Wheeler (October 2017): *Groundwater Sampling and Analysis Program, Selection of Statistical Method Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- Amec Foster Wheeler (April 2018a): *Groundwater Geochemical Evaluation at the Lower Colorado River Authority, Fayette Power Project, La Grange, Texas.*
- Amec Foster Wheeler (April 2018b): *Groundwater Monitoring System, Certification of Alternate Source Demonstration, Lower Colorado River Authority, Coal Combustion Residuals Unit: Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- Amec Foster Wheeler (April 2018c): *Groundwater Monitoring System Addendum Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- Bullock, Bennett & Associates (May 2021): *Groundwater Monitoring System Addendum Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas.*
- DUMPStat (2003) DUMPStat Statistical Guide, version 2.1.8., by Robert D. Gibbons Ltd., with accompanying DUMPStat 2.3 Release Notes.
- EPA (2009): *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (EPA 530/R-09-007).
- Gibbons, Bhaumik, and Aryal (2009): *Statistical Methods for Groundwater Monitoring, 2<sup>nd</sup> Edition*, 400 pages.
- Verma and Quiroz-Ruiz (2006): *Critical Values for Six Dixon's Tests for Outliers in Normal Samples up to Sizes 100, and Applications in Science and Engineering*, Revista Mexicana de Ciencias Geologicas, v. 23, num. 2, p. 133-161.

## **Attachment A**

### **DUMPStat 2.1.8 Statistical Guide**

An abstract background image featuring a swirling, marbled pattern in shades of blue and green, resembling water or a microscopic view of a fluid.

# DUMPStat 2.1.8

groundwater detection monitoring statistics

**STATISTICAL GUIDE**

# DUMPStat

---

## Statistical Guide

Version 2.1.8

Information in this document is subject to change without notice. Companies, names, and data used in examples herein are fictitious unless otherwise noted. No part of this document may be reproduced or transmitted, in whole or in part, in any form, or by any means, electronic or mechanical, for any purpose, without the express written permission of Robert D. Gibbons Ltd.

Copyright © 2003 Robert D. Gibbons Ltd. and Discerning Systems Inc. All rights reserved. DUMP-Stat is a trademark of Robert D. Gibbons Ltd. in the USA and other countries. Other brand and product names are trademarks or registered trademarks of their respective companies.

The information contained in this document represents the current views of Robert D. Gibbons Ltd. with respect to the subject matter and statistical methods and is provided solely for informational purposes. Robert D. Gibbons Ltd. MAKES NO WARRANTIES, EXPRESS OR IMPLIED, IN THIS DOCUMENT AND SHALL NOT BE LIABLE FOR ANY USE OF SUCH INFORMATION BY THE RECIPIENT.

# contents

---

<b>Chapter 1 Introduction</b>	<b>1</b>
Detection Monitoring .....	2
Upgradient versus Downgradient Comparisons .....	2
Intra-Well Comparisons .....	4
Verification Resampling .....	5
False Positive and False Negative Rates .....	6
Use of DLs and QLs in Groundwater Monitoring .....	6
Assessment or Corrective Action Monitoring .....	7
Comparison to Background .....	7
Comparison to a Standard .....	8
Air and Surface Water Monitoring .....	8
Implementation .....	10
<b>Chapter 2 Commonly Asked Questions</b>	<b>11</b>
<b>Chapter 3 Technical Details</b>	<b>21</b>
Upgradient versus Downgradient Comparisons .....	21
Compounds Quantified in All Background Samples .....	22
Compounds Quantified in at Least 50% of All Background Samples .....	23
Compounds Quantified in Less Than 50% of All Background Samples .....	24
Intra-Well Comparisons .....	28
Assumptions .....	28
Nondetects .....	28
Procedure .....	29
Outliers .....	32

---

Existing Trends .....	33
A Note on Verification Sampling .....	33
Updating the Control Chart .....	34
An Alternative Based on Prediction Limits .....	35
Comparison to a Standard .....	35
<b><i>Chapter 4 Methods to be Avoided</i></b> .....	<b>37</b>
Analysis of Variance—ANOVA .....	37
Cochran's Approximation to the Behrens Fisher t-test .....	41
Control of False Positive Rate by Constituent .....	43
Restriction of Background Samples .....	44
REFERENCES .....	47
INDEX .....	51

# Introduction

# 1

In this document, a statistical plan is described that includes an effective verification resampling plan, and selection of appropriate statistical methods (*e.g.*, parametric and nonparametric prediction limits, or control charts for intra-well comparison) that detect contamination when it is present and do not falsely conclude that the site is contaminated. Statistical significance of differences in groundwater quality cannot be properly determined without verification resampling. It is noted from the information presented herein that the final statistical detection monitoring plan cannot be fully specified until background samples for the required list of indicator constituents are available. In general, it is unwise to perform statistical computations on any fewer than eight background samples. This may be four quarterly samples in each of two upgradient wells, or eight samples taken in each well where intra-well comparisons are to be performed. To take any fewer samples will lead to high false negative rates due to the large size of the prediction limit (*i.e.*, with four samples and three degrees of freedom, the uncertainty in the true mean and standard deviation ( $\mu$  and  $\sigma$ ) given the sample based estimates ( $\bar{x}$  and  $s$ ) is enormous, resulting in extremely high prediction limits). Conversely, with only a few background measurements, our knowledge of the true sampling variability, distributional form and detection frequency may be completely inaccurate leading to a high false positive rate.

## Intra-well comparisons

Yet another major concern is whether the upgradient wells accurately characterize the natural spatial variability that is observed in the downgradient wells. The alternative is to



perform intra-well comparisons, which are generally preferable; however, we must first demonstrate that the well has not been impacted by the site.

It is noted that when justified, intra-well comparisons are generally more powerful than their inter-well counterparts because they completely eliminate the spatial component of variability. Due to the absence of spatial variability, the uncertainty in measured concentrations is decreased, making intra-well comparisons more sensitive to real releases (*i.e.*, fewer false negative results); and false positive results due to spatial variability are completely eliminated.

The following provides an outline of the general statistical procedure for groundwater monitoring implemented in the DUMPStat program. The references are to the USEPA Subtitle D regulation and associated guidance. Further technical details regarding the specific statistical methods used in DUMPStat are available in Chapter 3, Technical Details page 21 and in Gibbons (1994 and 1996). The DUMPStat algorithm forms the basis for the new ASTM Standard D6312-98.

## Detection Monitoring

### Upgradient versus Downgradient Comparisons

50-100% background  
detection frequency

1. Background detection frequency greater than 50%:
  - ▶ If normal, compute normal prediction limit (40CFR 258.53(h)(4))<sup>1</sup>, selecting false positive rate based on number of wells, constituents and verification resamples (40CFR 258.53(h)(2)), adjusting estimates of the sample mean and variance for nondetects.
  - ▶ If lognormal, compute a lognormal prediction limit (40CFR 258.53(h)(1)).

---

1. 40CFR Part 258 refers to USEPA Subtitle D regulations.

- Statistical Guide 3

## Intra-Well Comparisons

1. For those facilities that meet any of the following conditions, compute intra-well comparisons using combined Shewhart-CUSUM control charts (40CFR 258.53(h)(3))
  - ▶ if there is no definable gradient,
  - ▶ if there is no existing contamination,
  - ▶ if there are too few upgradient wells to meaningfully characterize spatial variability (*e.g.*, a site with one upgradient well or a facility in which upgradient water quality is not representative of downgradient water quality),
  - ▶ to satisfy specific hydrogeology criteria (*e.g.*, slow moving groundwater zones, no access to upgradient groundwater, in appropriate groundwater migration pathways) as defined by a groundwater professional.
2. For those wells and constituents that fail upgradient versus downgradient comparisons, compute combined Shewhart-CUSUM control charts. If no Volatile Organic Compounds (VOCs) or hazardous metals are detected and no trend is detected in other indicator constituents, use intra-well comparisons for detection monitoring of those wells and constituents.
3. If data are all nondetects after 13 quarterly sampling events, use the QL as statistical decision limit (40CFR 258.53(h)(5)). Thirteen samples provides a 99% confidence nonparametric prediction limit with one resample (40CFR 258.53(h)(1)) and USEPA 1992 section 5.2.3. Note that 99% confidence is equivalent to a 1% false positive rate and pertains to a single comparison (*i.e.*, one well and constituent). With Pass 1 of 2 verification resamples only eight background samples are required for 99% confidence. With Pass 2 of 2 resamples, 18 background samples are required for 99% confidence.
4. If the detection frequency is greater than zero (*i.e.*, the constituent is detected in at least one background sample) but

less than 25% set the control limit to the largest of at least 8, 13, or 18 background samples, depending on the verification resampling plan.

5. As an alternative to 3 and 4 compute a Poisson prediction limit following collection of a minimum of four background samples (USEPA 1992 section 2.2.4). Since the mean and variance of the Poisson distribution are the same, the Poisson prediction limit is defined even if there is no variability (*e.g.*, even if the constituent is never detected in background.) In this case, the reporting limits are used in place of the measurements and the Poisson prediction limit can be computed directly. Note that the Poisson prediction limits are not invariant with respect to changes in scale (*i.e.*, you get different results if data are in ppb vs. ppm). As such, DUMPStat transforms the data to a scale in which the measurements are greater than one, computes the prediction limit, and then transforms back to the original scale.

## Verification Resampling

- Verification resampling is an integral part of the statistical methodology (USEPA 1992 section 5).
- Without verification resampling much larger prediction limits would be required to obtain a site-wide false positive rate of 5%. The resulting false negative rate would be dramatically increased.
- Verification resampling allows sequential application of a much smaller prediction limit, therefore minimizing both false positive and false negative rates.
- A statistically significant exceedance is not declared and should not be reported until the results of the verification resample are known. The probability of an initial exceedance is much higher than 5% for the site as a whole.
- Note that requiring passage of two verification resamples (*e.g.*, in the state of California regulation) will generally lead to higher false negative rates because larger prediction lim-

its are required to achieve a site-wide false positive rate of 5% than for a single verification resample; hence, the preferred methods are passage of one verification resample, or, passage of one of two verification resamples. Also note that for nonparametric limits, requiring passage of two verification resamples may result in need for a larger number of background samples than are typically available (see Gibbons, 1994).

### False Positive and False Negative Rates

1. DUMPStat automatically conducts a simulation study based on current monitoring network, constituents, detection frequencies, and distributional form of each monitoring constituent (USEPA 1992 Appendix B).
2. DUMPStat then projects the frequency of false assessments for the site as a whole, for each monitoring event based on the results of the simulation study.
3. As a general guideline, we require a site-wide false positive rate of 5% (*i.e.*, when the true difference is zero) and a false negative rate of approximately 5% for differences on the order of 3 to 4 standard deviation units (see USEPA 1992 Appendix B). Note that following USEPA we simulate the most conservative case of a release that effects a single constituent in a single downgradient well. In practice, multiple constituents in multiple wells will be impacted; therefore, the actual false negative rates will be considerably smaller than estimates obtained via simulation.

### Use of DLs and QLs in Groundwater Monitoring

- ▶ Detection Limits (DLs) indicate that the analyte is present in the sample with confidence.
- ▶ Quantification Limits (QLs) indicate that the true quantitative value of the analyte is close to the measured value.

- ▶ For analytes with estimated concentration exceeding the DL but not the QL, it can only be concluded that the true concentration is greater than zero - there is no way of knowing the actual concentration with reasonable certainty.
- ▶ If the laboratory-specific DL for a given compound is 3 µg/l, and the QL for the same compound is 6 µg/l, then a detection of that compound at 4 µg/l could actually represent a true concentration of anywhere between 0 and 6 µg/l. The true concentration may well be less than the DL (see Currie 1968, Hubaux and Vos, 1970 and Gibbons 1994).
- ▶ Comparison of such a value to a Maximum Contaminant Level (MCL), or any other concentration limit, is generally not meaningful unless the concentration is larger than the QL.
- ▶ Verification resampling applies to this case as well.

## Assessment or Corrective Action Monitoring

### Comparison to Background

1. Define background for any Appendix II compounds detected (*i.e.*, a minimum of four background samples 40CFR 258.55(b)).
2. Compute the appropriate prediction limit based on distributional tests and detection frequency as previously described, based on upgradient data or historical data from each well (40CFR 258.55(e)).
3. Compare any Appendix II constituent concentrations found to the background prediction limit. If all values are below the prediction limit for two consecutive sampling events return to detection monitoring (40CFR 258.55(e)).
4. In Corrective Action (required if background is exceeded) use same statistic until background is achieved for three years (40CFR 258.58(e)(2)) or for the time period specified

in the site permit or state regulation. Use Sen's test to evaluate trends (declining) to demonstrate effectiveness of corrective action.

## Comparison to a Standard

- ▶ If an MCL or Alternate Concentration Limit (ACL) is used, and the ACL or MCL is greater than the background prediction limit, then new concentrations in the assessment or corrective action wells should be compared to the standard (*i.e.*, ACL or MCL) using the 95% normal confidence limit computed from the last four independent samples (USEPA 1992).
- ▶ For assessment monitoring, use a 95% LCL (lower confidence limit) to demonstrate that the onsite mean concentration does not exceed the standard. For corrective action monitoring, use a 95% UCL (upper confidence limit) to demonstrate that the onsite mean concentration is now below the standard. DUMPStat will compute normal LCLs and UCLs for the mean of a single monitoring well. For alternative distributional forms, site-wide analyses and other media, use CARStat.<sup>2</sup>
- ▶ In the case of anthropogenic compounds such as VOCs, if the standard is less than the QL, then the standard becomes the QL, since no smaller value can be quantified.
- ▶ Use Sen's test to evaluate trends (both increasing and decreasing) to demonstrate the effectiveness of corrective action.

## Air and Surface Water Monitoring

### Background conditions

The purpose of air and/or surface water monitoring programs at waste disposal facilities is to determine if a site is impacting

---

2. Contact Discerning Systems for information on CARStat.

background air and/or surface water quality levels through release of waste. Factoring critically in air and surface water monitoring programs, background does not necessarily represent pristine conditions but rather the combination of natural background conditions, plus the contribution of a myriad of industrial and other influences as well. As such, background air and surface water quality is a dynamic phenomenon, levels of which may vary dramatically from day to day, season to season, and year to year.

#### Paired comparisons

Based on these considerations, the primary experimental sampling strategy for evaluating air and surface water quality involves paired comparisons (*i.e.*, taken at the same time) of upwind and downwind air quality samples and upstream and downstream water quality samples. In general, an overall comparison of upwind and downwind or upstream and downstream measurements that were collected on different occasions will be of limited value. Furthermore, the ambient concentrations of air and surface water quality monitoring constituents can vary tremendously over sampling events; therefore, it seems unlikely that a parametric statistical method will be justified in this context.

#### Perform appropriate test

To begin, a minimum of one pair of upstream/downstream or upwind/downwind monitoring stations should be sampled on a regular basis until a minimum of 8 paired samples are available. A widely used nonparametric test for the comparison of related samples (*e.g.*, paired comparisons of upstream and downstream samples) is the Wilcoxon Matched-Pairs Signed-Ranks test (Wilcoxon, F. 1945). Relative to the parametric alternative (*i.e.*, the paired t-statistic), Mood has shown that the Wilcoxon test has 95.5% asymptotic efficiency and near 95% efficiency for small samples of the size proposed here (Mood, A.M. 1954). This means that the Wilcoxon test will have 95% of the power of a paired t-statistic when the data do in fact arise from a normal distribution. Of course, we cannot assume normality here, since these data are typically riddled with nondetects and when



detected, frequently exhibit lognormality or worse. As such, we pay a very small price for the needed generality of this statistical procedure.

#### Estimate average concentration

Once a statistically significant difference is recorded, we must estimate the average concentration of that particular constituent at both upstream and downstream or upwind and downwind sampling points so that the difference between average downstream and upstream water quality can be determined. DUMPStat automatically computes 95% Upper Confidence Limits, (UCL) for both upstream/downstream and/or upwind/downwind locations.

Finally, DUMPStat also automatically tests for trend in both upstream/downstream and/or upwind/downwind monitoring locations using Sen's test.

## Implementation

- ▶ DUMPStat implements your detection monitoring plan by encompassing all aspects of the previously presented statistical decision tree.
- ▶ DUMPStat automatically selects statistical methods based on the decision tree and all wells and analytes will be input as a complete file and analyzed on the basis of a single instruction.
- ▶ Once DUMPStat is configured, no further statistical decisions, choices or selections should be made so that it can be run by someone with or without adequate statistical background to make these decisions.
- ▶ DUMPStat has a graphical user interface that allows you to specify the format of each new data file, and add those data to your existing database rather than requiring a complete new database each quarter.

# Commonly Asked Questions

## 2

### **Do I have to take four independent samples from down-gradient wells per semi-annual monitoring event?**

The requirement for four semi-annual samples is for ANOVA only. All other methods require a single semi-annual sample once the background is established.

### **Over what period of time can I take my background samples?**

A minimum of eight background samples must be taken for prediction limits, tolerance limits, and control charts. The samples must be independent and representative of seasonal and spatial variability at the site. Spatial and seasonal variability apply to naturally occurring constituents only (e.g., inorganics). Spatial variability is addressed by either using intra-well comparisons and/or having multiple upgradient wells. Seasonal variability is addressed by collecting samples over a period of time that includes the seasons at which downgradient samples will be collected. For this reason, the eight background samples should be collected over a period of no less than one year, and preferably over a two year period in which a constant sampling interval is used (e.g., quarterly sampling over a two year period for intra-well comparisons, and quarterly sampling over a one year period from at least two upgradient wells for inter-well comparisons). However, all samples required to establish background should be collected prior to the date of statistical comparison as required by the regulations.

### **What can I do if I have only one upgradient well?**

With only one upgradient well, spatial variability and potential contamination are completely confounded (*i.e.*, you can't tell one from the other). To perform upgradient versus downgradient comparisons and consider spatial variability you need a minimum of two upgradient wells.

### **If I am using intra-well comparisons should I continue to monitor the upgradient well(s)?**

Yes. It is always wise to perform intra-well comparisons on both upgradient and downgradient wells. If an exceedance is seen in both upgradient and downgradient wells, it is usually good evidence that the potential impact is not from the site. Any data which help in evaluating off-site and/or seasonal, regional and climactic changes should be collected and investigated.

### **What is the difference between tolerance limits and prediction limits?**

Tolerance limits provide coverage of a percentage of the total distribution of measurements (*e.g.*, 95%) with a certain degree of confidence (*e.g.*, 95%). Prediction limits provide coverage of 100% of the next  $k$  measurements with a given level of confidence (*e.g.*, 95%). With 95% coverage, tolerance limits should be exceeded by 5% of the measurements with 95% confidence whereas prediction limits should fail for none of the next  $k$  measurements with 95% confidence.

### **When are nonparametric prediction limits appropriate?**

Nonparametric prediction limits are optimal in the sense that they make no assumptions regarding the specific form of the underlying distribution. However, as the number of wells and constituents increase, large numbers of background measurements are required in order to have reasonable confidence (*e.g.*, 16 or more). When the site-wide confidence level is poor (*i.e.*, lower than 90%) alternatives based on Poisson prediction limits are often useful. Poisson prediction limits can

---

be used regardless of detection frequency and their associated level of confidence is independent of number of background measurements. Note that Poisson prediction limits are approximate in that many constituents will not have a Poisson distribution. For this reason, Poisson prediction limits should only be used when statistical power analysis reveals that there is an insufficient number of background measurements to justify the nonparametric approach. In addition, Poisson prediction limits should only be used with constituents with detection frequencies of less than 50% whereas nonparametric prediction limits are valid regardless of detection frequency.

**I don't want nonparametric limits, but DUMPStat automatically uses them when the data are neither normally nor lognormally distributed—what can I do?**

In the DUMPStat statistical options, the "Rare Event Statistics" setting can be used to override the choice of nonparametric limits, even for events with high detection frequencies. (When "Poisson" is selected, you will never get a nonparametric limit.) When computing a prediction limit, if the detection frequency is insufficient to compute a parametric limit (a "Rare event"), you will either get a nonparametric limit or a Poisson limit, depending on the "Rare Event Statistics" setting in your statistical options. For inter-well comparisons, if the detection frequency is sufficient to compute a parametric limit, the background data are tested for normality.

- ▶ If they pass this test, you will get a normal limit.
- ▶ If they fail, the data are tested for lognormality.
- ▶ If they pass the lognormal test, you will get a lognormal limit.
- ▶ If they fail both tests, then the "Rare events" setting is checked, even though the detection frequency is high.
  - ▶ If "Nonparametric" is selected you will get a nonparametric limit

- If "Poisson" is selected, you will get a normal limit even though the data failed the normality test.

### How do control charts deal with multiple comparisons?

As described, combined Shewhart-CUSUM control charts do not explicitly adjust for multiple comparisons. The effects of verification resampling and increasing number of comparisons produced by multiple wells and constituents generally balance the site-wide false positive and false negative rates at reasonable levels; however, there is no statistical guarantee that they will. Please note that when using control charts it is particularly important to determine site-wide false positive and false negative rates via simulation. Certain states (*e.g.*, California) require that you select the control chart factor based on generating a 5% site-wide false positive rate. DUMPStat allows the user to input the factor in the Statistical Options item of the Settings Menu and the Intra-well Control Chart. Power Analysis can be used to determine the site-wide false positive rate for varying choices of the control chart factor<sup>1</sup>.

### When can I use intra-well comparisons?

Intra-well comparisons should **always** be used when predisposal data are available. When no data prior to disposal of waste are available, then the owner/operator must provide empirical justification that use of intra-well comparisons will not mask existing contamination at the facility. One good approach is to show that constituents of concern (*e.g.*, VOCs) are not present in the wells and that naturally occurring constituents show no evidence of increasing trend (*e.g.*, using Sen's test).

---

1. See Gibbons, 1999, "Use of combined Shewhart-CUSUM control charts for groundwater monitoring applications." *Groundwater*. vol. 37 (5), pp. 682-691.

---

### **How do I adjust for seasonal variability?**

In general, you can't adjust for seasonal variability because you typically do not have enough samples in each season to provide a reliable estimate of the effect. This is not a big problem because seasonal variability is incorporated into the usual estimate of the background standard deviation, even if it is not explicitly modeled as a separate variance component. Gibbons (1994) and Gilbert (1987) provide methods for seasonally adjusted trend estimators and this topic is also discussed in the new ASTM guidance D6312-98. Note that sample collection over a 12 month period is generally sufficient to incorporate seasonal variability into the background standard deviation.

### **Should I ever use ANOVA?**

ANOVA is an extremely useful statistical tool for designed experiments with random sampling. Unfortunately, groundwater monitoring data do not enjoy such luxuries. Spatial variability becomes confounded with upgradient versus downgradient comparisons; and in general, ANOVA can be more sensitive to spatial variability (*i.e.*, small but consistent differences) than a real release (*i.e.*, a large but highly variable increase). The reason is that ANOVA compares between-well variability to within-well variability. In the absence of contamination, within-well variability is a combination of temporal variability and analytic variability whereas between-well variability is due to spatial variability. Since spatial variability is invariably large relative to the combination of temporal and analytic variability, the ANOVA will conclude that the ratio of between-well variability to within-well variability is significantly larger than zero. Of course, the assumption of ANOVA is that under the null hypothesis (*i.e.*, no contamination) all wells are drawn from the same distribution with the same population mean. This assumption is justifiable under random sampling. However, this assumption is not justified in natural systems in which initial conditions are already different, for example due to natural spatial variability. One good application of ANOVA is in

testing whether or not the amount of spatial variability is statistically significant. Here we simply restrict the analysis to the upgradient or background wells (which could not be affected by a release from the site) and if a significant F-statistic results then we can conclude that there is significant spatial variability. However, even in the absence of a significant ANOVA, spatial variability may still be appreciable but simply not present in the small number of available upgradient or background wells.

### **Does nonparametric ANOVA correct the limitations of its parametric counterpart?**

The only difference between nonparametric and parametric ANOVA is that the nonparametric ANOVA does not assume a specific distributional form for the concentration measurements whereas the parametric ANOVA assumes normality. Both models assume independence of the measurements and homogeneity of variance and both models are severely compromised by spatial variability.

### **Should I use MDLs or PQLs for statistical analysis?**

The detection limit is used to determine if an analyte is present in a sample and the quantification limit is used to make a quantitative determination of the amount of the analyte in the sample. USEPA has used the terms MDL (method detection limit) and PQL (practical quantitation limit) to describe two specific approaches of estimating the detection and quantification limits respectively. If we are comparing a concentration directly to a standard then it must be greater than the quantification limit in order to provide a reliable estimate of whether or not the standard has actually been exceeded. If all that we care about is whether or not the analyte is present or absent in the sample, then measurements above the detection limit will provide that information. Measurements above the quantification limit can be used directly in the previously described statistical methods; however, measurements below the quantification limit are considered to be censored and the

---

appropriate adjustments for censored data should be used. DUMPStat uses Aitchison's method to adjust for nondetects in computing normal and lognormal prediction limits. No statistical adjustment is required for nonparametric or Poisson prediction limits. The primary advantage of Aitchison's method over other alternatives (*e.g.*, Cohen's method) is that it can accommodate varying reporting limits which are quite common in practice.

### **What should I do for VOCs?**

VOCs are not naturally occurring and therefore they should not be found in background groundwater samples. For VOCs, verified exceedance of the appropriate quantification limit is an indication of a significant exceedance. Do not apply the previously described statistical methods to VOCs unless you are doing assessment or corrective action monitoring and are attempting to determine if a known release of these compounds is getting better or worse or exceeds a standard. Alternatively, if VOCs are detected in upgradient wells due to an offsite source, statistical comparison (*i.e.*, up vs. down) may be appropriate.

### **Are different methods required for comparison to ACLs and MCLs?**

When comparing measurements to a standard, the same approach is used (*e.g.*, a 95% confidence limit for the mean of the last four measurements) regardless of how the standard was derived. In assessment monitoring we use the LCL, and in corrective action monitoring we use the UCL.

### **When computing tests of normality and lognormality, what data should be used?**

Tests of distributional form should only be performed on background data or data that are known with certainty not to be influenced by the facility. This would typically exclude use of downgradient data.



**If I have constituents with detection frequencies less than 25% for intra-well or less than 50% for inter-well comparisons, do I have to wait until I have a minimum of 13 background samples before I begin computing statistics?**

No. For inter-well comparisons, remember that the number of background samples is pooled over all upgradient wells, so with eight samples in each of two wells you have 16 background samples. For intra-well comparisons 13 background samples are required for a nonparametric prediction limit with one verification resample, but only eight background samples are required with two verification resamples (*i.e.*, fail the first and pass either one of two verification resamples). Alternatively, Poisson prediction limits can be used with as few as four background samples regardless of detection frequency.

**Do I have to conduct a statistical analysis if VOCs are detected only in the downgradient wells?**

Verified quantification of VOCs in a downgradient well is a statistical exceedance in and of itself. No statistical comparisons are required.

**What is the minimum background sample size required to compute detection monitoring statistics?**

A minimum of eight background samples (*e.g.*, eight samples in each well for intra-well comparisons or four samples in each of two upgradient wells for inter-well comparisons) are required for a meaningful statistical evaluation.

**Do I need to compute statistics when all of the background data are below the MDL/PQL/LOQ?**

The LOQ and PQL are both quantification limit estimates whereas the MDL is an estimate of a detection limit. For statistical purposes, the smallest measured concentration is the quantification limit (*e.g.*, PQL or LOQ) therefore if all values in the upgradient wells are nonquantifiable, the prediction limit becomes the QL. Our level of confidence in this decision rule is

---

based on the number of background measurements, the number of comparisons and the verification resampling strategy. If we have a small background sample size (*e.g.*, the minimum of eight background measurements) and nothing is detected, there is still appreciable probability that the true detection frequency is greater than zero. Since there are typically far more downgradient wells than upgradient wells, we will have a greater chance of detecting the constituent in a downgradient well, therefore giving the appearance of a potential release. For this reason, even when nothing is detected in background, confidence levels associated with using the QL as the nonparametric prediction limit should be determined. Note that this does not apply to VOCs which should not be detected in clean background wells with any frequency.

**Do I need to compute statistics when all of the downgradient data are below the MDL/PQL/LOQ?**

Statistical computations are based on background data only. The fact that a constituent has never been detected and/or quantified in a downgradient well is irrelevant to the statistical analysis; however, it may indicate that the constituent adds little to the monitoring program and should be eliminated from the suite of constituents used for statistical analysis.



# Technical Details

# 3

The purpose of this section is to provide a description of the specific statistical methods used in DUMPStat. Please note, however, that specific recommendations for any given facility require an interdisciplinary site-specific study that encompasses knowledge of the facility, its hydrogeology, geochemistry, and study of the false positive and false negative error rates that will result. In general, the appropriate statistical methods are available in DUMPStat; however, the program must be properly configured for each site to insure that the methods are properly implemented. Performing a correct statistical analysis, such as nonparametric prediction limits, in the wrong situation (*e.g.*, when there are too few background measurements) can lead to disaster. It is for this reason that DUMPStat's simulation capabilities are so important. In the following, the general DUMPStat algorithm is described.

## Upgradient versus Downgradient Comparisons

For those wells and constituents that show similar variability in upgradient and downgradient monitoring zones, inter-well comparisons can be performed by computing limits based on historical upgradient data to which individual new downgradient monitoring measurements can be compared. In the following, the decision rules by which various prediction limits can be computed is outlined. The decision points are based on detection frequency and distributional form of the upgradient data.

## Compounds Quantified in All Background Samples

1. Test normality of distribution using the multiple group version of the Shapiro-Wilk test (Wilk and Shapiro, 1968) applied to  $n$  background measurements. The multiple group version of the original Shapiro-Wilk test (Shapiro and Wilk, 1965) takes into consideration that upgradient measurements are nested within different upgradient monitoring wells, hence the original Shapiro-Wilk test does not apply (USEPA, 1992 section 1.1.4), unless the mean difference between the wells have already been removed.
2. If normality is not rejected, compute the 95% prediction limit as:

$$\bar{x} + t_{n-(1, \alpha)} s \sqrt{1 + \frac{1}{n}}$$

$$\text{where } \bar{x} = \sum_{i=1}^n \frac{x_i}{n}, \quad s = \sqrt{\sum_{i=1}^n \frac{(x_i - \bar{x})^2}{n-1}},$$

$\alpha$  is the false positive rate for an individual test,  $t_{[n-1, \alpha]}$  is the one-sided  $(1-\alpha)100\%$  point of Student's  $t$  distribution on  $n-1$  degrees of freedom, and  $n$  is the number of background measurements.

3. Select  $\alpha$  as the minimum of 0.01 or one of the following:
  - a. Pass the first or one of one verification resample

$$\alpha = \sqrt{1 - 0.95^{1/k}}$$

- b. Pass the first or one of two verification resample

$$\alpha = \sqrt[3]{1 - 0.95^{1/k}}$$

- c. Pass the first or two of two verification resample

$$\alpha = \sqrt{1 - 0.95^{1/k}} \sqrt{1/2}$$

where  $k$  is the number of comparisons (*i.e.*, monitoring

wells times constituents—see USEPA 1992 section 5.2.2).

4. If normality is rejected, take natural logarithms of the  $n$  background measurements and recompute the multiple group Shapiro-Wilk test.
5. If the transformation results in a nonsignificant  $G$  statistic (*i.e.*, the values  $\log_e(x)$  are normally distributed—see USEPA 1992 section 1.1), compute the lognormal prediction limit as:

$$\exp\left(\bar{y} + t_{[n-(1, \alpha)]} s_y \sqrt{1 + \frac{1}{n}}\right)$$

where

$$\bar{y} = \sum_{i=1}^n \frac{\log_e(x_i)}{n} \quad \text{and} \quad s_y = \sqrt{\sum_{i=1}^n \frac{(\log_e(x_i) - \bar{y})^2}{n-1}}.$$

If log transformation does not bring about normality (*i.e.*, the probability of  $G$  is less than 0.01), compute nonparametric prediction limits as in section 3 (USEPA 1992 section 5.2.3). (Option: compute Poisson prediction limits as in section 3.4—see USEPA 1992 section 2.2.4.)

## Compounds Quantified in at Least 50% of All Background Samples

1. Apply the multiple group version Shapiro-Wilk test to the  $n_I$  quantified measurements only.
2. If the data are normally distributed compute the mean of the  $n$  background samples as:

$$\bar{x} = \left(1 - \frac{n_0}{n}\right) \bar{x}'$$

where  $\bar{x}'$  is the average of the  $n_1$  detected values and  $n_0$  is the number of samples in which the compound is not detected or is below the QL. The standard deviation is:

$$s = \sqrt{\left(1 - \frac{n_0}{n}\right)s'^2 + \frac{n_0}{n}\left(1 - \frac{n_0 - 1}{n - 1}\right)x'}$$

where  $s'$  is the standard deviation of  $n_1$  quantifiable measurements. The normal prediction limit can then be computed as previously described. This method is due to Aitchison (1955)—see USEPA 1992 Section 2.2.2.

3. If the multiple group Shapiro-Wilk test reveals that the data are lognormally distributed, replace  $x'$  with  $y'$ , and  $s'$  with  $s_{y'}$  in the equations for  $x$  and  $s$ .
4. Note that if the measurements are less than 1.0 as is often the case when metals are reported in mg/l, then  $y = \log_e(x) < 0$  and the previous equations do not apply. In this case we use the transformation  $y = \log_e(x + 1)$  which is always positive for any nonzero concentration. The lognormal prediction limit is then computed as:

$$\exp\left(y' + t_{[n+1, \alpha]}s_{y'}\sqrt{1 + \frac{1}{n}}\right) - 1$$

5. If the data are neither normally or lognormally distributed, compute a nonparametric prediction limit. (Option: compute normal prediction limit.)

## Compounds Quantified in Less Than 50% of All Background Samples

1. In this application, the nonparametric prediction limit is the largest concentration found in  $n$  upgradient measurements (USEPA 1992 section 4.2.1).
2. Gibbons (1990a, 1991b) has shown that the confidence associated with this decision rule, following one or more verification resamples, is a function of the multivariate

extension of the hypergeometric distribution (USEPA 1992 section 5.2.3).

3. Complete tabulations of confidence levels for  $n = 4, \dots, 100$ ,  $k = 1, \dots, 100$  future comparisons (*e.g.*, monitoring wells), and a variety of verification resampling plans are presented in Gibbons (1994). For example, with 5 monitoring wells and 10 constituents (*i.e.*, 50 comparisons), we would require 40 background measurements to provide 95% confidence (USEPA 1992 section 5.2.3). Table 1 displays confidence levels for a single verification resample.
4. As an option to the nonparametric prediction limits, DUMPStat can compute Poisson prediction limits. Poisson prediction limits are useful for those cases in which there are too few background measurements to achieve an adequate site-wide false positive rate using the nonparametric approach. Gibbons (1987b) derived the Poisson prediction limit as:

$$\text{Poisson PL} = \frac{y}{n} + \frac{z^2}{2n} + \frac{z}{n} \sqrt{y(1 + n) + \frac{z^2}{4}}$$

where  $y$  is the sum of the detected measurements or reporting limit for those samples in which the constituent was not detected, and  $z$  is the  $(1-\alpha)100$  upper percentage point of the normal distribution. (USEPA 1992 section 2.2.4)



### 3 Technical Details

Previous	Number of Monitoring Wells (k)														
n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	.933	.881	.838	.802	.771	.744	.720	.698	.679	.661	.645	.630	.617	.604	.592
5	.952	.913	.879	.849	.823	.800	.779	.760	.742	.726	.711	.697	.684	.672	.661
6	.964	.933	.906	.882	.860	.840	.822	.805	.789	.774	.761	.748	.736	.725	.714
7	.972	.947	.925	.905	.886	.869	.853	.838	.825	.812	.799	.788	.777	.766	.757
8	.978	.958	.939	.922	.906	.891	.878	.864	.852	.841	.830	.819	.809	.800	.791
9	.982	.965	.949	.935	.921	.908	.896	.885	.874	.864	.854	.844	.835	.827	.818
10	.985	.971	.957	.945	.933	.922	.911	.901	.891	.882	.873	.865	.857	.849	.841
11	.987	.975	.964	.953	.942	.933	.923	.914	.906	.897	.889	.882	.874	.867	.860
12	.989	.979	.969	.959	.950	.941	.933	.925	.917	.910	.902	.896	.889	.882	.876
13	.990	.981	.973	.964	.956	.948	.941	.934	.927	.920	.914	.907	.901	.895	.889
14	.992	.984	.976	.969	.961	.954	.948	.941	.935	.929	.923	.917	.912	.906	.901
15	.993	.986	.979	.972	.966	.959	.953	.947	.942	.936	.931	.926	.920	.915	.910
16	.993	.987	.981	.975	.969	.964	.958	.953	.948	.943	.938	.933	.928	.923	.919
17	.994	.988	.983	.978	.972	.967	.962	.957	.953	.948	.943	.939	.935	.930	.926
18	.995	.990	.985	.980	.975	.970	.966	.961	.957	.953	.949	.944	.940	.937	.933
19	.995	.991	.986	.982	.977	.973	.969	.965	.961	.957	.953	.949	.946	.942	.938
20	.996	.991	.987	.983	.979	.975	.972	.968	.964	.960	.957	.953	.950	.947	.943
25	.997	.994	.992	.989	.986	.984	.981	.978	.976	.973	.971	.968	.966	.964	.961
30	.998	.996	.994	.992	.990	.988	.986	.984	.983	.981	.979	.977	.975	.974	.972
35	.998	.997	.996	.994	.993	.991	.990	.988	.987	.986	.984	.983	.981	.980	.979
40	.999	.998	.997	.995	.994	.993	.992	.991	.990	.989	.988	.987	.985	.984	.983
45	.999	.998	.997	.996	.995	.995	.994	.993	.992	.991	.990	.989	.988	.987	.987
50	.999	.998	.998	.997	.996	.996	.995	.994	.993	.993	.992	.991	.990	.990	.989
60	.999	.999	.998	.998	.997	.997	.996	.996	.995	.995	.994	.994	.993	.993	.992
70	1.000	.999	.999	.998	.998	.998	.997	.997	.997	.996	.996	.995	.995	.995	.994
80	1.000	.999	.999	.999	.998	.998	.998	.998	.997	.997	.997	.996	.996	.996	.996
90	1.000	1.000	.999	.999	.999	.999	.998	.998	.998	.998	.997	.997	.997	.997	.996
100	1.000	1.000	.999	.999	.999	.999	.999	.998	.998	.998	.998	.998	.997	.997	.997

**Table 1:** Probability that the first sample or the verification resample will be below the maximum of  $n$  background measurements at each of  $k$  monitoring wells for a single constituent.

Previous	Number of Monitoring Wells (k)														
n	20	25	30	35	40	45	50	55	60	65	70	75	80	90	100
4	.542	.504	.474	.449	.428	.410	.394	.380	.367	.356	.345	.336	.327	.312	.299
5	.612	.574	.543	.517	.495	.476	.459	.443	.430	.417	.406	.396	.386	.369	.355
6	.668	.631	.600	.574	.552	.532	.514	.499	.484	.472	.460	.449	.439	.420	.405
7	.713	.678	.648	.623	.600	.580	.563	.547	.532	.519	.507	.496	.485	.466	.450
8	.750	.717	.688	.664	.642	.622	.605	.589	.574	.561	.549	.537	.527	.507	.490
9	.781	.750	.723	.699	.678	.659	.642	.626	.612	.598	.586	.574	.564	.544	.527
10	.807	.777	.752	.729	.709	.691	.674	.659	.644	.631	.619	.608	.597	.578	.560
11	.828	.801	.777	.755	.736	.718	.702	.687	.674	.661	.649	.638	.627	.608	.590
12	.847	.821	.799	.778	.760	.743	.727	.713	.700	.687	.675	.664	.654	.635	.618
13	.862	.839	.817	.798	.781	.764	.750	.736	.723	.711	.699	.689	.678	.660	.643
14	.876	.854	.834	.816	.799	.784	.769	.756	.744	.732	.721	.710	.701	.682	.666
15	.888	.867	.848	.831	.815	.801	.787	.774	.762	.751	.740	.730	.721	.703	.686
16	.898	.879	.861	.845	.830	.816	.803	.791	.779	.768	.758	.748	.739	.722	.706
17	.907	.889	.872	.857	.843	.830	.817	.806	.794	.784	.774	.765	.756	.739	.723
18	.914	.898	.882	.868	.855	.842	.830	.819	.808	.798	.789	.780	.771	.754	.739
19	.921	.906	.891	.878	.865	.853	.842	.831	.821	.811	.802	.793	.785	.769	.754
20	.928	.913	.899	.886	.874	.863	.852	.842	.832	.823	.814	.806	.798	.782	.768
25	.950	.939	.929	.919	.910	.901	.892	.884	.876	.869	.862	.855	.848	.835	.823
30	.963	.955	.947	.940	.932	.925	.919	.912	.906	.900	.894	.888	.882	.872	.861
35	.972	.966	.959	.954	.948	.942	.937	.931	.926	.921	.916	.911	.907	.898	.889
40	.978	.973	.968	.963	.958	.954	.949	.945	.941	.936	.932	.928	.924	.917	.909
45	.982	.978	.974	.970	.966	.962	.959	.955	.951	.948	.944	.941	.938	.931	.925
50	.985	.982	.979	.975	.972	.969	.966	.963	.959	.956	.954	.951	.948	.942	.937
60	.990	.987	.985	.982	.980	.978	.975	.973	.971	.968	.966	.964	.962	.958	.954
70	.992	.990	.989	.987	.985	.983	.981	.980	.978	.976	.974	.973	.971	.968	.965
80	.994	.993	.991	.990	.988	.987	.986	.984	.983	.981	.980	.979	.977	.975	.972
90	.995	.994	.993	.992	.991	.990	.988	.987	.986	.985	.984	.983	.982	.980	.978
100	.996	.995	.994	.993	.992	.991	.991	.990	.989	.988	.987	.986	.985	.983	.982

Table 1 (continued)

## Intra-Well Comparisons

One particularly good method for computing intra-well comparisons is the combined Shewhart-CUSUM control chart. (USEPA 1992 section 6.1) The method is sensitive to both gradual and rapid releases and is also useful as a method of detecting ‘trends’ in data. Note that this method should be used on wells unaffected by the landfill. There are several approaches to implementing the method and in the following one useful way is described as well as discussion of some statistical properties.

## Assumptions

The combined Shewhart-CUSUM control chart procedure assumes that the data are **independent** and **normally** distributed with a **fixed** mean  $\mu$  and constant variance  $\sigma^2$ . The most important assumption is independence, and as a result wells should be sampled **no more** frequently than quarterly. In some cases, where groundwater moves relatively quickly, it may be possible to accelerate background sampling to eight samples in a single year; however, this should only be done to establish background and not for routine monitoring. The assumption of normality is somewhat less of a concern, and if problematic, natural log or square root transformation of the observed data should be adequate for most practical applications. For this method, nondetects can be replaced by the QL without serious consequence. This procedure should **only** be applied to those constituents that are quantified in at least 25% of all samples; otherwise,  $\sigma^2$  is not adequately defined.

## Nondetects

1. For those well and constituent combinations in which the detection frequency is less than 25%, DUMPStat will graphically display these data until a sufficient number of measurements are available to provide 99% confidence (*i.e.*, 1% false positive rate) for an individual well and constituent

using a nonparametric prediction limit; which, in this context, is the maximum quantified value out of the  $n$  historical measurements. As previously discussed, this amounts to 13 background samples for 1 resample, 8 background samples for pass 1 of 2 resamples and 18 background samples for pass 2 of 2 resamples. It should be obvious that if nonparametric prediction limits are to be used for intra-well comparisons of rarely detected constituents, two verification resamples will often be required and failure will only be indicated if **both** measurements exceed the limit (*i.e.*, the maximum of the first 8 samples).

2. For those cases in which the detection frequency is greater than 25%, DUMPStat substitutes the median reporting limit for the nondetects. In this way, changes in reporting limits do not appear to be significant trends. If manual reporting limits are selected, all nondetects will be replaced with the manual reporting limit.
3. If nothing is detected in 8, 13 or 18 independent samples (depending on resampling strategy), DUMPStat uses the reporting limit as the control limit.
4. As in the previously described inter-well comparisons, DUMPStat provides optional use of Poisson prediction limits as an alternative to nonparametric prediction limits for rarely detected constituents (*i.e.*, less than 25% detects). Poisson prediction limits can be computed after 4 background measurements regardless of detection frequency.

## Procedure

1. DUMPStat requires that at least 4 historical independent samples are available to provide reliable estimates of the mean  $\mu$  and standard deviation  $\sigma$ , of the constituent's concentration in each well, and a minimum of 8 background samples is recommended.
2. DUMPStat selects the three Shewhart-CUSUM parameters  $h$  (the value against which the cumulative sum will be com-

pared),  $k$  (a parameter related to the displacement that should be quickly detected), and  $SCL$  (the upper Shewhart limit which is the number of standard deviation units for an immediate release). Lucas (1982) and Starks (1988) suggest that  $k = 1$ ,  $h = 5$ , and  $SCL = 4.5$  are most appropriate for groundwater monitoring applications. This sentiment is echoed by USEPA in their interim final guidance document *Statistical analysis of ground-water monitoring data at RCRA facilities* (April, 1989). Also see USEPA 1992 section 6.1. For ease of application, however, we have selected  $h = SCL = 4.5$  as a default, which is slightly more conservative than the value of  $h = 5$  suggested by USEPA. To add increased statistical power, when  $n \geq 12$ , we set as defaults  $h = SCL = 4.0$  and  $k = 0.75$ .

Note that the user can select any multiplier for  $h$  and  $SCL$  between 2 and 10. In California, for example, facilities are required to select values of  $h$  and  $SCL$  that produce a site wide false positive rate of 5%. By selecting various values of  $h$  and  $SCL$  in the Statistical Options item of the Settings Menu, and running Intra-Well control charts and corresponding statistical power, the appropriate control factors can be empirically determined for a specific site. (See Gibbons, 1999.)

3. Denote the new measurement at time-point  $t_i$  as  $x_i$ .
4. Compute the standardized value  $z_i$ :

$$z_i = \frac{x_i - \bar{x}}{s}$$

where  $\bar{x}$  and  $s$  mean and standard deviation of the at least 8 historical measurements for that well and constituent (collected in a period of no less than one year.)

5. At each time period ( $t_i$ ) compute the cumulative sum ( $S_i$ ) as  $S_i = \max[0, (z_i - k) + S_{i-1}]$  where  $\max[A, B]$  is the maximum of A and B starting with  $S_0 = 0$ .

6. Plot the values of  $S_i$  (y-axis) versus  $t_i$  (x-axis) on a time chart. Declare an “out-of-control” situation on sampling period  $t_i$  if for the first time,  $S_i \geq h$  or  $z_i \geq SCL$ . Any such designation, however, must be verified on the next round of sampling, before further investigation is indicated.
7. The reader should note that unlike prediction limits which provide a fixed confidence level (*e.g.*, 95%) for a given number of future comparisons, control charts do not provide explicit confidence levels, and do not adjust for the number of future comparisons. The default selection of  $h = SCL = 4.5$  and  $k=1$  is based on USEPA’s own review of the literature and simulations (see Lucas, 1982; Starks, 1988; and USEPA, 1989). USEPA indicates that these values “allow a displacement of two standard deviations to be detected quickly.” Since 1.96 standard deviation units corresponds to 95% confidence on a normal distribution, we can have approximately 95% confidence for this method as well. Note that this logic applies only to a single well and constituent. Gibbons (1999) suggests alternative multipliers as a function of the number of background samples, comparisons, and resampling plan.
8. In terms of plotting the results, it is more intuitive to plot values in their original metric (*e.g.*,  $\mu\text{g/l}$ ) rather than in standard deviation units. In this case  $h = SCL = \bar{x} + 4.5s$  and the  $S_i$  are converted to the concentration metric by the transformation  $S_i * s + \bar{x}$ , noting that when normalized (*i.e.*, in standard deviation units)  $\bar{x}=0$  and  $s=1$  so that  $h = SCL = 4.5$  and  $S_i * 1 + 0 = S_i$ .
9. In computing the CUSUM ( $S_i$ ), nondetects are set to zero to insure that an elevated QL does not increase the CUSUM.
10. You may compute the CUSUM for all measurements (starting at the beginning of the background), or only for post-background monitoring data. (recommended).

## Outliers

1. From time to time, inconsistently large or small values (outliers) can be observed due to sampling, laboratory, transportation, transcription errors, or even by chance alone. The verification resampling procedure that we have proposed will tremendously reduce the probability of concluding that an impact has occurred if such an anomalous value is obtained for any of these reasons. However, nothing has eliminated the chance that such errors might be included in the background measurements for a particular well and constituent. If such erroneous values (either too high or too low) are included in the background database, the result would be an artificial increase in the magnitude of the control limit, and a corresponding increase in the false negative rate of the statistical test (*i.e.*, the conclusion that there is no site impact when in fact there is).
2. To remove the possibility of this type of error, the background data are screened for each well and constituent for the existence of outliers (USEPA 1992 section 6.2) using the well known method described by Dixon (1953). These outlying data points are indicated on the control charts (using a different symbol), but are excluded from the measurements that are used to compute the background mean and standard deviation. In the future, new measurements that turn out to be outliers, in that they exceed the control limit, will be dealt with by verification resampling in down-gradient wells only.
3. This same outlier detection algorithm is applied to each upgradient well and constituent to screen outliers for inter-well comparisons as well.
4. The purpose of automatic outlier rejection in DUMPStat is to eliminate extreme values that will bias the statistical limits (*i.e.*, make them too high). To this end, we use a two-stage screening criteria. First we use Dixon's test. If Dixon's test indicates an outlier we then determine if the value is ten

times the median value for inter-well comparisons or three times the median value for intra-well comparisons. An outlier is indicated only if both tests indicate the value is an outlier. The different factors used for inter-well and intra-well screening are due to the presence of spatial variability for inter-well comparisons. If another outlier screening tool is used outside of DUMPStat (see Gibbons 1994 for a review), outliers can be set manually within DUMPStat as desired. DUMPStat also declares extreme reporting limits as outliers if they are ten times the median reporting limit.

## Existing Trends

If contamination is pre-existing, trends will often be observed in the background database from which the mean and variance are computed. This will lead to upward biased estimates and grossly inflated control limits. To remove this possibility, we first screen the background data for each well and constituent for trend using Sen's (1968) nonparametric estimate of trend. Confidence limits for this trend estimate are given by Gilbert (1987). A significant trend is one in which the 99% lower confidence bound is greater than zero. In this way, even pre-existing trends in the background dataset will be detected. In large databases, very gradual trends can be statistically significant; however, such trends should not preclude the use of intra-well comparisons.

## A Note on Verification Sampling

1. It should be noted that when a new monitoring value is an outlier, perhaps due to an error in transcription, sampling, or analysis; the Shewhart and CUSUM portions of the control chart are affected quite differently. The Shewhart portion of the control chart compares each individual new measurement to the control limit, therefore, the next monitoring event measurement constitutes an independent verification of the original result. In contrast, however, the CUSUM procedure incorporates **all** historical values in the



computation; therefore, the effect of the outlier will be present for both the initial and verification sample; hence the statistical test will be invalid.

2. For example, assume  $\bar{x} = 50$  and  $s = 10$ . On quarter 1 the new monitoring value is 50, so  $z = (50-50)/10 = 0$  and  $S_i = \max[0, (z-1)+0] = 0$ . On quarter 2, a sampling error occurs and the reported value is 200, yielding  $z = (200-50)/10 = 15$  and  $S_i = \max[0, (15-1)+0] = 14$ , which is considerably larger than 4.5; hence an initial exceedance is recorded. On the next round of sampling, the previous result is not confirmed, because the result is back to 50. Inspection of the CUSUM, however, yields  $z = (50-50)/10 = 0$  and  $S_i = \max[0, (0-1)+14] = 13$ , which would be taken as a confirmation of the exceedance, when in fact, no such confirmation was observed. For this reason, the verification must **replace** the suspected result in order to have an unbiased confirmation.

## Updating the Control Chart

1. As monitoring continues and the process is shown to be in control, the background mean and variance should be updated periodically to incorporate these new data. Every two years, all new data that are **in control** should be pooled with the initial samples and  $\bar{x}$  and  $s$  recomputed. These new values of  $\bar{x}$  and  $s$  will then be used in constructing future control charts. This updating process should continue for the life of the facility and/or monitoring program (USEPA 1992 section 6.2).
2. DUMPStat allows the user to update background by changing the time window menu option. This option sets a window of time for which background summary statistics are computed. Changing the maximum date will incorporate new data into the background limit estimate. Note that this time window applies to computing background for both inter-well and intra-well comparisons, and can be set

uniquely for each well and pooled upgradient background. For inter-well comparisons all available data should be used in computing the prediction limit.

## **An Alternative Based on Prediction Limits**

1. An alternative approach to intra-well comparisons involves computation of well-specific prediction limits. Prediction limits are somewhat more sensitive to immediate releases but less sensitive to gradual releases than the combined Shewhart-CUSUM control charts. Prediction limits are also less robust to deviations from distributional assumptions.
2. As an alternative to combined Shewhart-CUSUM control charts, DUMPStat can compute normal prediction limit for detection frequencies  $> 25\%$ , or rare-event prediction limits otherwise, as described in the previous section on inter-well comparisons.
3. For detection frequencies greater than  $25\%$ , nondetects are replaced with the median reporting limit or manual reporting limit depending on whether one has been selected. For detection frequencies less than  $25\%$ , either nonparametric or Poisson prediction limits are computed depending on what option the user has selected (*i.e.*, rare-event statistic window).

## **Comparison to a Standard**

1. For assessment or corrective action, it is often required that samples from a potentially impacted well be compared to a groundwater quality protection standard such as a Maximum Contaminant Level (MCL) or Alternate Concentration Limit (ACL). DUMPStat's assessment monitoring module provides tabular and graphical display of this comparison based on tests of increasing and decreasing trends, and comparison of the standard to the upper or lower  $95\%$

normal confidence limit applied to the last 4–16 (user-selectable) independent samples.

2. The 95% confidence limit for the mean of the last  $m$  measurements is computed as:

$$\bar{x} + t_{[m-1, 0.05]} \frac{s}{\sqrt{m}}$$

3. Nondetects are replaced by one-half of the reporting limit.

# *Methods to be Avoided 4*

The following sections present descriptions of some statistical methods that should be avoided. These methods are not available in DUMPStat.

## **Analysis of Variance—ANOVA**

Application of ANOVA procedures to groundwater detection monitoring programs, both parametric and nonparametric, is inadvisable for the following reasons.

1. Univariate ANOVA procedures do not adjust for multiple comparisons due to multiple constituents which can be devastating to the site-wide false positive rate. As such, a site with 10 indicator constituents will have a 40% chance of failing at least one on every monitoring event (USEPA 1992 section 5.2.1).
2. ANOVA is more sensitive to spatial variability than contamination. Spatial variability affects mean concentrations but typically not the variance, hence small yet consistent differences will achieve statistical significance. In contrast, contamination affects both variability and mean concentration, therefore a much larger effect is required to achieve statistical significance. In fact, application of ANOVA methods to pre-disposal groundwater monitoring data can result in statistically significant differences between upgradient and downgradient wells, despite the fact that there is no waste in between. The reasons for this are:
  - a. The overall F-statistic tests the null hypothesis of no differences among any of the wells regardless of gradi-

- ent (*i.e.*, it will be significant if two downgradient wells are different), and
- b. The distribution of the mean of 4 measurements (*i.e.*, four measurements collected from the same well within a six month period) is normal with mean  $\mu$  and variance  $\sigma^2/4$  whereas the distribution of each of the individual measurements is normal with mean  $\mu$  and variance  $\sigma^2$ . This means that the standard deviation of the mean of four measurements is one-half the size of the standard deviation of the individual measurements themselves. As a result, small but consistent geochemical differences that are invariably observed naturally across a waste disposal facility will be attributed to contamination. To make matters worse, since there are far more downgradient than upgradient wells at these facilities, spatial variation has a far greater chance of occurrence downgradient than upgradient further increasing the likelihood of falsely concluding that contamination is present. While spatial variation is also a problem for prediction limits and tolerance limits for single future measurements, it is not nearly as severe a problem as for ANOVA since the distribution of the individual measurement is considered and not the more restrictive distribution of the sample mean.
  3. Nonparametric ANOVA is often presented as if it protects the user from all of the weaknesses of its parametric counterpart. This is **not** the case. Both methods assume identical distributions for the analyte in **all** monitoring wells. The only difference is that the parametric ANOVA assumes that the distribution is normal and the nonparametric ANOVA is indifferent to what the distribution is. Both parametric and nonparametric ANOVA assume homogeneity of variance, a condition that almost never occurs in practice. This is not a weakness of methods for single future samples (*i.e.*, prediction and tolerance limits) since the variance estimates rely solely on the background data. Why would anyone

want to use downgradient data from an existing site (which could be affected by the site) to characterize natural variability? Yet this is exactly what the ANOVA does. Furthermore, ANOVA is not a good statistical technique for detecting a narrow plume that might effect only one of 10 or 20 monitoring wells (USEPA 1992 section 5.2.1).

4. ANOVA requires the pooling of downgradient data. Specifically, USEPA has suggested that four samples per semi-annual monitoring event be collected (*i.e.*, eight samples per year). As such, on average, it will never most rapidly detect a release, since only a subset of the required four semi-annual samples will be affected by a site impact. This heterogeneity will decrease the mean concentration and dramatically increase the variance for the affected well thereby limiting the ability of the statistical test to detect contamination when it occurs. This is not true for tolerance limits, prediction limits and control charts, which can and **should** be applied to individual measurements. For these reasons, when applied to groundwater detection monitoring, ANOVA will maximize both false positive and false negative rates, and double the cost of monitoring (*i.e.*, ANOVA requires four samples per semi-annual event or eight per year versus a maximum of four quarterly samples per year for prediction or tolerance limits that test each new individual measurement and more typically only two samples per year).

To illustrate, consider the data in Table 2, which were obtained from a facility in which no disposal of waste has yet occurred (see Gibbons, 1994).

Well	Event	TOC	TKN	COD	ALK
MW01	1	5.2000	0.8000	44.0000	58.0000
MW01	2	6.8500	0.9000	13.0000	49.0000
MW01	3	4.1500	0.5000	13.0000	40.0000
MW01	4	15.1500	0.5000	40.0000	42.0000
MW02	1	1.6000	1.6000	11.0000	59.0000
MW02	2	6.2500	0.3000	10.0000	82.0000
MW02	3	1.4500	0.7000	10.0000	54.0000
MW02	4	1.0000	0.2000	13.0000	51.0000
MW03	1	1.0000	1.8000	28.0000	39.0000
MW03	2	1.9500	0.4000	10.0000	70.0000
MW03	3	1.5000	0.3000	11.0000	42.0000
MW03	4	4.8000	0.5000	26.0000	42.0000
MW04	1	4.1500	1.5000	41.0000	54.0000
MW04	2	1.0000	0.3000	10.0000	40.0000
MW04	3	1.9500	0.3000	24.0000	32.0000
MW04	4	1.2500	0.4000	45.0000	28.0000
MW05	1	2.1500	0.6000	39.0000	51.0000
MW05	2	1.0000	0.4000	26.0000	55.0000
MW05	3	19.6000	0.3000	31.0000	60.0000
MW05	4	1.0000	0.2000	48.0000	52.0000
MW06	1	1.4000	0.8000	22.0000	118.0000
MW06	2	1.0000	0.2000	23.0000	66.0000
MW06	3	1.5000	0.5000	25.0000	59.0000
MW06	4	20.5500	0.4000	28.0000	63.0000
P14	1	2.0500	0.2000	10.0000	79.0000
P14	2	1.0500	0.3000	10.0000	96.0000
P14	3	5.1000	0.5000	10.0000	89.0000

**Table 2:** Raw data for all detection monitoring wells and constituents (mg/l).  
This facility has no garbage in it.

Results of applying both parametric and nonparametric ANOVA to these predisposal data yielded an effect that approached significance for Chemical Oxygen Demand (COD) ( $p < 0.072$  parametric and  $p < 0.066$  nonparametric) and a significant difference for Alkalinity (ALK) ( $p < 0.002$  parametric and  $p < 0.009$  nonparametric). In terms of individual comparisons, significantly increased COD levels were found for well MW05 ( $p < 0.026$ ) and significantly increased ALK was found for wells MW06 ( $p < 0.026$ ) and P14 ( $p < 0.003$ ) relative to upgradient wells. Of course, these results represent false

positives due to spatial variability, since there is no garbage. What is perhaps most remarkable, however, is the absence of any significant results for TOC, where some of the values are as much as 20 times higher than the others. The reason, of course, is that these extreme values tremendously increase the within-well variance estimate, rendering the ANOVA powerless to detect any differences regardless of magnitude. This is yet another testimonial to why it is environmentally negligent to average measurements from downgradient monitoring wells, a problem that is inherent to ANOVA-type analyses when applied to dynamic groundwater quality measurements. The elevated TOC data are clearly inconsistent with chance expectations and should be investigated. In this case, however, they are likely due to insects getting into the wells since this greenfield facility is in the middle of the Mohave desert.

## Cochran's Approximation to the Behrens Fisher $t$ -test

Although no longer required, for years the RCRA regulation was based on application of the Cochran's approximation to the Behrens Fisher (CABF)  $t$ -test. The test was incorrectly implemented by requiring that four quarterly upgradient samples from a single well and single samples from a minimum of three downgradient wells each be divided into four aliquots and treated as if there were  $4n$  independent measurements. The net result was that every hazardous waste disposal facility regulated under RCRA was declared "leaking." As an illustration consider the data in Table 3.



Date	Replicate				Average
	1	2	3	4	
Background					
11/81	7.77	7.76	7.78	7.78	7.77
02/82	7.74	7.80	7.82	7.85	7.80
05/82	7.40	7.40	7.40	7.40	7.40
08/82	7.50	7.50	7.50	7.50	7.50
$x_B$		7.62			7.62
$sd_B$		0.18			0.20
$n_B$		16			4
Monitoring					
09/83	7.39	7.40	7.38	7.42	7.40
$x_B$		7.40			7.40
$sd_B$		0.02			
$n_B$		4			1

**Table 3:** Illustration of pH data used in computing the CABF  $t$ -test

Note that the aliquots are almost perfectly correlated and add virtually no independent information, yet they are assumed to be completely independent by the statistic. The CABF  $t$ -test is computed as:

$$t = \frac{\bar{x}_B - \bar{x}_M}{\sqrt{\frac{s_B^2}{n_B} + \frac{s_M^2}{n_M}}} = \frac{7.62 - 7.40}{\sqrt{\frac{0.032}{16} + \frac{0.0004}{4}}} = \frac{0.22}{0.05} = 4.82$$

The associated probability of this test statistic is 1 in 10,000 indicating that the chance that the new monitoring measurement came from the same population as the background measurements is 1 in 10,000. Note that in fact, the mean concentration of the four aliquots for the new monitoring measurement is identical to one of the four mean values for background (*i.e.*, 7.4), suggesting that intuitively the probability is closer to 1 in 4 rather than 1 in 10,000. Averaging the aliquots, which should have never been split in the first place, yields the

statistic:

$$t = \frac{x_B - x_M}{s_B \sqrt{\frac{1}{n_B} + 1}} = \frac{7.62 - 7.40}{0.20 \sqrt{\frac{1}{4} + 1}} = \frac{0.22}{0.22} = 1$$

which has an associated probability of 1 in 2. Had the sample size been increased to  $N_B=20$  the probability would have decreased to 1 in 3. In 1988 U.S. EPA recognized this flaw and changed this regulation (see USEPA 1988).

## Control of False Positive Rate by Constituent

Site-wide false positive and false negative rates are more important than choice of statistic; nonetheless, certain statistics make it impossible to control the site-wide false positive rate because the rate is controlled separately for each constituent (*e.g.*, parametric and nonparametric ANOVA—see USEPA 1992 section 5.2.1). The only important false positive rate is the one which includes all monitoring wells and all constituents, since any single exceedance can trigger an assessment. This criterion impacts greatly on the selection of statistical method. These error rates are dependent on the number of wells, number of constituents, number of background measurements, type of comparison (*i.e.*, intra-well versus inter-well), distributional form of the constituents, detection frequency of the constituents and the individual comparison false positive rate of the statistic being used. Invariably, this leads to a problem in interval estimation the solution of which is typically a prediction limit that incorporates the effects of verification resampling as well as multiple comparisons introduced by both multiple monitoring wells and multiple monitoring constituents.

## Restriction of Background Samples

Certain states have interpreted the Subtitle D regulation as indicating that background be confined to the first four samples collected in a day or a semi-annual monitoring event or a year. The first approach (*i.e.*, four samples in a day) violates the assumption of independence and confounds day-to-day temporal and seasonal variability with potential contamination. As an analogy, consider setting limits on yearly ambient temperatures in Chicago by taking four temperature readings on July 4th. Say the temperature varied between 75 and 85 degrees on that day yielding a prediction interval from 70 to 90 degrees. As I write this, the temperature in Chicago is -20 degrees. Something is clearly amiss. In the second example of restricting background to the first four events taken in 6 months, the measurements may be independent if ground water flows fast enough, but seasonal variability is confounded with contamination. The net result is that comparisons of background water quality in the summer may not be representative of point of compliance water quality in the winter (*e.g.*, disposal of road salts increasing conductivity in the winter). In the third example in which background is restricted to the first four quarterly measurements, independence is typically not an issue and background versus point-of-compliance monitoring well comparisons are not confounded with season. However, as previously pointed out, restriction of background to only four samples dramatically increases the size of the statistical prediction limit thereby increasing the false negative rate of the test (*i.e.*, the prediction limit is over five standard deviation units above the background mean concentration). The reason for this is that the uncertainty in the true mean concentration covers the majority of the normal distribution. As such we could obtain virtually any mean and standard deviation by chance alone. If by chance the values are low, false positive results will occur. If by chance the values are high, false negative results will occur. By increasing the background sample size,

uncertainty in the sample based mean and standard deviation decrease as does the size of the prediction limit, therefore both false positive and false negative rates are minimized.

Furthermore, use of statistical outlier detection procedures applied to the background data will remove the possibility of spurious background results falsely inflating the size of the prediction limit.



## references

---

1. ASTM D6312-98 Standard Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs. ASTM, West Conshohocken, PA, 1999.
2. Aitchison, J. (1955). On the distribution of a positive random variable having a discrete probability mass at the origin. *Journal of the American Statistical Association*, **50**, 901-908.
3. Currie, L.A. (1968). Limits for qualitative detection and quantitative determination: Application to radiochemistry. *Analytical Chemistry*, **40**, 586-593.
4. Davis, C. B. McNichols, R. J. (1987). One-sided intervals for at least  $p$  of  $m$  observations from a normal population on each of  $r$  future occasions. *Technometrics*, **29**, 359-370.
5. Davis, C. B. (1993). Environmental regulatory statistics. in *Handbook of Statistics, Vol. 12: Environmental Statistics* G.P. Patil & C.R. Rao, editors, Elsevier.
6. Dixon, W. J. (1953). Processing data for outliers. *Biometrics*, **9**, 74-89.
7. Gibbons, R. D. (1987a). Statistical prediction intervals for the evaluation of ground-water quality. *Ground Water*, **25**, 455-465.
8. Gibbons, R. D. (1987b). Statistical models for the analysis of volatile organic compounds in waste disposal facilities. *Ground Water*, **25**, 572-580.
9. Gibbons, R. D. (1999). Use of Combined Shewhart-CUSUM Control Charts for Ground-water Monitoring Applications. *Ground Water* **37**, 682-691.
10. Gibbons, R. D., Jarke, F. H., & Stoub, K. P. (1989). Method detection limits. Proceedings of *Fifth Annual USEPA Waste Testing and Quality Assurance Symposium*, Vol. **2**, 292-319.
11. Gibbons, R. D. (1990a). A general statistical procedure for ground-water detection monitoring at waste disposal facilities. *Ground Water*, **28**, 235-243.
12. Gibbons, R. D. (1990b). Estimating the precision of ground-water elevation data. *Ground Water*, **28**, 357-360.
13. Gibbons, R. D., Grams N. E., Jarke F. H., & Stoub K. P. (1990). Practical quantitation limits. *Proceedings of Sixth Annual USEPA Waste Testing and Quality Assurance Symposium Vol 1*, 126-142.

- 
14. Gibbons, R. D. & Baker J. (1991). The properties of various statistical prediction limits. *Journal of Environmental Science and Health, A26-4*, 535-553.
  15. Gibbons, R. D. (1991a). Statistical tolerance limits for ground-water monitoring. *Ground Water*, **29**, 563-570.
  16. Gibbons, R. D. (1991b). Some additional nonparametric prediction limits for ground-water monitoring at waste disposal facilities. *Ground Water*, **29**, 729-736.
  17. Gibbons, R. D., Jarke, F. H., & Stoub, K. P. (1991). Detection limits: for linear calibration curves with increasing variance and multiple future detection decisions. *Waste Testing and Quality Assurance*, **3**, ASTM SPT 1075, 377-390.
  18. Gibbons, R. D., Grams, N. E., Jarke, F. H., & Stoub, K. P. (1992). Practical quantitation limits: *Chemometrics and Intelligent Laboratory Systems*, **12**, 225-235.
  19. Gibbons, R. D. (1992). An overview of statistical methods for ground-water detection monitoring at waste disposal facilities. In *Ground-Water Contamination at Hazardous Waste Sites: Chemical Analysis*, S.D. Lesage & R.E. Jackson (eds.), New York: Marcel Dekker, Inc.
  20. Gibbons, R. D., Dolan, D., Keough H., O'Leary, K. & O'Hara R. (1992). A comparison of chemical constituents in leachate from industrial hazardous waste & municipal solid waste landfills. Proceedings of the *Fifteenth Annual Madison Waste Conference*, University of Wisconsin, Madison.
  21. Gibbons, R. D. (1994) *Statistical Methods for Ground-Water Monitoring*, John Wiley & Sons.
  22. Gibbons, R. D. (1996) Some conceptual and statistical issues in analysis of ground-water monitoring data. *Environmetrics*, **7**, 185-199.
  23. Gilbert, R. O. (1987). *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York.
  24. Hubaux, A. and Vos, G. (1970). Decision and detection limits for linear calibration curves. *Analytical Chemistry*, **42**, 849-855.
  25. Lucas, J. M. (1982). Combined Shewhart-CUSUM quality control schemes. *Journal of Quality Technology*, **14**, 51-59.
  26. Mood, A.M. (1954). On the asymptotic efficiency of certain nonparametric two-sample tests. *Annals of Mathematical Statistics*, **25**, 514-522.
  27. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, **63**, 1379-1389.

- 
28. Shapiro, S.S., and Wilk, M.B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, **52**, 591-611.
  29. Starks T. H. (1988). Evaluation of control chart methodologies for RCRA waste sites. USEPA technical report CR814342-01-3.
  30. USEPA, 40CFR Part 264: Statistical methods for evaluating ground-water monitoring from hazardous waste facilities; final rule. *Federal Register*, **53**, 196 (1988) 39720-39731.
  31. USEPA, Interim Final Guidance Document *Statistical analysis of ground-water monitoring data at RCRA facilities* (April, 1989).
  32. USEPA, Addendum to Interim Final Guidance Document *Statistical analysis of ground-water monitoring data at RCRA facilities* (July, 1992).
  33. Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin*, **1**, 80-83.
  34. Wilk, M.B., and Shapiro, S.S. (1968). The joint assessment of normality of several independent samples. *Technometrics*, **10**, no 4. 825-839.





# index

---

## A

### ACL

- commonly asked questions 17
- comparison to a standard 35

### Air monitoring

- statistical overview 8

### Aitchison's method 17, 24

### Alternate Concentration Limit

- comparison to a standard 8

### ANOVA 37, 43

- commonly asked questions 11, 15, 16

### Assessment

- statistical overview 7
- technical details 35

## C

### CABF t-test 41

### Comparison to a standard 8

### Comparison to background 7

### Corrective action monitoring, statistical overview 7

## D

### Dixon's test, and outliers 32

## F

### False negative

- ANOVA 39
- control charts 14

### intra-well 2

### outliers 32

### restriction of background samples 44

### simulation of rate 6

### statistical overview 1

### verification resampling 5

### False positive

#### ANOVA 37, 39

#### control by constituent 43

#### control charts 14

#### intra-well 2, 4

#### simulation of rate 6

#### up vs. down 2, 22

#### verification resampling 5

## G

### Groundwater monitoring, statistical overview 1

## I

### Intra-well

#### prediction limits 5

#### technical details 28

### Intra-well comparisons

#### false positive 4

### Intra-well comparisons

#### nondetects 4

#### Shewhart-CUSUM control charts 4

#### statistical overview 4

---

## M

Maximum contaminant level

- commonly asked questions 17

- comparison to a standard 8, 35

MCL. See Maximum contaminant level

MDL. See Method detection limit

Method detection limit

Method detection limit, commonly asked questions 16, 18, 19

## N

Nondetects

- air and surface water monitoring 9

- comparison to a standard 36

- intra-well comparisons 4

- replacing 35

- technical information 28

- up vs. down comparisons 2

Nonparametric limits 13

## O

Outliers

- restriction of background samples 45

- technical details 32

- verification resampling 33

## P

Poisson

- prediction limits 13

PQL. See Practical quantitation limit

Practical quantitation limit 16

- commonly asked questions 16, 18, 19

Prediction limits

- ANOVA 38

- commonly asked questions 11, 12

lognormal

- up vs. down 2, 23, 24

nonparametric 12

- commonly asked questions 12, 18

- intra-well 4, 29

- up vs. down 3, 23, 24

normal

- intra-well 35

- up vs. down 2, 22, 24

Poisson 13

- commonly asked questions 18

- intra-well 5, 29

- up vs. down 3, 23, 25

- vs. tolerance limits 12

## R

Rare event statistics 13

## S

Seasonal variability 11, 15, 44

Sen's test 8, 10, 33

Sen's test, and intra-well comparisons 14

Shapiro-Wilk test 23

- up vs. down comparisons 22

Shewhart-CUSUM control charts

- assumptions 28

- commonly asked questions 14

- intra-well comparisons 4, 28

- selecting parameters 29

- verification resampling 33

Standard, comparison to 8

Surface water monitoring, statistical overview 8

---

## **T**

Tolerance limits

ANOVA 38

commonly asked questions 11, 12

Trend testing 8, 10

## **U**

Up vs. down

false positive 2

nondetects 2

prediction limits 2

statistical overview 2

technical details 21

## **V**

Verification resampling

false negative 5

false positive 5

statistical overview 5

technical details 33

Volatile organic compounds

commonly asked questions 17, 18

comparison to a standard 8

## **W**

Wilcoxon test

air monitoring 9

surface water monitoring 9

# **Attachment B**

## **DUMPStat 2.3 Release Notes**

An abstract background image featuring a swirling, marbled pattern in shades of blue and teal, resembling water or a microscopic view of a liquid. The pattern is more intense and detailed in the center, fading slightly towards the edges.

# DUMPStat 2.3

groundwater detection monitoring statistics

**RELEASE NOTES**

# DUMPStat

---

Release Notes

Version 2.3





<b>Changes since version 2.1.8</b>	<b>7</b>
Statistical Options	7
General Options	7
Use Gamma Prediction Limits	7
Allow Low Confidence	8
Analysis Options	10
Trend Test Method	10
Confidence Level	11
Limits must exceed Manual RL	11
Show J/Trace Values in Data Summaries and Time Series	12
Data Value Options	14
Outlier Significance Level	14
Remove Calculated Outliers	14
Use Median Value Heuristic	14
Perform Iterative Outlier Testing	15
Censored Data Outlier Table	15
Field Codes	15
Analyses	16
Confidence Limits (Assessment)	16
Intra-Well Control Charts	16
Statistical Methods	17
Dixon's Outlier Test	17
Censored Data Outlier Testing	17
Trend Testing	17
Sen's Test of Trend	17
Mann-Kendall Test	17
Gamma Prediction Limits	18
Nonparametric Prediction Limits	18
Graph Viewer	18
New Options	18
Vertical Axis Offset	18
Order By	19
Export Current Graph	19
Copy to Clipboard	19
Symbol Size	20
Line Thickness	20

---

Annotations .....	20
Modifications .....	21
Vertical Axis Override .....	21
New Tables .....	21
Dixon's Test Outliers .....	21
Censored Data Outliers Test .....	22
Analytical Data and CUSUM Summary .....	22
Table Improvements .....	23
Summary Statistics .....	23
Analytical Data Summary .....	23
Confidence Limits (Assessment) .....	24
Historical Downgradient Data .....	24
Table Titles .....	24
Site Settings .....	24
Print Noted Rows Only .....	25
Worksheets .....	25
Trend Detection .....	25
Database .....	25
Sample Identifiers .....	25
Edit / Add Comment .....	27
Edit Database Log .....	27
Data Merge .....	27
Time Windows .....	28
Date Changes .....	28
Per Well Per Constituent .....	28
Individual Upgradient Time Windows .....	28
Zones .....	29
Manual Reporting Limits .....	29
Per Constituent Per Individual Well .....	29
Printing .....	30
Print Setup .....	30
Miscellaneous .....	30
License Transfer .....	30
Serial Number .....	30

---

## **Documentation Updates** **31**

Printing Format .....	31
Statistical Options .....	31
Statistical Methods .....	31

## **Appendix A** **32**



# DUMPStat 2.3 Release Notes

These release notes cover all the changes made to DUMPStat since version 2.1.8 as well as documentation updates from the 2.1.8 User's and Statistical Guides.

## Changes since version 2.1.8

### Statistical Options

See "Statistical Options" on page 37 of the *User's Guide*.

The Statistical Options dialog's new layout includes three new tabs, General, Analysis and Data Values. These provide better organization of the existing statistical options, and of the new ones described below.

#### General Options

The General tab contains settings that affect the majority of the analyses and their output.

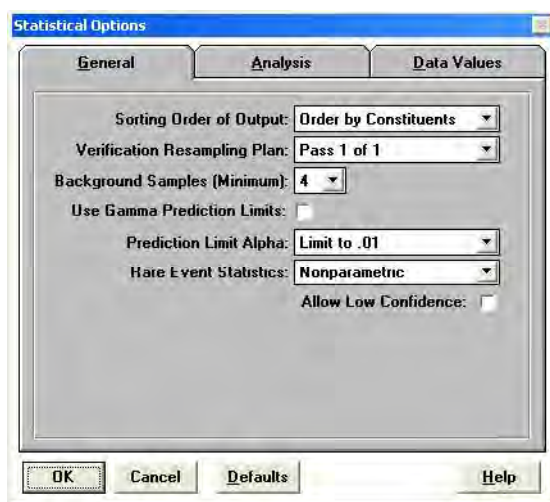


Figure 1

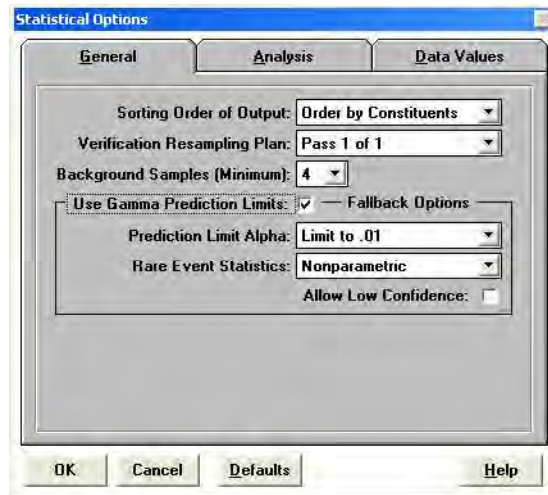
#### Use Gamma Prediction Limits

See "Use Gamma Prediction Limits" on page 38 of the *User's Guide*.

The Use Gamma Prediction Limits option specifies that an upper prediction limit based on a gamma distribution should be computed instead of a normal distribution, nonparametric or Poisson prediction limit in the Up vs. Down and Intra-Well Prediction Limits, and Intra-Well Control Charts analyses.

---

When Use Gamma Prediction Limits is checked, the Prediction Limit Alpha, Rare Event Statistics and Allow Low Confidence options are labelled Fallback Options to indicate that they may be used to determine the type of limit to calculate in those cases where a gamma limit cannot be computed (*e.g.* due to very small variance in the data).



**Figure 2**

The default setting is unchecked to preserve consistency with previous versions.

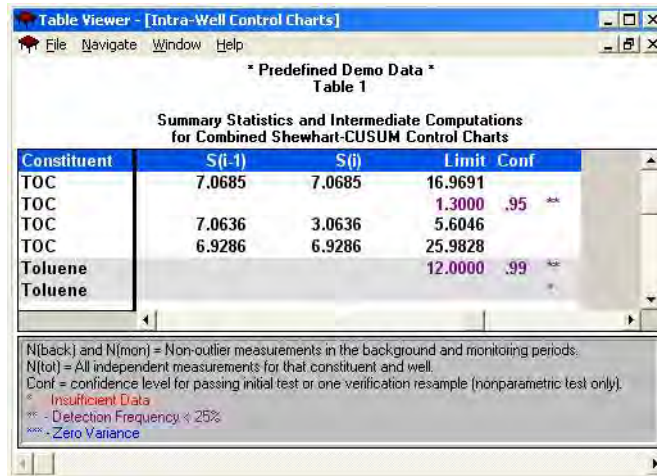
### **Allow Low Confidence**

See "Allow Low Confidence" on page 39 of the *User's Guide*.

Allow Low Confidence eliminates the requirement that enough background samples are present for computing nonparametric prediction limits with 99% confidence in Intra-well analyses.

This option is available only when the Rare Event Statistics selection is Nonparametric.

The confidence level for the computed nonparametric limit is shown in a new Conf column in the summary tables.



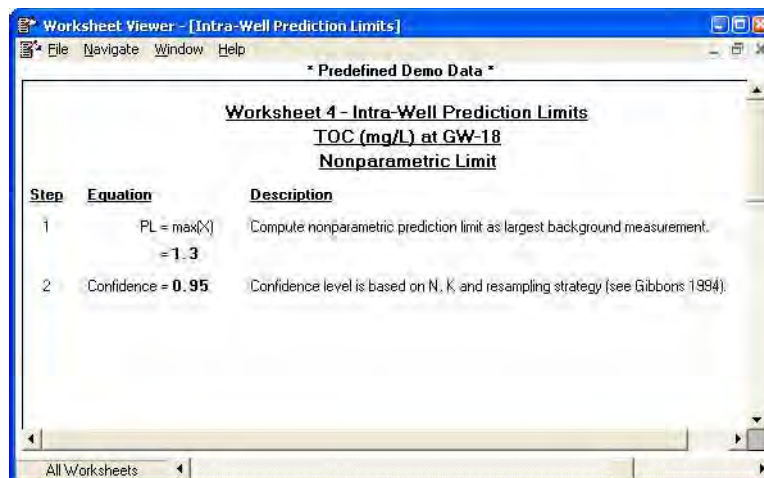
**Table 1**  
Summary Statistics and Intermediate Computations  
for Combined Shewhart-CUSUM Control Charts

Constituent	S(i-1)	S(i)	Limit	Conf
TOC	7.0685	7.0685	16.9691	
TOC			1.3000	.95
TOC	7.0636	3.0636	5.6046	
TOC	6.9286	6.9286	25.9828	
Toluene			12.0000	.99
Toluene				

N(back) and N(mon) = Non-outlier measurements in the background and monitoring periods.  
N(tot) = All independent measurements for that constituent and well.  
Conf = confidence level for passing initial test or one verification resample (nonparametric test only).  
Insufficient Data  
- Detection Frequency < 25%  
- Zero Variance

**Figure 3**

The confidence level is also displayed on the worksheets.



**Worksheet 4 - Intra-Well Prediction Limits**  
TOC (mg/L) at GW-18  
Nonparametric Limit

Step	Equation	Description
1	PL = max(X) = 1.3	Compute nonparametric prediction limit as largest background measurement.
2	Confidence = 0.95	Confidence level is based on N, K and resampling strategy (see Gibbons 1994).

All Worksheets

**Figure 4**

The default setting is unchecked to preserve consistency with previous versions.

---

## Analysis Options

The Analysis tab contains settings that allow further customization of the parameters and statistical methods used in the statistical analyses.

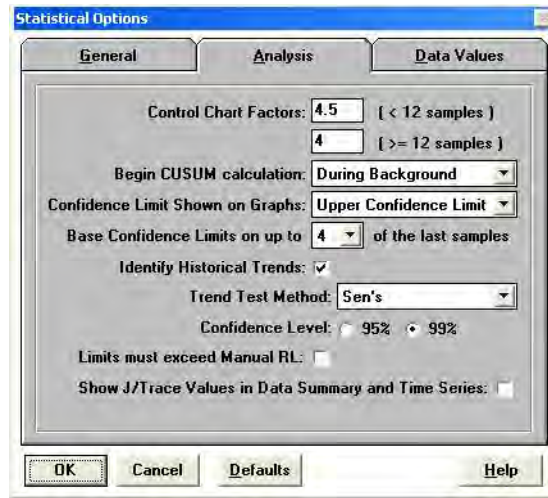


Figure 5

### Trend Test Method

See "Trend Test Method" on page 41 of the *User's Guide*.

Trend Test Method specifies whether to perform the Sen's test of trend or the Mann-Kendall test when identifying historical trends.

Detailed trend test information is displayed on the worksheets.

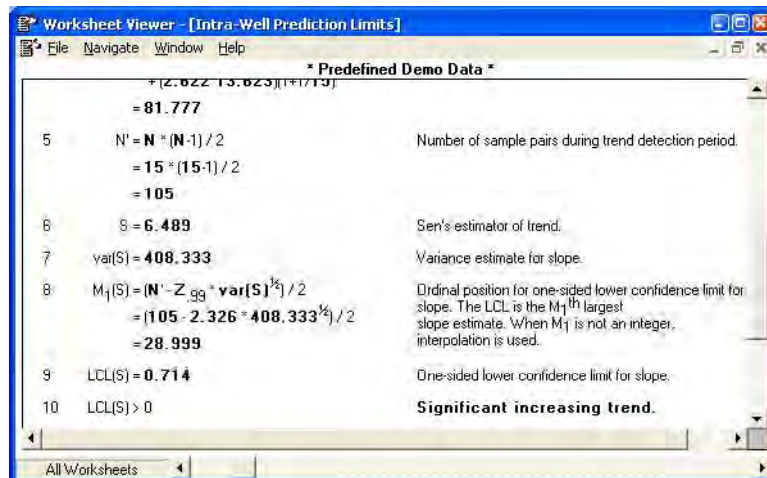


Figure 6

The default setting is Sen's to preserve consistency with previous versions.



See "Confidence Level" on page 41 of the *User's Guide*.

## Confidence Level

Confidence Level specifies whether 95% or 99% confidence is required when identifying historical trends.

Detailed trend test information is displayed on the worksheets.

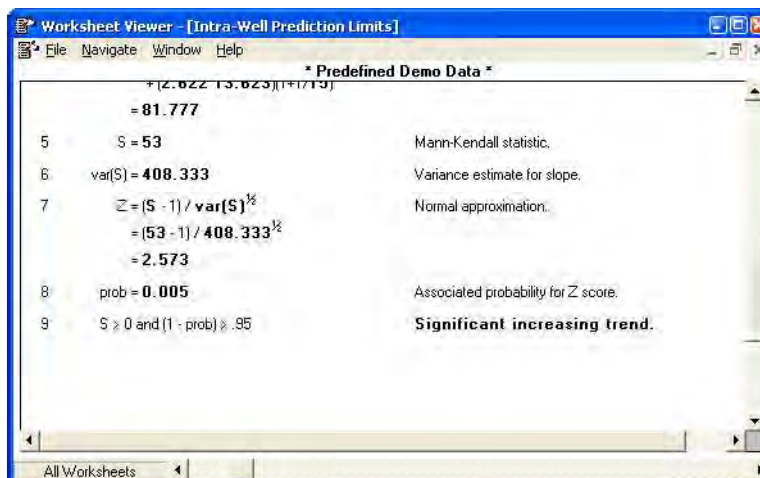


Figure 7

The default setting is 99% to preserve consistency with previous versions.

See "Limits must exceed Manual RL" on page 41 of the *User's Guide*.

## Limits must exceed Manual RL

When 'Limits must exceed Manual RL' is checked and the manual reporting limit is greater than the computed limit, the constituent's manual reporting limit is displayed on graphs and worksheets instead of the computed limit. The constituent must have a manual reporting limit specified and Enable Manual Reporting Limits must also be checked.



Figure 8

In the previous example, when the computed limit is less than 8 mg/L for Chloride at a particular sample point, the limit is shown on the graph as a horizontal line at 8 and more detail is provided in steps 4 and 5 of the worksheet.

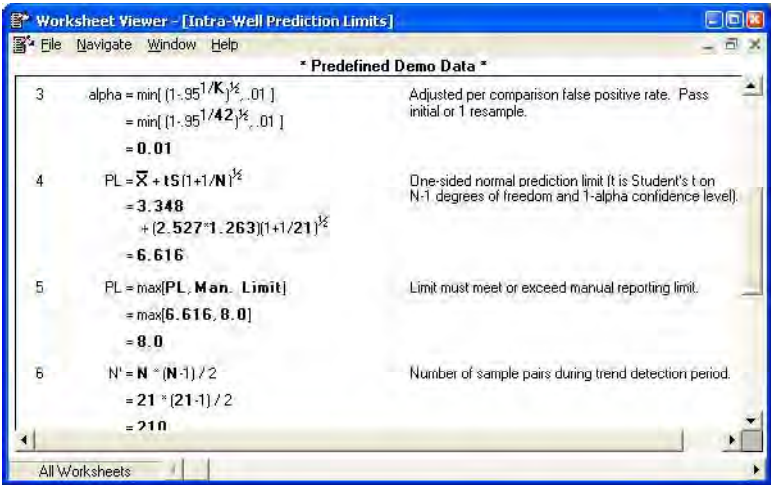


Figure 9

The default setting is unchecked to preserve consistency with previous versions.

### Show J/Trace Values in Data Summaries and Time Series

See "Show J/Trace Values in Data Summary and Time Series" on page 42 of the User's Guide.

When 'Show J/Trace Values in Data Summaries and Time Series' is checked the Analytical Data Summary table displays both the Limit and the Result values of a nondetect sample that has a non-zero Result value that is different from its Limit.

*Example: <1.0 .35J will be displayed for a nondetect TOC sample at GW-10 on 7/11/1989 that has a reporting limit of 1.0 and a result of .35. See Fig. 11.*

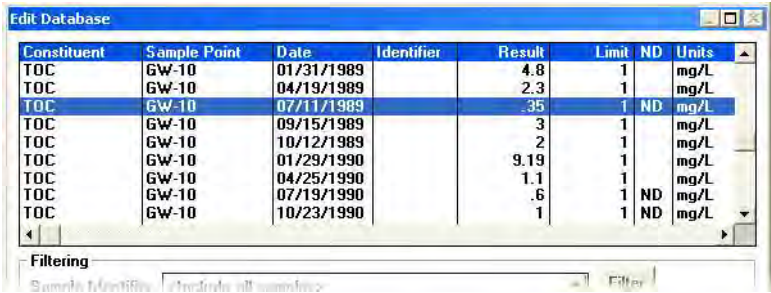


Figure 10

Table Viewer - [Analytical Data Summary]

File Navigate Window Help

\* Predefined Demo Data \*


Table 5

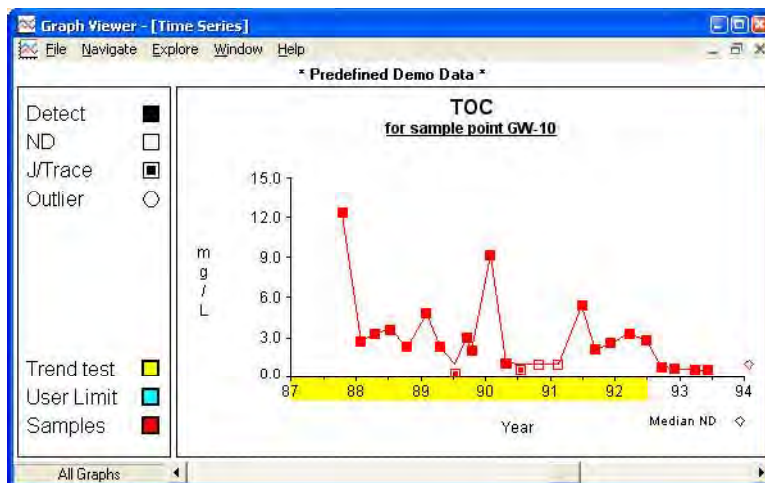
Analytical Data Summary for TOC (mg/L)

Dates	AIR07	GW-10	GW-18	SW-01	SW-02	S
4/19/1989 - 4/20/1989		2.30		7.15		
7/10/1989 - 7/11/1989		<1.00 .35J				
9/13/1989 - 9/14/1989						
9/14/1989 - 9/15/1989		3.00				
10/10/1989						
10/12/1989 - 10/13/1989		2.00				
10/16/1989 - 10/17/1989						
1/29/1990 - 1/30/1990		9.19			2.72	
4/24/1990 - 4/25/1990		1.10			3.10	
7/19/1990		<1.00 .60J				
7/23/1990 - 7/24/1990			<1.0 .6J			

\* The displayed value is the arithmetic mean of multiple database matches.

**Figure 11**

The Time Series graph displays the J/Trace symbol  at the sample's Result value and the line connecting the samples is drawn through the sample's Limit value.



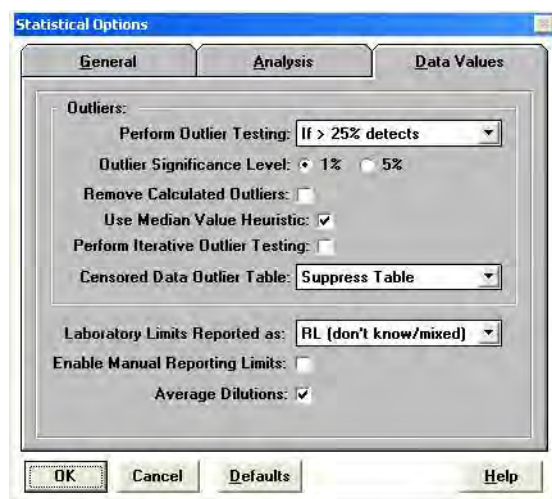
**Figure 12**

The default setting is unchecked to preserve consistency with previous versions.

---

## Data Value Options

The Data Values tab contains settings that specify how samples are treated in the analyses or displayed on the analysis output.



**Figure 13**

### Outlier Significance Level

See "Outlier Significance Level" on page 43 of the *User's Guide*.

Outlier Significance Level allows the selection of 1% or 5% for the significance level used in the Dixon's outlier test. The selected significance level is displayed in the subtitle of the Dixon's Test Outliers table in the Up vs Down and Intra-Well analyses.

The default selection is 1% to preserve consistency with previous versions.

### Remove Calculated Outliers

See "Remove Calculated Outliers" on page 43 of the *User's Guide*.

Remove Calculated Outliers excludes samples identified as outliers from further statistical tests, such as the calculation of a prediction limit.

When unchecked, two additional statistical options become available: Use Median Value Heuristic and Perform Iterative Outlier Testing. Outlier testing is still performed and a report of the samples identified as outliers is provided in the Dixon's Test Outliers table, but these samples are not excluded from statistical tests.

The default setting is checked to preserve consistency with previous versions.

### Use Median Value Heuristic

See "Use Median Value Heuristic" on page 43 of the *User's Guide*.

Use Median Value Heuristic ensures that only Dixon's test outliers that are also greater than or equal to three times the median or less than or equal to a third of the median are treated as calculated outliers.

---

This option can only be unchecked when calculated outliers are not excluded from statistical tests. When unchecked, Dixon's Test Outliers table provides a report of samples that meet the Dixon's outlier test criteria, but do not need to be larger or lower with respect to the median value.

Previously a median value heuristic of 10 was used in the Up vs. Down Prediction Limits analysis.

The default setting is checked to preserve consistency with previous versions. If the Remove Calculated Outliers option is checked the additional median value test is performed regardless of the Use Median Value Heuristic setting.

### Perform Iterative Outlier Testing

See "Perform Iterative Outlier Testing" on page 43 of the *User's Guide*.

When calculated outliers are not excluded from statistical tests, Perform Iterative Outlier Testing causes the Dixon's outlier test to be performed repeatedly on a data set after eliminating the outliers found in each previous test instance. Whether the median value heuristic is performed as part of this test depends on the Use Median Value Heuristic selection.

The default setting is unchecked to preserve consistency with previous versions. If the Remove Calculated Outliers option is checked outlier testing is performed only once regardless of the Perform Iterative Outlier Testing setting.

### Censored Data Outlier Table

See "Censored Data Outlier Table" on page 44 of the *User's Guide*.

When Show All Results or Show Relevant Only is selected, an additional test is performed to identify potential outliers in data sets that are comprised of 75% or more nondetects as per the Ohio Environmental Protection Agency's guidance. The potential outliers identified by this test are reported in the Censored Data Outliers Test table, but are not excluded from statistical tests.

The default setting is Suppress Table to preserve consistency with previous versions.

## Field Codes

See "Field Codes" on page 180 of the *User's Guide*.

The following field codes have been added to help indicate the selection status of several new statistical options in table titles or analysis headers:

- **<TrendEstimator>** – Trend Test Method: 'Sen's Test' or 'Mann-Kendall'
- **<TrendConfLevel>** – Confidence Level: '95%' or '99%'
- **<DixonSigLevel>** – Outlier Significance Level: '1%' or '5%'
- **<GammaPL>** – Use Gamma Prediction Limits: enabled or disabled
- **<ManualOverridesRL>** – Limits must exceed Manual RL

See "Sample Identifiers" on page 25.

The **<ManualOutliers>** field code has become obsolete due to the introduction of Sample Identifiers. If previously in use, it will be evaluated to 'Manual Outliers are now ID specific.'

A new **<TableItem>** field code is evaluated to the 'Base tables on a unique...' selection on the Set Analytical Data Summary Layout dialog.

## Analyses

### Confidence Limits (Assessment)

The Confidence Limits (Assessment) analysis can now be performed on constituents that do not have a standard specified on the Select Assessment Constituents and Standards dialog. This is indicated on the graph through a 'No Standard Supplied' third title line.

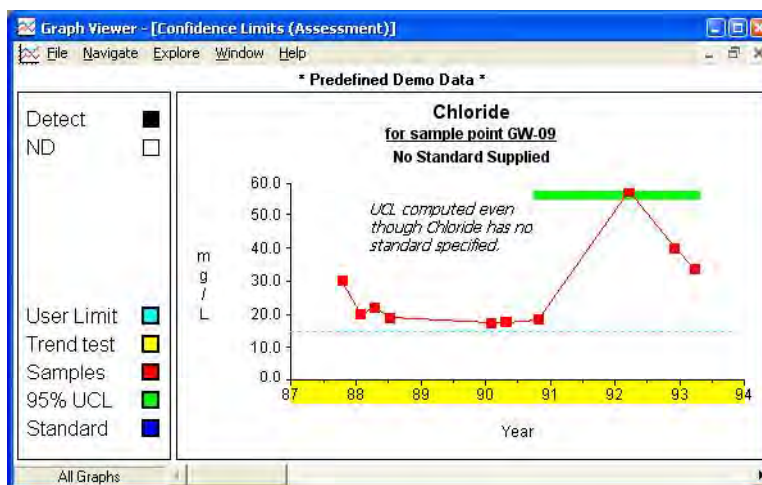


Figure 14

### Intra-Well Control Charts

The title displayed on printed graphs and worksheets has been changed to "Intra-Well Control Charts / Prediction Limits" to account for either a nonparametric prediction limit or a Poisson limit being computed when the detection frequency is less than 25%.

Previously the title was "Intra-Well Control Charts."

---

## Statistical Methods

### Dixon's Outlier Test

See "Outlier Detection" on page 22 of the *Statistical Guide*.

The Dixon's Outlier Test has been modified to analyze all background samples, as opposed to the most recent 25 background samples.

Additional improvements include increased critical value precision and the ability to choose between a 1% and a 5% outlier significance level. Previously a 1% outlier significance level was used.

The results are displayed in a Dixon's Test Outliers table (Fig. 18).

### Censored Data Outlier Testing

See "Censored Data Outlier Testing" on page 23 of the *Statistical Guide*.

The Censored Data Outlier Test was developed as per the Ohio Environmental Protection Agency's guidance, to provide an automated way of performing one of the tests used to identify outliers in data sets that are comprised of 75% or more nondetects.

Whether a detected measurement is identified as a potential outlier by this test depends on:

- the number of detected measurements,
- the percentage of detections above the MDL (Method Detection Limit),
- and the detected sample being either the highest value, or higher than the PQL (Practical Quantitation Limit) by a certain factor.

All the potential outliers found are reported in the Censored Data Outliers Test table (Fig. 19), but are not excluded from other statistical tests.

### Trend Testing

See "Trend Detection" on page 24 of the *Statistical Guide*.

Trend testing has been modified to allow the selection of the trend test method from Sen's or Mann-Kendall, and the confidence level as 95% or 99%. Previously a 99% confidence Sen's test of trend was performed when identifying historical trends.

More detailed information is provided in the worksheets to better illustrate the steps taken in determining whether a trend is significant.

### Sen's Test of Trend

The Sen's Test of Trend was modified to take into consideration the sampling date of each measurement when computing the slope estimate. Previously the slope estimate was based on the order of the measurement within the chronologically sorted set of measurements, and assumed that all measurements were sampled at regular intervals.

### Mann-Kendall Test

The Mann-Kendall test was developed as per methodology described in Statistical Methods for Groundwater Monitoring by Robert D. Gibbons.

---

## Gamma Prediction Limits

See “Gamma Prediction Limits” on page 26 of the *Statistical Guide*.

The Gamma Prediction Limits test was developed as per methodology described in “Simultaneous Gamma Prediction Limits for Ground Water Monitoring Applications” by Robert D. Gibbons and Dulal K. Bhaumik. It provides a more statistically powerful alternative to the normal, lognormal and nonparametric approaches commonly used, in those cases where the data are not normally distributed.

Gamma prediction limits are remarkably robust to censoring of the data based on limits of detection, and the use of the gamma distribution permits association between the mean and variance of the distribution, a phenomenon commonly observed in practice. Furthermore, the gamma distribution permits analysis of skewed distributions, only some of which were previously amenable to computation based on a lognormal assumption.

Gamma Prediction Limits can be computed in the following analyses:

- Up vs. Down Prediction Limits and Power
- Intra-Well Control Charts, Sublist and Power for those comparisons where the detection frequency is less than 25%
- Intra-Well Prediction Limits, Sublist and Power

## Nonparametric Prediction Limits

See “Nonparametric Prediction Limits” on page 27 of the *Statistical Guide*.

When the background period consists entirely of nondetected samples (*i.e.*, 100% NDs), a detected sample in the monitoring period that has a Result value equal to the nonparametric prediction limit will be flagged as an exceedance.

## Graph Viewer

### New Options

See “Vertical Offset” on page 182 of the *User's Guide*.

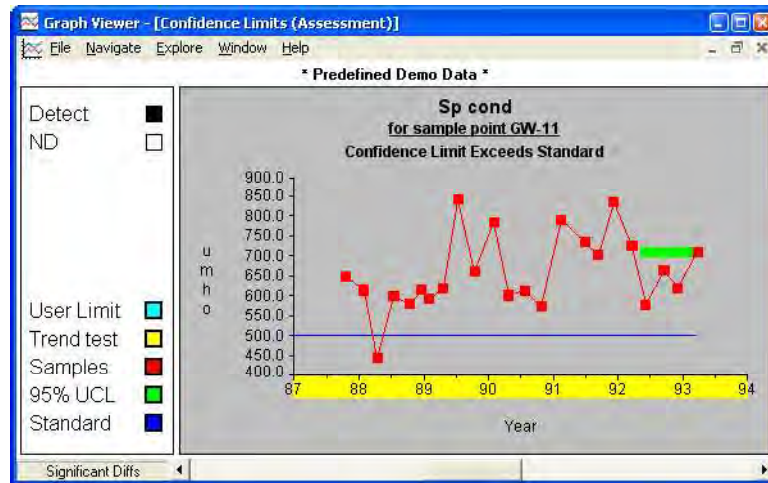
### Vertical Axis Offset

Vertical Axis Offset specifies where the vertical axis starts when displaying or printing a graph that uses linear vertical scaling. The selections available are Fixed at 0, Floating and Auto. When Floating, the vertical axis starts and ends such that all data are included for the current graph, with minimal blank space at the bottom and top. This is useful for data sets comprised of large closely related values.



---

In the graph below, the vertical axis starts at 400 instead of 0, just below the lowest sample value. This results in a clearer picture of all the samples and their relation to the standard and confidence limit, rather than having them all compressed in the top half of a 0 to 1000 vertical axis.



**Figure 15**

Vertical Axis Offset can be found on the Graph Viewer's File menu and on the Page Layout dialog.

### Order By

See "Order By" on page 143 of the *User's Guide*.

The graphs produced by a specific analysis can be ordered by Constituent or Sample Point from within the Graph Viewer without having to re-run that analysis. Previously this change could only be made through the Sorting Order of Output setting on the Statistical Options dialog, but the analysis had to be performed again in order for the change to be reflected in the output.

Order By can be found on the Graph Viewer's Navigate menu.

### Export Current Graph

See "Export Current Graph" on page 140 of the *User's Guide*.

Export Current Graph saves the current graph in the Windows Metafile (\*.wmf) graphics file format. The saved file can be imported into other applications such as word processors or presentation programs.

Export Current Graph can be found on the Graph Viewer's File menu.

### Copy to Clipboard

See "Copy to Clipboard" on page 140 of the *User's Guide*.

Copy to Clipboard allows the pasting of an image of the current graph into other applications such as word processors, presentation or image editing programs.

Copy to Clipboard can be found on the Graph Viewer's File menu.

---

See "Page Layout" on page 137 of the *User's Guide*.

### Symbol Size

Symbol Size on the Page Layout dialog allows customization of printed output.

See "Page Layout" on page 137 of the *User's Guide*.

### Line Thickness

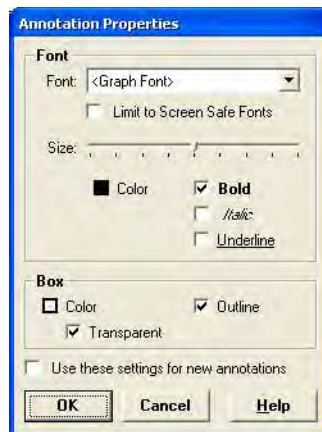
Line Thickness on the Page Layout dialog allows customization of printed output.

See "Annotations" on page 143 of the *User's Guide*.

### Annotations

Annotations provide a way to display and print customizable text notes on graphs. They can be edited, moved, resized, brought to front or sent to back, and deleted from a particular graph.

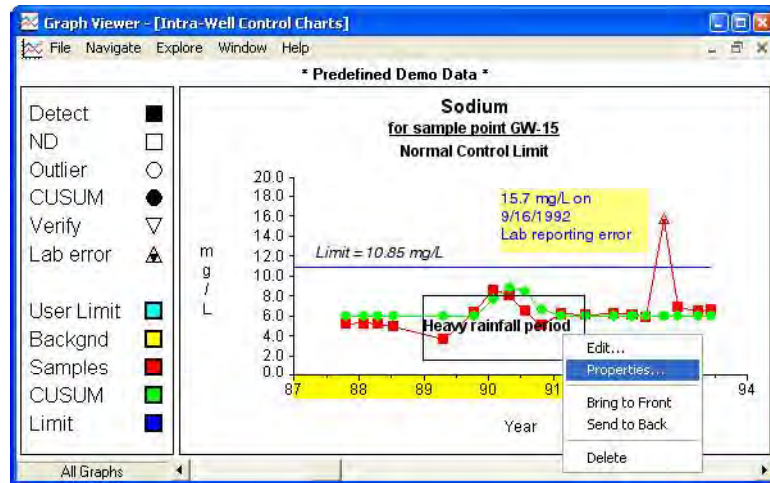
Properties such as font, font size, color and style, and box outline, background color and transparency can also be configured for a specific annotation on the Annotation Properties dialog, and used as default settings for all future annotations added.



**Figure 16**

In Fig. 17, the following three annotations were added, each with different display properties:

- Limit - Helvetica Italic font, transparent box without an outline
- Lab error - Helvetica blue font, light yellow box without an outline
- Rainfall - Bold <Graph font>, transparent box with outline



**Figure 17**

Annotations are saved for the current analysis, constituent and sample point, so that even if the Graph Viewer is closed, the analysis is performed again, or the associated constituent or sample point is aliased, the annotations are still present the next time the analysis output file is opened in the Graph Viewer.

## Modifications

### Vertical Axis Override

The vertical axis scaling and offset selected can be overridden for the current graph by clicking anywhere in the label section to the left of the vertical axis. This cycles through the linear fixed at 0, logarithmic and linear floating display modes.

To ensure consistency in display when navigating from the current graph to another, the scaling and offset settings are reset to those selected on the File menu or on the Page Layout dialog.

## New Tables

### Dixon's Test Outliers

Dixon's Test Outliers is a new table produced by the Up vs Down Prediction Limits and Intra-Well analyses. It displays all the samples identified as outliers by the Dixon's test.

Table Viewer - [Up vs. Down Prediction Limits]

\* Predefined Demo Data \*

Table 6

Dixon's Test Outliers  
5% Significance Level

Constituent	Units	Well	Date	Result	ND Qualifier	Date Range	N	Critical Value
Chloride	mg/L	GW-11	10/16/1987	42.0000		10/16/1987-03/25/1993	23	0.4305
Chloride	mg/L	GW-11	06/27/1991	27.0000		10/16/1987-03/25/1993	23	0.4305
Sodium	mg/L	GW-11	10/16/1987	28.0000		10/16/1987-03/25/1993	23	0.4305
Sodium	mg/L	GW-11	01/31/1989	28.0000		10/16/1987-03/25/1993	23	0.4305
Sp cond	umho	GW-10	06/03/1992	1900.0000		10/16/1987-03/24/1993	24	0.4133
Sulfate	mg/L	GW-11	01/30/1990	653.4000		10/16/1987-03/25/1993	23	0.4305
Sulfate	mg/L	GW-11	04/24/1990	357.3000		10/16/1987-03/25/1993	23	0.4305

N = Total number of independent measurements in background at each well.  
Date Range = Dates of the first and last measurements included in background at each well.  
Critical Value depends on the significance level and on N-1 when the two most extreme values are tested or N for the most extreme value.

Figure 18

### Censored Data Outliers Test

Censored Data Outliers Test is a new table produced by the Up vs Down Prediction Limits and Intra-Well analyses. It displays all the samples identified as potential outliers in data sets that are comprised of 75% or more nondetects as per the Ohio Environmental Protection Agency's guidance.

Table Viewer - [Up vs. Down Prediction Limits]

\* Predefined Demo Data \*

Table 7

Censored Data Outliers Test  
for datasets with 75% or more NDs

Constituent	Result	Detects	N	% > PQL	% > MDL	Manual RL	Median	> Med	> 2x	> 3x	Highest
Toluene	6.5000	3	24	13	13	yes	6.0000	yes	no	no	no
Toluene	7.8000	3	24	13	13	yes	6.0000	yes	no	no	no
Toluene	9.2000	3	24	13	13	yes	6.0000	yes	no	no	yes

(tiled test - potential outlier)  
Potential outliers are not removed from statistical analyses:  
> Med - indicates if the result is greater than the median value  
> 2x - indicates if the result is greater than 2 x the median value  
> 3x - indicates if the result is greater than 3 x the median value  
Highest - indicates if the result is the highest value in background for that well and constituent.

Figure 19

### Analytical Data and CUSUM Summary

Analytical Data and CUSUM Summary is a new table produced by the Intra-Well Control Charts and Intra-Well Sublist Control Charts analyses. It displays a detailed report of all the samples and their associated CUSUM values for each constituent and sample point pair, indicating which samples are outliers, in background, or nondetect values replaced by either the median or the manual reporting limit.

---

## Table Improvements

### Summary Statistics

The following columns were added to the ‘Summary Statistics and Intermediate Computations for Combined Shewart-CUSUM Control Charts’ and the ‘Summary Statistics and Intermediate Computations for Intra-Well Prediction Limits’ tables:

- N(back) – non-outlier measurements in the background period
- N(mon) – non-outlier measurements in the monitoring period
- N(tot) – all independent measurements, including outliers
- R(i-1) and R(i) – the result values of the two most recent samples
- Conf – confidence level for a nonparametric limit

See “Prediction Limit Alpha” on page 39 of the *User’s Guide*.

A new column, alpha – indicating the false positive rate, was added to the ‘Summary Statistics and Prediction Limits’ and the ‘Summary Statistics and Intermediate Computations for Intra-Well Prediction Limits’ tables.

### Analytical Data Summary

Values are displayed using only the required number of decimal places for a constituent and well pair over the entire range of dates, instead of the automatic four decimal places previously used. This greatly improves clarity and saves space when both viewing and printing the Analytical Data Summary table.

The table size can be additionally reduced for both the viewing and printing of tables by choosing to ‘Eliminate blank rows’ and / or ‘Eliminate blank columns’, two new options on the Data Summary Layout dialog, prior to running the Analytical Data Summary analysis.

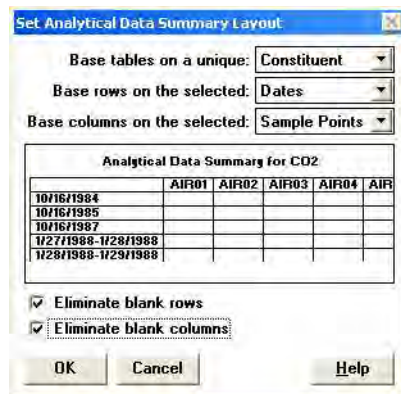
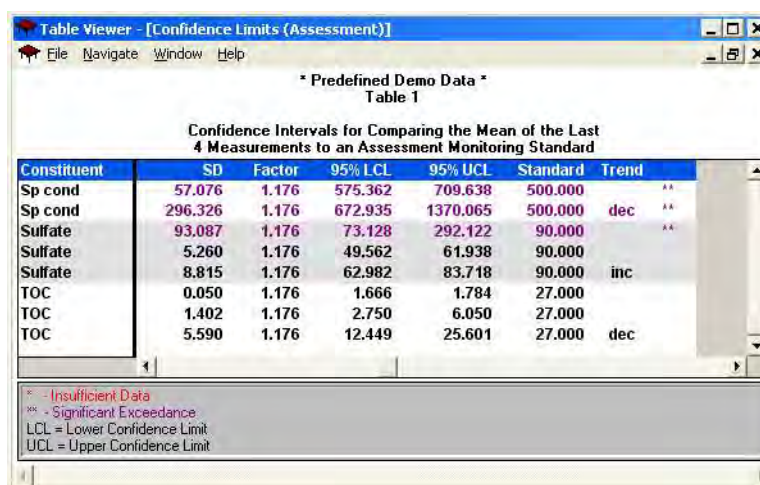


Figure 20

---

## Confidence Limits (Assessment)

A Trend column, indicating the detection of a significantly increasing or decreasing trend, was added to the 'Confidence Intervals for Comparing the Mean of the Last 4 Measurements to an Assessment Monitoring Standard' table. The Trend column is not displayed when the statistical option Identify Historical Trends is unchecked.



Constituent	SD	Factor	95% LCL	95% UCL	Standard	Trend
Sp cond	57.076	1.176	575.362	709.638	500.000	AA
Sp cond	296.326	1.176	672.935	1370.065	500.000	dec AA
Sulfate	93.087	1.176	73.128	292.122	90.000	AA
Sulfate	5.260	1.176	49.562	61.938	90.000	
Sulfate	8.815	1.176	62.982	83.718	90.000	inc
TOC	0.050	1.176	1.666	1.784	27.000	
TOC	1.402	1.176	2.750	6.050	27.000	
TOC	5.590	1.176	12.449	25.601	27.000	dec

\* - Insufficient Data  
\*\* - Significant Exceedance  
LCL = Lower Confidence Limit  
UCL = Upper Confidence Limit

Figure 21

## Historical Downgradient Data

Samples tagged with a Sample Identifier whose Exclude property is checked are flagged as '\*\*\* - Manual exclusion.' in the Up vs. Down Prediction Limits analysis 'Historical Downgradient Data for Constituent-Well Combinations that Failed the Current Statistical Evaluation or are in Verification Resampling Mode' table.

## Table Titles

New customizable table titles were added to the Table Titles tab of the Program Option dialog for the new tables previously outlined.

Analytical Data Summary tables can have the same table number, which is easily configurable through the new 'Set all to ...' checkbox on the Table Titles tab. In addition, their title can be customized as well.

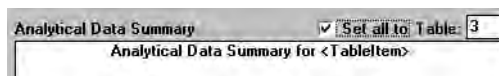


Figure 22

## Site Settings

The Statistical Options table has been updated to include the new options described starting on page 7.

---

## Print Noted Rows Only

Print Noted Rows Only specifies that only rows marked with one or more asterisks (\*) in the last column will be printed.

This option is available from the Print option on the File menu in the Table Viewer and is unchecked by default to preserve consistency with previous versions.

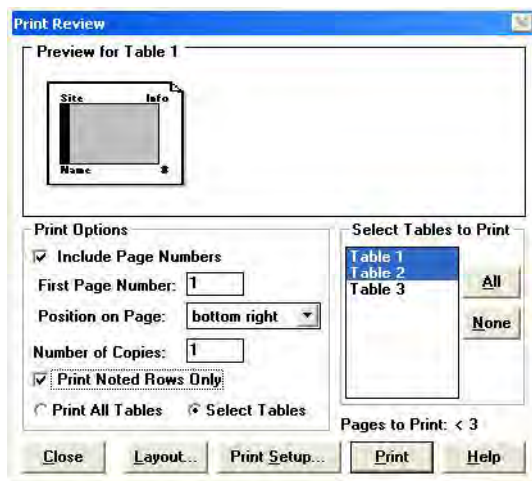


Figure 23

## Worksheets

### Trend Detection

Added intermediate calculations to the trend detection section to provide more detailed information on the trend test method selected, Sen's or Mann-Kendall test, and on the factors taken into consideration when identifying a trend as significant. See Fig. 6 and Fig. 7.

## Database

### Sample Identifiers

See "Set Sample Identifiers" on page 74 of the *User's Guide*.

When adding or editing a record in the analytical database, an identifier can be specified for that particular sample (Fig. 24).



**Edit Database Record**

**Original Values**

Constituent: SODIUM

Sample Point: GW-15 Date: Sep-16-1992

Result: 15.7 Limit: 1 Units: mg/L ND: ☐

Identifier:

**Current Values**

Constituent: SODIUM

Sample Point: GW-15 Date: Sep-16-1992

Result: 15.7 Limit: 1 Units: mg/L ND: ☐

Identifier:

Edit Comment: Manual Outlier  
Lab Error

OK Cancel Help

**Figure 24**

A sample identifier's label, symbol, and whether samples tagged with that identifier are being excluded from statistical tests, can be specified on the Set Sample Identifiers dialog. New sample identifiers can be added to help differentiate samples such as statistically significant increases (SSI) on graphs.

In the example below, a Lab Error identifier was previously added to flag laboratory reporting errors and a Statistically Significant Increase identifier is in the process of being added. All points tagged with an identifier can be excluded or included in the statistical tests. Here, SSI samples are being included.

**Set Sample Identifiers**

Identifier	Label	Symbol	Exclude	Revert
Manual Outlier	Man. outlier		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Lab Error	Lab error		<input checked="" type="checkbox"/>	<input type="checkbox"/>
Stat Sig Increase	SSI		<input type="checkbox"/>	<input type="checkbox"/>

Close Add... Delete Help

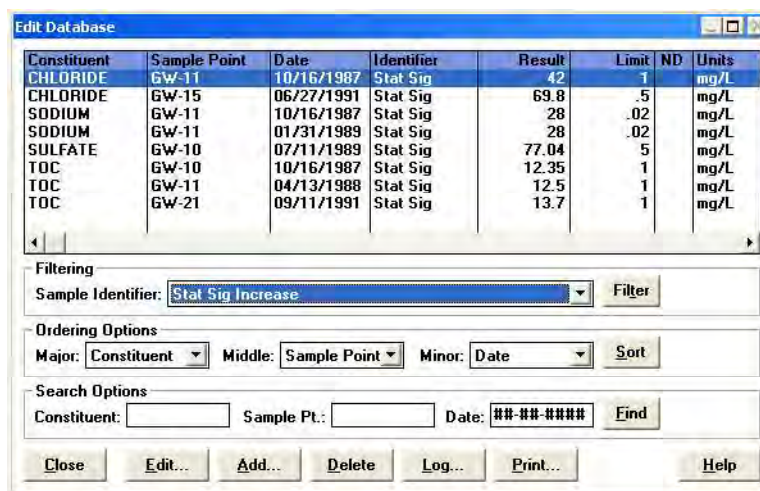
**Figure 25**

See Appendix A for an example of a printed graph that includes a sample flagged as a Statistically Significant Increase.



Samples that have been previously specified as manual outliers in the database will automatically be converted to a Manual Outlier sample identifier. The Manual Outlier identifier label, symbol and statistical test exclusion setting will be initially set to preserve consistency with previous versions, but can be later modified just like any other newly created sample identifiers.

The database records displayed on the Edit Database menu can now be filtered by sample identifier. The Outlier column was replaced by an Identifier column.



**Figure 26**

### Edit / Add Comment

See "Editing Records" on page 71 and "Adding Records" on page 72 of the *User's Guide*.

When editing or adding a record in the database a comment can be entered to provide a brief description of that specific database change. The comment can later be viewed when reviewing database changes on the Edit Database Log dialog.

### Edit Database Log

See "Print / Export Database Changes" on page 73 of the *User's Guide*.

The log of database changes available on the Edit Database dialog can now be printed or exported to a text file. The output can be limited to database modifications, additions and / or deletions.

### Data Merge

Nondetect records with a blank Result and 0 Limit or a 0 Result and blank Limit can be merged into the database.

---

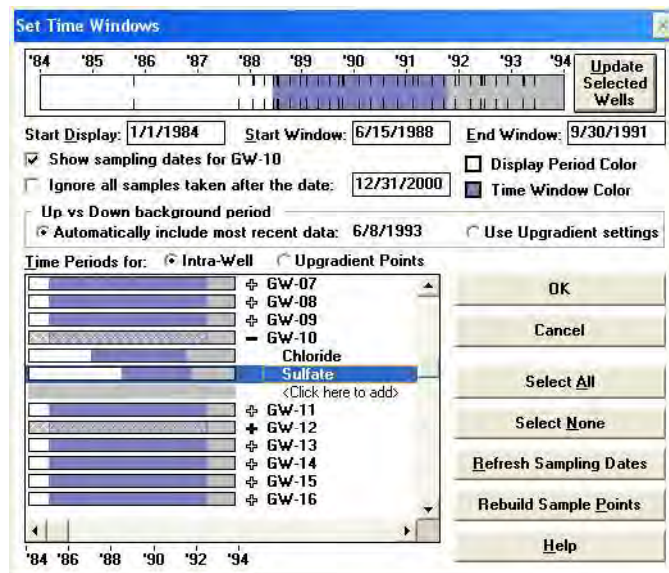
## Time Windows

### Date Changes

All the dates on the Set Time Windows dialog can be specified to include the day and are displayed in the mm/dd/yyyy format. Dates can still be entered in the previous month-only format, and in many other formats as well: *e.g. 3-6-93; 3/6/93; March 27, 1993; Mar 27, 93; 4 April 1993.*

### Per Well Per Constituent

Different Time Windows can be specified for each constituent at a sample point. This is indicated by a plus sign to the left of the sample point name in the Time Periods for Sample Points list. Expanding the plus sign allows the selection of a constituent from a list of available constituents.



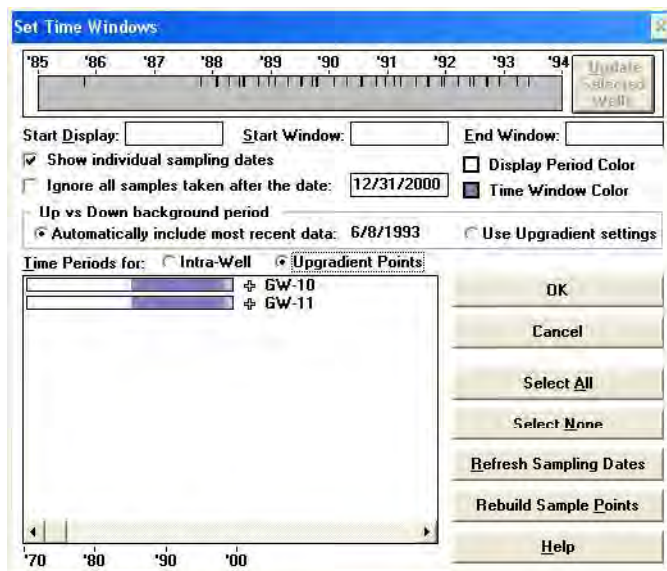
**Figure 27**

Sample Points that have at least one constituent window specified are displayed with a patterned window graphic and a filled-in plus sign.

### Individual Upgradient Time Windows

See "Set Time Windows" on page 97 of the *User's Guide*.

Time Windows can now be specified for individual upgradient wells, with per constituent overrides, instead of using the site-wide Up vs Down time window. The Time Periods for Sample Points list has been divided into two lists: Intra-Well and Upgradient Points (Fig. 28).



**Figure 28**

To preserve consistency with previous versions, all upgradient points are initially set to the previously specified Up vs. Down time window, including any constituent overrides.

## Zones

When working with a zone file, changing any settings on the Set Time Windows dialog results in the addition of ' (altered)' to the zone name displayed in the lower right corner of the main window.

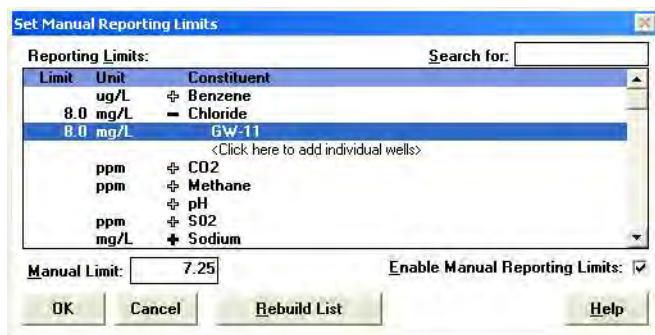
## Manual Reporting Limits

### Per Constituent Per Individual Well

See "Set Manual Reporting Limits" on page 92 of the *User's Guide*.

Different manual reporting limits can be specified for a constituent at each individual well. This is indicated by a plus sign to the left of the constituent name in the Reporting Limits list. Expanding the plus sign allows the selection of a specific well from a list of available wells.

Constituents that have at least one individual well override specified are displayed with a filled-in plus sign.



**Figure 29**

Individual legend markings identify the Median ND and Manual ND on the Surface Water Monitoring and Air Monitoring graphs to allow for the case in which the constituent has a manual reporting limit defined at one of the two wells, but not the other.

## Printing

### Print Setup

On certain versions of Microsoft Windows clicking on OK on the Print Setup dialog even if no changes had been made, caused printing of the analysis output to halt. In some instances graphs could be printed, but nothing happened when trying to print tables. The problem persisted until the default printer was reset from Printers and Faxes under the Control Panel.

This issue has been resolved and Print Setup can be used to view or select the destination printer.

## Miscellaneous

### License Transfer

See "Transfer License" on page 128 of the *User's Guide*.

The software license can be transferred from one computer to another via any type of storage device. Previously the software license could only be transferred via floppy diskette.

### Serial Number

In some cases transferring the software license from one computer to another could result in a modified serial number. This serial number was different from the one originally assigned to that software installation.

This issue has been corrected to prevent the modification of the serial number during the license transfer. Any already modified serial numbers (displayed on the System Information dialog) can be reset by contacting Discerning Systems.

---

## Documentation Updates

The following documentation updates contain references to the appropriate page numbers in the PDF versions of the User's and Statistical Guides. As of version 2.3, these guides are distributed in electronic format only.

### Printing Format

The page size was changed from 7 x 8.5 inches to 8.5 x 11 to allow printing to standard 8.5 x 11 paper.

### Statistical Options

See "Statistical Options" on page 37 of the *User's Guide*.

The Statistical Options section of the User's Guide was updated to reflect the Statistical Options dialog's new tabbed format and options (see "Statistical Options" on page 7).

### Statistical Methods

See "Statistical Methods" on page 22 of the *Statistical Guide*.

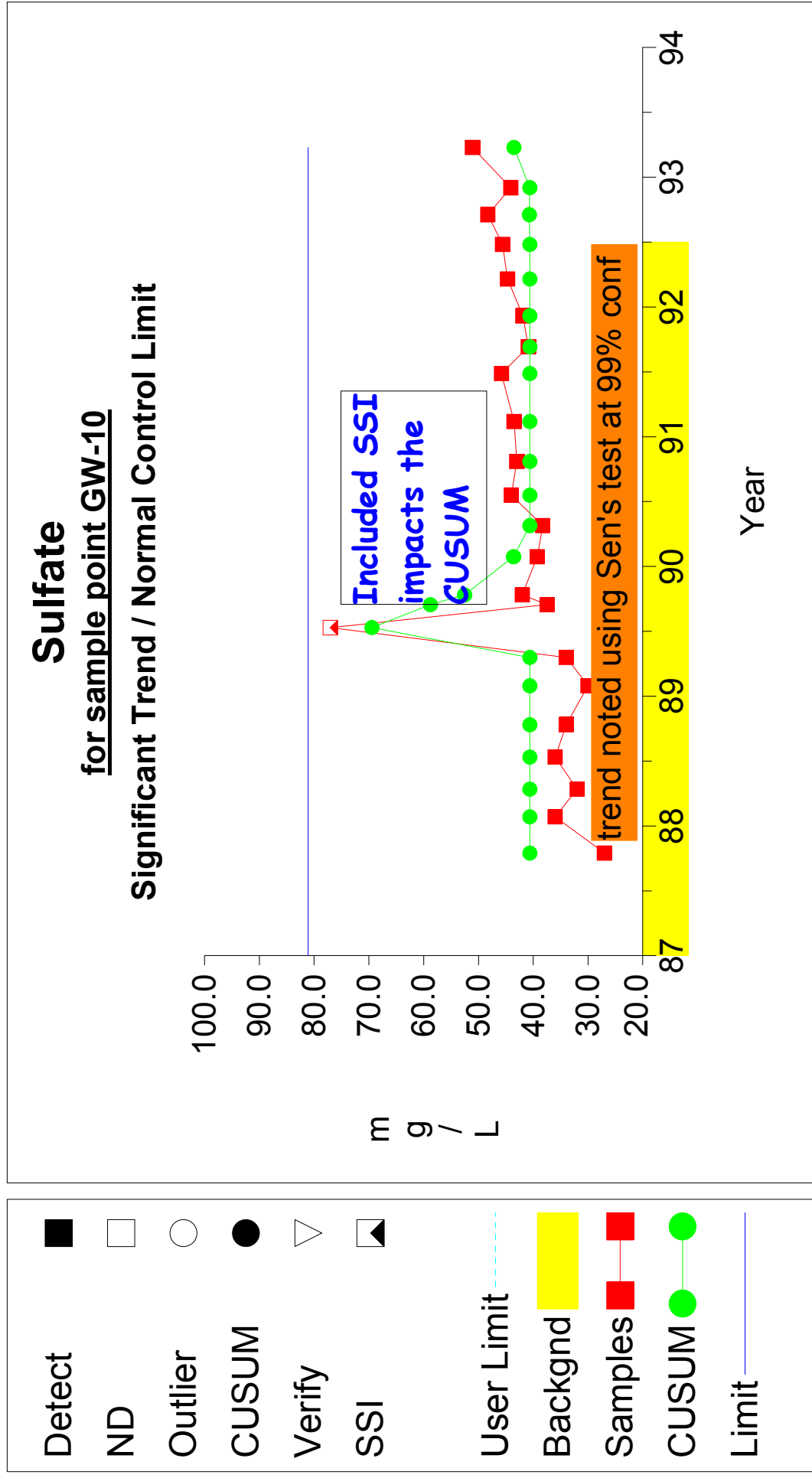
A new Statistical Methods section was added to Chapter 3, Technical Details, of the *Statistical Guide* to provide more detail on how statistical methods such as outlier detection, censored data outlier testing, trend detection, gamma prediction limits and rare event statistics are performed in DUMPStat.

# Appendix A

\* Predefined Demo Data \*

Analysis prepared on: 11/8/2010

## Intra-Well Control Charts / Prediction Limits



Sulfate

for sample point GW-10

Significant Trend / Normal Control Limit

mg / L

100.0

90.0

80.0

70.0

60.0

50.0

40.0

30.0

20.0

87

88

89

90

91

92

93

94

Year

Included SSI impacts the CUSUM

trend noted using Sen's test at 99% conf

Prepared by: Discerning Systems Inc.

1

**Updated Attachment 14 - Background Evaluation Report**  
Redline/Strikeout BER  
Pages Revised BER

**BACKGROUND EVALUATION REPORT  
COMBUSTION BYPRODUCTS LANDFILL  
FAYETTE POWER PROJECT  
LA GRANGE, TEXAS**

October 1, 2024

**REDLINE/STRIKEOUT PAGES**

---

Bullock, Bennett & Associates, LLC  
Engineering and Geoscience  
Registrations: Engineering F-8542, Geoscience 50127  
[www.bbaengineering.com](http://www.bbaengineering.com)





In developing the statistical background, the historical data must be thoroughly screened for anomalous data (too high or too low) due to a sampling error, lab error, transcription error, ~~or shipping error~~, or chance alone other anomalies. An erroneous data point, if not removed prior to the mean and variance computations, would yield a larger control limit thus increasing the false negative rate.

The DUMPStat® program evaluates extreme background values for data sets with at least 25% detections screens for outliers using the Dixon's test. A detected background concentration is defined as an extreme value when a concentration is at least three times (or less than one-third) the median background concentration. DUMPStat® labels a detected background concentration as an outlier when it is defined as an extreme value and it fails the Dixon's test. If the Dixon test indicates an outlier, the value is compared to three times the median concentration of the background data for intrawell analyses. If the value fails both criteria of the two-stage screening, the value is considered a statistical outlier and will not be used in the mean and variance determinations. Anomalous detected data identified by DUMPStat® as described above will still be plotted on the graphs (with a unique symbol) but will not be included in the calculations.

Additionally, data can be manually designated as an outlier if the statistician has a justifiable reason. The outlier data, either statistically detected or manually selected, will be graphically displayed (with a unique symbol) but not included in background calculations.

Note, as the Unified Guidance (EPA, 2009) document suggests, the Dixon's test should not be utilized for nonparametric data.

In the case of non-parametric data the Dixon's test should not be used. The DUMPStat program's default approach for data sets with less than 25 datapoints is to first run Dixon's Test. If the results are flagged as potential outliers, then the suspect outlier results are compared to three times the median value. However, as stated in the USEPA document Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance (EPA, 2009), the Dixon's test performance can suffer when more than 50% of the data are non-detects" and "the guidance generally recommends non-parametric options when non-detect data exceed 50%." Unified Guidance Section 15.6)

The verification resample plan is an integral function of the statistical plan to reduce the probability that anomalous data obtained after the background has been established are indicative of a landfill release. Should a control limit exceedance be identified, the resampling plan is implemented by the operator to collect a verification sample. If the resample data obtained confirm the control limit exceedance, the exceedance is considered statistically significant for parametric data. For non-parametric data, two sampling events are necessary to confirm the SSI.

Statistical background includes all data collected for that well and parameter during the background time period indicated. Resample verification data are considered valid data points. In some cases, an errant data point is replaced with the resample data. In other situations, the resample data confirms the semi-annual data obtained. *Unified Guidance* §5.3.3 and the TCEQ document, *Guidelines for Updating Background Data Sets for Municipal Solid Waste*

### 3. ESTABLISHING BACKGROUND CONCENTRATIONS USING DUMPSTAT

The Appendix III parameter data from wells CBL-301I, CBL-302I, CBL-306I, CBL-308I, and CBL-341I were evaluated using the combined Shewhart-CUSUM control chart method as described above. The background dataset used to determine updated control limits includes data obtained from 2016 through 2022. A summary of the intrawell statistics is included in Attachment C, Table 1 “Summary Statistics and Intermediate Computations for Combined Shewhart-CUSUM Control Charts.” The control charts or time series graphs follow the summary table.

Prior to calculating control limits, the data were screened for outliers as described above.

#### Summary of outliers determined using DUMPstat

Well	Parameter	Result	Date
CBL-301I	Calcium	156	1/17/2019
	Chloride	619	1/17/2019
	Sulfate	104	1/17/2019
	TDS	1460	1/17/2019
<del>CBL-302I</del>	<del>Boron</del>	<del>0.156</del>	<del>10/24/2016</del>
	<del>Boron</del>	<del>0.297</del>	<del>3/22/2017</del>
CBL-306I	Chloride	20.0	5/4/2016
	Fluoride	12.6	3/22/2017
	Sulfate	29.5	5/4/2016
	TDS	431	5/4/2016
CBL-308I	Fluoride	9.05	3/22/2017

Outliers detected by the program are summarized in Table 4: “Dixon's Test Outliers 1% Significance Level” of the statistical report in Attachment C. ~~The boron data points at CBL-302I (0.156 mg/L and 0.297 mg/L) meet the outlier criteria. These data were not previously excluded by ProUCL and were thus retained as valid data by DUMPstat. This Background Evaluation Report does not include these concentrations in the background.~~

Additionally, data can be manually designated as outliers in the opinion of a qualified statistician. Manual outliers were previously assigned to calcium and chloride data points at CBL-306I and a pH data point at CBL-341I. The July 2019 monitoring data at CBL-306I were not used due to an anomaly during sampling. The well was later resampled.

#### Summary of previously defined manual outliers

Well	Parameter	Result	Date
CBL-306I	Boron	0.0824	7/31/2019
	Calcium	47.2	5/4/2016
	Calcium	105	7/26/2016
	Calcium	106	7/31/2019
	Chloride	114	7/26/2016
	Chloride	538	7/31/2019
	Fluoride	9.26	7/31/2019
	pH	6.92	7/31/2019
	Sulfate	816	7/31/2019
	TDS	676	7/31/2019
CBL-341I	pH	5.23	2/23/2017

Outliers are identified using unique symbols whether detected statistically or designated manually. Those data points are not included in the determination of statistical limits.

For cases where the detection frequency for a parameter at a well during background is  $\geq 25\%$ , the control limit is simply defined as:

$$\text{control limit} = (\text{control chart factor})(\text{standard deviation}) + \text{mean}$$

The control chart factor typically ranges from 4.5 to 6.5 for  $N < 12$  and from 4.0 to 6.5 for  $N \geq 12$ . In this case, the control chart factor utilized was 5.0. A statistical power curve indicates the expected false assessments for the site as a whole. The statistical power is a function of the number of wells included, the number of constituents compared, the detection frequencies, and the data distributions involved. For intrawell comparisons, the recommended site-wide false positive rate is 5%. Evaluating and adjusting the factor to achieve false assessment objectives is done each time background is established. Generally, the factor is lowered as background is updated to include more data points.

In addition to comparing the compliance data to background concentrations using a control chart, the Shewhart-CUSUM control chart used provides additional information. The CUSUM portion identifies cumulative increases over time as described in Chapter 20 of the *Unified Guidance*.

Compute the standardized concentration  $Z_i$  for each  $x_i$  after background:

$$Z_i = (x_i - \text{mean}) / \text{standard deviation}$$

use  $Z_i$  to compute the standardized CUSUM  $S_i$ . Set  $S_0 = 0$

$$S_i^* = \max [0, Z_i - k + S_{i-1}]$$

where in this case,  $k = 0.75$ .

The cumulative sum is expressed as:

$$S_i = S_i^* (\text{standard deviation}) + \text{mean}$$

The CUSUM portion of the control chart is compared to the same control limit as was established for the data concentration. The cumulative sum sequentially analyzes each new measurement with prior compliance data.

The only rare events, where the detection frequency was  $< 25\%$ , were for boron at CBL-301I and boron at CBL-302I. Nonparametric prediction limits were used in these cases. In these cases, the use of the Dixon's test for outliers is not recommended.

The background data for each well and analyte are tested for existing trends using Sen's nonparametric estimate of trend. A slight increasing trend was detected in the background data for sulfate at CBL-302I. The trend was evaluated and was determined to be attributed to the initial few rounds of data in 2016-2017. The more recent data do not demonstrate this increase and are not believed to contribute to an artificially high control limit due to the trend. Trends such as this do not preclude the use of intrawell comparisons.

**LOWER COLORADO RIVER AUTHORITY**  
**Austin, Texas**

---

**BACKGROUND EVALUATION REPORT**  
**COMBUSTION BYPRODUCTS LANDFILL**  
**FAYETTE POWER PROJECT**  
**LA GRANGE, TEXAS**

**October 1, 2024**



**Bullock, Bennett & Associates, LLC**  
**Engineering and Geoscience**  
**Registrations: Engineering F-8542, Geoscience 50127**  
**[www.bbaengineering.com](http://www.bbaengineering.com)**



## Table of Contents

1.	INTRODUCTION .....	1
1.1	Background Groundwater Monitoring Program .....	1
2.	STATISTICAL METHODOLOGIES FOR DETECTION MONITORING .....	3
2.1	Intrawell Statistics .....	3
3.	ESTABLISHING BACKGROUND CONCENTRATIONS USING DUMPSTAT ....	5
4.	REFERENCES .....	7

## Attachments

Attachment A: Time Series Graphs

Attachment B: Analytical Data Summary Tables 1-6

Attachment C: Summary Statistics, Raw Data, Calculations, and Control Charts

# 1. INTRODUCTION

This report describes the groundwater data background evaluation conducted at the Lower Colorado River Authority's (LCRA's) Fayette Power Project (FPP) Combustion Byproducts Landfill (CBL) from 2016-2022. The CBL is a coal combustion residuals (CCR) landfill subject to the U.S. Environmental Protection Agency's (EPA's) CCR regulations and the Texas Commission on Environmental Quality's (TCEQ's) CCR registration program. EPA's CCR regulations, also referred to as the "CCR Rule," are codified in 40 CFR Part 257, Subpart D, and have been adopted by TCEQ under Chapter 352 of Title 30 of the Texas Administrative Code (30 TAC Ch. 352).

The uppermost groundwater bearing unit (GWMU) beneath the CBL is identified as the "Intermediate Sand" and is monitored by the CBL's groundwater monitoring system (GWMS), consisting of wells CBL-301I, CBL-302I, CBL-306I, CBL-308I, CBL-340I, and CBL-341I, which are all screened within the Intermediate Sand. The background evaluation, including statistical analysis of background data documented herein, has been conducted as required by 40 CFR § 257.93.

Statistical comparisons and evaluation for statistically significant increases (SSIs) are conducted on all wells with the exception of former background (side-gradient) monitoring well CBL-340I. Based on the Alternative Source Determination (ASD) study conducted in 2018 (Amec Foster Wheeler, April 2018a, and 2018b), the identification of natural aquifer heterogeneity resulted in the determination that CBL-340I could not be reliably used to characterize the background geochemistry of the groundwater flowing beneath the CCR unit. As such, intrawell analysis of wells potentially affected by CCR operations was selected at that time, and the need for use of CBL-340I geochemical data for statistical comparison was negated. A Groundwater Monitoring System Addendum Certification was prepared in 2018 (Amec Foster Wheeler, April 2018c), documenting the transition from former interwell analysis to intrawell analysis.

## 1.1 Background Groundwater Monitoring Program

The CCR Rule went into effect on October 19, 2015, and required the installation, certification and collection of eight independent groundwater samples from each well by October 17, 2017. Although the groundwater monitoring system contained the required number of wells in accordance with 40 CFR § 257.90, an additional well (CBL 341I) was installed late in 2016 and the only way to satisfy the requirement for eight samples by October 2017 was to institute monthly sampling.

Initial background groundwater quality data for wells CBL-301I, CBL-302I, CBL-306I, CBL-308I, and CBL-340I were obtained in 2016 and 2017. Quarterly monitoring is generally accepted for background because the samples are distinct and collected at times to account for seasonal variation. Background groundwater quality data for monitoring well CBL-341I were collected in 2017 at monthly intervals. Given the site hydrogeology data, monthly monitoring is believed to provide sufficiently distinct groundwater at this well. An average horizontal flow velocity of 50 feet per year is equivalent to 4 feet every 30 days, producing a unique water column between events. Groundwater flow rate is not a statistical test and not everything moves in the groundwater at the same speed. Because of this, the monitoring data from each well were tested for independence using the Rank von Neumann Ratio Test as described in *Statistical*

*Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (EPA 530/R-09-007) (“*Unified Guidance*”) §14.2.4. Based on this testing, the data are considered statistically independent.

The conclusion reached after conducting the 2016-2017 background monitoring evaluation was that Intermediate Sand groundwater has not been impacted by a release from the CBL. This finding was also reached at the conclusion of the Affected Property Assessment, and the CBL hydrogeologic study conducted prior to promulgation of the CCR Rule (Amec 2013, 2014). TCEQ reviewed and approved the conclusions reached in both of those reports. The detection monitoring program was implemented in 2018, and sampling frequency transitioned to semiannual monitoring. During the 2018-2020 detection monitoring period, as background evaluation continued, there were trends and uncharacteristic data points reported, which were resolved by conducting an ASD. No SSIs or trends were identified which suggested a CBL release. Some data points were documented as outliers.

Regarding the background assumption of spatial and temporal stationarity, the spatial stationarity component is not considered applicable to intrawell analyses, which was the statistical analysis method adopted in 2018 (Amec Foster Wheeler, April 2018b, and 2018c). The temporal stationarity component is considered addressed after evaluation of the 2016-2020 background data as a whole, showing general consistency with the data obtained.

In January of 2018, box plots were used as a qualitative tool to screen for spatial heterogeneity in the sample data. This analysis suggested spatial heterogeneity within the groundwater monitoring system (Amec Foster Wheeler, January 2018), which was confirmed when the ASD was conducted in 2018 and the system moved to intra-well statistics. Therefore, the continued use of box plots is not necessary or appropriate.

Each of the CBL GWMS groundwater monitoring wells is to be sampled at least semiannually and analyzed for the detection monitoring parameters (also referenced as analytes) listed in Appendix III of 40 CFR Part 257, consisting of: boron, calcium, chloride, fluoride, pH, sulfate, and total dissolved solids (TDS).

Statistical analysis is conducted on data from all GWMS wells with the exception of former background well CBL-340I, as described above. The initial background evaluation conducted in 2017 to meet the October 2017 deadline for GWMS certification was established with the ProUCL software using data collected during the background sampling conducted in 2016 and 2017. This background was used to compute baseline threshold values (BTVs), to which future data were compared. These BTVs were used, with some adjustments, through the 2020 monitoring events.

Monitoring well background datasets must be periodically updated with valid detection monitoring results that are representative of background groundwater quality. Failure to update background datasets will exclude factors such as natural temporal variation, changes in field or laboratory methodologies, and changes in the water table due to meteorological conditions or other influences. Since it has been concluded that there have been no SSIs attributed to releases from the CBL, the background data in this evaluation documented herein include historical data obtained from 2016 through 2022 for wells CBL-301I, CBL-302I, CBL-306I, CBL-308I, and CBL-341I. Historical Appendix III data are summarized in Attachment A. Time series plots of these data are shown in Attachment B.

## 2. STATISTICAL METHODOLOGIES FOR DETECTION MONITORING

The CCR Rule provides several options for evaluating groundwater data [40 CFR 257.93(f)]. As referenced in the *Unified Guidance*, the preferred methods for comparing groundwater data are using either prediction limits or using control charts. The control chart procedure offers an advantage over the prediction limits procedure as more data are generated over time, because the control chart procedure generates a graph of compliance data over time and allows for better identification of long-term trends.

In 2021, an intrawell control chart method was applied to the CBL data using the DUMPStat® statistical program. DUMPStat® is a program for the statistical analysis of groundwater monitoring data using methods described in *Statistical Methods for Groundwater Monitoring* by Dr. Robert D. Gibbons.

The statistical plan is designed to detect a release from the facility at the earliest indication. An intrawell methodology is described and then applied to the FPP data. The statistical method conforms with the CCR Rule (40 CFR Part 257), the *Unified Guidance*, and the American Society for Testing and Materials (ASTM) Standard D 6312-98, *Standard Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs*.

### 2.1 Intrawell Statistics

Intrawell statistics compare new measurements to the historical data at each groundwater monitoring well independently. The *Unified Guidance*-recommended technique for intrawell comparisons is the combined Shewhart-CUSUM control chart. This control chart procedure detects changes in analyte concentrations both in terms of constituent concentration and cumulative concentration increases. This method is also extremely sensitive to sudden and gradual releases. A requirement for constructing these control charts is that the parameter is detected at a frequency greater than or equal to 25%, otherwise the data variance is not properly defined (ASTM D 6312-98).

The combined Shewhart-CUSUM control chart assumes that the data are independent and normally distributed with a fixed mean and a constant variance. Independent data are much more critical than the normality assumption. To achieve independence, it is recommended that data are collected no more frequently than quarterly to account for seasonal variation. The combined Shewhart-CUSUM control chart is robust to deviations from normality. Because the control charts do not use a specific multiplier based on a normal distribution, it is more conservative to assume normality.

Some groundwater monitoring parameters are not detected at a frequency great enough to generate the combined Shewhart-CUSUM control charts. For constituents that are detected less than 25% of the time at a particular well, the data are plotted as a time series until a sufficient number of data points are available to provide a 99% confidence nonparametric prediction limit. Thirteen independent measurements (with 1 resample) are necessary to achieve a 99% confidence (1% false positive rate) nonparametric prediction limit. Eight independent measurements (for pass 1 of 2 resamples) are necessary to achieve a 99% confidence nonparametric prediction limit. The nonparametric prediction limit is the largest determination out of the dataset collected for that well and parameter. If the detection frequency is 0% after thirteen samples have been collected, the reporting limit (practical quantitation limit) becomes the nonparametric prediction limit.



In developing the statistical background, the historical data must be thoroughly screened for anomalous data (too high or too low) due to a sampling error, lab error, transcription error, shipping error, or other anomalies. An erroneous data point, if not removed prior to the mean and variance computations, would yield a larger control limit thus increasing the false negative rate.

The DUMPStat® program evaluates extreme background values for data sets with at least 25% detections using Dixon's test. A detected background concentration is defined as an extreme value when a concentration is at least three times (or less than one-third) the median background concentration. DUMPStat® labels a detected background concentration as an outlier when it is defined as an extreme value, and it fails Dixon's test. Anomalous detected data identified by DUMPStat® as described above will still be plotted on the graphs (with a unique symbol) but will not be included in the calculations.

Additionally, data can be manually designated as an outlier if the statistician has a justifiable reason. The outlier data, either statistically detected or manually selected, will be graphically displayed (with a unique symbol) but not included in background calculations. Note, as the Unified Guidance (EPA, 2009) document suggests, Dixon's test should not be utilized for nonparametric data.

The verification resample plan is an integral function of the statistical plan to reduce the probability that anomalous data obtained after the background has been established are indicative of a landfill release. Should a control limit exceedance be identified, the resampling plan is implemented by the operator to collect a verification sample. If the resample data obtained confirm the control limit exceedance, the exceedance is considered statistically significant for parametric data. For non-parametric data, two sampling events are necessary to confirm the SSI.

Statistical background includes all data collected for that well and parameter during the background time period indicated. Resample verification data are considered valid data points. In some cases, an errant data point is replaced with the resample data. In other situations, the resample data confirms the semi-annual data obtained. *Unified Guidance* §5.3.3 and the TCEQ document, *Guidelines for Updating Background Data Sets for Municipal Solid Waste Groundwater Monitoring*, allow for inclusion of both routine monitoring data and resample verification data in future background sets.

The background data for each well and analyte are tested for existing trends using Sen's nonparametric estimate of trend. As documented in the DUMPStat software manual, a significant trend is one in which the 99% lower confidence bound is greater than zero. In this way, even pre-existing trends in the background dataset will be detected. In large databases, very gradual trends can be statistically significant; however, such trends should not preclude the use of intrawell comparisons.

Background should be updated periodically with data that are representative of background groundwater quality. The frequency that background should be updated is generally considered to be every four events (if semiannual) or every two years (*Unified Guidance*, Chapter 5.3). The procedures used for a background update must be protective of human health and the environment and must comply with the statistical performance standards specified in 30 TAC §330.233(f) and (g). Ongoing operations at a facility such as excavations or drainage control may affect the groundwater flow direction and water quality. An increase in the number of statistical failures, unrelated to the facility, is routinely observed for sites neglecting to update the statistical background with valid data points.

### 3. ESTABLISHING BACKGROUND CONCENTRATIONS USING DUMPSTAT

The Appendix III parameter data from wells CBL-301I, CBL-302I, CBL-306I, CBL-308I, and CBL-341I were evaluated using the combined Shewhart-CUSUM control chart method as described above. The background dataset used to determine updated control limits includes data obtained from 2016 through 2022. A summary of the intrawell statistics is included in Attachment C, Table 1 “Summary Statistics and Intermediate Computations for Combined Shewhart-CUSUM Control Charts.” The control charts or time series graphs follow the summary table.

Prior to calculating control limits, the data were screened for outliers as described above.

#### Summary of outliers determined using DUMPstat

Well	Parameter	Result	Date
CBL-301I	Calcium	156	1/17/2019
	Chloride	619	1/17/2019
	Sulfate	104	1/17/2019
	TDS	1460	1/17/2019
CBL-306I	Chloride	20.0	5/4/2016
	Fluoride	12.6	3/22/2017
	Sulfate	29.5	5/4/2016
	TDS	431	5/4/2016
CBL-308I	Fluoride	9.05	3/22/2017

Outliers detected by the program are summarized in Table 4: “Dixon's Test Outliers 1% Significance Level” of the statistical report in Attachment C.

Additionally, data can be manually designated as outliers in the opinion of a qualified statistician. Manual outliers were previously assigned to calcium and chloride data points at CBL-306I and a pH data point at CBL-341I. The July 2019 monitoring data at CBL-306I were not used due to an anomaly during sampling. The well was later resampled.

#### Summary of previously defined manual outliers

Well	Parameter	Result	Date
CBL-306I	Boron	0.0824	7/31/2019
	Calcium	47.2	5/4/2016
	Calcium	105	7/26/2016
	Calcium	106	7/31/2019
	Chloride	114	7/26/2016
	Chloride	538	7/31/2019
	Fluoride	9.26	7/31/2019
	pH	6.92	7/31/2019
	Sulfate	816	7/31/2019
	TDS	676	7/31/2019
CBL-341I	pH	5.23	2/23/2017

Outliers are identified using unique symbols whether detected statistically or designated manually. Those data points are not included in the determination of statistical limits.

For cases where the detection frequency for a parameter at a well during background is  $\geq 25\%$ ,

the control limit is simply defined as:

$$\text{control limit} = (\text{control chart factor})(\text{standard deviation}) + \text{mean}$$

The control chart factor typically ranges from 4.5 to 6.5 for  $N < 12$  and from 4.0 to 6.5 for  $N \geq 12$ . In this case, the control chart factor utilized was 5.0. A statistical power curve indicates the expected false assessments for the site as a whole. The statistical power is a function of the number of wells included, the number of constituents compared, the detection frequencies, and the data distributions involved. For intrawell comparisons, the recommended site-wide false positive rate is 5%. Evaluating and adjusting the factor to achieve false assessment objectives is done each time background is established. Generally, the factor is lowered as background is updated to include more data points.

In addition to comparing the compliance data to background concentrations using a control chart, the Shewhart-CUSUM control chart used provides additional information. The CUSUM portion identifies cumulative increases over time as described in Chapter 20 of the *Unified Guidance*.

Compute the standardized concentration  $Z_i$  for each  $x_i$  after background:

$$Z_i = (x_i - \text{mean}) / \text{standard deviation}$$

use  $Z_i$  to compute the standardized CUSUM  $S_i$ . Set  $S_0 = 0$

$$S_i^* = \max [0, Z_i - k + S_{i-1}]$$

where in this case,  $k = 0.75$ .

The cumulative sum is expressed as:

$$S_i = S_i^* (\text{standard deviation}) + \text{mean}$$

The CUSUM portion of the control chart is compared to the same control limit as was established for the data concentration. The cumulative sum sequentially analyzes each new measurement with prior compliance data.

The only rare events, where the detection frequency was <25%, were for boron at CBL-301I and boron at CBL-302I. Nonparametric prediction limits were used in these cases.

The background data for each well and analyte are tested for existing trends using Sen's nonparametric estimate of trend. A slight increasing trend was detected in the background data for sulfate at CBL-302I. The trend was evaluated and was determined to be attributed to the initial few rounds of data in 2016-2017. The more recent data do not demonstrate this increase and are not believed to contribute to an artificially high control limit due to the trend. Trends such as this do not preclude the use of intrawell comparisons.

A control chart factor was selected to provide a balance of the site-wide false positive and false negative rates. A statistical power curve indicates the expected false assessments for the site as a whole. The site-wide false positive rate is 3% and the test becomes sensitive to 3 standard deviation units over background.

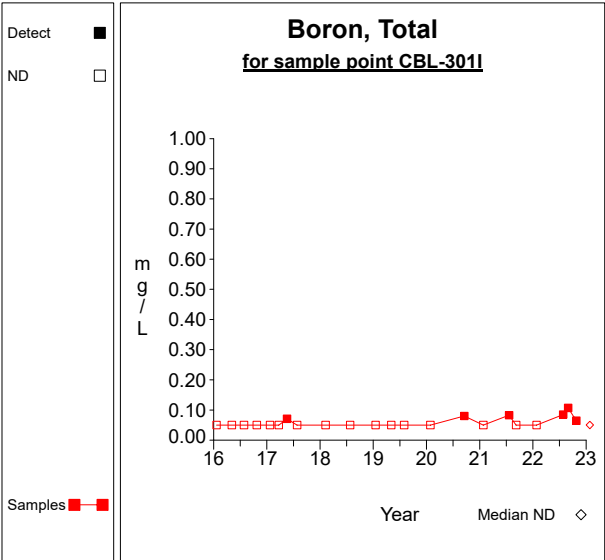
## 4. REFERENCES

- AMEC Environment & Infrastructure, Inc. (December 2013): *Hydrogeologic Evaluation of Combustion Byproducts Landfill (CBL) Area Report, Fayette Power Project*.
- AMEC Environment & Infrastructure, Inc. (March 2014): *Affected Property Assessment Report Supplement, Fayette Power Project, La Grange, Texas*
- Amec Foster Wheeler (October 2017): *Groundwater Sampling and Analysis Program, Selection of Statistical Method Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas*.
- Amec Foster Wheeler (January 2018): *Statistical Analysis of Initial Detection Monitoring Appendix III Constituent Data, Fayette Power Project, La Grange, Texas*.
- Amec Foster Wheeler (April 2018b): *Groundwater Geochemical Evaluation at the Lower Colorado River Authority, Fayette Power Project, La Grange, Texas*.
- Amec Foster Wheeler (April 2018c): *Groundwater Monitoring System, Certification of Alternate Source Demonstration, Lower Colorado River Authority, Coal Combustion Residuals Unit: Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas*.
- Amec Foster Wheeler (April 2018d): *Groundwater Monitoring System Addendum Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas*.
- Bullock, Bennett & Associates (May 2021): *Groundwater Monitoring System Addendum Certification, Lower Colorado River Authority, Coal Combustion Residuals Unit, Combustion Byproducts Landfill, Fayette Power Project, La Grange, Texas*.
- DUMPStat (2003) DUMPStat Statistical Guide, version 2.1.8., by Robert D. Gibbons Ltd., with accompanying DUMPStat 2.3 Release Notes.
- EPA (2009): *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance (EPA 530/R-09-007)*.
- Gibbons, Bhaumik, and Aryal (2009): *Statistical Methods for Groundwater Monitoring, 2<sup>nd</sup> Edition*, 400 pages.

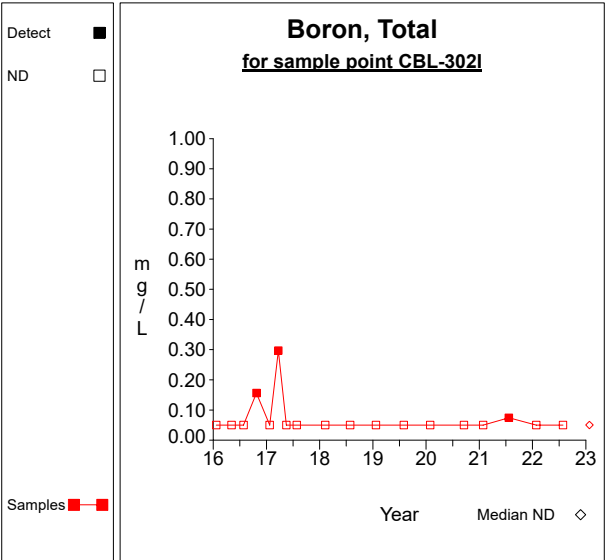
## **Attachment A**

### Time Series Graphs

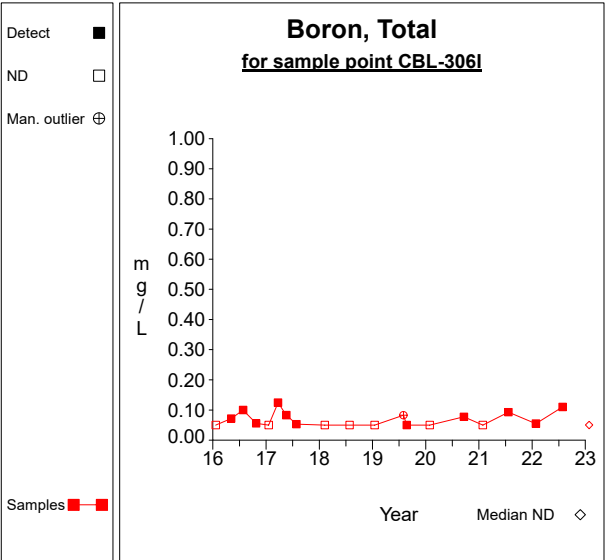
Time Series



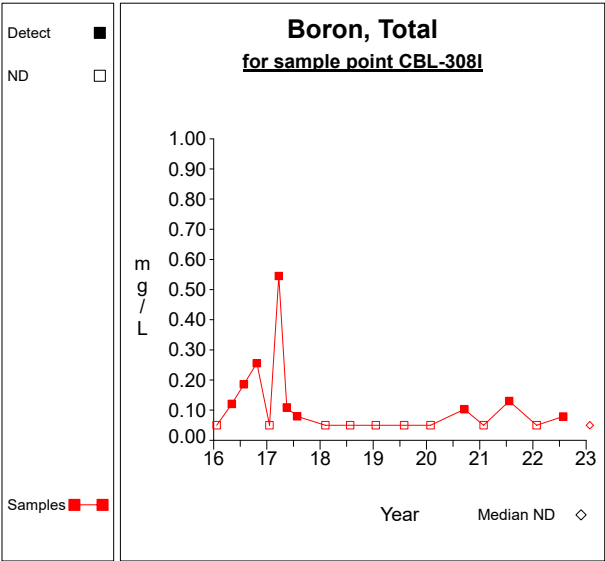
Graph 1



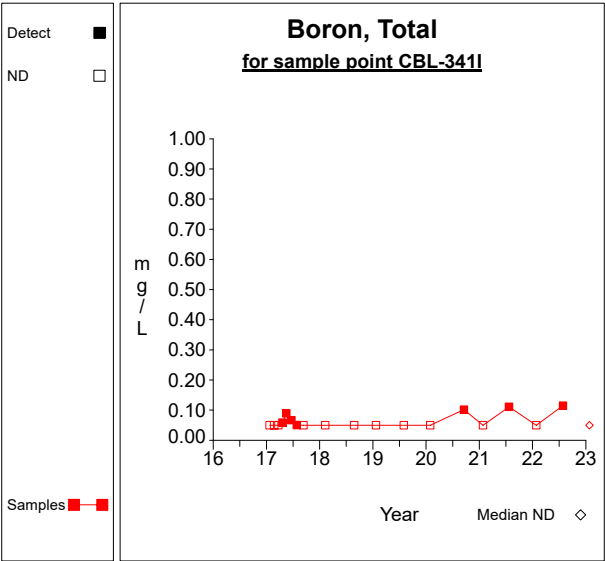
Graph 2



Graph 3

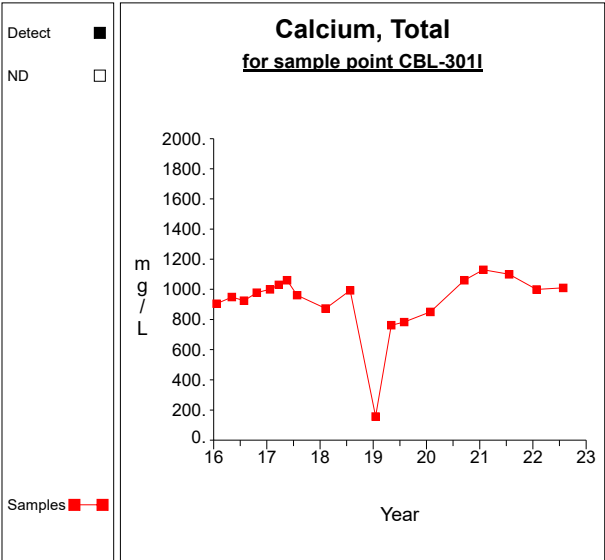


Graph 4

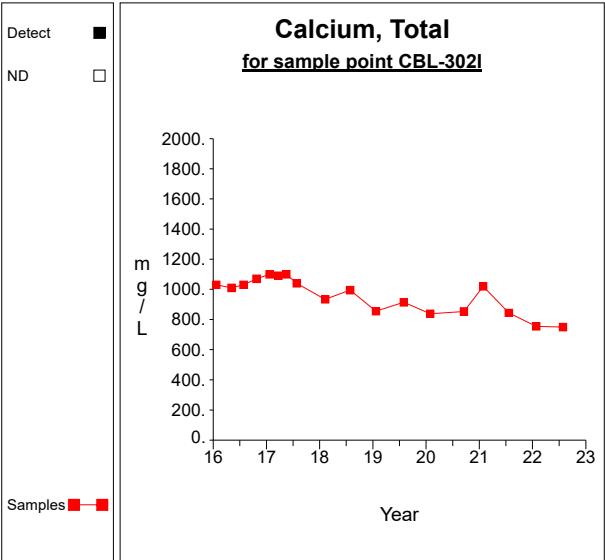


Graph 5

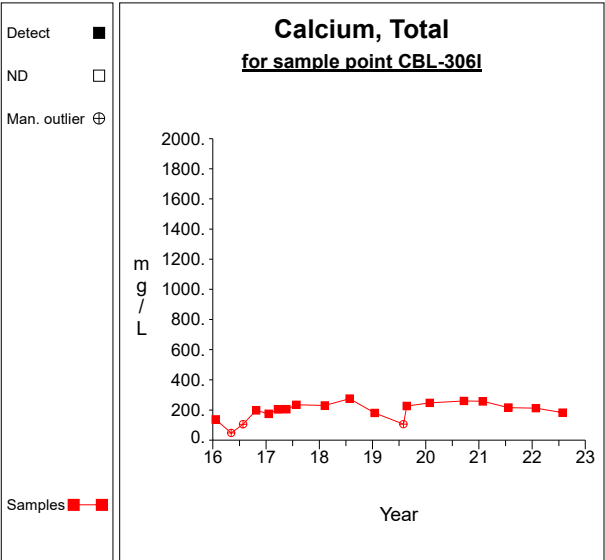
Time Series



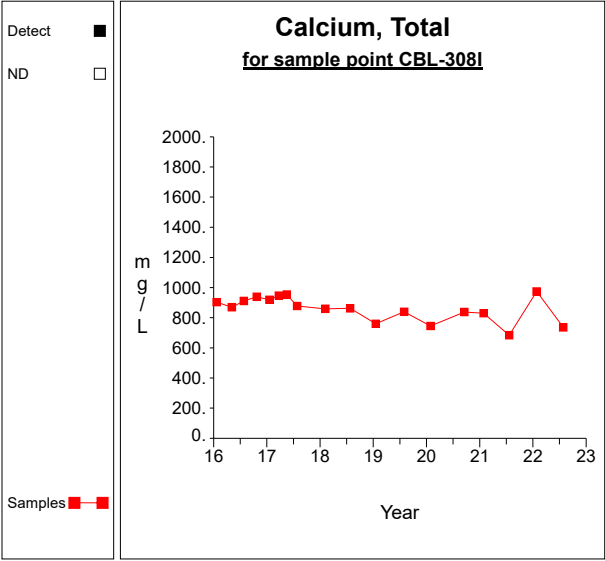
Graph 6



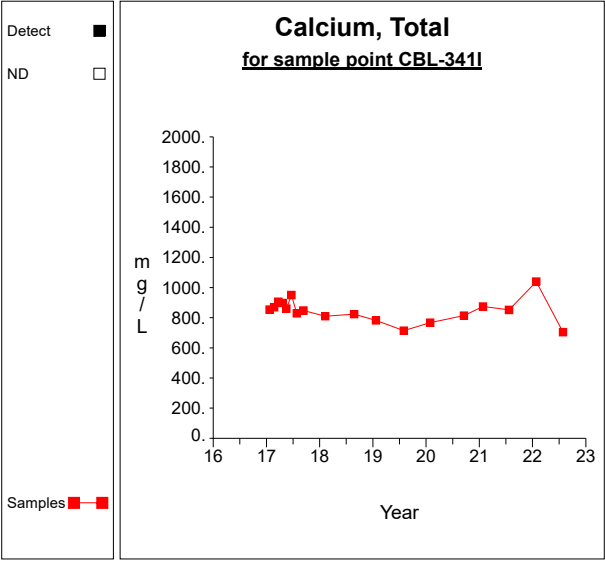
Graph 7



Graph 8

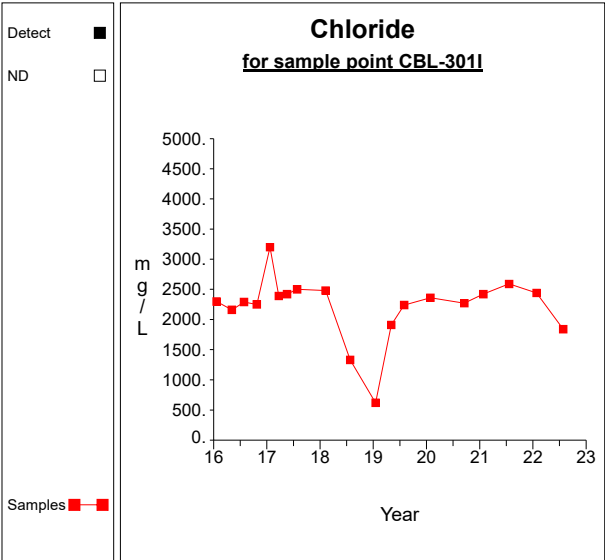


Graph 9

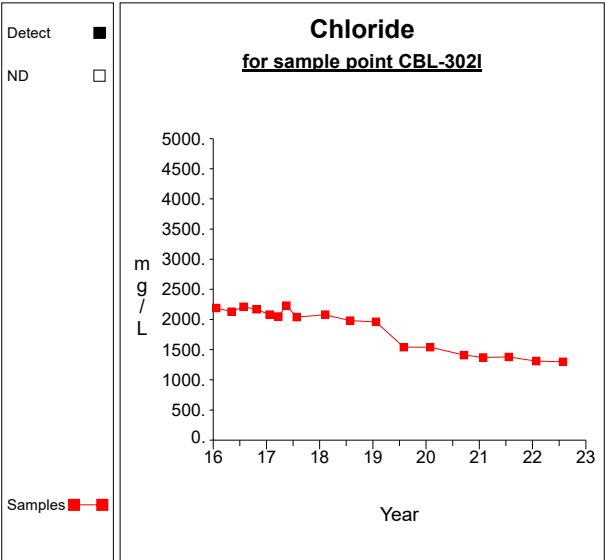


Graph 10

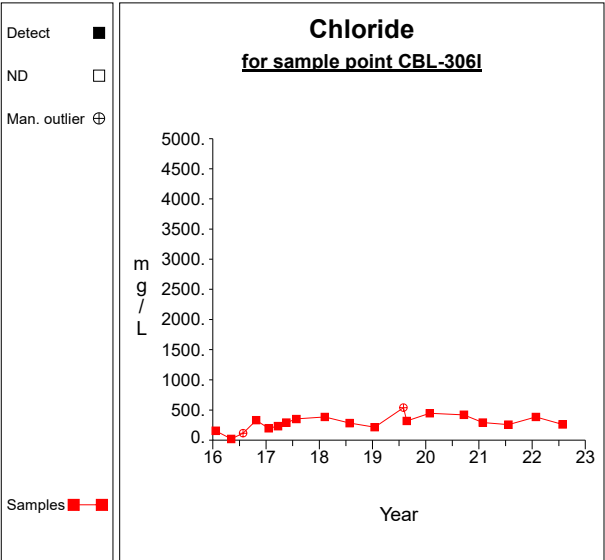
Time Series



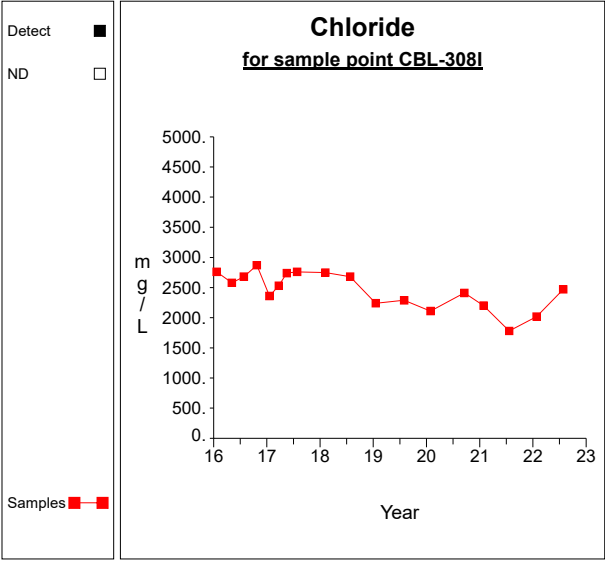
Graph 11



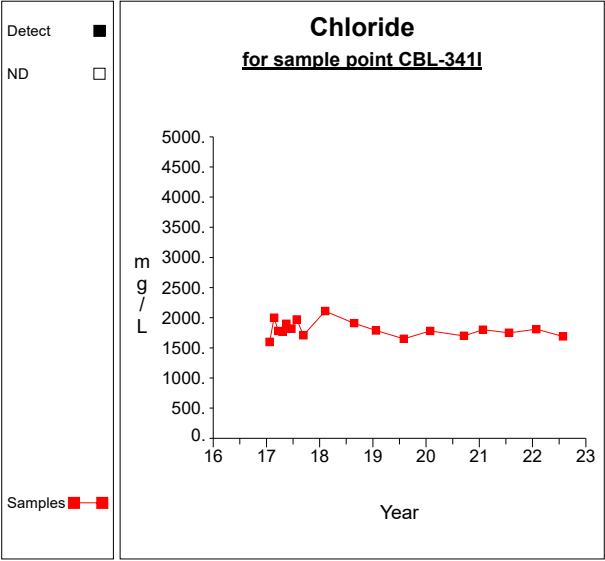
Graph 12



Graph 13



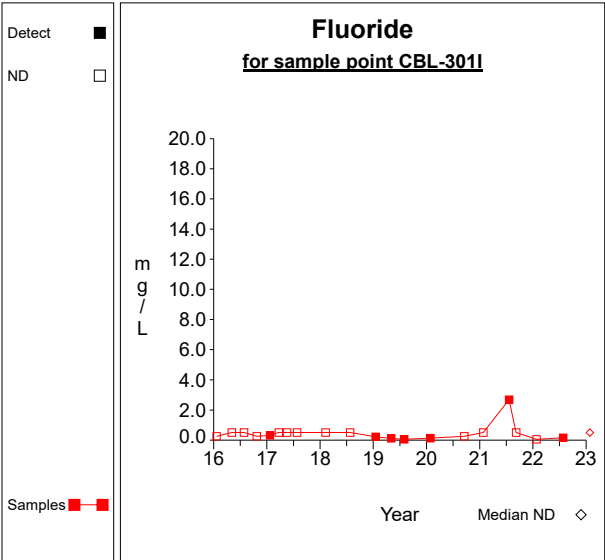
Graph 14



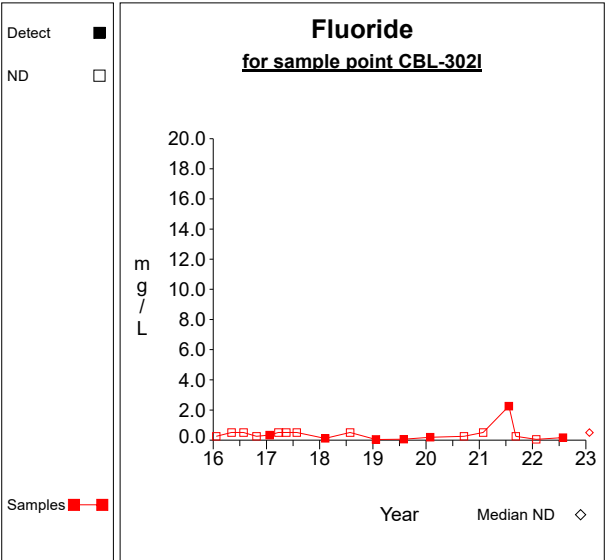
Graph 15



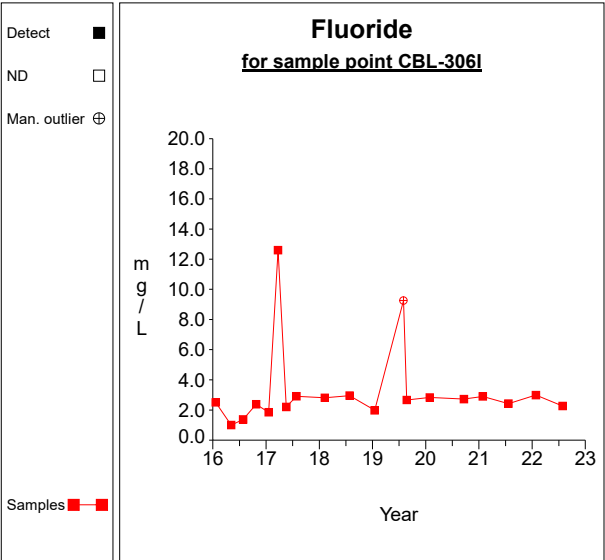
Time Series



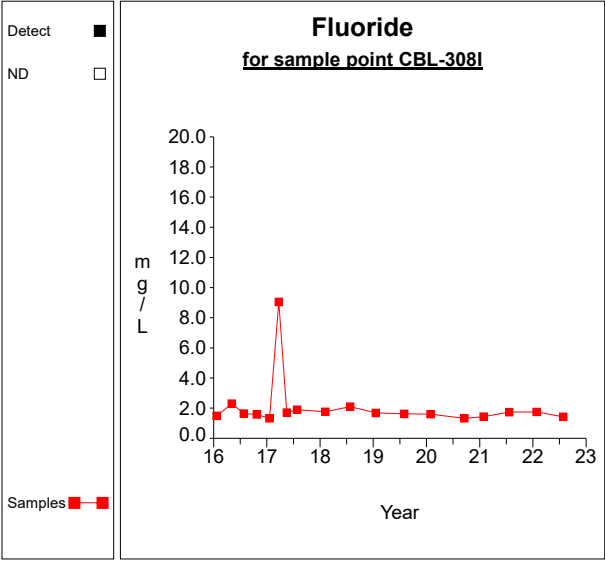
Graph 16



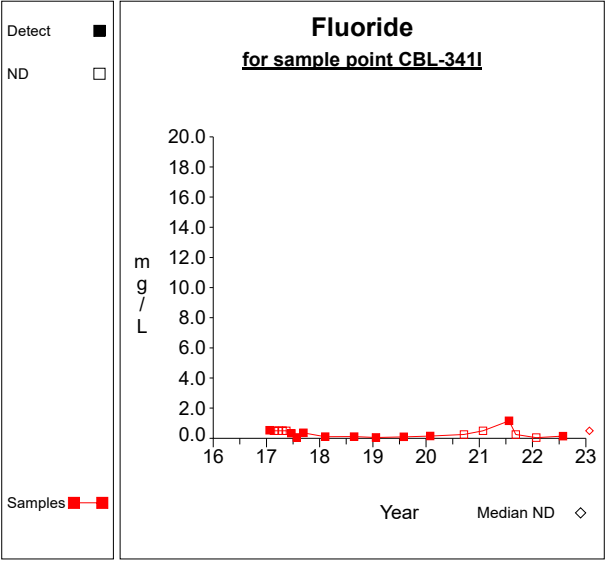
Graph 17



Graph 18

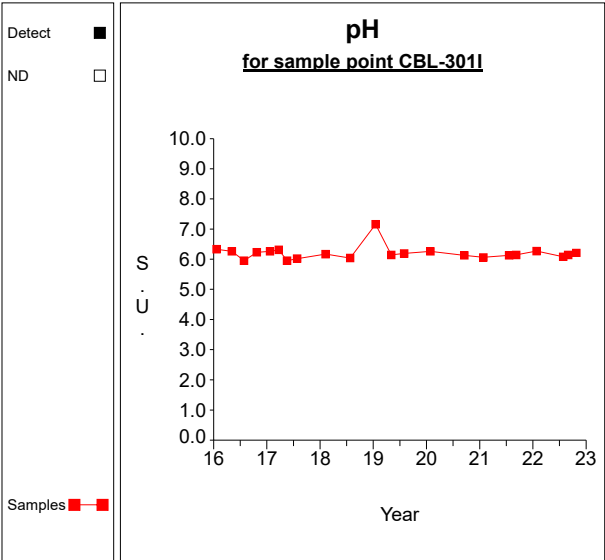


Graph 19

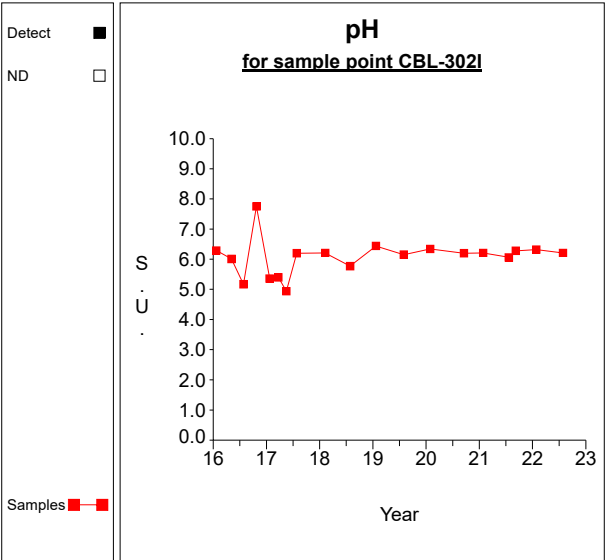


Graph 20

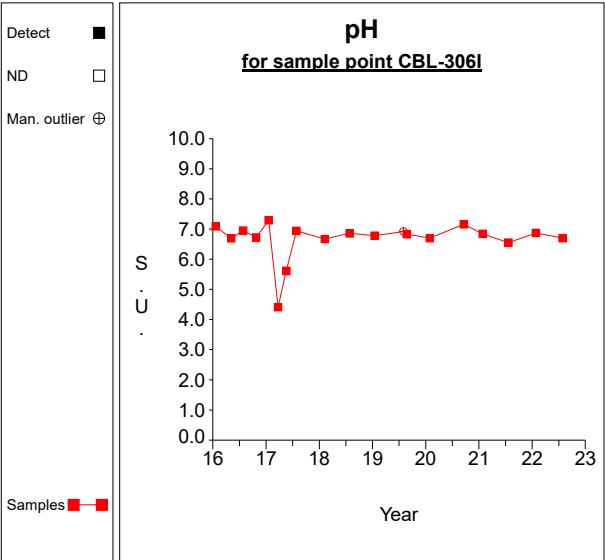
Time Series



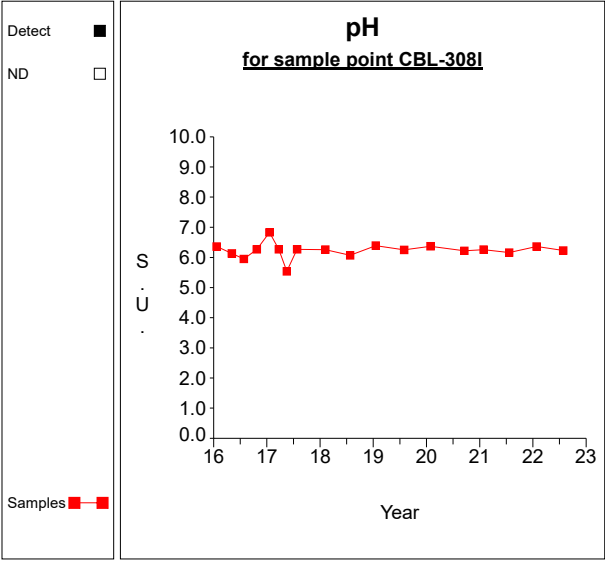
Graph 21



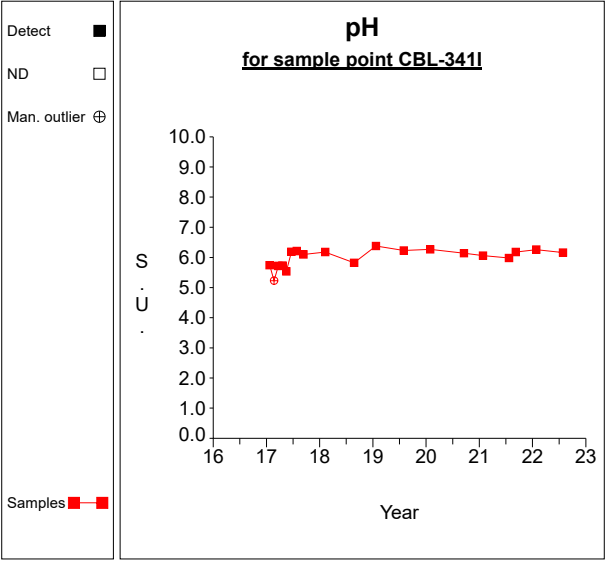
Graph 22



Graph 23

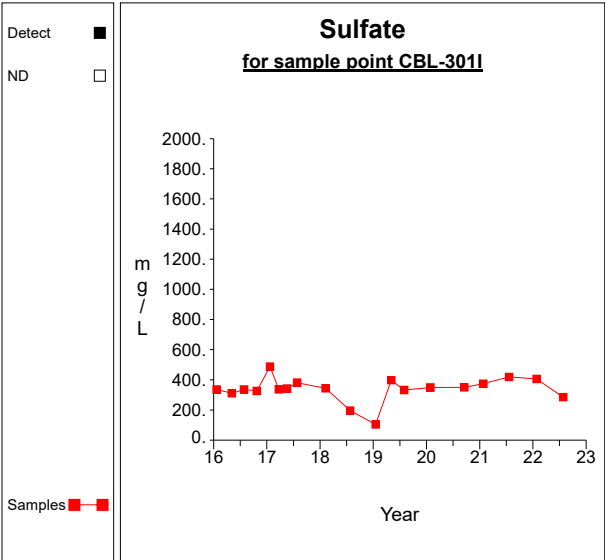


Graph 24

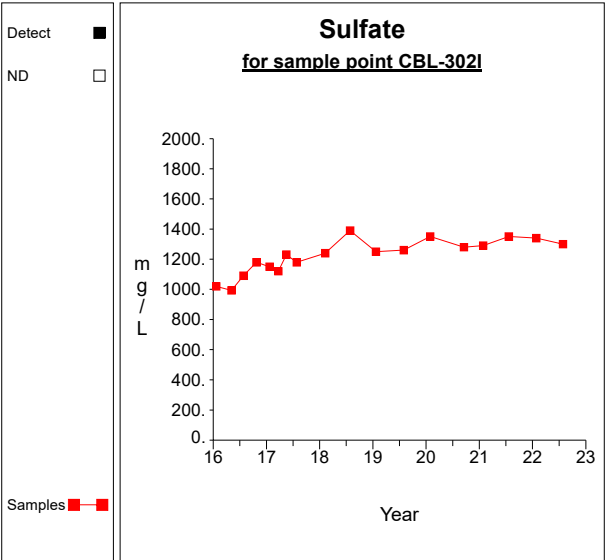


Graph 25

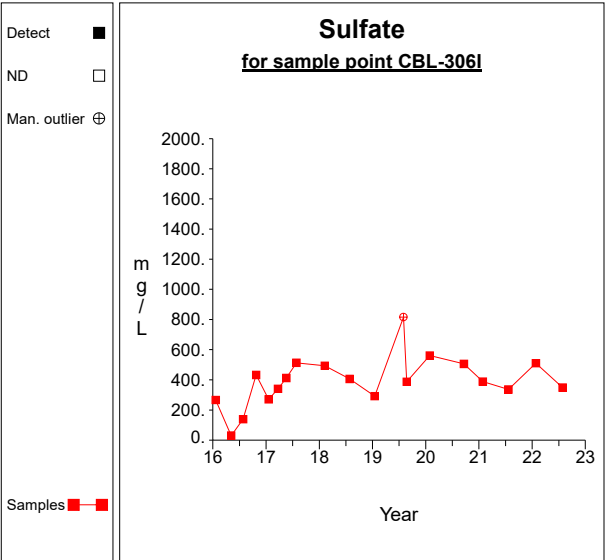
Time Series



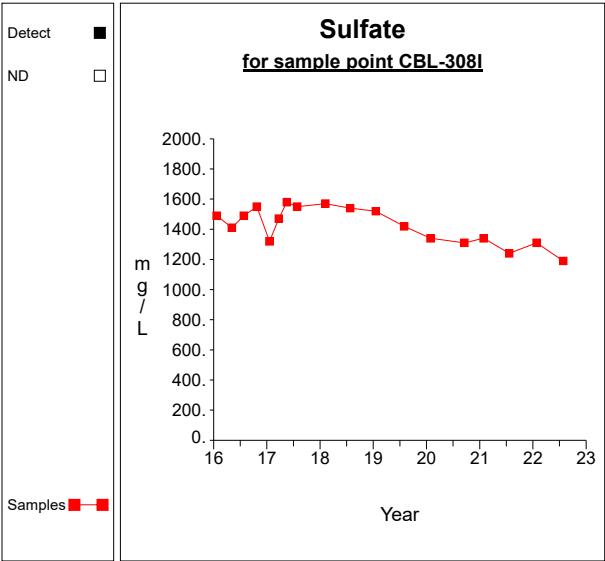
Graph 26



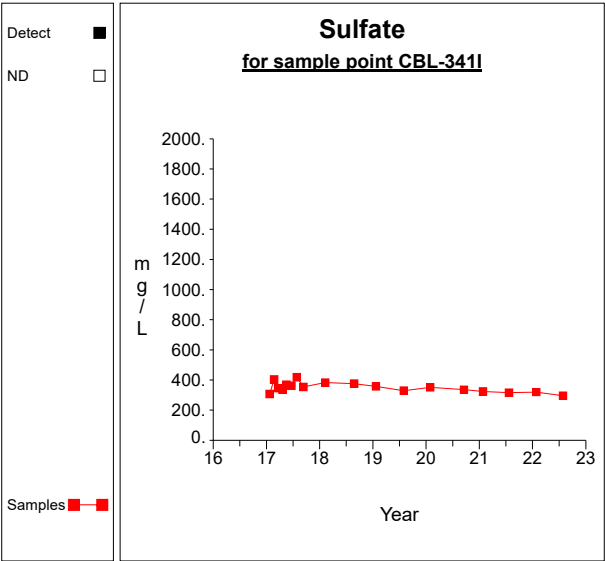
Graph 27



Graph 28

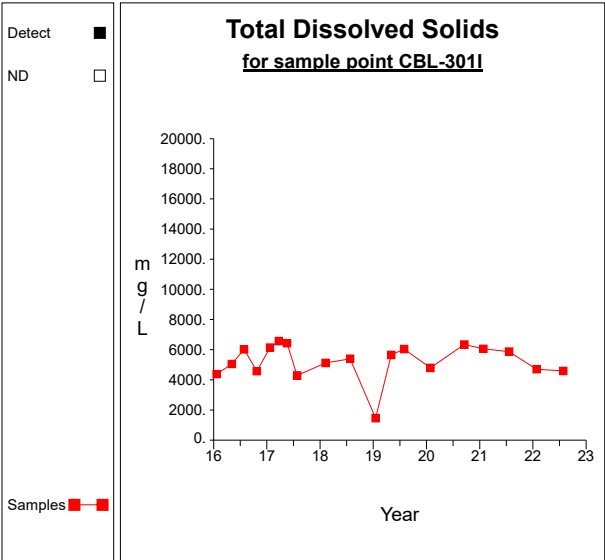


Graph 29

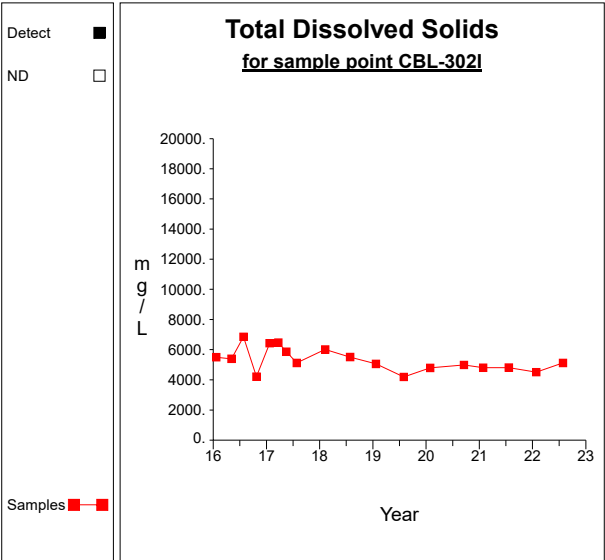


Graph 30

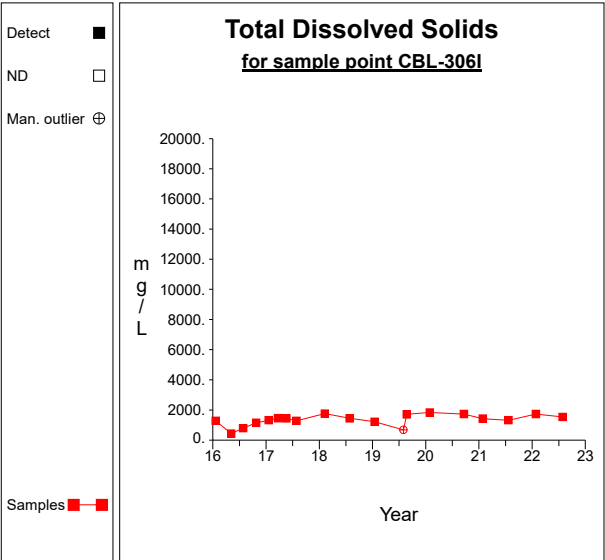
Time Series



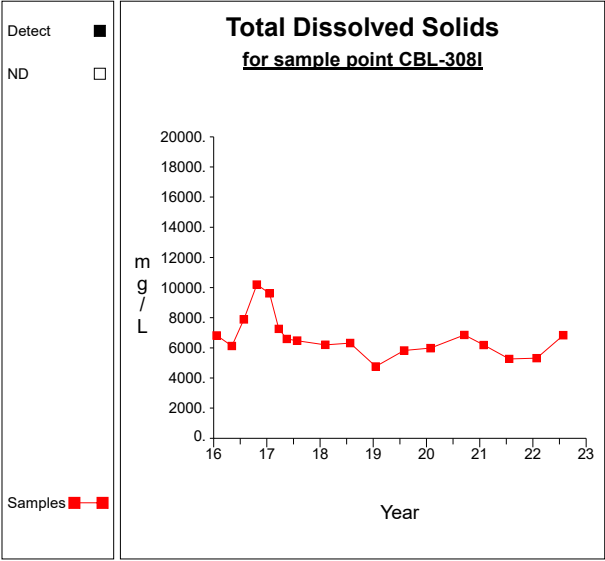
Graph 31



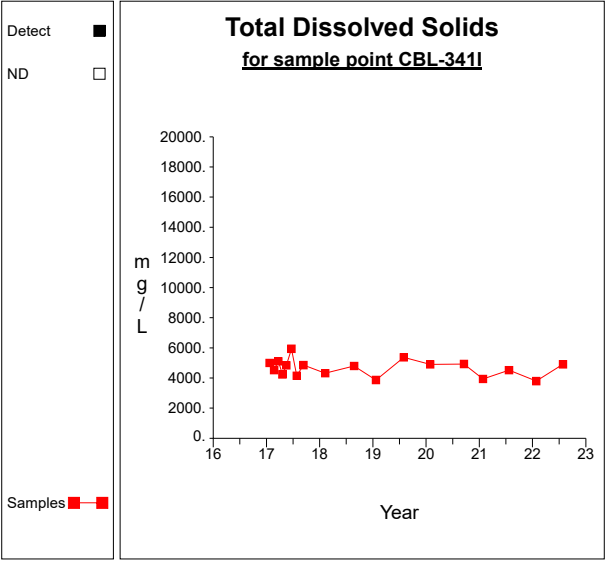
Graph 32



Graph 33



Graph 34



Graph 35

## **Attachment B**

Analytical Data Summary Tables 1-6

Table 1

## Analytical Data Summary for CBL-301I

Constituents	Units	1/21/2016	5/4/2016	7/27/2016	10/24/2016	1/23/2017	3/22/2017	5/18/2017	7/26/2017	2/8/2018	7/25/2018	1/17/2019	5/2/2019	7/31/2019
Boron, Total	mg/L	<.0500	<.0500	<.0500	<.0500	<.0500	<.0500	.0707	<.0500	<.0500	<.0500	<.0500	<.0500	<.0500
Calcium, Total	mg/L	905	949	925	978	1000	1030	1060	961	873	993	156	762	783
Chloride	mg/L	2300	2160	2290	2250	3200	2390	2420	2500	2480	1330	619	1910	2240
Fluoride	mg/L	<.250	<.500	<.500	<.250	.312	<.500	<.500	<.500	<.500	<.500	.219	.112	.051
pH	S.U.	6.33	6.26	5.95	6.23	6.26	6.31	5.95	6.02	6.17	6.04	7.16	6.14	6.19
Sulfate	mg/L	336	311	336	326	488	337	342	381	344	196	104	398	332
Total Dissolved Solids	mg/L	4380	5050	6020	4570	6140	6570	6430	4290	5120	5390	1460	5650	6040

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 1

Analytical Data Summary for CBL-301I

Constituents	1/28/2020	9/17/2020	1/26/2021	7/20/2021	9/7/2021	1/26/2022	7/27/2022	8/30/2022	10/25/2022
Boron, Total	<.0500	.0801	<.0500	.0826	<.0500	<.0500	.0850	.1070	.0645
Calcium, Total	851	1060	1130	1100		999	1010		
Chloride	2360	2270	2420	2590		2440	1840		
Fluoride	.130	<.250	<.500	2.680	<.500	<.050	.156		
pH	6.26	6.13	6.06	6.13	6.14	6.27	6.08	6.14	6.21
Sulfate	349	350	374	419		406	285		
Total Dissolved Solids	4790	6340	6060	5870		4700	4590		

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 2

## Analytical Data Summary for CBL-302I

Constituents	Units	1/22/2016	5/4/2016	7/27/2016	10/24/2016	1/23/2017	3/22/2017	5/16/2017	7/27/2017	2/8/2018	7/27/2018	1/22/2019	7/31/2019	1/30/2020
Boron, Total	mg/L	<.0500	<.0500	<.0500	.1560	<.0500	.2970	<.0500	<.0500	<.0500	<.0500	<.0500	<.0500	<.0500
Calcium, Total	mg/L	1030	1010	1030	1070	1100	1090	1100	1040	934	995	855	914	838
Chloride	mg/L	2190	2130	2210	2170	2080	2050	2230	2040	2080	1980	1960	1540	1540
Fluoride	mg/L	<.2500	<.5000	<.5000	<.2500	.3320	<.5000	<.5000	<.5000	.1120	<.5000	.0402	.0605	.1930
pH	S.U.	6.29	6.01	5.17	7.75	5.36	5.40	4.94	6.20	6.21	5.77	6.44	6.15	6.34
Sulfate	mg/L	1020	993	1090	1180	1150	1120	1230	1180	1240	1390	1250	1260	1350
Total Dissolved Solids	mg/L	5500	5390	6850	4210	6430	6460	5860	5120	6010	5510	5060	4190	4790

\* - The displayed value is the arithmetic mean of multiple database matches.



Table 2

Analytical Data Summary for CBL-302I

Constituents	9/17/2020	1/28/2021	7/21/2021	9/7/2021	1/27/2022	7/28/2022
Boron, Total	<.0500	<.0500	.0743		<.0500	<.0500
Calcium, Total	853	1020	844		754	750
Chloride	1410	1370	1380		1310	1300
Fluoride	<.2500	<.5000	2.2500	<.2500	<.0500	.1650
pH	6.20	6.21	6.06	6.28	6.32	6.21
Sulfate	1280	1290	1350		1340	1300
Total Dissolved Solids	4990	4800	4810		4510	5120

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 3

## Analytical Data Summary for CBL-306I

Constituents	Units	1/21/2016	5/4/2016	7/26/2016	10/24/2016	1/19/2017	3/22/2017	5/18/2017	7/27/2017	2/8/2018	7/27/2018	1/16/2019	7/31/2019	8/23/2019
Boron, Total	mg/L	<.0500	.0717	.0998	.0556	<.0500	.1240	.0832	.0531	<.0500	<.0500	<.0500	.0824	.0500
Calcium, Total	mg/L	137.0	47.2	105.0	198.0	174.0	204.0	205.0	234.0	230.0	275.0	180.0	106.0	226.0
Chloride	mg/L	155	20	114	330	197	231	289	350	385	283	215	538	318
Fluoride	mg/L	2.50	1.00	1.37	2.38	1.85	12.60	2.20	2.91	2.81	2.95	1.98	9.26	2.66
pH	S.U.	7.09	6.69	6.95	6.72	7.29	4.41	5.61	6.94	6.67	6.86	6.78	6.92	6.83
Sulfate	mg/L	266.0	29.5	139.0	432.0	270.0	340.0	412.0	513.0	493.0	406.0	292.0	816.0	387.0
Total Dissolved Solids	mg/L	1280	431	790	1150	1320	1460	1440	1280	1760	1450	1220	676	1710

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 3

Analytical Data Summary for CBL-306I

Constituents	1/29/2020	9/19/2020	1/28/2021	7/21/2021	1/27/2022	7/28/2022
Boron, Total	<.0500	.0773	<.0500	.0927	.0548	.1100
Calcium, Total	247.0	260.0	257.0	216.0	212.0	182.0
Chloride	445	420	292	255	384	261
Fluoride	2.83	2.72	2.90	2.42	2.99	2.26
pH	6.70	7.16	6.84	6.55	6.87	6.70
Sulfate	561.0	506.0	388.0	336.0	510.0	348.0
Total Dissolved Solids	1830	1730	1420	1320	1730	1540

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 4

## Analytical Data Summary for CBL-308I

Constituents	Units	1/22/2016	5/4/2016	7/26/2016	10/24/2016	1/19/2017	3/22/2017	5/16/2017	7/26/2017	2/6/2018	7/25/2018	1/18/2019	7/31/2019	1/29/2020
Boron, Total	mg/L	<.0500	.1210	.1860	.2560	<.0500	.5450	.1090	.0799	<.0500	<.0500	<.0500	<.0500	<.0500
Calcium, Total	mg/L	903	870	911	939	919	947	954	878	859	863	760	840	745
Chloride	mg/L	2760	2580	2680	2870	2360	2530	2740	2760	2750	2680	2240	2290	2110
Fluoride	mg/L	1.49	2.30	1.64	1.59	1.33	9.05	1.70	1.90	1.76	2.10	1.68	1.62	1.60
pH	S.U.	6.36	6.13	5.95	6.27	6.83	6.27	5.54	6.27	6.26	6.07	6.39	6.25	6.37
Sulfate	mg/L	1490	1410	1490	1550	1320	1470	1580	1550	1570	1540	1520	1420	1340
Total Dissolved Solids	mg/L	6820	6120	7890	10200	9620	7260	6590	6480	6200	6320	4760	5820	5980

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 4

Analytical Data Summary for CBL-308I

Constituents	9/18/2020	1/28/2021	7/21/2021	1/27/2022	7/27/2022
Boron, Total	.1030	<.0500	.1300	<.0500	.0790
Calcium, Total	838	830	684	974	736
Chloride	2410	2200	1780	2020	2470
Fluoride	1.33	1.44	1.74	1.75	1.43
pH	6.22	6.26	6.16	6.36	6.23
Sulfate	1310	1340	1240	1310	1190
Total Dissolved Solids	6860	6190	5270	5320	6840

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 5

## Analytical Data Summary for CBL-340I

Constituents	Units	1/21/2016	5/4/2016	7/27/2016	10/24/2016	1/23/2017	3/22/2017	5/16/2017	7/27/2017	2/8/2018	7/27/2018	1/22/2019	7/31/2019	1/30/2020
Boron, Total	mg/L	<.0500	.0832	.0810	.1580	<.0500	.1740	.1040	.0816	.0638	<.0500	<.0500	.1240	.0562
Calcium, Total	mg/L	564	560	575	607	627	581	584	571	555	544	518	518	539
Chloride	mg/L	2370	2260	2350	2380	2070	2280	2520	2380	2730	2450	2250	2280	2240
Fluoride	mg/L	1.090	1.920	1.060	1.260	.840	8.440	1.010	.850	1.000	1.300	.830	.880	.870
pH	S.U.	6.52	6.13	6.95	6.19	5.46	6.49	5.77	6.42	6.41	6.25	6.59	6.45	6.49
Sulfate	mg/L	652	616	668	675	571	635	715	685	752	711	639	684	637
Total Dissolved Solids	mg/L	4990	5230	6250	5670	6230	5480	5470	4880	5290	5100	4720	5560	5080

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 5

Analytical Data Summary for CBL-340I

Constituents	9/18/2020	1/28/2021	7/22/2021	1/28/2022	7/28/2022
Boron, Total	.1460	<.0500	.3840	.1600	.2850
Calcium, Total	547	607	532	597	538
Chloride	2130	2260	2200	2200	2160
Fluoride	.725	.835	.865	1.060	.865
pH	6.32	6.32	6.24	6.42	6.35
Sulfate	608	634	618	619	614
Total Dissolved Solids	5430	5520	4990	4870	5490

\* - The displayed value is the arithmetic mean of multiple database matches.

Table 6

## Analytical Data Summary for CBL-341I

Constituents	Units	1/23/2017	2/23/2017	3/22/2017	4/20/2017	5/16/2017	6/20/2017	7/27/2017	9/11/2017	2/8/2018	8/24/2018	1/22/2019	7/31/2019	1/30/2020
Boron, Total	mg/L	<.0500	<.0500	<.0500	.0587	.0896	.0668	.0507	<.0500	<.0500	<.0500	<.0500	<.0500	<.0500
Calcium, Total	mg/L	854	870	906	898	860	950	829	848	810	824	782	714	767
Chloride	mg/L	1600	2000	1780	1770	1900	1820	1970	1710	2110	1910	1790	1650	1780
Fluoride	mg/L	.5300	<.5000	<.5000	<.5000	<.5000	.3350	.0550	.3670	.1060	.1140	.0546	.1000	.1530
pH	S.U.	5.74	5.23	5.72	5.73	5.54	6.19	6.21	6.10	6.18	5.82	6.38	6.23	6.27
Sulfate	mg/L	307	404	346	336	369	363	419	354	383	376	358	329	351
Total Dissolved Solids	mg/L	5000	4520	5110	4240	4840	5940	4150	4860	4320	4800	3870	5370	4900

\* - The displayed value is the arithmetic mean of multiple database matches.



Table 6

Analytical Data Summary for CBL-341I

Constituents	9/17/2020	1/27/2021	7/22/2021	9/7/2021	1/27/2022	7/28/2022
Boron, Total	.1020	<.0500	.1110		<.0500	.1150
Calcium, Total	814	874	852		1040	704
Chloride	1700	1800	1750		1810	1690
Fluoride	<.2500	<.5000	1.1600	<.2500	<.0500	.1410
pH	6.14	6.06	5.98	6.18	6.26	6.16
Sulfate	336	324	316		320	296
Total Dissolved Solids	4930	3940	4520		3800	4910

\* - The displayed value is the arithmetic mean of multiple database matches.

## **Attachment C**

Summary Statistics, Raw Data, Calculations, and Control Charts

Table 1

**Summary Statistics and Intermediate Computations  
for Combined Shewhart-CUSUM Control Charts**

Constituent	Units	Well	N(back)	N(mon)	N(tot)	Mean	SD	R(i-1)	R(i)	S(i-1)	S(i)	Limit	Type	Conf	
Boron, Total	mg/L	CBL-301I	22	0	22	0.0586	0.0161	0.1070	0.0645			0.1391	normal		
Boron, Total	mg/L	CBL-302I	18	0	18			0.0500	0.0500			0.2970	nonpar	.99	**
Boron, Total	mg/L	CBL-306I	18	0	19	0.0679	0.0242	0.0548	0.1100			0.1891	normal		
Boron, Total	mg/L	CBL-308I	18	0	18	0.1144	0.1215	0.0500	0.0790			0.7217	normal		
Boron, Total	mg/L	CBL-341I	18	0	18	0.0635	0.0234	0.0500	0.1150			0.1803	normal		
Calcium, Total	mg/L	CBL-301I	18	0	19	964.9444	101.2710	999.0000	1010.0000			1471.2996	normal		
Calcium, Total	mg/L	CBL-302I	18	0	18	957.0556	116.7478	754.0000	750.0000			1540.7947	normal		
Calcium, Total	mg/L	CBL-306I	16	0	19	214.8125	36.2569	212.0000	182.0000			396.0970	normal		
Calcium, Total	mg/L	CBL-308I	18	0	18	858.3333	82.3615	974.0000	736.0000			1270.1407	normal		
Calcium, Total	mg/L	CBL-341I	18	0	18	844.2222	79.4752	1040.0000	704.0000			1241.5980	normal		
Chloride	mg/L	CBL-301I	18	0	19	2299.4444	372.4241	2440.0000	1840.0000			4161.5647	normal		
Chloride	mg/L	CBL-302I	18	0	18	1831.6667	360.2654	1310.0000	1300.0000			3632.9938	normal		
Chloride	mg/L	CBL-306I	16	0	19	300.6250	82.0828	384.0000	261.0000			711.0389	normal		
Chloride	mg/L	CBL-308I	18	0	18	2457.2222	303.1755	2020.0000	2470.0000			3973.0995	normal		
Chloride	mg/L	CBL-341I	18	0	18	1807.7778	129.1399	1810.0000	1690.0000			2453.4775	normal		
Fluoride	mg/L	CBL-301I	20	0	20	0.5080	0.5367	0.5000	0.1560			3.1915	normal		
Fluoride	mg/L	CBL-302I	19	0	19	0.4817	0.4622	0.5000	0.1650			2.7929	normal		
Fluoride	mg/L	CBL-306I	17	0	19	2.3959	0.5730	2.9900	2.2600			5.2610	normal		
Fluoride	mg/L	CBL-308I	17	0	18	1.6706	0.2554	1.7500	1.4300			2.9477	normal		
Fluoride	mg/L	CBL-341I	19	0	19	0.3745	0.2679	0.5000	0.1410			1.7141	normal		
pH	S.U.	CBL-301I	22	0	22	6.2014	0.2396	6.1400	6.2100			5.00 - 7.40	normal		
pH	S.U.	CBL-302I	19	0	19	6.0689	0.5972	6.3200	6.2100			3.08 - 9.05	normal		
pH	S.U.	CBL-306I	18	0	19	6.6478	0.6569	6.8700	6.7000			3.36 - 9.93	normal		
pH	S.U.	CBL-308I	18	0	18	6.2328	0.2475	6.3600	6.2300			5.00 - 7.47	normal		
pH	S.U.	CBL-341I	18	0	19	6.0494	0.2377	6.2600	6.1600			4.86 - 7.24	normal		
Sulfate	mg/L	CBL-301I	18	0	19	350.5556	60.2936	406.0000	285.0000			652.0236	normal		
Sulfate	mg/L	CBL-302I	18	0	18	1222.9444	114.1137	1340.0000	1300.0000			1793.5130	normal		
Sulfate	mg/L	CBL-306I	17	0	19	388.1765	110.3564	510.0000	348.0000			939.9583	normal		
Sulfate	mg/L	CBL-308I	18	0	18	1424.4444	121.4240	1310.0000	1190.0000			2031.5645	normal		
Sulfate	mg/L	CBL-341I	18	0	18	349.2778	32.8898	320.0000	296.0000			513.7270	normal		
Total Dissolved Solids	mg/L	CBL-301I	18	0	19	5444.4444	767.6950	4700.0000	4590.0000			9282.9193	normal		
Total Dissolved Solids	mg/L	CBL-302I	18	0	18	5311.6667	764.8702	4510.0000	5120.0000			9136.0178	normal		
Total Dissolved Solids	mg/L	CBL-306I	17	0	19	1437.0588	267.0853	1730.0000	1540.0000			2772.4853	normal		
Total Dissolved Solids	mg/L	CBL-308I	18	0	18	6696.6667	1385.2713	5320.0000	6840.0000			13623.0230	normal		
Total Dissolved Solids	mg/L	CBL-341I	18	0	18	4667.7778	554.0180	3800.0000	4910.0000			7437.8678	normal		

N(back) and N(mon) = Non-outlier measurements in the background and monitoring periods.

N(tot) = All independent measurements for that constituent and well.

For transformed data, mean and SD in transformed units and control limit in original units.

Conf = confidence level for passing initial test or one of two verification resamples (nonparametric test only).

\* - Insufficient Data.

\*\* - Detection Frequency < 25%.

\*\*\* - Zero Variance.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Boron, Total	mg/L	CBL-301I	01/21/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	05/04/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	07/27/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	10/24/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	01/23/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	03/22/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	05/18/2017	yes	0.0707					
Boron, Total	mg/L	CBL-301I	07/26/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	02/08/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	07/25/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	01/17/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	05/02/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	07/31/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	01/28/2020	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	09/17/2020	yes	0.0801					
Boron, Total	mg/L	CBL-301I	01/26/2021	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	07/20/2021	yes	0.0826					
Boron, Total	mg/L	CBL-301I	09/07/2021	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	01/26/2022	yes	0.0500	ND				
Boron, Total	mg/L	CBL-301I	07/27/2022	yes	0.0850					
Boron, Total	mg/L	CBL-301I	08/30/2022	yes	0.1070					
Boron, Total	mg/L	CBL-301I	10/25/2022	yes	0.0645					
Boron, Total	mg/L	CBL-302I	01/22/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	05/04/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	07/27/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	10/24/2016	yes	0.1560					
Boron, Total	mg/L	CBL-302I	01/23/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	03/22/2017	yes	0.2970					
Boron, Total	mg/L	CBL-302I	05/16/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	07/27/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	02/08/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	07/27/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	01/22/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	07/31/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	01/30/2020	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	09/17/2020	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	01/28/2021	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	07/21/2021	yes	0.0743					
Boron, Total	mg/L	CBL-302I	01/27/2022	yes	0.0500	ND				
Boron, Total	mg/L	CBL-302I	07/28/2022	yes	0.0500	ND				
Boron, Total	mg/L	CBL-306I	01/21/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-306I	05/04/2016	yes	0.0717					
Boron, Total	mg/L	CBL-306I	07/26/2016	yes	0.0998					
Boron, Total	mg/L	CBL-306I	10/24/2016	yes	0.0556					
Boron, Total	mg/L	CBL-306I	01/19/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-306I	03/22/2017	yes	0.1240					
Boron, Total	mg/L	CBL-306I	05/18/2017	yes	0.0832					
Boron, Total	mg/L	CBL-306I	07/27/2017	yes	0.0531					
Boron, Total	mg/L	CBL-306I	02/08/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-306I	07/27/2018	yes	0.0500	ND				

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Boron, Total	mg/L	CBL-306I	01/16/2019	yes	0.0500	ND	yes			*
Boron, Total	mg/L	CBL-306I	07/31/2019	yes	0.0824					
Boron, Total	mg/L	CBL-306I	08/23/2019	yes	0.0500					
Boron, Total	mg/L	CBL-306I	01/29/2020	yes	0.0500	ND				
Boron, Total	mg/L	CBL-306I	09/19/2020	yes	0.0773					
Boron, Total	mg/L	CBL-306I	01/28/2021	yes	0.0500	ND				
Boron, Total	mg/L	CBL-306I	07/21/2021	yes	0.0927					
Boron, Total	mg/L	CBL-306I	01/27/2022	yes	0.0548					
Boron, Total	mg/L	CBL-306I	07/28/2022	yes	0.1100					
Boron, Total	mg/L	CBL-308I	01/22/2016	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	05/04/2016	yes	0.1210					
Boron, Total	mg/L	CBL-308I	07/26/2016	yes	0.1860					
Boron, Total	mg/L	CBL-308I	10/24/2016	yes	0.2560					
Boron, Total	mg/L	CBL-308I	01/19/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	03/22/2017	yes	0.5450					
Boron, Total	mg/L	CBL-308I	05/16/2017	yes	0.1090					
Boron, Total	mg/L	CBL-308I	07/26/2017	yes	0.0799					
Boron, Total	mg/L	CBL-308I	02/06/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	07/25/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	01/18/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	07/31/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	01/29/2020	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	09/18/2020	yes	0.1030					
Boron, Total	mg/L	CBL-308I	01/28/2021	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	07/21/2021	yes	0.1300					
Boron, Total	mg/L	CBL-308I	01/27/2022	yes	0.0500	ND				
Boron, Total	mg/L	CBL-308I	07/27/2022	yes	0.0790					
Boron, Total	mg/L	CBL-341I	01/23/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	02/23/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	03/22/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	04/20/2017	yes	0.0587					
Boron, Total	mg/L	CBL-341I	05/16/2017	yes	0.0896					
Boron, Total	mg/L	CBL-341I	06/20/2017	yes	0.0668					
Boron, Total	mg/L	CBL-341I	07/27/2017	yes	0.0507					
Boron, Total	mg/L	CBL-341I	09/11/2017	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	02/08/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	08/24/2018	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	01/22/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	07/31/2019	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	01/30/2020	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	09/17/2020	yes	0.1020					
Boron, Total	mg/L	CBL-341I	01/27/2021	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	07/22/2021	yes	0.1110					
Boron, Total	mg/L	CBL-341I	01/27/2022	yes	0.0500	ND				
Boron, Total	mg/L	CBL-341I	07/28/2022	yes	0.1150					
Calcium, Total	mg/L	CBL-301I	01/21/2016	yes	905.0000					
Calcium, Total	mg/L	CBL-301I	05/04/2016	yes	949.0000					
Calcium, Total	mg/L	CBL-301I	07/27/2016	yes	925.0000					
Calcium, Total	mg/L	CBL-301I	10/24/2016	yes	978.0000					
Calcium, Total	mg/L	CBL-301I	01/23/2017	yes	1000.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Calcium, Total	mg/L	CBL-301I	03/22/2017	yes	1030.0000					
Calcium, Total	mg/L	CBL-301I	05/18/2017	yes	1060.0000					
Calcium, Total	mg/L	CBL-301I	07/26/2017	yes	961.0000					
Calcium, Total	mg/L	CBL-301I	02/08/2018	yes	873.0000					
Calcium, Total	mg/L	CBL-301I	07/25/2018	yes	993.0000					
Calcium, Total	mg/L	CBL-301I	01/17/2019	yes	156.0000		yes			*
Calcium, Total	mg/L	CBL-301I	05/02/2019	yes	762.0000					
Calcium, Total	mg/L	CBL-301I	07/31/2019	yes	783.0000					
Calcium, Total	mg/L	CBL-301I	01/28/2020	yes	851.0000					
Calcium, Total	mg/L	CBL-301I	09/17/2020	yes	1060.0000					
Calcium, Total	mg/L	CBL-301I	01/26/2021	yes	1130.0000					
Calcium, Total	mg/L	CBL-301I	07/20/2021	yes	1100.0000					
Calcium, Total	mg/L	CBL-301I	01/26/2022	yes	999.0000					
Calcium, Total	mg/L	CBL-301I	07/27/2022	yes	1010.0000					
Calcium, Total	mg/L	CBL-302I	01/22/2016	yes	1030.0000					
Calcium, Total	mg/L	CBL-302I	05/04/2016	yes	1010.0000					
Calcium, Total	mg/L	CBL-302I	07/27/2016	yes	1030.0000					
Calcium, Total	mg/L	CBL-302I	10/24/2016	yes	1070.0000					
Calcium, Total	mg/L	CBL-302I	01/23/2017	yes	1100.0000					
Calcium, Total	mg/L	CBL-302I	03/22/2017	yes	1090.0000					
Calcium, Total	mg/L	CBL-302I	05/16/2017	yes	1100.0000					
Calcium, Total	mg/L	CBL-302I	07/27/2017	yes	1040.0000					
Calcium, Total	mg/L	CBL-302I	02/08/2018	yes	934.0000					
Calcium, Total	mg/L	CBL-302I	07/27/2018	yes	995.0000					
Calcium, Total	mg/L	CBL-302I	01/22/2019	yes	855.0000					
Calcium, Total	mg/L	CBL-302I	07/31/2019	yes	914.0000					
Calcium, Total	mg/L	CBL-302I	01/30/2020	yes	838.0000					
Calcium, Total	mg/L	CBL-302I	09/17/2020	yes	853.0000					
Calcium, Total	mg/L	CBL-302I	01/28/2021	yes	1020.0000					
Calcium, Total	mg/L	CBL-302I	07/21/2021	yes	844.0000					
Calcium, Total	mg/L	CBL-302I	01/27/2022	yes	754.0000					
Calcium, Total	mg/L	CBL-302I	07/28/2022	yes	750.0000					
Calcium, Total	mg/L	CBL-306I	01/21/2016	yes	137.0000					
Calcium, Total	mg/L	CBL-306I	05/04/2016	yes	47.2000		yes			*
Calcium, Total	mg/L	CBL-306I	07/26/2016	yes	105.0000		yes			*
Calcium, Total	mg/L	CBL-306I	10/24/2016	yes	198.0000					
Calcium, Total	mg/L	CBL-306I	01/19/2017	yes	174.0000					
Calcium, Total	mg/L	CBL-306I	03/22/2017	yes	204.0000					
Calcium, Total	mg/L	CBL-306I	05/18/2017	yes	205.0000					
Calcium, Total	mg/L	CBL-306I	07/27/2017	yes	234.0000					
Calcium, Total	mg/L	CBL-306I	02/08/2018	yes	230.0000					
Calcium, Total	mg/L	CBL-306I	07/27/2018	yes	275.0000					
Calcium, Total	mg/L	CBL-306I	01/16/2019	yes	180.0000					
Calcium, Total	mg/L	CBL-306I	07/31/2019	yes	106.0000		yes			*
Calcium, Total	mg/L	CBL-306I	08/23/2019	yes	226.0000					
Calcium, Total	mg/L	CBL-306I	01/29/2020	yes	247.0000					
Calcium, Total	mg/L	CBL-306I	09/19/2020	yes	260.0000					
Calcium, Total	mg/L	CBL-306I	01/28/2021	yes	257.0000					
Calcium, Total	mg/L	CBL-306I	07/21/2021	yes	216.0000					
Calcium, Total	mg/L	CBL-306I	01/27/2022	yes	212.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Calcium, Total	mg/L	CBL-308I	07/28/2022	yes	182.0000					
Calcium, Total	mg/L	CBL-308I	01/22/2016	yes	903.0000					
Calcium, Total	mg/L	CBL-308I	05/04/2016	yes	870.0000					
Calcium, Total	mg/L	CBL-308I	07/26/2016	yes	911.0000					
Calcium, Total	mg/L	CBL-308I	10/24/2016	yes	939.0000					
Calcium, Total	mg/L	CBL-308I	01/19/2017	yes	919.0000					
Calcium, Total	mg/L	CBL-308I	03/22/2017	yes	947.0000					
Calcium, Total	mg/L	CBL-308I	05/16/2017	yes	954.0000					
Calcium, Total	mg/L	CBL-308I	07/26/2017	yes	878.0000					
Calcium, Total	mg/L	CBL-308I	02/06/2018	yes	859.0000					
Calcium, Total	mg/L	CBL-308I	07/25/2018	yes	863.0000					
Calcium, Total	mg/L	CBL-308I	01/18/2019	yes	760.0000					
Calcium, Total	mg/L	CBL-308I	07/31/2019	yes	840.0000					
Calcium, Total	mg/L	CBL-308I	01/29/2020	yes	745.0000					
Calcium, Total	mg/L	CBL-308I	09/18/2020	yes	838.0000					
Calcium, Total	mg/L	CBL-308I	01/28/2021	yes	830.0000					
Calcium, Total	mg/L	CBL-308I	07/21/2021	yes	684.0000					
Calcium, Total	mg/L	CBL-308I	01/27/2022	yes	974.0000					
Calcium, Total	mg/L	CBL-308I	07/27/2022	yes	736.0000					
Calcium, Total	mg/L	CBL-341I	01/23/2017	yes	854.0000					
Calcium, Total	mg/L	CBL-341I	02/23/2017	yes	870.0000					
Calcium, Total	mg/L	CBL-341I	03/22/2017	yes	906.0000					
Calcium, Total	mg/L	CBL-341I	04/20/2017	yes	898.0000					
Calcium, Total	mg/L	CBL-341I	05/16/2017	yes	860.0000					
Calcium, Total	mg/L	CBL-341I	06/20/2017	yes	950.0000					
Calcium, Total	mg/L	CBL-341I	07/27/2017	yes	829.0000					
Calcium, Total	mg/L	CBL-341I	09/11/2017	yes	848.0000					
Calcium, Total	mg/L	CBL-341I	02/08/2018	yes	810.0000					
Calcium, Total	mg/L	CBL-341I	08/24/2018	yes	824.0000					
Calcium, Total	mg/L	CBL-341I	01/22/2019	yes	782.0000					
Calcium, Total	mg/L	CBL-341I	07/31/2019	yes	714.0000					
Calcium, Total	mg/L	CBL-341I	01/30/2020	yes	767.0000					
Calcium, Total	mg/L	CBL-341I	09/17/2020	yes	814.0000					
Calcium, Total	mg/L	CBL-341I	01/27/2021	yes	874.0000					
Calcium, Total	mg/L	CBL-341I	07/22/2021	yes	852.0000					
Calcium, Total	mg/L	CBL-341I	01/27/2022	yes	1040.0000					
Calcium, Total	mg/L	CBL-341I	07/28/2022	yes	704.0000					
Chloride	mg/L	CBL-301I	01/21/2016	yes	2300.0000					
Chloride	mg/L	CBL-301I	05/04/2016	yes	2160.0000					
Chloride	mg/L	CBL-301I	07/27/2016	yes	2290.0000					
Chloride	mg/L	CBL-301I	10/24/2016	yes	2250.0000					
Chloride	mg/L	CBL-301I	01/23/2017	yes	3200.0000					
Chloride	mg/L	CBL-301I	03/22/2017	yes	2390.0000					
Chloride	mg/L	CBL-301I	05/18/2017	yes	2420.0000					
Chloride	mg/L	CBL-301I	07/26/2017	yes	2500.0000					
Chloride	mg/L	CBL-301I	02/08/2018	yes	2480.0000					
Chloride	mg/L	CBL-301I	07/25/2018	yes	1330.0000					
Chloride	mg/L	CBL-301I	01/17/2019	yes	619.0000					
Chloride	mg/L	CBL-301I	05/02/2019	yes	1910.0000		yes			*
Chloride	mg/L	CBL-301I	07/31/2019	yes	2240.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Chloride	mg/L	CBL-301I	01/28/2020	yes	2360.0000					
Chloride	mg/L	CBL-301I	09/17/2020	yes	2270.0000					
Chloride	mg/L	CBL-301I	01/26/2021	yes	2420.0000					
Chloride	mg/L	CBL-301I	07/20/2021	yes	2590.0000					
Chloride	mg/L	CBL-301I	01/26/2022	yes	2440.0000					
Chloride	mg/L	CBL-301I	07/27/2022	yes	1840.0000					
Chloride	mg/L	CBL-302I	01/22/2016	yes	2190.0000					
Chloride	mg/L	CBL-302I	05/04/2016	yes	2130.0000					
Chloride	mg/L	CBL-302I	07/27/2016	yes	2210.0000					
Chloride	mg/L	CBL-302I	10/24/2016	yes	2170.0000					
Chloride	mg/L	CBL-302I	01/23/2017	yes	2080.0000					
Chloride	mg/L	CBL-302I	03/22/2017	yes	2050.0000					
Chloride	mg/L	CBL-302I	05/16/2017	yes	2230.0000					
Chloride	mg/L	CBL-302I	07/27/2017	yes	2040.0000					
Chloride	mg/L	CBL-302I	02/08/2018	yes	2080.0000					
Chloride	mg/L	CBL-302I	07/27/2018	yes	1980.0000					
Chloride	mg/L	CBL-302I	01/22/2019	yes	1960.0000					
Chloride	mg/L	CBL-302I	07/31/2019	yes	1540.0000					
Chloride	mg/L	CBL-302I	01/30/2020	yes	1540.0000					
Chloride	mg/L	CBL-302I	09/17/2020	yes	1410.0000					
Chloride	mg/L	CBL-302I	01/28/2021	yes	1370.0000					
Chloride	mg/L	CBL-302I	07/21/2021	yes	1380.0000					
Chloride	mg/L	CBL-302I	01/27/2022	yes	1310.0000					
Chloride	mg/L	CBL-302I	07/28/2022	yes	1300.0000					
Chloride	mg/L	CBL-306I	01/21/2016	yes	155.0000					
Chloride	mg/L	CBL-306I	05/04/2016	yes	20.0000		yes			*
Chloride	mg/L	CBL-306I	07/26/2016	yes	114.0000		yes			*
Chloride	mg/L	CBL-306I	10/24/2016	yes	330.0000					
Chloride	mg/L	CBL-306I	01/19/2017	yes	197.0000					
Chloride	mg/L	CBL-306I	03/22/2017	yes	231.0000					
Chloride	mg/L	CBL-306I	05/18/2017	yes	289.0000					
Chloride	mg/L	CBL-306I	07/27/2017	yes	350.0000					
Chloride	mg/L	CBL-306I	02/08/2018	yes	385.0000					
Chloride	mg/L	CBL-306I	07/27/2018	yes	283.0000					
Chloride	mg/L	CBL-306I	01/16/2019	yes	215.0000					
Chloride	mg/L	CBL-306I	07/31/2019	yes	538.0000		yes			*
Chloride	mg/L	CBL-306I	08/23/2019	yes	318.0000					
Chloride	mg/L	CBL-306I	01/29/2020	yes	445.0000					
Chloride	mg/L	CBL-306I	09/19/2020	yes	420.0000					
Chloride	mg/L	CBL-306I	01/28/2021	yes	292.0000					
Chloride	mg/L	CBL-306I	07/21/2021	yes	255.0000					
Chloride	mg/L	CBL-306I	01/27/2022	yes	384.0000					
Chloride	mg/L	CBL-306I	07/28/2022	yes	261.0000					
Chloride	mg/L	CBL-308I	01/22/2016	yes	2760.0000					
Chloride	mg/L	CBL-308I	05/04/2016	yes	2580.0000					
Chloride	mg/L	CBL-308I	07/26/2016	yes	2680.0000					
Chloride	mg/L	CBL-308I	10/24/2016	yes	2870.0000					
Chloride	mg/L	CBL-308I	01/19/2017	yes	2360.0000					
Chloride	mg/L	CBL-308I	03/22/2017	yes	2530.0000					
Chloride	mg/L	CBL-308I	05/16/2017	yes	2740.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.



Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Chloride	mg/L	CBL-308I	07/26/2017	yes	2760.0000					
Chloride	mg/L	CBL-308I	02/06/2018	yes	2750.0000					
Chloride	mg/L	CBL-308I	07/25/2018	yes	2680.0000					
Chloride	mg/L	CBL-308I	01/18/2019	yes	2240.0000					
Chloride	mg/L	CBL-308I	07/31/2019	yes	2290.0000					
Chloride	mg/L	CBL-308I	01/29/2020	yes	2110.0000					
Chloride	mg/L	CBL-308I	09/18/2020	yes	2410.0000					
Chloride	mg/L	CBL-308I	01/28/2021	yes	2200.0000					
Chloride	mg/L	CBL-308I	07/21/2021	yes	1780.0000					
Chloride	mg/L	CBL-308I	01/27/2022	yes	2020.0000					
Chloride	mg/L	CBL-308I	07/27/2022	yes	2470.0000					
Chloride	mg/L	CBL-341I	01/23/2017	yes	1600.0000					
Chloride	mg/L	CBL-341I	02/23/2017	yes	2000.0000					
Chloride	mg/L	CBL-341I	03/22/2017	yes	1780.0000					
Chloride	mg/L	CBL-341I	04/20/2017	yes	1770.0000					
Chloride	mg/L	CBL-341I	05/16/2017	yes	1900.0000					
Chloride	mg/L	CBL-341I	06/20/2017	yes	1820.0000					
Chloride	mg/L	CBL-341I	07/27/2017	yes	1970.0000					
Chloride	mg/L	CBL-341I	09/11/2017	yes	1710.0000					
Chloride	mg/L	CBL-341I	02/08/2018	yes	2110.0000					
Chloride	mg/L	CBL-341I	08/24/2018	yes	1910.0000					
Chloride	mg/L	CBL-341I	01/22/2019	yes	1790.0000					
Chloride	mg/L	CBL-341I	07/31/2019	yes	1650.0000					
Chloride	mg/L	CBL-341I	01/30/2020	yes	1780.0000					
Chloride	mg/L	CBL-341I	09/17/2020	yes	1700.0000					
Chloride	mg/L	CBL-341I	01/27/2021	yes	1800.0000					
Chloride	mg/L	CBL-341I	07/22/2021	yes	1750.0000					
Chloride	mg/L	CBL-341I	01/27/2022	yes	1810.0000					
Chloride	mg/L	CBL-341I	07/28/2022	yes	1690.0000					
Fluoride	mg/L	CBL-301I	01/21/2016	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-301I	05/04/2016	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	07/27/2016	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	10/24/2016	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-301I	01/23/2017	yes	0.3120					
Fluoride	mg/L	CBL-301I	03/22/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	05/18/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	07/26/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	02/08/2018	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	07/25/2018	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	01/17/2019	yes	0.2190					
Fluoride	mg/L	CBL-301I	05/02/2019	yes	0.1120					
Fluoride	mg/L	CBL-301I	07/31/2019	yes	0.0510					
Fluoride	mg/L	CBL-301I	01/28/2020	yes	0.1300					
Fluoride	mg/L	CBL-301I	09/17/2020	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-301I	01/26/2021	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	07/20/2021	yes	2.6800					
Fluoride	mg/L	CBL-301I	09/07/2021	yes	0.5000	ND				
Fluoride	mg/L	CBL-301I	01/26/2022	yes	0.0500	ND			0.5000	***
Fluoride	mg/L	CBL-301I	07/27/2022	yes	0.1560					
Fluoride	mg/L	CBL-302I	01/22/2016	yes	0.2500	ND			0.5000	***

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Fluoride	mg/L	CBL-302I	05/04/2016	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	07/27/2016	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	10/24/2016	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-302I	01/23/2017	yes	0.3320					
Fluoride	mg/L	CBL-302I	03/22/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	05/16/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	07/27/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	02/08/2018	yes	0.1120					
Fluoride	mg/L	CBL-302I	07/27/2018	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	01/22/2019	yes	0.0402					
Fluoride	mg/L	CBL-302I	07/31/2019	yes	0.0605					
Fluoride	mg/L	CBL-302I	01/30/2020	yes	0.1930					
Fluoride	mg/L	CBL-302I	09/17/2020	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-302I	01/28/2021	yes	0.5000	ND				
Fluoride	mg/L	CBL-302I	07/21/2021	yes	2.2500					
Fluoride	mg/L	CBL-302I	09/07/2021	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-302I	01/27/2022	yes	0.0500	ND			0.5000	***
Fluoride	mg/L	CBL-302I	07/28/2022	yes	0.1650					
Fluoride	mg/L	CBL-306I	01/21/2016	yes	2.5000					
Fluoride	mg/L	CBL-306I	05/04/2016	yes	1.0000					
Fluoride	mg/L	CBL-306I	07/26/2016	yes	1.3700					
Fluoride	mg/L	CBL-306I	10/24/2016	yes	2.3800					
Fluoride	mg/L	CBL-306I	01/19/2017	yes	1.8500					
Fluoride	mg/L	CBL-306I	03/22/2017	yes	12.6000		yes			*
Fluoride	mg/L	CBL-306I	05/18/2017	yes	2.2000					
Fluoride	mg/L	CBL-306I	07/27/2017	yes	2.9100					
Fluoride	mg/L	CBL-306I	02/08/2018	yes	2.8100					
Fluoride	mg/L	CBL-306I	07/27/2018	yes	2.9500					
Fluoride	mg/L	CBL-306I	01/16/2019	yes	1.9800					
Fluoride	mg/L	CBL-306I	07/31/2019	yes	9.2600		yes			*
Fluoride	mg/L	CBL-306I	08/23/2019	yes	2.6600					
Fluoride	mg/L	CBL-306I	01/29/2020	yes	2.8300					
Fluoride	mg/L	CBL-306I	09/19/2020	yes	2.7200					
Fluoride	mg/L	CBL-306I	01/28/2021	yes	2.9000					
Fluoride	mg/L	CBL-306I	07/21/2021	yes	2.4200					
Fluoride	mg/L	CBL-306I	01/27/2022	yes	2.9900					
Fluoride	mg/L	CBL-306I	07/28/2022	yes	2.2600					
Fluoride	mg/L	CBL-308I	01/22/2016	yes	1.4900					
Fluoride	mg/L	CBL-308I	05/04/2016	yes	2.3000					
Fluoride	mg/L	CBL-308I	07/26/2016	yes	1.6400					
Fluoride	mg/L	CBL-308I	10/24/2016	yes	1.5900					
Fluoride	mg/L	CBL-308I	01/19/2017	yes	1.3300					
Fluoride	mg/L	CBL-308I	03/22/2017	yes	9.0500		yes			*
Fluoride	mg/L	CBL-308I	05/16/2017	yes	1.7000					
Fluoride	mg/L	CBL-308I	07/26/2017	yes	1.9000					
Fluoride	mg/L	CBL-308I	02/06/2018	yes	1.7600					
Fluoride	mg/L	CBL-308I	07/25/2018	yes	2.1000					
Fluoride	mg/L	CBL-308I	01/18/2019	yes	1.6800					
Fluoride	mg/L	CBL-308I	07/31/2019	yes	1.6200					
Fluoride	mg/L	CBL-308I	01/29/2020	yes	1.6000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Fluoride	mg/L	CBL-308I	09/18/2020	yes	1.3300					
Fluoride	mg/L	CBL-308I	01/28/2021	yes	1.4400					
Fluoride	mg/L	CBL-308I	07/21/2021	yes	1.7400					
Fluoride	mg/L	CBL-308I	01/27/2022	yes	1.7500					
Fluoride	mg/L	CBL-308I	07/27/2022	yes	1.4300					
Fluoride	mg/L	CBL-341I	01/23/2017	yes	0.5300					
Fluoride	mg/L	CBL-341I	02/23/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-341I	03/22/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-341I	04/20/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-341I	05/16/2017	yes	0.5000	ND				
Fluoride	mg/L	CBL-341I	06/20/2017	yes	0.3350					
Fluoride	mg/L	CBL-341I	07/27/2017	yes	0.0550					
Fluoride	mg/L	CBL-341I	09/11/2017	yes	0.3670					
Fluoride	mg/L	CBL-341I	02/08/2018	yes	0.1060					
Fluoride	mg/L	CBL-341I	08/24/2018	yes	0.1140					
Fluoride	mg/L	CBL-341I	01/22/2019	yes	0.0546					
Fluoride	mg/L	CBL-341I	07/31/2019	yes	0.1000					
Fluoride	mg/L	CBL-341I	01/30/2020	yes	0.1530					
Fluoride	mg/L	CBL-341I	09/17/2020	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-341I	01/27/2021	yes	0.5000	ND				
Fluoride	mg/L	CBL-341I	07/22/2021	yes	1.1600					
Fluoride	mg/L	CBL-341I	09/07/2021	yes	0.2500	ND			0.5000	***
Fluoride	mg/L	CBL-341I	01/27/2022	yes	0.0500	ND			0.5000	***
Fluoride	mg/L	CBL-341I	07/28/2022	yes	0.1410					
pH	S.U.	CBL-301I	01/21/2016	yes	6.3300					
pH	S.U.	CBL-301I	05/04/2016	yes	6.2600					
pH	S.U.	CBL-301I	07/27/2016	yes	5.9500					
pH	S.U.	CBL-301I	10/24/2016	yes	6.2300					
pH	S.U.	CBL-301I	01/23/2017	yes	6.2600					
pH	S.U.	CBL-301I	03/22/2017	yes	6.3100					
pH	S.U.	CBL-301I	05/18/2017	yes	5.9500					
pH	S.U.	CBL-301I	07/26/2017	yes	6.0200					
pH	S.U.	CBL-301I	02/08/2018	yes	6.1700					
pH	S.U.	CBL-301I	07/25/2018	yes	6.0400					
pH	S.U.	CBL-301I	01/17/2019	yes	7.1600					
pH	S.U.	CBL-301I	05/02/2019	yes	6.1400					
pH	S.U.	CBL-301I	07/31/2019	yes	6.1900					
pH	S.U.	CBL-301I	01/28/2020	yes	6.2600					
pH	S.U.	CBL-301I	09/17/2020	yes	6.1300					
pH	S.U.	CBL-301I	01/26/2021	yes	6.0600					
pH	S.U.	CBL-301I	07/20/2021	yes	6.1300					
pH	S.U.	CBL-301I	09/07/2021	yes	6.1400					
pH	S.U.	CBL-301I	01/26/2022	yes	6.2700					
pH	S.U.	CBL-301I	07/27/2022	yes	6.0800					
pH	S.U.	CBL-301I	08/30/2022	yes	6.1400					
pH	S.U.	CBL-301I	10/25/2022	yes	6.2100					
pH	S.U.	CBL-302I	01/22/2016	yes	6.2900					
pH	S.U.	CBL-302I	05/04/2016	yes	6.0100					
pH	S.U.	CBL-302I	07/27/2016	yes	5.1700					
pH	S.U.	CBL-302I	10/24/2016	yes	7.7500					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
pH	S.U.	CBL-302I	01/23/2017	yes	5.3600					
pH	S.U.	CBL-302I	03/22/2017	yes	5.4000					
pH	S.U.	CBL-302I	05/16/2017	yes	4.9400					
pH	S.U.	CBL-302I	07/27/2017	yes	6.2000					
pH	S.U.	CBL-302I	02/08/2018	yes	6.2100					
pH	S.U.	CBL-302I	07/27/2018	yes	5.7700					
pH	S.U.	CBL-302I	01/22/2019	yes	6.4400					
pH	S.U.	CBL-302I	07/31/2019	yes	6.1500					
pH	S.U.	CBL-302I	01/30/2020	yes	6.3400					
pH	S.U.	CBL-302I	09/17/2020	yes	6.2000					
pH	S.U.	CBL-302I	01/28/2021	yes	6.2100					
pH	S.U.	CBL-302I	07/21/2021	yes	6.0600					
pH	S.U.	CBL-302I	09/07/2021	yes	6.2800					
pH	S.U.	CBL-302I	01/27/2022	yes	6.3200					
pH	S.U.	CBL-302I	07/28/2022	yes	6.2100					
pH	S.U.	CBL-306I	01/21/2016	yes	7.0900					
pH	S.U.	CBL-306I	05/04/2016	yes	6.6900					
pH	S.U.	CBL-306I	07/26/2016	yes	6.9500					
pH	S.U.	CBL-306I	10/24/2016	yes	6.7200					
pH	S.U.	CBL-306I	01/19/2017	yes	7.2900					
pH	S.U.	CBL-306I	03/22/2017	yes	4.4100					
pH	S.U.	CBL-306I	05/18/2017	yes	5.6100					
pH	S.U.	CBL-306I	07/27/2017	yes	6.9400					
pH	S.U.	CBL-306I	02/08/2018	yes	6.6700					
pH	S.U.	CBL-306I	07/27/2018	yes	6.8600					
pH	S.U.	CBL-306I	01/16/2019	yes	6.7800					
pH	S.U.	CBL-306I	07/31/2019	yes	6.9200		yes			*
pH	S.U.	CBL-306I	08/23/2019	yes	6.8300					
pH	S.U.	CBL-306I	01/29/2020	yes	6.7000					
pH	S.U.	CBL-306I	09/19/2020	yes	7.1600					
pH	S.U.	CBL-306I	01/28/2021	yes	6.8400					
pH	S.U.	CBL-306I	07/21/2021	yes	6.5500					
pH	S.U.	CBL-306I	01/27/2022	yes	6.8700					
pH	S.U.	CBL-306I	07/28/2022	yes	6.7000					
pH	S.U.	CBL-308I	01/22/2016	yes	6.3600					
pH	S.U.	CBL-308I	05/04/2016	yes	6.1300					
pH	S.U.	CBL-308I	07/26/2016	yes	5.9500					
pH	S.U.	CBL-308I	10/24/2016	yes	6.2700					
pH	S.U.	CBL-308I	01/19/2017	yes	6.8300					
pH	S.U.	CBL-308I	03/22/2017	yes	6.2700					
pH	S.U.	CBL-308I	05/16/2017	yes	5.5400					
pH	S.U.	CBL-308I	07/26/2017	yes	6.2700					
pH	S.U.	CBL-308I	02/06/2018	yes	6.2600					
pH	S.U.	CBL-308I	07/25/2018	yes	6.0700					
pH	S.U.	CBL-308I	01/18/2019	yes	6.3900					
pH	S.U.	CBL-308I	07/31/2019	yes	6.2500					
pH	S.U.	CBL-308I	01/29/2020	yes	6.3700					
pH	S.U.	CBL-308I	09/18/2020	yes	6.2200					
pH	S.U.	CBL-308I	01/28/2021	yes	6.2600					
pH	S.U.	CBL-308I	07/21/2021	yes	6.1600					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
pH	S.U.	CBL-308I	01/27/2022	yes	6.3600					
pH	S.U.	CBL-308I	07/27/2022	yes	6.2300					
pH	S.U.	CBL-341I	01/23/2017	yes	5.7400		yes			*
pH	S.U.	CBL-341I	02/23/2017	yes	5.2300					
pH	S.U.	CBL-341I	03/22/2017	yes	5.7200					
pH	S.U.	CBL-341I	04/20/2017	yes	5.7300					
pH	S.U.	CBL-341I	05/16/2017	yes	5.5400					
pH	S.U.	CBL-341I	06/20/2017	yes	6.1900					
pH	S.U.	CBL-341I	07/27/2017	yes	6.2100					
pH	S.U.	CBL-341I	09/11/2017	yes	6.1000					
pH	S.U.	CBL-341I	02/08/2018	yes	6.1800					
pH	S.U.	CBL-341I	08/24/2018	yes	5.8200					
pH	S.U.	CBL-341I	01/22/2019	yes	6.3800					
pH	S.U.	CBL-341I	07/31/2019	yes	6.2300					
pH	S.U.	CBL-341I	01/30/2020	yes	6.2700					
pH	S.U.	CBL-341I	09/17/2020	yes	6.1400					
pH	S.U.	CBL-341I	01/27/2021	yes	6.0600					
pH	S.U.	CBL-341I	07/22/2021	yes	5.9800					
pH	S.U.	CBL-341I	09/07/2021	yes	6.1800					
pH	S.U.	CBL-341I	01/27/2022	yes	6.2600					
pH	S.U.	CBL-341I	07/28/2022	yes	6.1600					
Sulfate	mg/L	CBL-301I	01/21/2016	yes	336.0000		yes			*
Sulfate	mg/L	CBL-301I	05/04/2016	yes	311.0000					
Sulfate	mg/L	CBL-301I	07/27/2016	yes	336.0000					
Sulfate	mg/L	CBL-301I	10/24/2016	yes	326.0000					
Sulfate	mg/L	CBL-301I	01/23/2017	yes	488.0000					
Sulfate	mg/L	CBL-301I	03/22/2017	yes	337.0000					
Sulfate	mg/L	CBL-301I	05/18/2017	yes	342.0000					
Sulfate	mg/L	CBL-301I	07/26/2017	yes	381.0000					
Sulfate	mg/L	CBL-301I	02/08/2018	yes	344.0000					
Sulfate	mg/L	CBL-301I	07/25/2018	yes	196.0000					
Sulfate	mg/L	CBL-301I	01/17/2019	yes	104.0000					
Sulfate	mg/L	CBL-301I	05/02/2019	yes	398.0000					
Sulfate	mg/L	CBL-301I	07/31/2019	yes	332.0000					
Sulfate	mg/L	CBL-301I	01/28/2020	yes	349.0000					
Sulfate	mg/L	CBL-301I	09/17/2020	yes	350.0000					
Sulfate	mg/L	CBL-301I	01/26/2021	yes	374.0000					
Sulfate	mg/L	CBL-301I	07/20/2021	yes	419.0000					
Sulfate	mg/L	CBL-301I	01/26/2022	yes	406.0000					
Sulfate	mg/L	CBL-301I	07/27/2022	yes	285.0000					
Sulfate	mg/L	CBL-302I	01/22/2016	yes	1020.0000					
Sulfate	mg/L	CBL-302I	05/04/2016	yes	993.0000					
Sulfate	mg/L	CBL-302I	07/27/2016	yes	1090.0000					
Sulfate	mg/L	CBL-302I	10/24/2016	yes	1180.0000					
Sulfate	mg/L	CBL-302I	01/23/2017	yes	1150.0000					
Sulfate	mg/L	CBL-302I	03/22/2017	yes	1120.0000					
Sulfate	mg/L	CBL-302I	05/16/2017	yes	1230.0000					
Sulfate	mg/L	CBL-302I	07/27/2017	yes	1180.0000					
Sulfate	mg/L	CBL-302I	02/08/2018	yes	1240.0000					
Sulfate	mg/L	CBL-302I	07/27/2018	yes	1390.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Sulfate	mg/L	CBL-302I	01/22/2019	yes	1250.0000					
Sulfate	mg/L	CBL-302I	07/31/2019	yes	1260.0000					
Sulfate	mg/L	CBL-302I	01/30/2020	yes	1350.0000					
Sulfate	mg/L	CBL-302I	09/17/2020	yes	1280.0000					
Sulfate	mg/L	CBL-302I	01/28/2021	yes	1290.0000					
Sulfate	mg/L	CBL-302I	07/21/2021	yes	1350.0000					
Sulfate	mg/L	CBL-302I	01/27/2022	yes	1340.0000					
Sulfate	mg/L	CBL-302I	07/28/2022	yes	1300.0000					
Sulfate	mg/L	CBL-306I	01/21/2016	yes	266.0000					
Sulfate	mg/L	CBL-306I	05/04/2016	yes	29.5000		yes			*
Sulfate	mg/L	CBL-306I	07/26/2016	yes	139.0000					
Sulfate	mg/L	CBL-306I	10/24/2016	yes	432.0000					
Sulfate	mg/L	CBL-306I	01/19/2017	yes	270.0000					
Sulfate	mg/L	CBL-306I	03/22/2017	yes	340.0000					
Sulfate	mg/L	CBL-306I	05/18/2017	yes	412.0000					
Sulfate	mg/L	CBL-306I	07/27/2017	yes	513.0000					
Sulfate	mg/L	CBL-306I	02/08/2018	yes	493.0000					
Sulfate	mg/L	CBL-306I	07/27/2018	yes	406.0000					
Sulfate	mg/L	CBL-306I	01/16/2019	yes	292.0000					
Sulfate	mg/L	CBL-306I	07/31/2019	yes	816.0000		yes			*
Sulfate	mg/L	CBL-306I	08/23/2019	yes	387.0000					
Sulfate	mg/L	CBL-306I	01/29/2020	yes	561.0000					
Sulfate	mg/L	CBL-306I	09/19/2020	yes	506.0000					
Sulfate	mg/L	CBL-306I	01/28/2021	yes	388.0000					
Sulfate	mg/L	CBL-306I	07/21/2021	yes	336.0000					
Sulfate	mg/L	CBL-306I	01/27/2022	yes	510.0000					
Sulfate	mg/L	CBL-306I	07/28/2022	yes	348.0000					
Sulfate	mg/L	CBL-308I	01/22/2016	yes	1490.0000					
Sulfate	mg/L	CBL-308I	05/04/2016	yes	1410.0000					
Sulfate	mg/L	CBL-308I	07/26/2016	yes	1490.0000					
Sulfate	mg/L	CBL-308I	10/24/2016	yes	1550.0000					
Sulfate	mg/L	CBL-308I	01/19/2017	yes	1320.0000					
Sulfate	mg/L	CBL-308I	03/22/2017	yes	1470.0000					
Sulfate	mg/L	CBL-308I	05/16/2017	yes	1580.0000					
Sulfate	mg/L	CBL-308I	07/26/2017	yes	1550.0000					
Sulfate	mg/L	CBL-308I	02/06/2018	yes	1570.0000					
Sulfate	mg/L	CBL-308I	07/25/2018	yes	1540.0000					
Sulfate	mg/L	CBL-308I	01/18/2019	yes	1520.0000					
Sulfate	mg/L	CBL-308I	07/31/2019	yes	1420.0000					
Sulfate	mg/L	CBL-308I	01/29/2020	yes	1340.0000					
Sulfate	mg/L	CBL-308I	09/18/2020	yes	1310.0000					
Sulfate	mg/L	CBL-308I	01/28/2021	yes	1340.0000					
Sulfate	mg/L	CBL-308I	07/21/2021	yes	1240.0000					
Sulfate	mg/L	CBL-308I	01/27/2022	yes	1310.0000					
Sulfate	mg/L	CBL-308I	07/27/2022	yes	1190.0000					
Sulfate	mg/L	CBL-341I	01/23/2017	yes	307.0000					
Sulfate	mg/L	CBL-341I	02/23/2017	yes	404.0000					
Sulfate	mg/L	CBL-341I	03/22/2017	yes	346.0000					
Sulfate	mg/L	CBL-341I	04/20/2017	yes	336.0000					
Sulfate	mg/L	CBL-341I	05/16/2017	yes	369.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Sulfate	mg/L	CBL-341I	06/20/2017	yes	363.0000					
Sulfate	mg/L	CBL-341I	07/27/2017	yes	419.0000					
Sulfate	mg/L	CBL-341I	09/11/2017	yes	354.0000					
Sulfate	mg/L	CBL-341I	02/08/2018	yes	383.0000					
Sulfate	mg/L	CBL-341I	08/24/2018	yes	376.0000					
Sulfate	mg/L	CBL-341I	01/22/2019	yes	358.0000					
Sulfate	mg/L	CBL-341I	07/31/2019	yes	329.0000					
Sulfate	mg/L	CBL-341I	01/30/2020	yes	351.0000					
Sulfate	mg/L	CBL-341I	09/17/2020	yes	336.0000					
Sulfate	mg/L	CBL-341I	01/27/2021	yes	324.0000					
Sulfate	mg/L	CBL-341I	07/22/2021	yes	316.0000					
Sulfate	mg/L	CBL-341I	01/27/2022	yes	320.0000					
Sulfate	mg/L	CBL-341I	07/28/2022	yes	296.0000					
Total Dissolved Solids	mg/L	CBL-301I	01/21/2016	yes	4380.0000					
Total Dissolved Solids	mg/L	CBL-301I	05/04/2016	yes	5050.0000					
Total Dissolved Solids	mg/L	CBL-301I	07/27/2016	yes	6020.0000					
Total Dissolved Solids	mg/L	CBL-301I	10/24/2016	yes	4570.0000					
Total Dissolved Solids	mg/L	CBL-301I	01/23/2017	yes	6140.0000					
Total Dissolved Solids	mg/L	CBL-301I	03/22/2017	yes	6570.0000					
Total Dissolved Solids	mg/L	CBL-301I	05/18/2017	yes	6430.0000					
Total Dissolved Solids	mg/L	CBL-301I	07/26/2017	yes	4290.0000					
Total Dissolved Solids	mg/L	CBL-301I	02/08/2018	yes	5120.0000					
Total Dissolved Solids	mg/L	CBL-301I	07/25/2018	yes	5390.0000					
Total Dissolved Solids	mg/L	CBL-301I	01/17/2019	yes	1460.0000		yes			*
Total Dissolved Solids	mg/L	CBL-301I	05/02/2019	yes	5650.0000					
Total Dissolved Solids	mg/L	CBL-301I	07/31/2019	yes	6040.0000					
Total Dissolved Solids	mg/L	CBL-301I	01/28/2020	yes	4790.0000					
Total Dissolved Solids	mg/L	CBL-301I	09/17/2020	yes	6340.0000					
Total Dissolved Solids	mg/L	CBL-301I	01/26/2021	yes	6060.0000					
Total Dissolved Solids	mg/L	CBL-301I	07/20/2021	yes	5870.0000					
Total Dissolved Solids	mg/L	CBL-301I	01/26/2022	yes	4700.0000					
Total Dissolved Solids	mg/L	CBL-301I	07/27/2022	yes	4590.0000					
Total Dissolved Solids	mg/L	CBL-302I	01/22/2016	yes	5500.0000					
Total Dissolved Solids	mg/L	CBL-302I	05/04/2016	yes	5390.0000					
Total Dissolved Solids	mg/L	CBL-302I	07/27/2016	yes	6850.0000					
Total Dissolved Solids	mg/L	CBL-302I	10/24/2016	yes	4210.0000					
Total Dissolved Solids	mg/L	CBL-302I	01/23/2017	yes	6430.0000					
Total Dissolved Solids	mg/L	CBL-302I	03/22/2017	yes	6460.0000					
Total Dissolved Solids	mg/L	CBL-302I	05/16/2017	yes	5860.0000					
Total Dissolved Solids	mg/L	CBL-302I	07/27/2017	yes	5120.0000					
Total Dissolved Solids	mg/L	CBL-302I	02/08/2018	yes	6010.0000					
Total Dissolved Solids	mg/L	CBL-302I	07/27/2018	yes	5510.0000					
Total Dissolved Solids	mg/L	CBL-302I	01/22/2019	yes	5060.0000					
Total Dissolved Solids	mg/L	CBL-302I	07/31/2019	yes	4190.0000					
Total Dissolved Solids	mg/L	CBL-302I	01/30/2020	yes	4790.0000					
Total Dissolved Solids	mg/L	CBL-302I	09/17/2020	yes	4990.0000					
Total Dissolved Solids	mg/L	CBL-302I	01/28/2021	yes	4800.0000					
Total Dissolved Solids	mg/L	CBL-302I	07/21/2021	yes	4810.0000					
Total Dissolved Solids	mg/L	CBL-302I	01/27/2022	yes	4510.0000					
Total Dissolved Solids	mg/L	CBL-302I	07/28/2022	yes	5120.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.

Table 2

## Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Total Dissolved Solids	mg/L	CBL-306I	01/21/2016	yes	1280.0000					
Total Dissolved Solids	mg/L	CBL-306I	05/04/2016	yes	431.0000		yes			*
Total Dissolved Solids	mg/L	CBL-306I	07/26/2016	yes	790.0000					
Total Dissolved Solids	mg/L	CBL-306I	10/24/2016	yes	1150.0000					
Total Dissolved Solids	mg/L	CBL-306I	01/19/2017	yes	1320.0000					
Total Dissolved Solids	mg/L	CBL-306I	03/22/2017	yes	1460.0000					
Total Dissolved Solids	mg/L	CBL-306I	05/18/2017	yes	1440.0000					
Total Dissolved Solids	mg/L	CBL-306I	07/27/2017	yes	1280.0000					
Total Dissolved Solids	mg/L	CBL-306I	02/08/2018	yes	1760.0000					
Total Dissolved Solids	mg/L	CBL-306I	07/27/2018	yes	1450.0000					
Total Dissolved Solids	mg/L	CBL-306I	01/16/2019	yes	1220.0000					
Total Dissolved Solids	mg/L	CBL-306I	07/31/2019	yes	676.0000		yes			*
Total Dissolved Solids	mg/L	CBL-306I	08/23/2019	yes	1710.0000					
Total Dissolved Solids	mg/L	CBL-306I	01/29/2020	yes	1830.0000					
Total Dissolved Solids	mg/L	CBL-306I	09/19/2020	yes	1730.0000					
Total Dissolved Solids	mg/L	CBL-306I	01/28/2021	yes	1420.0000					
Total Dissolved Solids	mg/L	CBL-306I	07/21/2021	yes	1320.0000					
Total Dissolved Solids	mg/L	CBL-306I	01/27/2022	yes	1730.0000					
Total Dissolved Solids	mg/L	CBL-306I	07/28/2022	yes	1540.0000					
Total Dissolved Solids	mg/L	CBL-308I	01/22/2016	yes	6820.0000					
Total Dissolved Solids	mg/L	CBL-308I	05/04/2016	yes	6120.0000					
Total Dissolved Solids	mg/L	CBL-308I	07/26/2016	yes	7890.0000					
Total Dissolved Solids	mg/L	CBL-308I	10/24/2016	yes	10200.0000					
Total Dissolved Solids	mg/L	CBL-308I	01/19/2017	yes	9620.0000					
Total Dissolved Solids	mg/L	CBL-308I	03/22/2017	yes	7260.0000					
Total Dissolved Solids	mg/L	CBL-308I	05/16/2017	yes	6590.0000					
Total Dissolved Solids	mg/L	CBL-308I	07/26/2017	yes	6480.0000					
Total Dissolved Solids	mg/L	CBL-308I	02/06/2018	yes	6200.0000					
Total Dissolved Solids	mg/L	CBL-308I	07/25/2018	yes	6320.0000					
Total Dissolved Solids	mg/L	CBL-308I	01/18/2019	yes	4760.0000					
Total Dissolved Solids	mg/L	CBL-308I	07/31/2019	yes	5820.0000					
Total Dissolved Solids	mg/L	CBL-308I	01/29/2020	yes	5980.0000					
Total Dissolved Solids	mg/L	CBL-308I	09/18/2020	yes	6860.0000					
Total Dissolved Solids	mg/L	CBL-308I	01/28/2021	yes	6190.0000					
Total Dissolved Solids	mg/L	CBL-308I	07/21/2021	yes	5270.0000					
Total Dissolved Solids	mg/L	CBL-308I	01/27/2022	yes	5320.0000					
Total Dissolved Solids	mg/L	CBL-308I	07/27/2022	yes	6840.0000					
Total Dissolved Solids	mg/L	CBL-341I	01/23/2017	yes	5000.0000					
Total Dissolved Solids	mg/L	CBL-341I	02/23/2017	yes	4520.0000					
Total Dissolved Solids	mg/L	CBL-341I	03/22/2017	yes	5110.0000					
Total Dissolved Solids	mg/L	CBL-341I	04/20/2017	yes	4240.0000					
Total Dissolved Solids	mg/L	CBL-341I	05/16/2017	yes	4840.0000					
Total Dissolved Solids	mg/L	CBL-341I	06/20/2017	yes	5940.0000					
Total Dissolved Solids	mg/L	CBL-341I	07/27/2017	yes	4150.0000					
Total Dissolved Solids	mg/L	CBL-341I	09/11/2017	yes	4860.0000					
Total Dissolved Solids	mg/L	CBL-341I	02/08/2018	yes	4320.0000					
Total Dissolved Solids	mg/L	CBL-341I	08/24/2018	yes	4800.0000					
Total Dissolved Solids	mg/L	CBL-341I	01/22/2019	yes	3870.0000					
Total Dissolved Solids	mg/L	CBL-341I	07/31/2019	yes	5370.0000					
Total Dissolved Solids	mg/L	CBL-341I	01/30/2020	yes	4900.0000					

\* - Outlier for that well and constituent.

\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.

\*\*\* - ND value replaced with median RL.

\*\*\*\* - ND value replaced with manual RL.

ND = Not detected, Result = detection limit.



Table 2

Analytical Data and CUSUM Summary

Constituent	Units	Well	Date	Background	Result		Outlier	CUSUM	Adjusted	
Total Dissolved Solids	mg/L	CBL-341I	09/17/2020	yes	4930.0000					
Total Dissolved Solids	mg/L	CBL-341I	01/27/2021	yes	3940.0000					
Total Dissolved Solids	mg/L	CBL-341I	07/22/2021	yes	4520.0000					
Total Dissolved Solids	mg/L	CBL-341I	01/27/2022	yes	3800.0000					
Total Dissolved Solids	mg/L	CBL-341I	07/28/2022	yes	4910.0000					

\* - Outlier for that well and constituent.  
\*\* - Non-outlier detected sample Result and / or CUSUM value exceeds limit.  
\*\*\* - ND value replaced with median RL.  
\*\*\*\* - ND value replaced with manual RL.  
ND = Not detected, Result = detection limit.

Table 4

**Dixon's Test Outliers  
1% Significance Level**

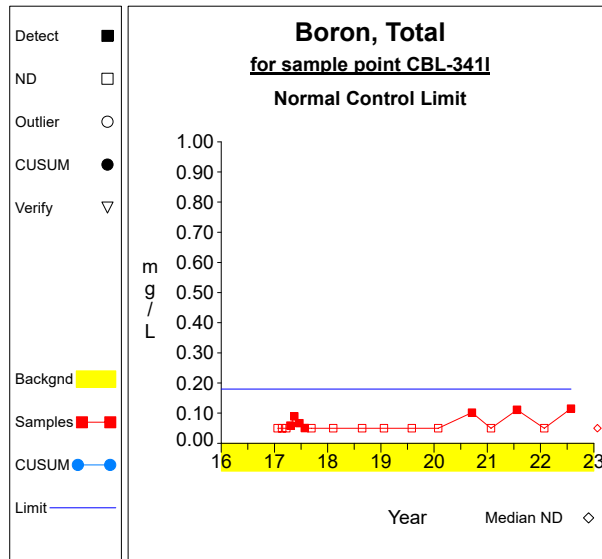
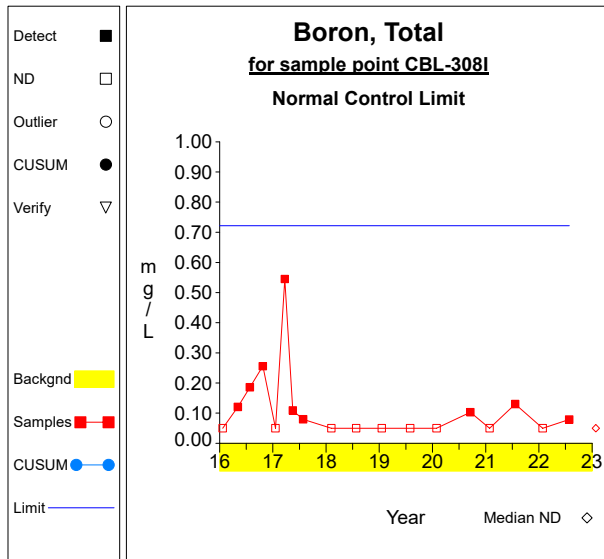
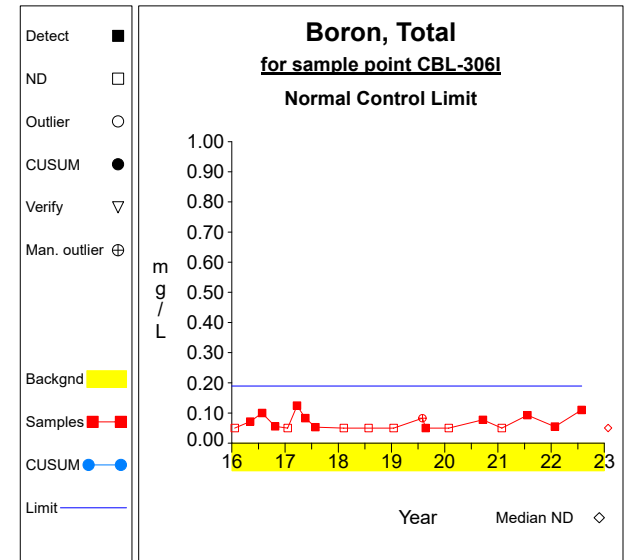
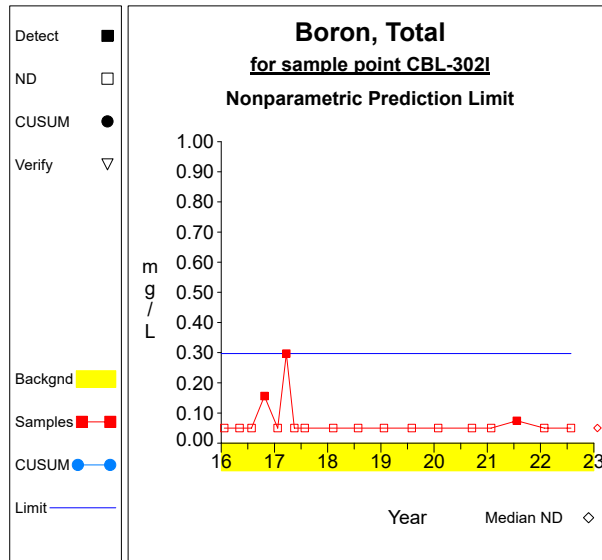
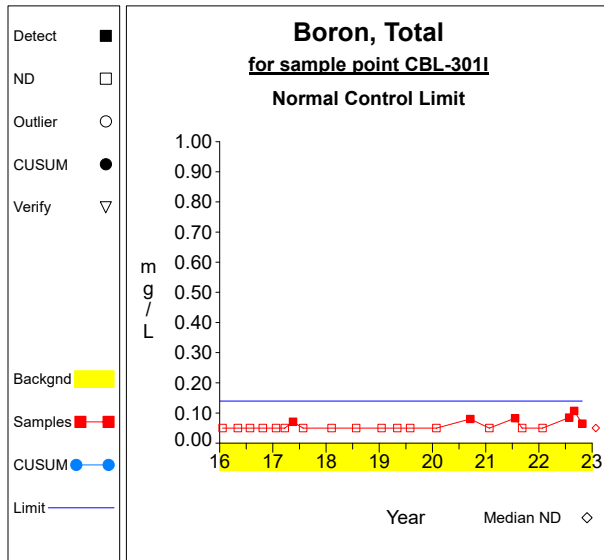
Constituent	Units	Well	Date	Result	ND Qualifier	Date Range	N	Critical Value
Calcium, Total	mg/L	CBL-301I	01/17/2019	156.0000		01/21/2016-07/27/2022	19	0.5503
Chloride	mg/L	CBL-301I	01/17/2019	619.0000		01/21/2016-07/27/2022	19	0.5503
Chloride	mg/L	CBL-306I	05/04/2016	20.0000		01/21/2016-07/28/2022	17	0.5798
Fluoride	mg/L	CBL-306I	03/22/2017	12.6000		01/21/2016-07/28/2022	18	0.5643
Fluoride	mg/L	CBL-308I	03/22/2017	9.0500		01/22/2016-07/27/2022	18	0.5643
Sulfate	mg/L	CBL-301I	01/17/2019	104.0000		01/21/2016-07/27/2022	19	0.5503
Sulfate	mg/L	CBL-306I	05/04/2016	29.5000		01/21/2016-07/28/2022	18	0.5643
Total Dissolved Solids	mg/L	CBL-301I	01/17/2019	1460.0000		01/21/2016-07/27/2022	19	0.5503
Total Dissolved Solids	mg/L	CBL-306I	05/04/2016	431.0000		01/21/2016-07/28/2022	18	0.5643

N = Total number of independent measurements in background at each well.

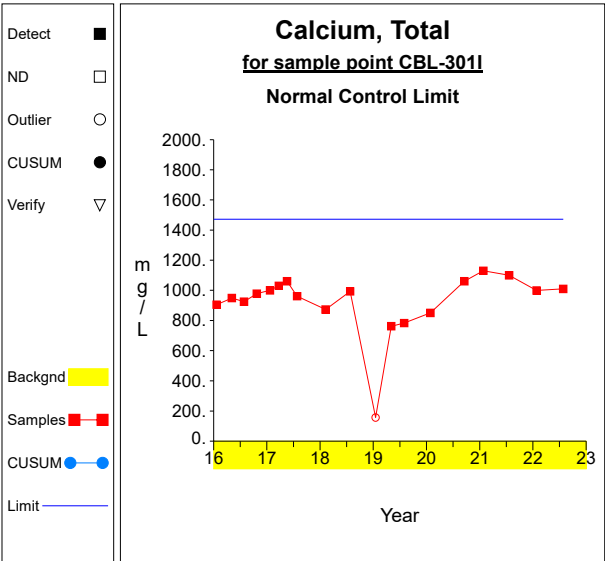
Date Range = Dates of the first and last measurements included in background at each well.

Critical Value depends on the significance level and on N-1 when the two most extreme values are tested or N for the most extreme value.

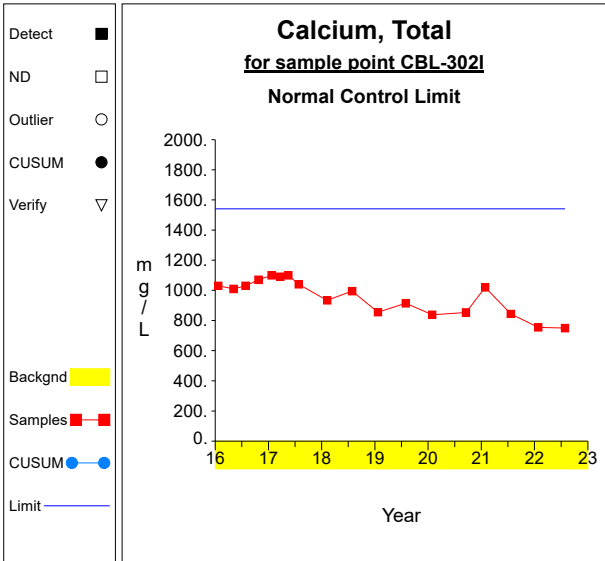
## Intra-Well Control Charts / Prediction Limits



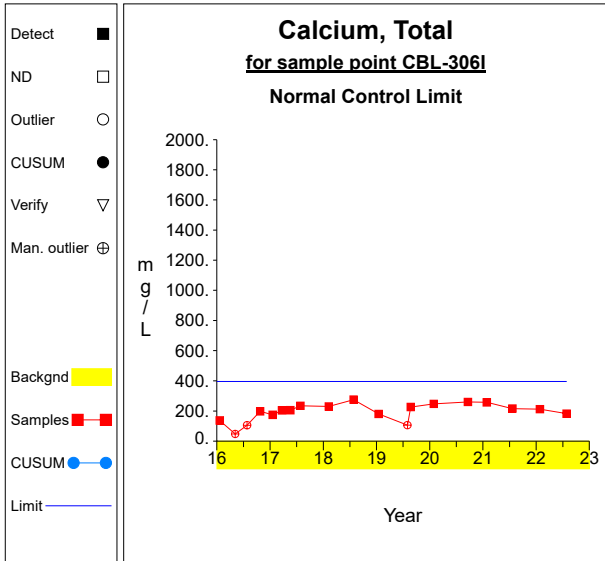
**Intra-Well Control Charts / Prediction Limits**



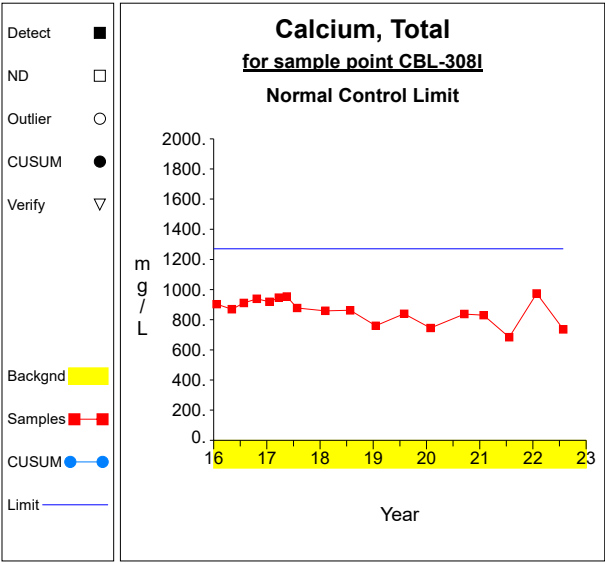
**Graph 6**



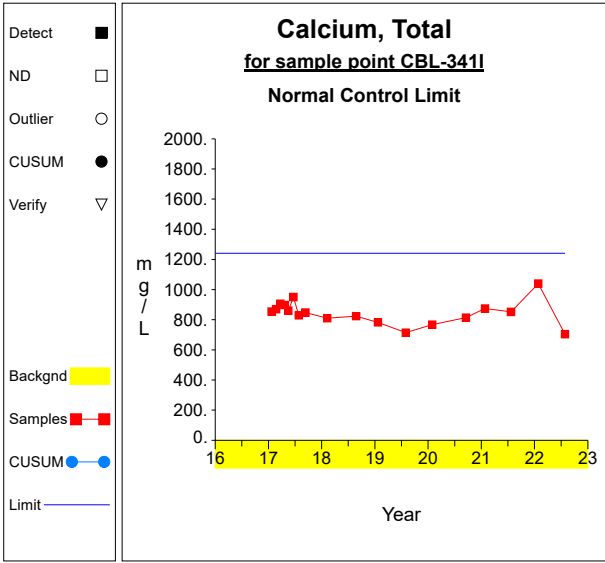
**Graph 7**



**Graph 8**

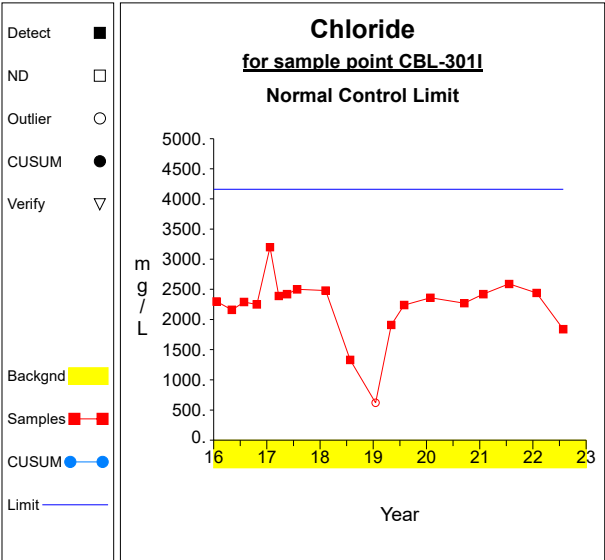


**Graph 9**

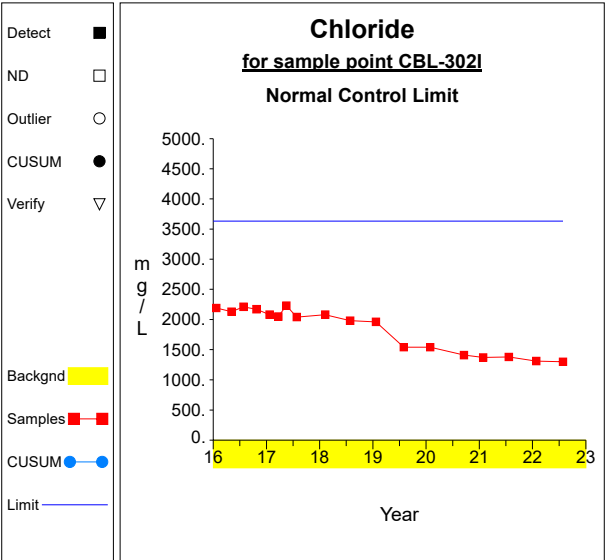


**Graph 10**

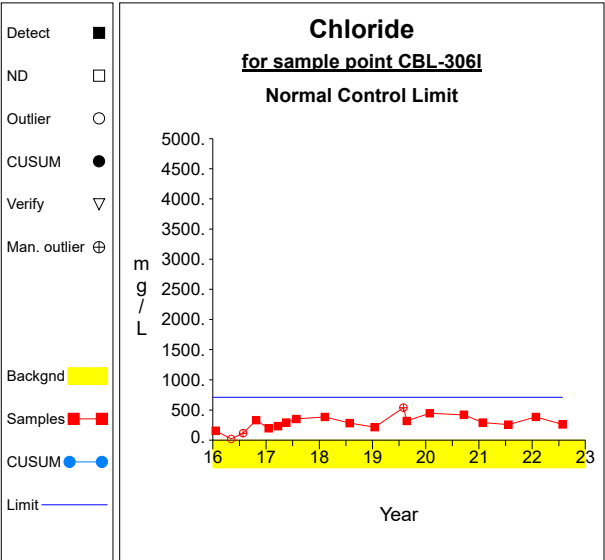
**Intra-Well Control Charts / Prediction Limits**



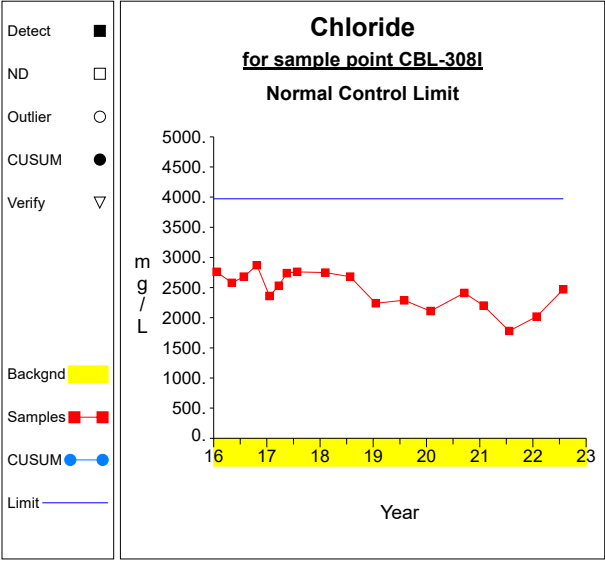
Graph 11



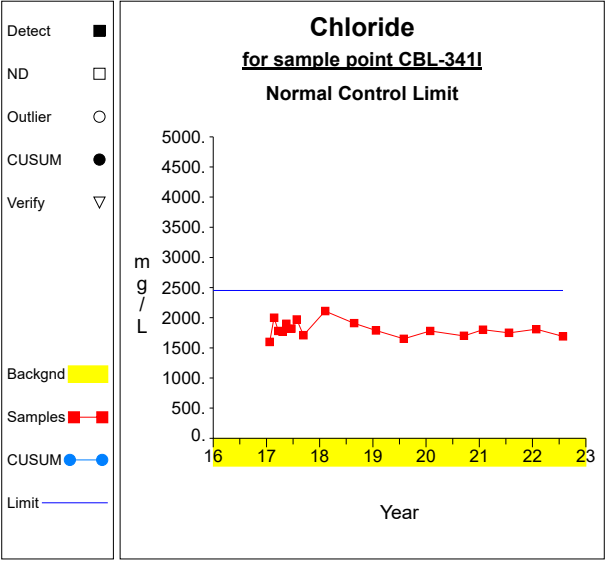
Graph 12



Graph 13

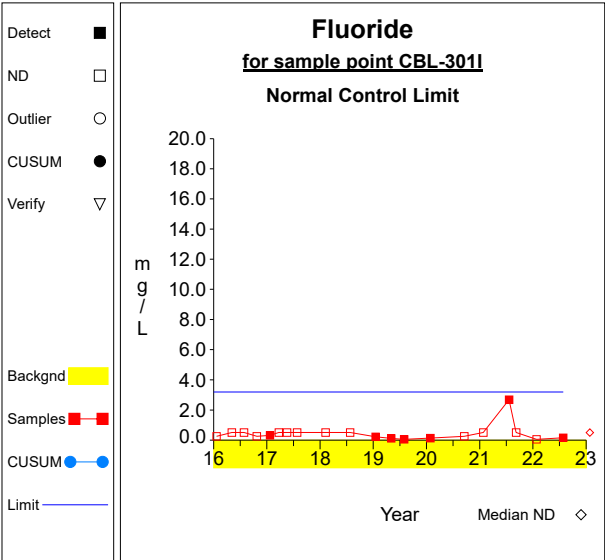


Graph 14

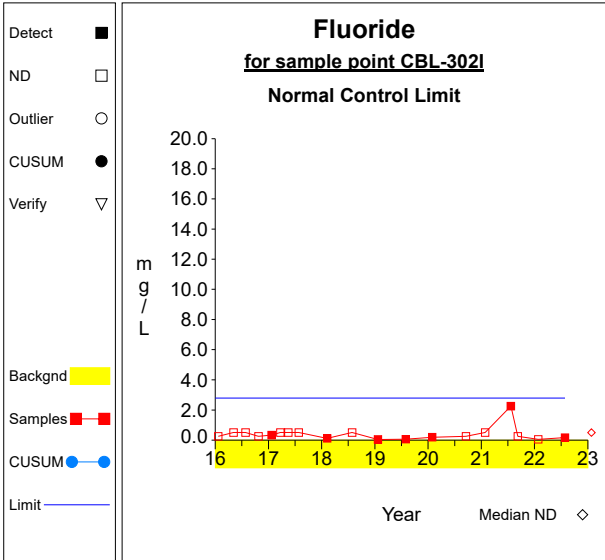


Graph 15

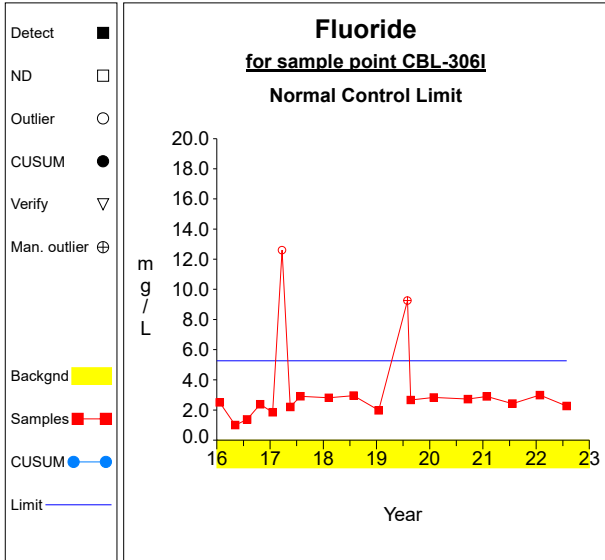
Intra-Well Control Charts / Prediction Limits



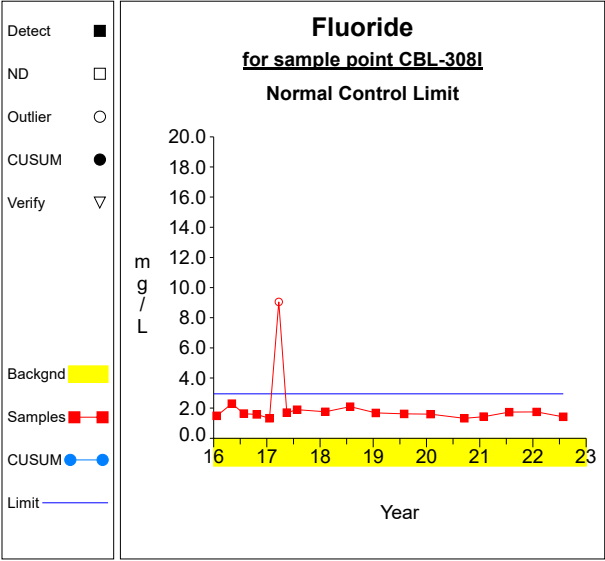
Graph 16



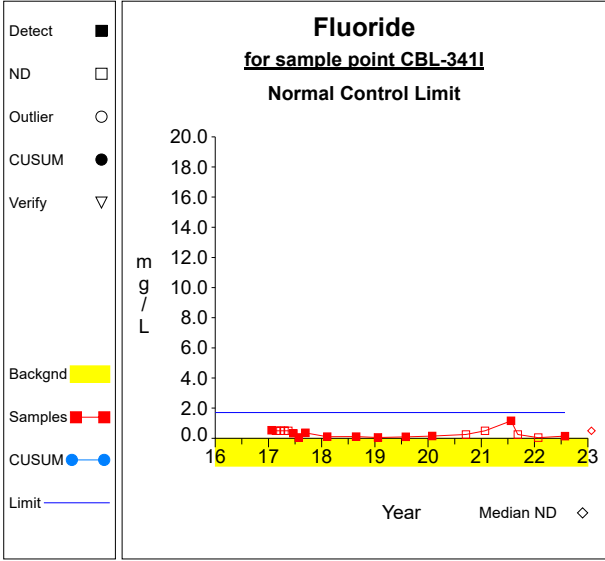
Graph 17



Graph 18



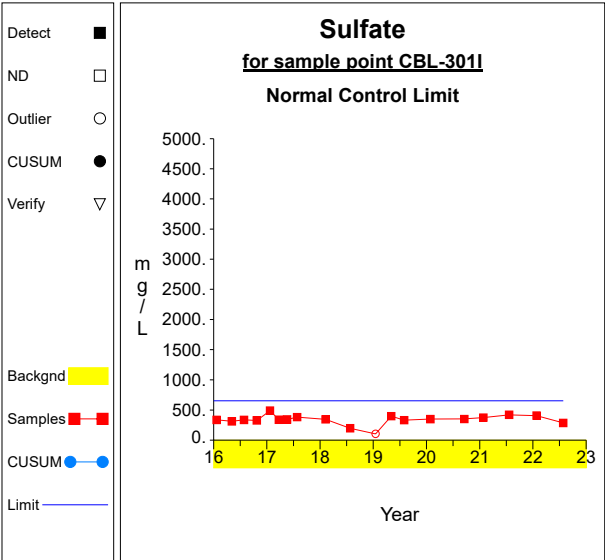
Graph 19



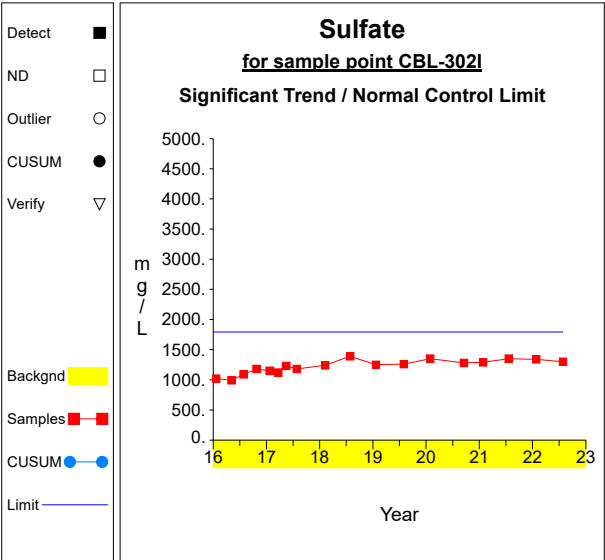
Graph 20



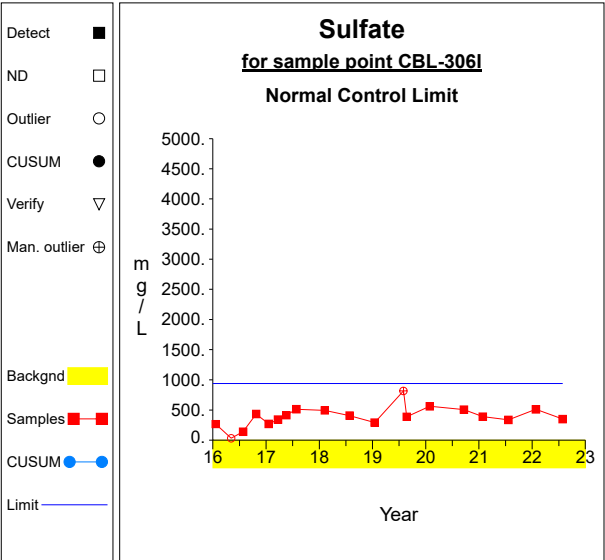
Intra-Well Control Charts / Prediction Limits



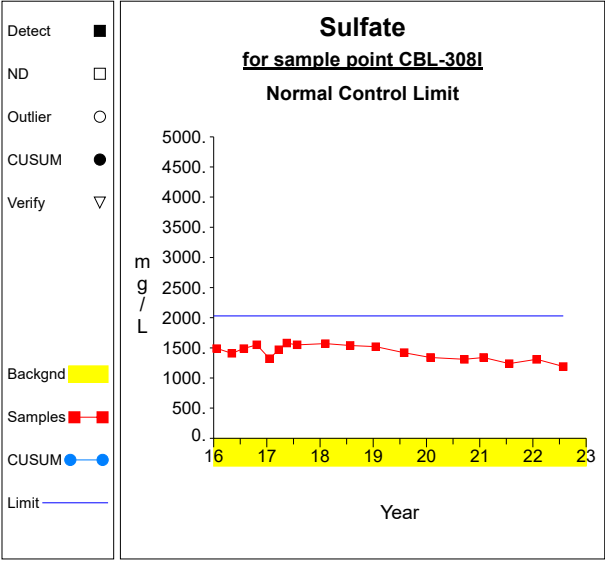
Graph 26



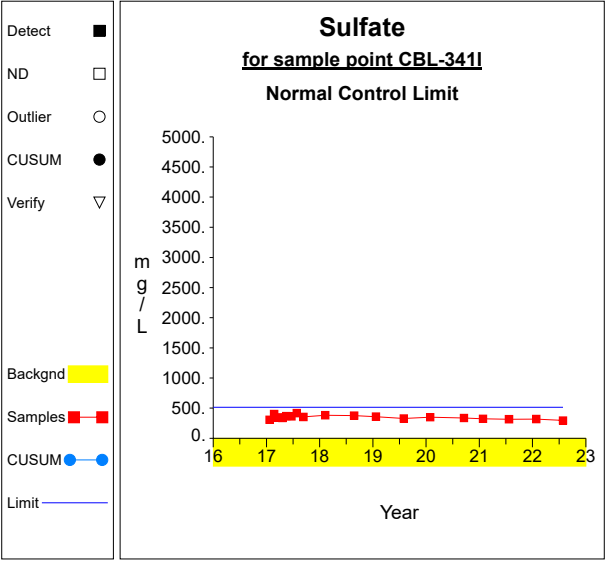
Graph 27



Graph 28



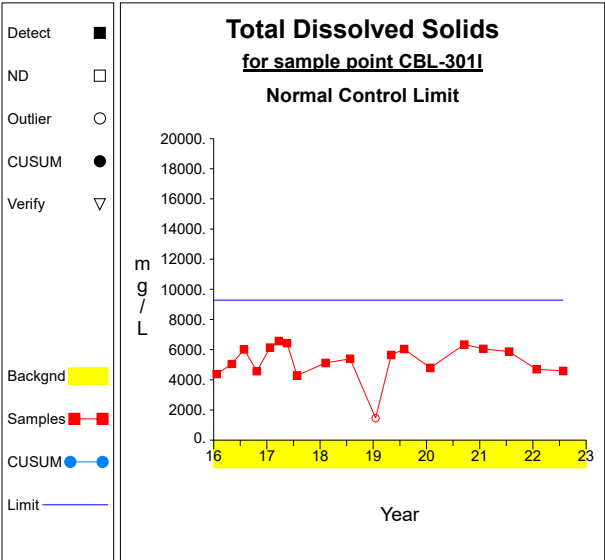
Graph 29



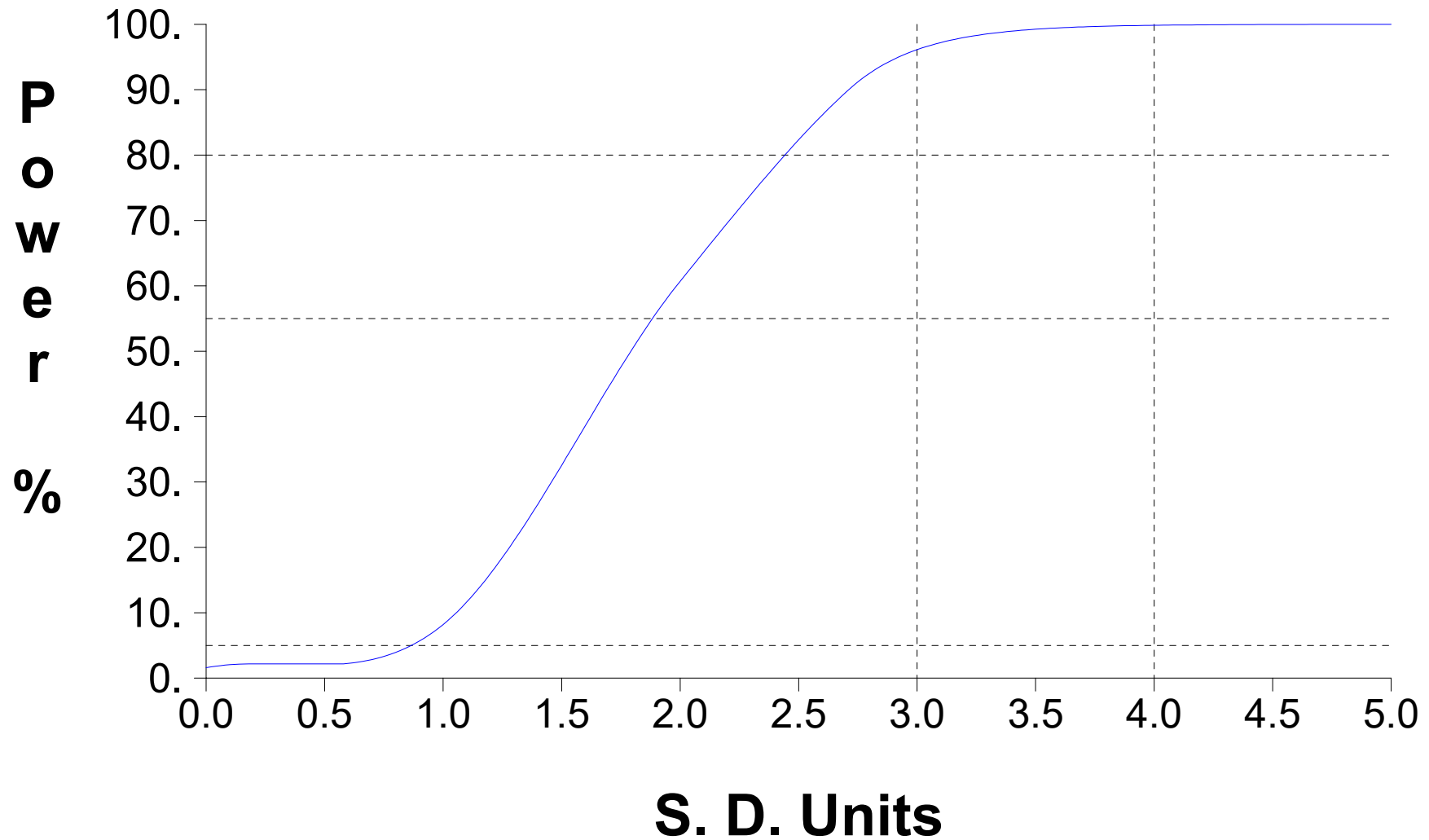
Graph 30



Intra-Well Control Charts / Prediction Limits



# False Positive and False Negative Rates for Current Intra-Well Control Charts Monitoring Program



**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Boron, Total (mg/L) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 1.29 / 22$ $= 0.059$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (0.081 - 1.664/22) / (22-1) )^{1/2}$ $= 0.016$	Compute background sd.
3	$\text{SCL} = \bar{X} + F * S$ $= 0.059 + 5.0 * 0.016$ $= 0.139$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 22 * (22-1) / 2$ $= 231$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 764.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (231 - 2.326 * 764.333^{1/2}) / 2$ $= 83.347$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$\text{LCL}(S) = 0.0$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits**

**Boron, Total (mg/L) at CBL-302I**

**Nonparametric Prediction Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	PL = max(X) = <b>0.297</b>	Compute nonparametric prediction limit as largest background measurement.
2	Conf = <b>0.99</b>	Confidence level is based on N, K and resampling strategy (see Gibbons 1994).

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Boron, Total (mg/L) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 1.222 / 18$ $= 0.068$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (0.093 - 1.494/18) / (18-1) )^{1/2}$ $= 0.024$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 0.068 + 5.0 * 0.024$ $= 0.189$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 631.667$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 631.667^{1/2}) / 2$ $= 47.27$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.003$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Boron, Total (mg/L) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 2.059 / 18$ $= 0.114$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (0.486 - 4.239/18) / (18-1) )^{1/2}$ $= 0.121$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 0.114 + 5.0 * 0.121$ $= 0.722$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 605.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 605.0^{1/2}) / 2$ $= 47.894$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.027$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Boron, Total (mg/L) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 1.144 / 18$ $= 0.064$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (0.082 - 1.308/18) / (18-1) )^{1/2}$ $= 0.023$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 0.064 + 5.0 * 0.023$ $= 0.18$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 532.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 532.0^{1/2}) / 2$ $= 49.675$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$\text{LCL}(S) = 0.0$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Calcium, Total (mg/L) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 17369.0 / 18$ $= 964.944$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((1.69 \times 10^7 - 3.02 \times 10^8 / 18) / (18-1))^{1/2}$ $= 101.271$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 964.944 + 5.0 * 101.271$ $= 1471.3$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 16.171$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -27.044$	One-sided lower confidence limit for slope.



**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Calcium, Total (mg/L) at CBL-302I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 17227.0 / 18$ $= 957.056$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (1.67 \times 10^7 - 2.97 \times 10^8 / 18) / (18-1) )^{1/2}$ $= 116.748$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 957.056 + 5.0 * 116.748$ $= 1540.795$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -46.655$	Sen's estimator of trend.
6	$\text{var}(S) = 695.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 695.0^{1/2}) / 2$ $= 45.84$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -66.423$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Calcium, Total (mg/L) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 3437.0 / 16$ $= 214.813$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((758029.0 - 1.18 \times 10^7 / 16) / (16-1))^{1/2}$ $= 36.257$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 214.813 + 5.0 * 36.257$ $= 396.097$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 16 * (16-1) / 2$ $= 120$	Number of sample pairs during trend detection period.
5	$S = 9.18$	Sen's estimator of trend.
6	$\text{var}(S) = 493.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (120 - 2.326 * 493.333^{1/2}) / 2$ $= 34.168$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -4.826$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Calcium, Total (mg/L) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 15450.0 / 18$ $= 858.333$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2 / N) / (N-1))^{1/2}$ $= ((1.34 \times 10^7 - 2.39 \times 10^8 / 18) / (18-1))^{1/2}$ $= 82.361$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 858.333 + 5.0 * 82.361$ $= 1270.141$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -24.047$	Sen's estimator of trend.
6	$\text{var}(S) = 697.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 697.0^{1/2}) / 2$ $= 45.796$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -45.396$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Calcium, Total (mg/L) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 15196.0 / 18$ $= 844.222$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((1.29 \times 10^7 - 2.31 \times 10^8 / 18) / (18-1))^{1/2}$ $= 79.475$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 844.222 + 5.0 * 79.475$ $= 1241.598$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -24.621$	Sen's estimator of trend.
6	$\text{var}(S) = 697.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 697.0^{1/2}) / 2$ $= 45.796$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -46.4$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Chloride (mg/L) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 41390.0 / 18$ $= 2299.444$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((9.75 \times 10^7 - 1.71 \times 10^9 / 18) / (18-1))^{1/2}$ $= 372.424$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 2299.444 + 5.0 * 372.424$ $= 4161.565$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 10.311$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -82.048$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Chloride (mg/L) at CBL-302I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 32970.0 / 18$ $= 1831.667$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (6.26 \times 10^7 - 1.09 \times 10^9 / 18) / (18-1) )^{1/2}$ $= 360.265$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 1831.667 + 5.0 * 360.265$ $= 3632.994$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -159.984$	Sen's estimator of trend.
6	$\text{var}(S) = 695.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 695.0^{1/2}) / 2$ $= 45.84$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -190.868$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Chloride (mg/L) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 4810.0 / 16$ $= 300.625$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2 / N) / (N-1))^{1/2}$ $= ((1.55 \times 10^6 - 2.31 \times 10^7 / 16) / (16-1))^{1/2}$ $= 82.083$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 300.625 + 5.0 * 82.083$ $= 711.039$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 16 * (16-1) / 2$ $= 120$	Number of sample pairs during trend detection period.
5	$S = 16.104$	Sen's estimator of trend.
6	$\text{var}(S) = 493.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (120 - 2.326 * 493.333^{1/2}) / 2$ $= 34.168$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -15.759$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Chloride (mg/L) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 44230.0 / 18$ $= 2457.222$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2 / N) / (N-1))^{1/2}$ $= ((1.10 \times 10^8 - 1.96 \times 10^9 / 18) / (18-1))^{1/2}$ $= 303.175$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 2457.222 + 5.0 * 303.175$ $= 3973.1$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -106.468$	Sen's estimator of trend.
6	$\text{var}(S) = 695.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 695.0^{1/2}) / 2$ $= 45.84$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -174.502$	One-sided lower confidence limit for slope.



**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Chloride (mg/L) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 32540.0 / 18$ $= 1807.778$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (5.91 \times 10^7 - 1.06 \times 10^9 / 18) / (18-1) )^{1/2}$ $= 129.14$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 1807.778 + 5.0 * 129.14$ $= 2453.477$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -16.82$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -57.489$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Fluoride (mg/L) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 10.16 / 20$ $= 0.508$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (10.634 - 103.226/20) / (20-1) )^{1/2}$ $= 0.537$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 0.508 + 5.0 * 0.537$ $= 3.191$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 20 * (20-1) / 2$ $= 190$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 681.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (190 - 2.326 * 681.333^{1/2}) / 2$ $= 64.643$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.035$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Fluoride (mg/L) at CBL-302I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 9.153 / 19$ $= 0.482$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (8.255 - 83.772/19) / (19-1) )^{1/2}$ $= 0.462$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 0.482 + 5.0 * 0.462$ $= 2.793$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 19 * (19-1) / 2$ $= 171$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 604.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (171 - 2.326 * 604.333^{1/2}) / 2$ $= 56.91$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.031$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Fluoride (mg/L) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 40.73 / 17$ $= 2.396$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((102.838 - 1658.933/17) / (17-1))^{1/2}$ $= 0.573$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 2.396 + 5.0 * 0.573$ $= 5.261$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 17 * (17-1) / 2$ $= 136$	Number of sample pairs during trend detection period.
5	$S = 0.119$	Sen's estimator of trend.
6	$\text{var}(S) = 589.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (136 - 2.326 * 589.333^{1/2}) / 2$ $= 39.767$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.032$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Fluoride (mg/L) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 28.4 / 17$ $= 1.671$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (48.489 - 806.56/17) / (17-1) )^{1/2}$ $= 0.255$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 1.671 + 5.0 * 0.255$ $= 2.948$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 17 * (17-1) / 2$ $= 136$	Number of sample pairs during trend detection period.
5	$S = -0.02$	Sen's estimator of trend.
6	$\text{var}(S) = 588.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (136 - 2.326 * 588.333^{1/2}) / 2$ $= 39.791$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.111$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Fluoride (mg/L) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 7.116 / 19$ $= 0.375$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (3.957 - 50.632/19) / (19-1) )^{1/2}$ $= 0.268$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 0.375 + 5.0 * 0.268$ $= 1.714$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 19 * (19-1) / 2$ $= 171$	Number of sample pairs during trend detection period.
5	$S = 0.0$	Sen's estimator of trend.
6	$\text{var}(S) = 751.667$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (171 - 2.326 * 751.667^{1/2}) / 2$ $= 53.615$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.133$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****pH (S.U.) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 136.43 / 22$ $= 6.201$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (847.258 - 18613.145/22) / (22-1) )^{1/2}$ $= 0.24$	Compute background sd.
3	$SCL = \bar{X} \pm F * S$ $= 6.201 \pm 5.0 * 0.24$ $= 5.003, 7.4$	Compute combined Shewhart-CUSUM normal control interval.
4	$N' = N * (N-1) / 2$ $= 22 * (22-1) / 2$ $= 231$	Number of sample pairs during trend detection period.
5	$S = -0.007$	Sen's estimator of trend.
6	$\text{var}(S) = 1248.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (231 - 2.326 * 1248.333^{1/2}) / 2$ $= 74.409$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.036$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****pH (S.U.) at CBL-302I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 115.31 / 19$ $= 6.069$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (706.23 - 13296.396/19) / (19-1) )^{1/2}$ $= 0.597$	Compute background sd.
3	$SCL = \bar{X} \pm F * S$ $= 6.069 \pm 5.0 * 0.597$ $= 3.083, 9.055$	Compute combined Shewhart-CUSUM normal control interval.
4	$N' = N * (N-1) / 2$ $= 19 * (19-1) / 2$ $= 171$	Number of sample pairs during trend detection period.
5	$S = 0.044$	Sen's estimator of trend.
6	$\text{var}(S) = 812.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (171 - 2.326 * 812.333^{1/2}) / 2$ $= 52.353$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.04$	One-sided lower confidence limit for slope.



**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****pH (S.U.) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 119.66 / 18$ $= 6.648$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (802.809 - 14318.516/18) / (18-1) )^{1/2}$ $= 0.657$	Compute background sd.
3	$SCL = \bar{X} \pm F * S$ $= 6.648 \pm 5.0 * 0.657$ $= 3.363, 9.932$	Compute combined Shewhart-CUSUM normal control interval.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -0.011$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.094$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****pH (S.U.) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 112.19 / 18$ $= 6.233$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (700.296 - 12586.596/18) / (18-1) )^{1/2}$ $= 0.247$	Compute background sd.
3	$SCL = \bar{X} \pm F * S$ $= 6.233 \pm 5.0 * 0.247$ $= 4.996, 7.47$	Compute combined Shewhart-CUSUM normal control interval.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -0.002$	Sen's estimator of trend.
6	$\text{var}(S) = 691.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 691.333^{1/2}) / 2$ $= 45.921$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.03$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****pH (S.U.) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 108.89 / 18$ $= 6.049$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (659.685 - 11857.032/18) / (18-1) )^{1/2}$ $= 0.238$	Compute background sd.
3	$SCL = \bar{X} \pm F * S$ $= 6.049 \pm 5.0 * 0.238$ $= 4.861, 7.238$	Compute combined Shewhart-CUSUM normal control interval.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 0.067$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -0.015$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Sulfate (mg/L) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 6310.0 / 18$ $= 350.556$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (2.27 \times 10^6 - 3.98 \times 10^7 / 18) / (18-1) )^{1/2}$ $= 60.294$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 350.556 + 5.0 * 60.294$ $= 652.024$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 6.483$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -8.207$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Sulfate (mg/L) at CBL-302I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 22013.0 / 18$ $= 1222.944$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (2.71 \times 10^7 - 4.85 \times 10^8 / 18) / (18-1) )^{1/2}$ $= 114.114$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 1222.944 + 5.0 * 114.114$ $= 1793.513$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 45.342$	Sen's estimator of trend.
6	$\text{var}(S) = 695.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 695.0^{1/2}) / 2$ $= 45.84$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = 25.012$	One-sided lower confidence limit for slope.
9	$LCL(S) > 0$	<b>Significant increasing trend.</b>

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Sulfate (mg/L) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 6599.0 / 17$ $= 388.176$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (2.76 \times 10^6 - 4.35 \times 10^7 / 17) / (17-1) )^{1/2}$ $= 110.356$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 388.176 + 5.0 * 110.356$ $= 939.958$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 17 * (17-1) / 2$ $= 136$	Number of sample pairs during trend detection period.
5	$S = 18.243$	Sen's estimator of trend.
6	$\text{var}(S) = 589.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (136 - 2.326 * 589.333^{1/2}) / 2$ $= 39.767$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -14.639$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Sulfate (mg/L) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 25640.0 / 18$ $= 1424.444$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2 / N) / (N-1))^{1/2}$ $= ((3.68 \times 10^7 - 6.57 \times 10^8 / 18) / (18-1))^{1/2}$ $= 121.424$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 1424.444 + 5.0 * 121.424$ $= 2031.565$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -41.243$	Sen's estimator of trend.
6	$\text{var}(S) = 693.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 693.0^{1/2}) / 2$ $= 45.884$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -65.458$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Sulfate (mg/L) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 6287.0 / 18$ $= 349.278$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (2.21 \times 10^6 - 3.95 \times 10^7 / 18) / (18-1) )^{1/2}$ $= 32.89$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 349.278 + 5.0 * 32.89$ $= 513.727$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -10.817$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -19.435$	One-sided lower confidence limit for slope.



**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Total Dissolved Solids (mg/L) at CBL-301I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 98000.0 / 18$ $= 5444.444$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2 / N) / (N-1))^{1/2}$ $= ((5.44 \times 10^8 - 9.60 \times 10^9 / 18) / (18-1))^{1/2}$ $= 767.695$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 5444.444 + 5.0 * 767.695$ $= 9282.919$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = 8.889$	Sen's estimator of trend.
6	$\text{var}(S) = 697.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 697.0^{1/2}) / 2$ $= 45.796$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -248.456$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Total Dissolved Solids (mg/L) at CBL-302I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 95610.0 / 18$ $= 5311.667$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((5.18 \times 10^8 - 9.14 \times 10^9 / 18) / (18-1))^{1/2}$ $= 764.87$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 5311.667 + 5.0 * 764.87$ $= 9136.018$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -219.811$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -407.793$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Total Dissolved Solids (mg/L) at CBL-306I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 24430.0 / 17$ $= 1437.059$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((3.62 \times 10^7 - 5.97 \times 10^8 / 17) / (17-1))^{1/2}$ $= 267.085$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 1437.059 + 5.0 * 267.085$ $= 2772.485$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 17 * (17-1) / 2$ $= 136$	Number of sample pairs during trend detection period.
5	$S = 76.005$	Sen's estimator of trend.
6	$\text{var}(S) = 586.333$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (136 - 2.326 * 586.333^{1/2}) / 2$ $= 39.839$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -5.732$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Total Dissolved Solids (mg/L) at CBL-308I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 120540.0 / 18$ $= 6696.667$	Compute background mean.
2	$S = ((\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1))^{1/2}$ $= ((8.40 \times 10^8 - 1.45 \times 10^{10}/18) / (18-1))^{1/2}$ $= 1385.271$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 6696.667 + 5.0 * 1385.271$ $= 13623.023$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -270.134$	Sen's estimator of trend.
6	$\text{var}(S) = 697.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 697.0^{1/2}) / 2$ $= 45.796$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -711.043$	One-sided lower confidence limit for slope.

**Worksheet 2 - Intra-Well Control Charts / Prediction Limits****Total Dissolved Solids (mg/L) at CBL-341I****Normal Control Limit**

<b><u>Step</u></b>	<b><u>Equation</u></b>	<b><u>Description</u></b>
1	$\bar{X} = \text{sum}[X] / N$ $= 84020.0 / 18$ $= 4667.778$	Compute background mean.
2	$S = ( (\text{sum}[X^2] - \text{sum}[X]^2/N) / (N-1) )^{1/2}$ $= ( (3.97 \times 10^8 - 7.06 \times 10^9 / 18) / (18-1) )^{1/2}$ $= 554.018$	Compute background sd.
3	$SCL = \bar{X} + F * S$ $= 4667.778 + 5.0 * 554.018$ $= 7437.868$	Compute combined Shewhart-CUSUM normal control limit.
4	$N' = N * (N-1) / 2$ $= 18 * (18-1) / 2$ $= 153$	Number of sample pairs during trend detection period.
5	$S = -76.49$	Sen's estimator of trend.
6	$\text{var}(S) = 696.0$	Variance estimate for slope.
7	$M_1(S) = (N' - Z_{.99} * \text{var}(S)^{1/2}) / 2$ $= (153 - 2.326 * 696.0^{1/2}) / 2$ $= 45.818$	Ordinal position for one-sided lower confidence limit for slope. The LCL is the $M_1^{\text{th}}$ largest slope estimate. When $M_1$ is not an integer, interpolation is used.
8	$LCL(S) = -305.108$	One-sided lower confidence limit for slope.