Lake Goodwin Landfill
First Quarter 2016 Environmental Monitoring Report

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1.0 INTRODUCTION

The following report presents the first quarter 2016 groundwater monitoring results at the Lake Goodwin Landfill (*Landfill, Site*). The Site is located at 18520 Frank Waters Road, Stanwood, Washington, immediately west of Frank Waters Road in northwestern Snohomish County, about 1.5 miles northwest of Lake Goodwin and about 5 miles south of Stanwood (*T31N, R4E, Sections 17 and 20, Willamette Meridian*). The location of the Site relative to existing municipal improvements is shown on the **Vicinity Map** (*Figure 1*).

This report has been prepared in compliance with the current, approved **Sampling & Analysis Plan** (*SAP*) for this landfill (*Snohomish County Public Works, 2013*). This SAP eliminated one well from the groundwater sampling program (*LG-03*), removed volatile organic compounds (*VOC*) analysis from the standard sampling suite, and limited metals analysis to only those detected in the last 10 years, as compared to the previous SAP.

1.1 Background

The Lake Goodwin Landfill is sited within a former County gravel pit. Waste disposed at the landfill reportedly consisted of municipal waste, including garbage and demolition debris, and some industrial waste. Waste was placed in the landfill starting in the early 1960s under the direction of **Snohomish County's Road Maintenance Division**. The landfill was closed in September 1982, and upon closure, a cover system was installed. The landfill is not lined nor does it have leachate or gas collection systems. The Site is currently permitted for post-closure monitoring by the **Snohomish Health District** (*SHD*) with a Solid Waste Facility Permit (*SW-085, 2016*). Monitoring results are reviewed by both the **SHD** and the **Department of Ecology**.

1.2 Permit Information

Monitoring activities at the Site are governed by the Solid Waste Facility Permit SW-085 (*landfill permit, Snohomish Health District 2016*). This permit requires post-closure groundwater monitoring on a quarterly basis until the facility has been shown to be stable and/or not harmful to human health or the environment. The **SHD** permits and evaluates post-closure conditions at the Site using the Snohomish Health District Sanitary Codes, *Chapter 3.1, Solid Waste Handling Regulations*; *Chapter 173-304 WAC Minimum Functional Standards for Solid Waste*; *Chapter 173-200 WAC Water Quality Standards for Groundwaters*; and *Chapter 246-290 WAC Drinking Water Regulations.*

1.3 Site Description and Physical Conditions

The closed Landfill is approximately 11.5 acres in size and is part of a larger County owned parcel of land. The Site is bounded by private residential property or commercial forest to the south, west, and north. Frank Waters Road is located along the eastern side of the Site. Access into the Site is from Frank Waters Road on a partially-paved driveway. Existing Site improvements are shown on the **Site Map** (*Figure 2*).

The Landfill is located on a topographic feature known as the Tulalip Plateau, a rolling upland area bounded by the Stillaguamish River to the north, the Puget Sound to the west and south, and by a topographic low called the Marysville Trough to the east. The general topography in the immediate vicinity of the Site is typical of glaciated areas within western Washington State – gently rolling landscapes bisected by seasonal and/or year round drainages, creeks and rivers. Several small to medium sized lakes are found on the Tulalip Plateau close to the project Site. Lake Martha, Lake Howard and Lake Goodwin are all located within a few miles of the Landfill. There are no named drainages, creeks or rivers located within a 0.5-mile radius of the landfill. The Stillaquamish River is located approximately 3 miles north of the Site.

Elevations in the immediate vicinity of the landfill range from approximately 320 to 380 feet above mean sea level. Relative to existing surrounding topography the landfill itself is approximately 60 feet high. It has been graded and slopes gently to the north-northeast. Site Topography is shown on the **Topographic Map** (*Figure 3*). In most places the landfill cover is well vegetated with grass, clover and weeds. A few Douglas fir have naturally reseeded in the fill cover near the edge of the Site. There are no stormwater detention ponds or leachate collection ponds located onsite.

1.4 Local Hydrogeology

The surficial geology of the Site area is shown on the **Geologic Map** (*Figure 4*). Based on the geologic map and our interpretation of historical Site investigations, surficial geology at the Site consists of Advance Outwash (*Qva*) sands and gravels locally overlain on the south side of the landfill by sandy silts to silty sands and gravels of the Vashon Glacial Till (*Qvt*).

The most productive aquifer below the Tulalip Plateau is the Advance Outwash (*Qva*) aquifer, which is underlain by Transitional Bed (*Qtb*) silts and clays. Where overlain by Glacial Till (*Qvt*), the aquifer is confined. In the vicinity of the Landfill where Glacial Till (*Qvt*) is absent, the aquifer is unconfined. With the exception of the surficial Glacial Till (*Qvt*) found overlying the Advance Outwash (*Qva*) sands and gravels along the southern edge of the landfill (at monitoring well *LG-02*), permeable soils were encountered from the surface down in all perimeter Site explorations. Groundwater elevations beneath the landfill during the first quarter sampling event ranged from 150.37 feet above mean sea level (*ft MSL*) to 152.83 ft MSL with a northeasterly gradient within the unconfined Advance Outwash (*Qva*) aquifer.

1.5 Existing Monitoring Network

As outlined in the Solid Waste Facility Permit SW-085, quarterly monitoring of groundwater, monthly monitoring of methane gas production and annual monitoring of landfill settlement has been carried out by Snohomish County personnel. Landfill gas is monitored at the Site via three bar hole punches.

There are currently four groundwater monitoring wells (*LG-01 and LG-02, and LG-04 and LG-05*) at the Lake Goodwin Landfill Site that are monitored on a quarterly basis. The groundwater monitoring well locations are shown on the **Network Monitoring Map** (*Figure 5*). Of these wells, LG-02 is located upgradient of the landfill and characterizes the background groundwater conditions in the immediate vicinity of the Site. The remaining three-(*3*) wells are located downgradient of the landfill (*LG-01, LG-04, and LG-05*) and monitor groundwater zones that may be impacted from the Site. Groundwater monitoring results are discussed in *Section 2.0* below.

There is no methane gas collection system at the landfill. During the fourth quarter of 2011 a monthly methane gas monitoring program was initiated at the Lake Goodwin Landfill. Monitoring of methane gas production at the landfill is accomplished by a monthly walking gas probe survey. The three-(*3*) bar hole punch probe locations used for gas monitoring are shown on the **Network Monitoring Map** (*Figure 5*). The results of the first quarter methane gas monitoring are discussed in *Section 3.0* below.

Additionally, an annual settlement monitoring program was initiated during the last quarter of 2011 at the Lake Goodwin Landfill. Annually, a topographic survey is performed, and the new topographic survey data is compared to previous recorded surveys to delineate changes to the landfill cap. In 2014, a County survey crew installed a permanent 100' grid on the landfill biomass to more accurately record changes in the landfills topography to comply with **Department of Ecology's** "*Guidance for Preparation for Termination of Post Closure Care at Municipal Landfills*". A discussion of the annual settlement monitoring is included in the **Annual Monitoring Report** for the Site.

2.0 GROUNDWATER MONITORING

Groundwater quality within Snohomish County is generally good. There are no wide spread areas of groundwater contamination found within Snohomish County. However, salt water intrusion, agricultural, and septic system impacts do occur locally. According to the 1996 **USGS** groundwater study, the most common and wide-spread water quality problems in Snohomish County are from natural causes. High iron and manganese concentrations are fairly common throughout the County. These minerals cause mostly nuisance issues (*such as objectionable odors and/or stained laundry and plumbing fixtures*). Another naturally occurring water quality problem in Snohomish County is arsenic. Arsenic levels vary depending on the groundwater aquifer and the proximity to bedrock units. Arsenic concentrations are the highest in areas located closest to surficial bedrock, such as in and around the Granite Falls area, where tested arsenic levels present health concerns. In most areas of the County arsenic levels in groundwater exceed current USEPA MCL reporting limits, but are not high enough to present health concerns.

First quarter 2016 groundwater monitoring was performed at the Site by **Snohomish County** personnel on January 14, 2016. Depth to water was measured and groundwater samples were collected following approved sampling protocol. The following sections describe field procedures used and analytical results derived from the sampling event.

2.1 Groundwater Level Measurements

The depth to groundwater within each well was measured prior to groundwater sampling activities. The depth to groundwater was measured using an electronic water level indicator in increments to the nearest 0.01 foot as taken from a marked survey point on the top of each well casing.

The **First Quarter Groundwater Measurements and Elevations** are shown in *Table 1* below. **Hydrographs** including the first quarter water level data are included in *Appendix A* of this report. Measured groundwater elevations over the last six-(*6*) years indicate increasing groundwater elevations beneath the landfill. The groundwater level data also confirm that the aquifer is unconfined in the immediate vicinity of the Site. The **First Quarter Groundwater Contour Map** developed from the field data is included as *Figure 6* of this report.

Measured precipitation at the Stanwood Weather Station (*WA-SN-11, http://www.cocorahs.org/state.aspx?state=wa*) during the first quarter monitoring period through March 31, 2016 was 10.21 inches. This is a decrease of 8.41 inches compared to the previous quarter precipitation total of 18.62 inches. For reference purposes, the precipitation totals measured at station WA-SN-11 during the monitoring period have been included on the hydrographs.

Table 1 – First Quarter Groundwater Measurements and Elevations

Well ID	Casing Elevation	Groundwater Elevation	Change from Previous Quarter
LG-01	239.18	150.49	-2.05*
LG-02	268.67	152.83	-0.45
LG-04	206.93	150.37	0.28
LG-05	235.00	151.05	0.60

* Compared to third quarter 2015 (well was dry during fourth quarter 2015 event)

2.2 First Quarter Groundwater Sampling Event

Approximately 5.2 to 9.0 gallons of water was purged from each of the wells sampled during this sampling event. Well LG-01 did not contain sufficient water for sampling and was not tested during this event. Water samples were collected from the other wells by slowly filling laboratory-supplied containers so that no headspace or air bubbles remained within the container. Samples were placed in coolers and packed in ice to keep samples at approximately 4°C for delivery to the laboratory for testing. Samples were picked up by **Am Test, Inc.** and taken to their Kirkland, Washington laboratory for analysis of dissolved metals and conventional chemistry parameters. A summary table of the analytical data is included as *Appendix B* of this report. The analytical data was compared to the groundwater and secondary drinking water standards. A complete statistical analysis of the data was also performed utilizing **DUMPStat** statistical analysis software (*version 2.1.9 by Robert D. Gibbons Lt., 2000*). Results are discussed below.

2.3 Evaluation of First Quarter Groundwater Analytical Results

The First Quarter 2015 Groundwater Test Results for each well are summarized in *Table 2* below. Comparison of results to the regulatory criteria indicates:

<u>First Quarter</u>: There were exceedances to arsenic in all tested wells during this sampling event. In addition, LG-04 had an exdeceedance of pH and LG-05 tested out with exceedances in conductivity, sodium and TDS. Besides pH, no other dissolved metals exceeded WAC level groundwater or secondary drinking water standards during this sampling event.

Table 2 – First Quarter 2016 Groundwater Test Results

Well	Groundwater Standard Exceedances Summary
LG-01	No sample - insufficient water
LG-02	Arsenic
LG-04	pH, arsenic
LG-05	Conductivity, sodium, TDS, arsenic

2.4 Statistical Evaluation

State health regulations under which Site closure is permitted require that the landfill "…shall not cause exceedances of *Chapter 173-200 WAC*, **Water Quality Standards for Groundwater**, and *Chapter 246-290 WAC*, **Drinking Water Regulations**." The intent of these regulations is to limit the impact that a landfill will have on the surrounding groundwater resources. Collected groundwater samples are tested for primary and secondary drinking water standards and dissolved metals, and the results are compared to the standards listed in the above-referenced WACs. Where an exceedance to the standards occurs, a statistical analysis is provided to determine the significance of the change or exceedance. Each of these exceedances has been statistically analyzed using **DUMPStat** per the *Subtitle D* regulations and as specifically referenced in the **U.S. EPA** guidance manual. Mean, standard deviation, prediction limits, and confidence values were calculated using **DUMPStat**.

The Sens Trend analysis test was performed for the entire data set stretching back to 1988 and the results of that analysis – increasing or decreasing trends are recorded on the spreadsheet in Appendix B. The trend analysis in Appendix C is run from 2006 to present. This allows us to place multiple constituents on a single graph to better see any potential correlation between the geochemistry and dissolved metals. Per Ecology and Snohomish Health District request, the prediction limit is updated in the first quarter of the year and subsequent data sets are compared against that prediction limit.

Based on the statistical analysis, the most exceedances to the statistically-derived prediction limits for conventional chemistry parameters were observed in downgradient well LG-05. Barium, copper, and manganese were the only metals that exceeded the prediction limit in well LG-05. Downgradient well LG-04 appeared less impacted by leachate and had only two exceedances to the calculated prediction limits (*for barium and copper*) during the first quarter sampling event. Overall, there were 16 exceedances to the calculated prediction limits for all wells during this quarter, which equals the exceedance totals for the previous quarter. Calculated exceedances to the prediction limits in the first quarter are shown in *Table 3* below.

Table 3 – First Quarter 2016 Statistical Summary Prediction Limit Exceedances

Well	2nd Quarter 2015 Exceedances
LG-01	No sample – insufficient water
LG-02	None
LG-04	Barium, copper
LG-05	Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrite, potassium, sodium, sulfate, TDS, barium, copper, manganese

There were 12 increasing concentration trends, mostly found in well LG-05, and 7 decreasing trends, mostly found in well LG-04. **Stiff Diagrams, Trilinear Diagrams** and **Statistically Significant Trends Analyses** results are included in *Appendix C* of this report.

3.0 METHANE GAS MONITORING

The landfill is not lined and there is no landfill gas collection system. In 2011, nine bar holes were installed for the purpose of monitoring landfill generated methane gas at appropriate locations through the top of the biomass. Monthly methane gas monitoring of the Site was initiated during the fourth quarter of 2011. The probes were vandalized in March 2012, and three replacement bar holes were installed in November 2013. The existing bar hole probe locations are shown on the **Monitoring Network Map** (*Figure 5*). **Bar Hole Punch Gas Probe Installation Details** are shown in *Table 4* below.

Table 4 – Bar Hole Punch Gas Probe Installation Details

Probe I.D.	Depth of Bar Hole *(inches)*	Depth to Garbage *(inches)*	Depth to Screen *(inches)*
LG-A1	46	18	30
LG-B2	44	14	32
LG-C2	37	17	31

3.1 Landfill Gas Monitoring Requirements

A monthly monitoring program was initiated by Snohomish County Solid Waste personnel in order to establish a database to be used in part for landfill stability determination and for post-closure planning. Because the bar holes are placed through the cap and into the waste, it is anticipated that measureable amounts of methane gas will be present within these monitoring points for many years.

3.2 Gas Probe Measurements

New landfill gas probes were placed in three of the original nine gas probe locations at the Site on November 15, 2013. These gas probes were monitored for methane, oxygen, and carbon dioxide on a monthly basis during the current quarter, and the results are shown below on ***Table 5***.

Table 5 – First Quarter 2016 Landfill Gas Monitoring Results

Probe	Date	% Methane	Oxygen	CO2
LG-A1	1/28/16	14	0	15
	2/24/16	13	0	16
	3/11/16	13	0	15
LG-B2	1/28/16	27	0	10
	2/24/16	26	0	12
	3/11/16	26	0	12
LG-C2	1/28/16	16	0	12
	2/24/16	17	0	13
	3/11/16	17	0	13

Gas probe measurements were consistently zero for oxygen between the fourth quarter 2015 and first quarter 2016 measurements while methane and carbon dioxide decreased slightly.

4.0 SUMMARY AND RECOMMENDATIONS

The groundwater data collected during the first quarter 2016 sampling events indicates the following:

- The precipitation totals for the first quarter 2016 were lower than those measured during previous quarter. Groundwater elevations decreased in LG-01 and LG-02, and increased in LG-04 and in LG-05. Overall, the groundwater elevation trend of all wells has been steadily rising since 2005.
- The metals and general chemistry parameters detected in well LG-05 were significantly higher than the surrounding wells during this sampling event.
- Based on the exceedance of groundwater standards and statistical prediction limits, well LG-05 appears to be impacted. Lesser impacts were indicated in well LG-04, and the only constituent that exceeded regulatory goals in upgradient well LG-02 was for arsenic, which is naturally-occurring and not likely related to the landfill. Time series plots based on the **DUMPStat** analysis indicates that there were fewer significant decreasing trends (*7)* than increasing trends (12*)* during this sampling event.
- There were very few dissolved metals impacts to the groundwater. Small exceedances to the calculated prediction limits for barium and copper were found in wells LG-04 and LG-05, and manganese also exceeded the prediction limit in well LG-05 during the current monitoring period.
- Every well exceeded the arsenic groundwater standard.
- Gas probe measurements for oxygen were generally consistently zero throughout the quarter, which is consistent with the previous quarter. Methane and carbon dioxide generally decreased between the previous quarter and current quarter.

4.1 *Conclusions/Recommendations*

The first quarter 2016 analytical data indicates a continued moderate leachate impact to the underlying Advance Outwash (*Qva*) aquifer below the Site, particularly at well LG-05. Statistical analysis indicates a number of significantly increasing trends LG-05, which is consistent with the last several sampling events. Downgradient well LG-04 has shown a significant number of decreasing trends during this same time period.

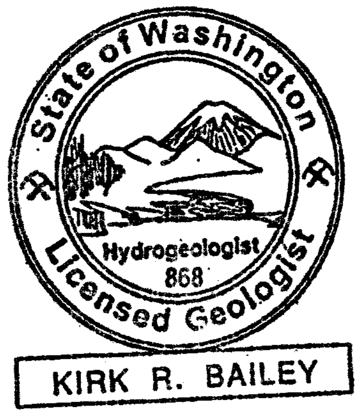
Interpretation of the data suggests that a leachate plume impacting groundwater extends beyond the landfill boundaries downgradient to the north-northeast in the immediate vicinity of LG-05.

4.2 Signatures and Licenses

8/26/16

Kirk R. Bailey, LEG, LHG
SCPW – Engineering Services

Date



8/26/16

Brian K. Eytcheson, LG
SCPW – Solid Waste Division

Date

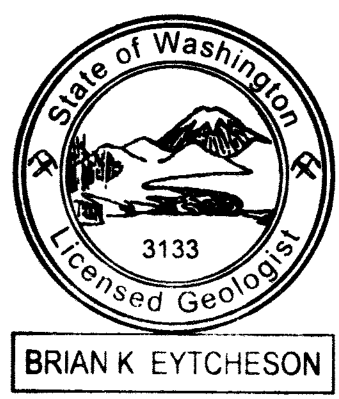
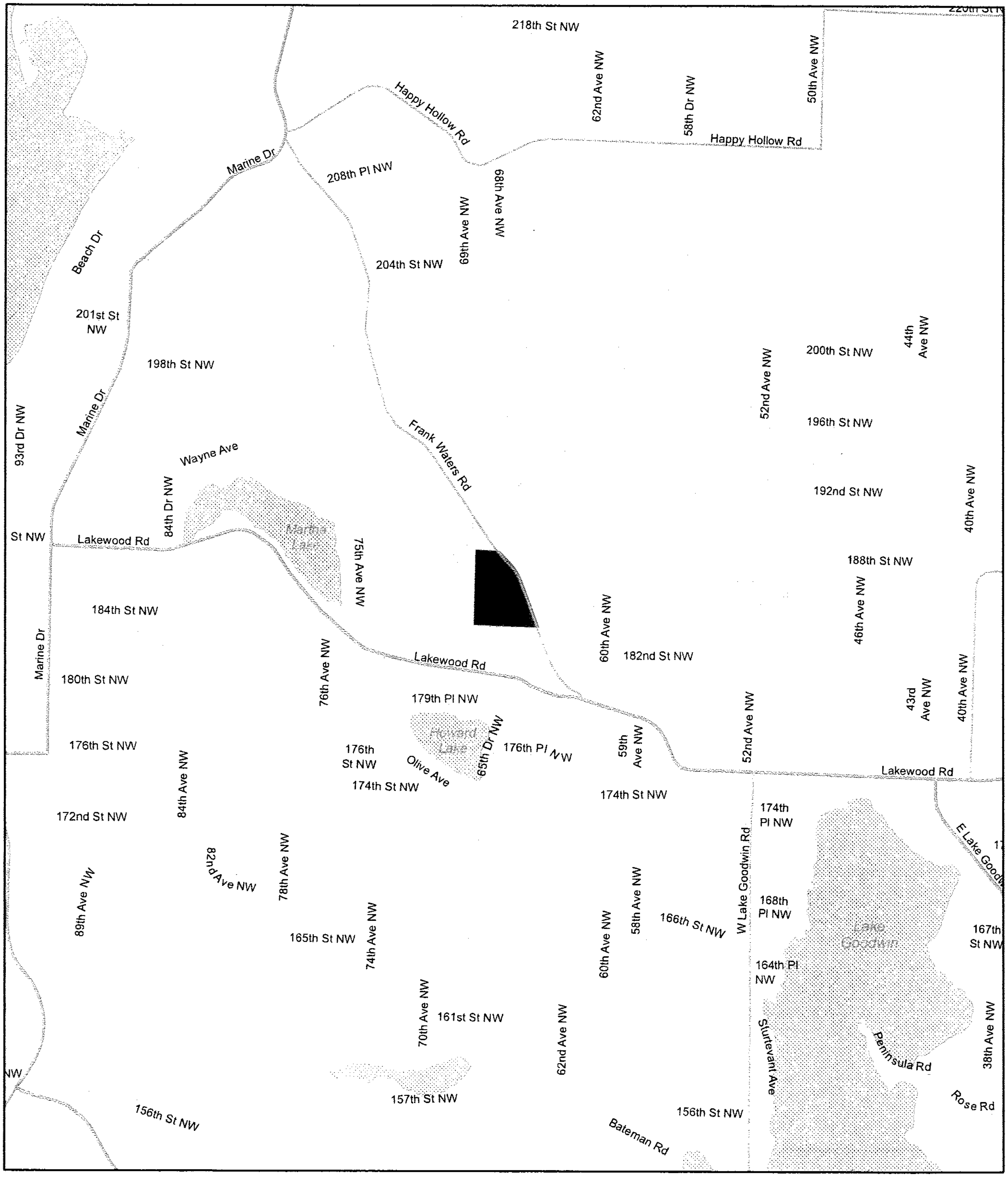
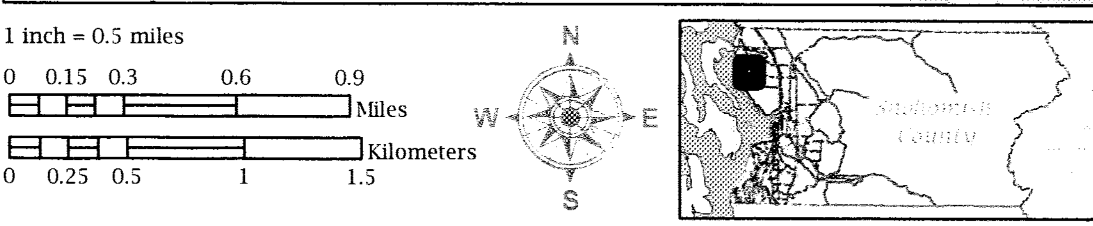


Figure 1

Lake Goodwin Landfill





Snohomish County
Public Works
Solid Waste Division
March 22, 2010

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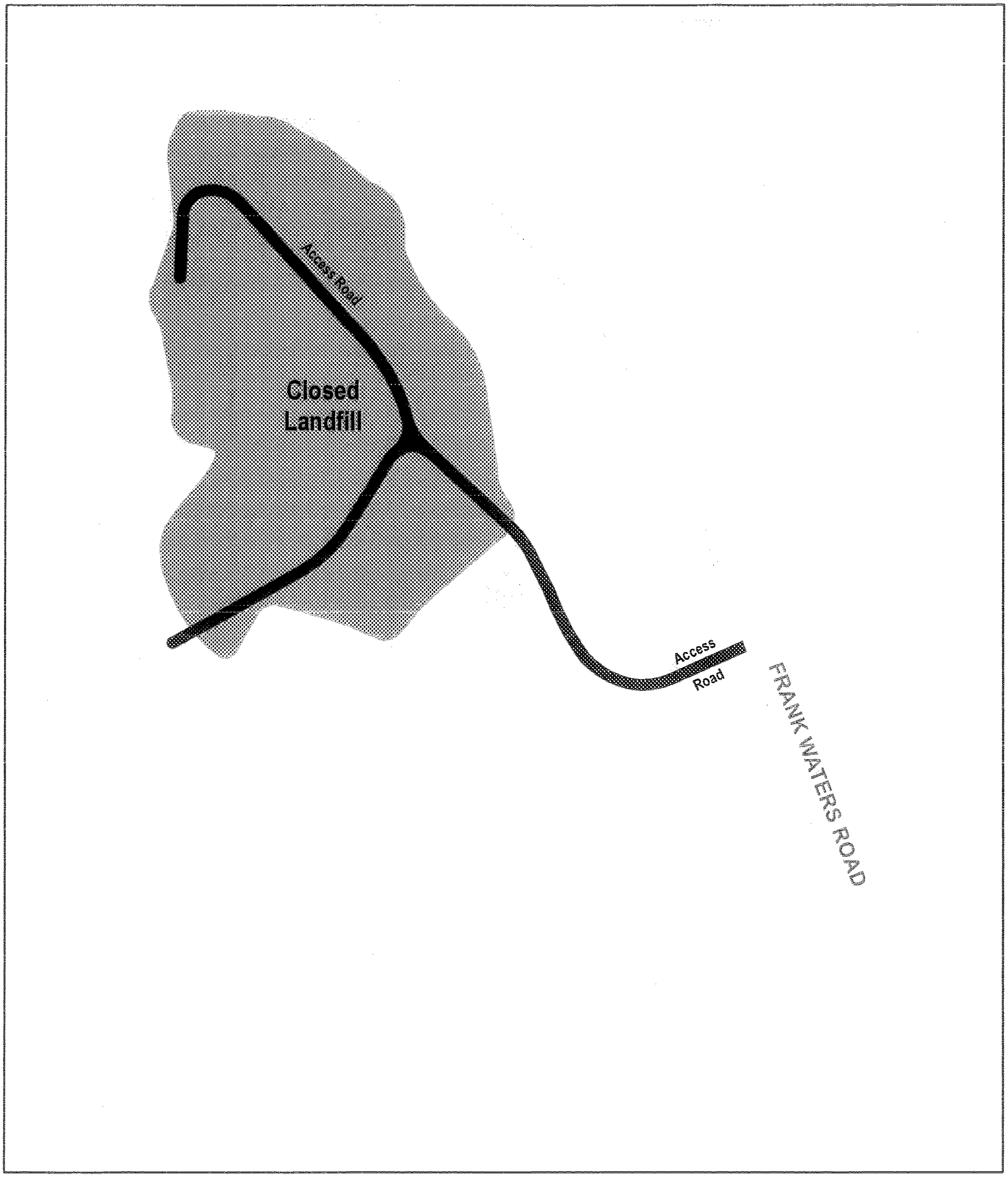
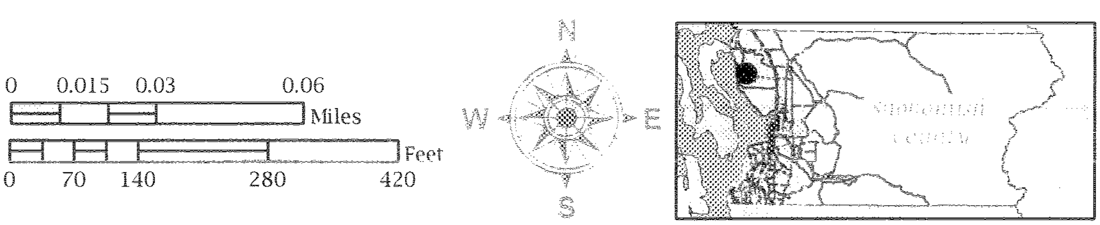
Figure 2

Lake Goodwin Landfill Site Map





Snohomish County

Public Works

Solid Waste Division

March 25, 2010

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Figure 3

Lake Goodwin Landfill

Topography

Map Features

Parcel Boundary

Subject Property Boundary

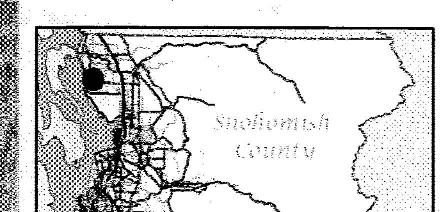
5 Foot Contours

N
W E
S

1 inch = 200 feet

0 0.0125 0.025 0.05 0.075 0.1 0.125 Miles

0 85 170 340 510 680 Feet



Snohomish County
Public Works
Solid Waste Division
March 23, 2010

Figure 4

Lake Goodwin Landfill

Geologic Map

Map Features

Parcel Boundary

Subject Property Boundary

Geologic Description

Vashon advance outwash (Qva)

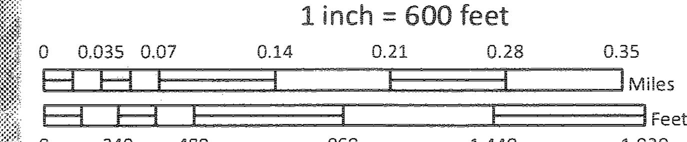
Vashon recessional outwash

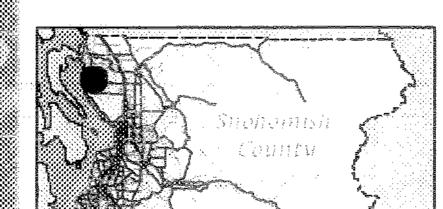
Vashon till (Qvt)

Water

Modified Land

1 inch = 600 feet





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Solid Waste Division
May 6, 2010

Figure 5

Lake Goodwin Landfill

Monitoring Network

Map Features

Parcel Boundary

Subject Property Boundary

Aquifer Unit (Active Wells)

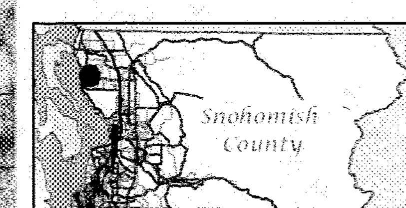
Deep Aquifer

Additional Sampling Points

Bar Hole Punch Gas Probe

0 0.02 0.04 0.08 0.12 Miles

0 80 160 320 480 640 Feet



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Snohomish County Public Works

Solid Waste Division

May 11, 2016

Figure 6

Lake Goodwin Landfill

Groundwater Elevation Contours
1st Quarter 2016

DIRECTION OF GROUNDWATER FLOW
1.46 ft / day
534 ft / year
29.92 degrees to the positive x - axis

PARCEL BOUNDARY

SUBJECT PROPERTY BOUNDARY

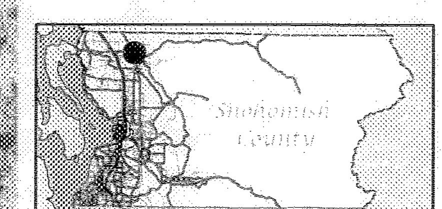
1 FT CONTOUR

WELL LOCATION

WELL_ID	SAMP_DATE	MEAS_HEAD
LG-01	1/14/2016	150.49
LG-02	1/14/2016	152.83
LG-04	1/14/2016	150.37
LG-05	1/14/2016	151.05

0 85 170 340 510 680 Feet

0 0.02 0.04 0.08 0.12 Miles



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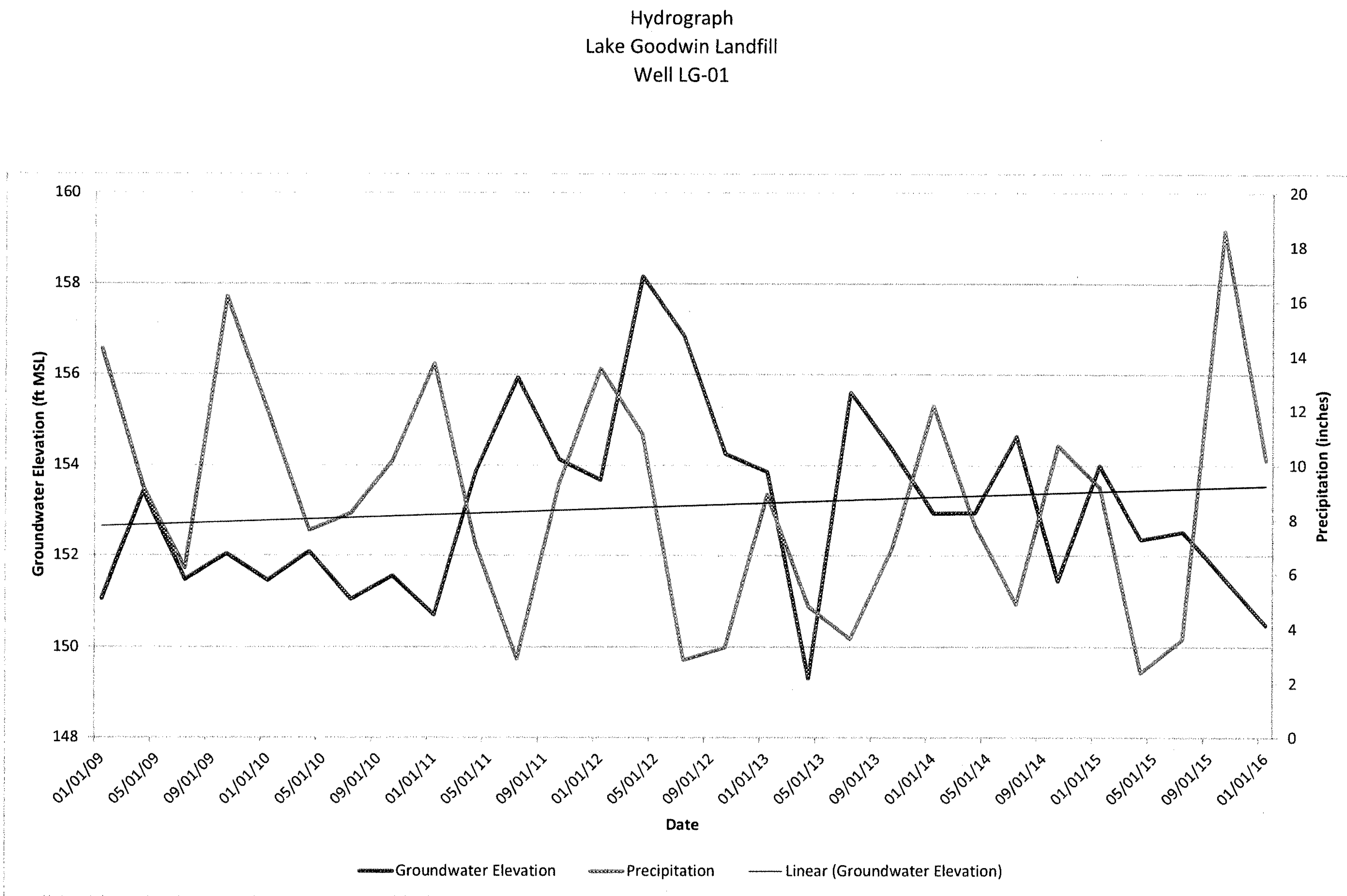
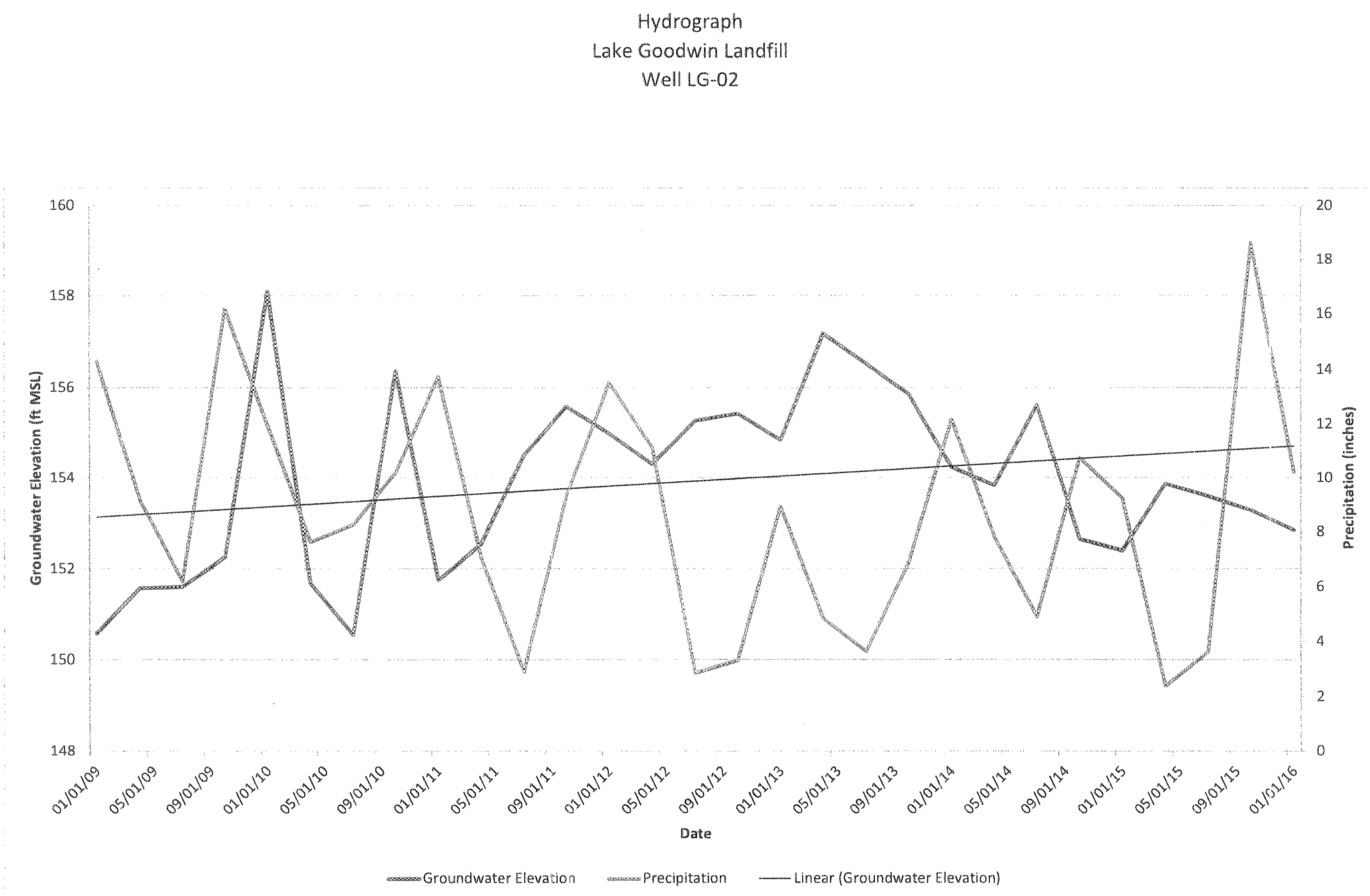
Solid Waste Division
July 8, 2016

Appendix A

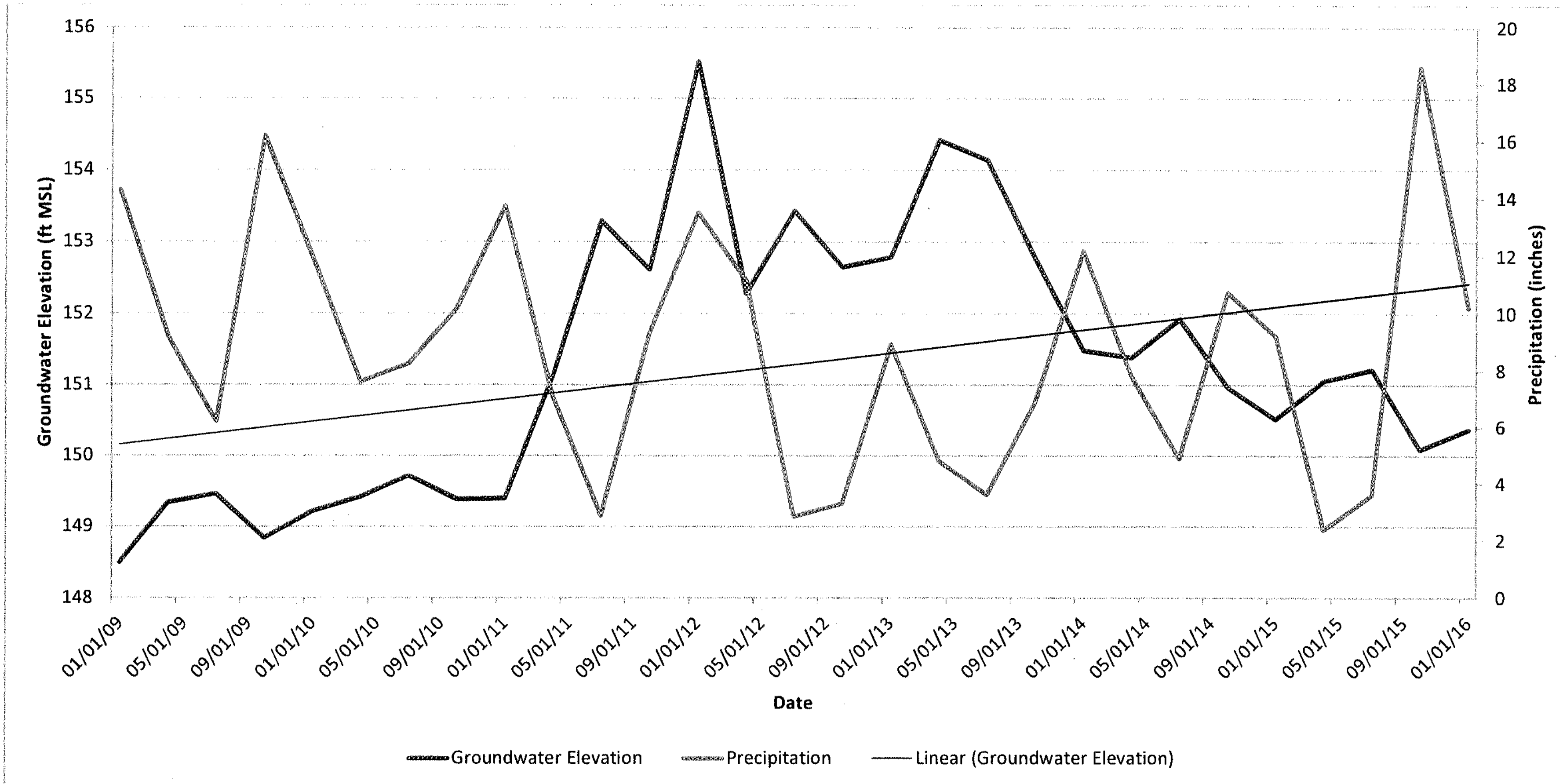
Well Hydrographs


Hydrograph
Lake Goodwin Landfill
Well LG-01
Groundwater Elevation (ft MSL)
160
158
156
154
152
150
148
Precipitation (inches)
20
18
16
14
12
10
8
6
4
2
0
01/01/09
05/01/09
09/01/09
01/01/10
05/01/10
09/01/10
01/01/11
05/01/11
09/01/11
01/01/12
05/01/12
09/01/12
01/01/13
05/01/13
09/01/13
01/01/14
05/01/14
09/01/14
01/01/15
05/01/15
09/01/15
01/01/16
Date
Groundwater Elevation
Precipitation
Linear (Groundwater Elevation)

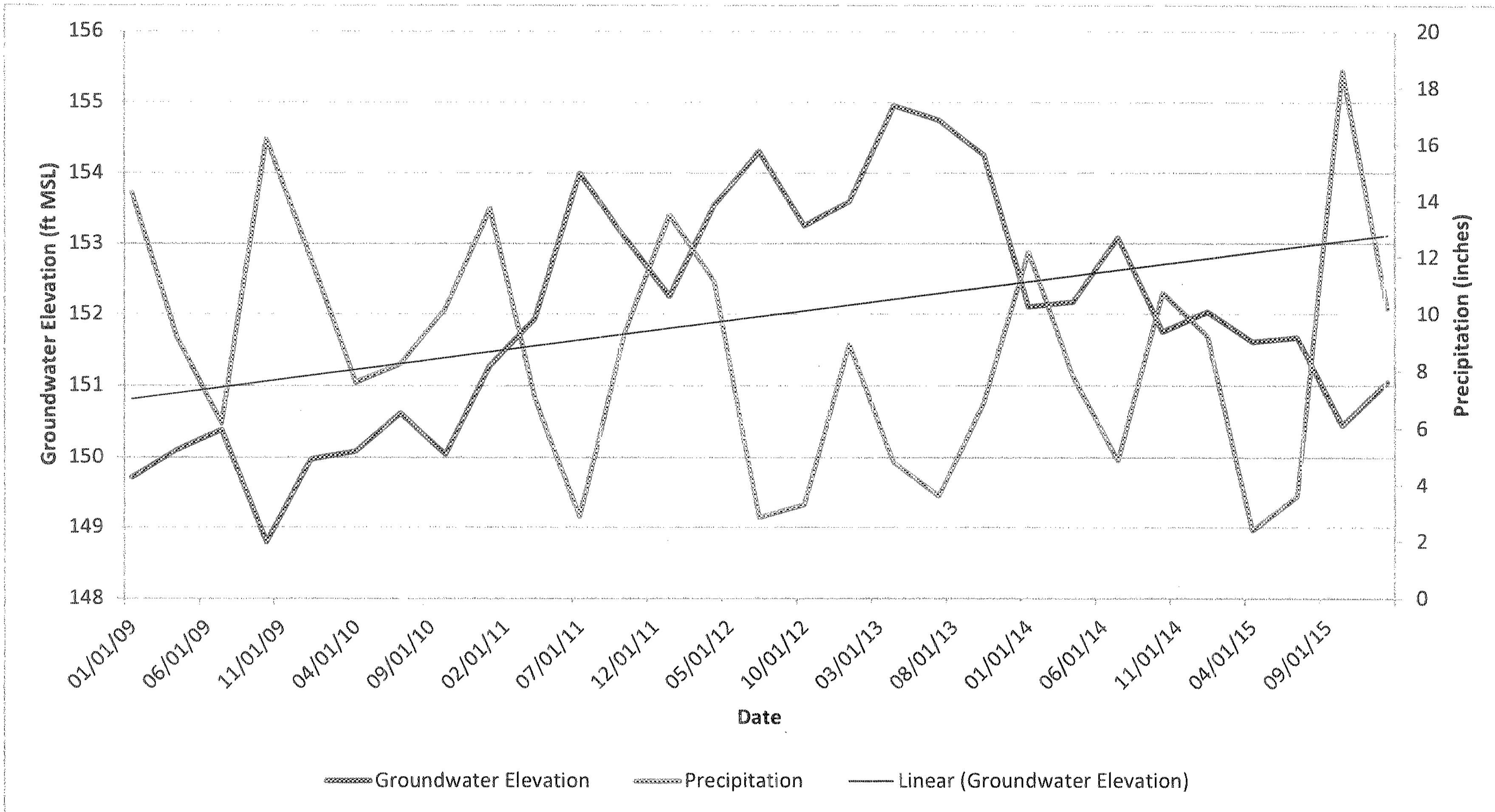


Hydrograph
Lake Goodwin Landfill
Well LG-02
Groundwater Elevation (ft MSL)
Precipitation (inches)
160
158
156
154
152
150
148
20
18
16
14
12
10
8
6
4
2
0
01/01/09
05/01/09
09/01/09
01/01/10
05/01/10
09/01/10
01/01/11
05/01/11
09/01/11
01/01/12
05/01/12
09/01/12
01/01/13
05/01/13
09/01/13
01/01/14
05/01/14
09/01/14
01/01/15
05/01/15
09/01/15
01/01/16
Date
Groundwater Elevation
Precipitation
Linear (Groundwater Elevation)

Hydrograph
Lake Goodwin Landfill
Well LG-04



Hydrograph
Lake Goodwin Landfill
Well LG-05



Snohomish County Solid Waste
Environmental Services Section
8915 Cathcart Way
Snohomish, WA 98296
Tel: (360) 668-7652

GROUND WATER ELEVATIONS

Lk Goodwin

Location	Aquifer	Date	MSL Water Elev (Ft)
LG-01	D	1/14/2016	150.49
LG-02	D	1/14/2016	152.83
LG-04	D	1/14/2016	150.37
LG-05	D	1/14/2016	151.05

This spreadsheet is from the paper, "A Spreadsheet Method For Estimating Hydraulic Gradient With Heads From Multiple Wells" submitted to Ground Water, March, 2002. To use the program, enter the coordinates for the well locations in the columns labeled x and y (part of the [X] matrix), and the water levels in the z column. The matrices are automatically updated and the gradient magnitude and direction are calculated in cell H36 and H41.

Site **Goodwin Landfill**
Measurement Date **1/14/2016**

	[X] matrix			[D] matrix
Well ID	**X-axis**	**Y-axis**	**GW Elev.**	D
LG-01	646.57	299.26	**150.49**	1
LG-02	21.47	2.50	**152.83**	1
LG-04	458.30	579.89	**150.37**	1
LG-05	205.32	748.45	**151.05**	1
5	0	0	0	1
6	0	0	0	1
7	0	0	0	1
8	0	0	0	1
9	0	0	0	1
10	0	0	0	1
11	0	0	0	1
12	0	0	0	1
13	0	0	0	1
14	0	0	0	1
15	0	0	0	1
16	0	0	0	1
17	0	0	0	1
18	0	0	0	1
19	0	0	0	1
20	0	0	0	1

Pt

646.57	21.47	458.3	205.32	0	0
299.26	2.5	579.89	748.45	0	0
150.49	152.83	150.37	151.05	0	0

{[P]t[P]}

670708.9182	612981.5542	200511.7364
612981.5542	986012.6122	245669.1442
200511.7364	245669.1442	91431.4884

{[P]t[P]}'

4.67119E-06	-1.06378E-06	-7.38574E-06
-1.06378E-06	3.3105E-06	-6.56216E-06
-7.38574E-06	-6.56216E-06	4.47663E-05

{[P]t[P]}'[P]t

0.001590422	-0.001031132	0.000413334	-0.00095	0	0
-0.000684647	-0.001017458	0.000445445	0.001268	0	0
-2.31297E-06	0.006666653	-0.00045871	0.000334	0	0

{[P]t[P]}'[P]t [D] = [A] matrix

A	1.99081E-05
B	1.1457E-05
C	0.00653969

Groundwater Gradient:	**0.0035**	
Conductivity (ft/day):	**83.3**	
Effective porosity:	**20%**	
GW velocity:	**1.46**	**ft/day**
	534	**ft/year**
Angle off x axis	**29.92**	**degrees to the positive x-axis**

Appendix B

Analytical Data Summary Table

	Upgradient Well				
	LG-02				
	'14/16	D	V	Tr	Ch
CONVENTIONAL CHEI					
Alkalinity (as CaCO3)	86				Y
Ammonia Nitrogen	).036				
Bicarbonate	86				
Calcium, Dissolved	17.9				
Chemical Oxygen Dema	10	U			
Chloride	5.29				
Conductivity (umhos/cm	220				
Magnesium, Dissolved	16				
Nitrate Nitrogen (mg-N/L	1.6				
Nitrite Nitrogen (mg-N/L)	.001	U			
pH (std units)	7.05			D	N
Potassium, Dissolved	3.08				
Sodium, Dissolved	9.5				
Sulfate	11.8				
Total Dissolved Solids	150				
Total Organic Carbon	0.5	U			
DISSOLVED METALS E					
Arsenic	**00475**				
Barium	.0109				
Cadmium	)00025	U			
Chromium	.0039				
Cobalt	).001	U			
Copper	).005	U			
Iron	).009	U			
Manganese	.0009	U			
Nickel	).005	U			
TOTAL METALS EPA N					
Arsenic	**.0044**				
Barium	.0109				
Cadmium	.0005				
Chromium	.0039				
Cobalt	).001	U			
Copper	).007				
Iron	).009	U			
Manganese	.0009	U			
Nickel	).005	U			

D: U = Indicates compound was not

V: E= Exceedance, waiting verificat

Tr: I=increasing Trend, D=Decreasi

Ch: Y indicates a change in trend fr

The groundwater standards listed a

* = Non-detect; exceedance due to

Table 2

Most Current Downgradient Monitoring Data

Constituent	Units	Well	Date		Result		Pred. Limit
Alkalinity (as caco3)	mg/L	LG-01	07/15/2015		160.0000	**	185.2145
Ammonia nitrogen	mg/L	LG-01	07/15/2015	ND	0.0050		0.0560
Bicarbonate	mg/L	LG-01	07/15/2015		160.0000	**	160.8580
Chemical oxygen demand	mg/L	LG-01	07/15/2015	ND	10.0000		26.0000
Chloride	mg/L	LG-01	07/15/2015		9.0500		9.7304
Conductivity	umhos/cm	LG-01	07/15/2015		360.0000	**	364.6602
Dissolved antimony	U mg/l	LG-01	04/29/2014		0.0000		0.0100
Dissolved arsenic	mg/L	LG-01	07/15/2015		0.0006		0.0078
Dissolved barium	mg/L	LG-01	07/15/2015		0.0154	**	0.0193
Dissolved beryllium	U mg/l	LG-01	07/15/2015	ND	0.0003		0.0005
Dissolved cadmium	U mg/l	LG-01	07/15/2015		0.0001		0.0002
Dissolved calcium	mg/L	LG-01	07/15/2015		18.5000		31.2000
Dissolved chromium	U mg/l	LG-01	07/15/2015	ND	0.0010		0.0091
Dissolved cobalt	U mg/l	LG-01	07/15/2015	ND	0.0010		0.0080
Dissolved copper	mg/L	LG-01	07/15/2015	ND	0.0050		0.0050
Dissolved iron	U mg/l	LG-01	07/15/2015	ND	0.0090		0.0310
Dissolved lead	U mg/l	LG-01	04/29/2014	ND	0.0001		0.0010
Dissolved magnesium	mg/L	LG-01	07/15/2015		25.5000	***	25.1500
Dissolved manganese	U mg/l	LG-01	07/15/2015	ND	0.0009		0.0061
Dissolved nickel	U mg/l	LG-01	07/15/2015	ND	0.0050		0.0050
Dissolved potassium	mg/L	LG-01	07/15/2015		3.2400	**	3.5404
Dissolved selenium	U mg/l	LG-01	04/29/2014		0.0003		0.0020
Dissolved silver	U mg/l	LG-01	04/29/2014	ND	0.0001		4.2501
Dissolved sodium	mg/L	LG-01	07/15/2015		7.9400		13.8000
Dissolved thallium	U mg/l	LG-01	04/29/2014	ND	0.0000		0.0010
Dissolved vanadium	U mg/l	LG-01	04/29/2014	ND	0.0050		0.0100
Dissolved zinc	mg/L	LG-01	04/29/2014		0.0030		0.0070
Nitrate nitrogen	mg-N/L	LG-01	07/15/2015		2.5000		6.0000
Nitrite nitrogen	mg-N/L	LG-01	07/15/2015	ND	0.0010		0.0110
pH	std units	LG-01	07/15/2015		6.4300		5.99 - 7.51
Sulfate	mg/L	LG-01	07/15/2015		20.9000	**	24.0000
Total dissolved solids	mg/L	LG-01	07/15/2015		240.0000		550.0000
Total organic carbon	U mg/l	LG-01	07/15/2015		2.9000		19.0000
Alkalinity (as caco3)	mg/L	LG-04	01/14/2016		130.0000		185.2145
Ammonia nitrogen	mg/L	LG-04	01/14/2016	ND	0.0050		0.0560
Bicarbonate	mg/L	LG-04	01/14/2016		130.0000		160.8580
Chemical oxygen demand	mg/L	LG-04	01/14/2016	ND	10.0000		26.0000
Chloride	mg/L	LG-04	01/14/2016		8.8300	**	9.7304
Conductivity	umhos/cm	LG-04	01/14/2016		300.0000		364.6602
Dissolved antimony	U mg/l	LG-04	04/29/2014	ND	0.0000		0.0100
Dissolved arsenic	mg/L	LG-04	01/14/2016		0.0004		0.0078
Dissolved barium	mg/L	LG-04	01/14/2016		0.0231	***	0.0193
Dissolved beryllium	U mg/l	LG-04	01/14/2016	ND	0.0003		0.0005
Dissolved cadmium	U mg/l	LG-04	01/14/2016	ND	0.0000		0.0002
Dissolved calcium	mg/L	LG-04	01/14/2016		23.8000		31.2000
Dissolved chromium	U mg/l	LG-04	01/14/2016	ND	0.0050		0.0091
Dissolved cobalt	U mg/l	LG-04	01/14/2016	ND	0.0050		0.0080
Dissolved copper	mg/L	LG-04	01/14/2016		0.0060	*	0.0050
Dissolved iron	U mg/l	LG-04	01/14/2016	ND	0.0050		0.0310
Dissolved lead	U mg/l	LG-04	04/29/2014	ND	0.0001		0.0010
Dissolved magnesium	mg/L	LG-04	01/14/2016		22.4000		25.1500
Dissolved manganese	U mg/l	LG-04	01/14/2016		0.0010		0.0061
Dissolved nickel	U mg/l	LG-04	01/14/2016	ND	0.0020		0.0050

* - Current value failed - awaiting verification.
** - Current value passed - previous exceedance not verified.
*** - Current value failed - exceedance verified.
**** - Current value passed - awaiting one more verification.
***** - Insufficient background data to compute prediction limit.
ND = Not Detected, result = detection limit.

Table 2

Most Current Downgradient Monitoring Data

Constituent	Units	Well	Date		Result		Pred. Limit
Dissolved potassium	mg/L	LG-04	01/14/2016		3.5300		3.5404
Dissolved selenium	U mg/l	LG-04	04/29/2014		0.0003		0.0020
Dissolved silver	U mg/l	LG-04	04/29/2014	ND	0.0001		4.2501
Dissolved sodium	mg/L	LG-04	01/14/2016		12.3000		13.8000
Dissolved thallium	U mg/l	LG-04	04/29/2014	ND	0.0000		0.0010
Dissolved vanadium	U mg/l	LG-04	04/29/2014	ND	0.0050		0.0100
Dissolved zinc	mg/L	LG-04	04/29/2014	ND	0.0010		0.0070
Nitrate nitrogen	mg-N/L	LG-04	01/14/2016		1.2000		6.0000
Nitrite nitrogen	mg-N/L	LG-04	01/14/2016	ND	0.0010		0.0110
pH	std units	LG-04	01/14/2016		6.1300	**	5.99 - 7.51
Sulfate	mg/L	LG-04	01/14/2016		14.9000		24.0000
Total dissolved solids	mg/L	LG-04	01/14/2016		250.0000		550.0000
Total organic carbon	U mg/l	LG-04	01/14/2016	ND	0.5000		19.0000
Alkalinity (as caco3)	mg/L	LG-05	01/14/2016		470.0000	***	185.2145
Ammonia nitrogen	mg/L	LG-05	01/14/2016	ND	0.0050		0.0560
Bicarbonate	mg/L	LG-05	01/14/2016		470.0000	***	160.8580
Chemical oxygen demand	mg/L	LG-05	01/14/2016	ND	10.0000		26.0000
Chloride	mg/L	LG-05	01/14/2016		27.7000	***	9.7304
Conductivity	umhos/cm	LG-05	01/14/2016		1000.0000	***	364.6602
Dissolved antimony	U mg/l	LG-05	04/29/2014		0.0001		0.0100
Dissolved arsenic	mg/L	LG-05	01/14/2016		0.0010		0.0078
Dissolved barium	mg/L	LG-05	01/14/2016		0.0836	***	0.0193
Dissolved beryllium	U mg/l	LG-05	01/14/2016	ND	0.0003		0.0005
Dissolved cadmium	U mg/l	LG-05	01/14/2016		0.0000		0.0002
Dissolved calcium	mg/L	LG-05	01/14/2016		55.9000	***	31.2000
Dissolved chromium	U mg/l	LG-05	01/14/2016	ND	0.0050		0.0091
Dissolved cobalt	U mg/l	LG-05	01/14/2016		0.0020		0.0080
Dissolved copper	mg/L	LG-05	01/14/2016		0.0120	***	0.0050
Dissolved iron	U mg/l	LG-05	01/14/2016		0.0160		0.0310
Dissolved lead	U mg/l	LG-05	04/29/2014		0.0001		0.0010
Dissolved magnesium	mg/L	LG-05	01/14/2016		77.7000	***	25.1500
Dissolved manganese	U mg/l	LG-05	01/14/2016		0.0144	*	0.0061
Dissolved nickel	U mg/l	LG-05	01/14/2016	ND	0.0020	**	0.0050
Dissolved potassium	mg/L	LG-05	01/14/2016		8.7900	***	3.5404
Dissolved selenium	U mg/l	LG-05	04/29/2014		0.0010		0.0020
Dissolved silver	U mg/l	LG-05	04/29/2014	ND	0.0001		4.2501
Dissolved sodium	mg/L	LG-05	01/14/2016		71.6000	***	13.8000
Dissolved thallium	U mg/l	LG-05	04/29/2014		0.0000		0.0010
Dissolved vanadium	U mg/l	LG-05	04/29/2014	ND	0.0050		0.0100
Dissolved zinc	mg/L	LG-05	04/29/2014		0.0030		0.0070
Nitrate nitrogen	mg-N/L	LG-05	01/14/2016		4.3000		6.0000
Nitrite nitrogen	mg-N/L	LG-05	01/14/2016		0.0470	***	0.0110
pH	std units	LG-05	01/14/2016		6.4200		5.99 - 7.51
Sulfate	mg/L	LG-05	01/14/2016		40.2000	***	24.0000
Total dissolved solids	mg/L	LG-05	01/14/2016		640.0000	***	550.0000
Total organic carbon	U mg/l	LG-05	01/14/2016		5.4000		19.0000

* - Current value failed - awaiting verification.
** - Current value passed - previous exceedance not verified.
*** - Current value failed - exceedance verified.
**** - Current value passed - awaiting one more verification.
***** - Insufficient background data to compute prediction limit.
ND = Not Detected, result = detection limit.

Table 5

Summary Statistics and Prediction Limits

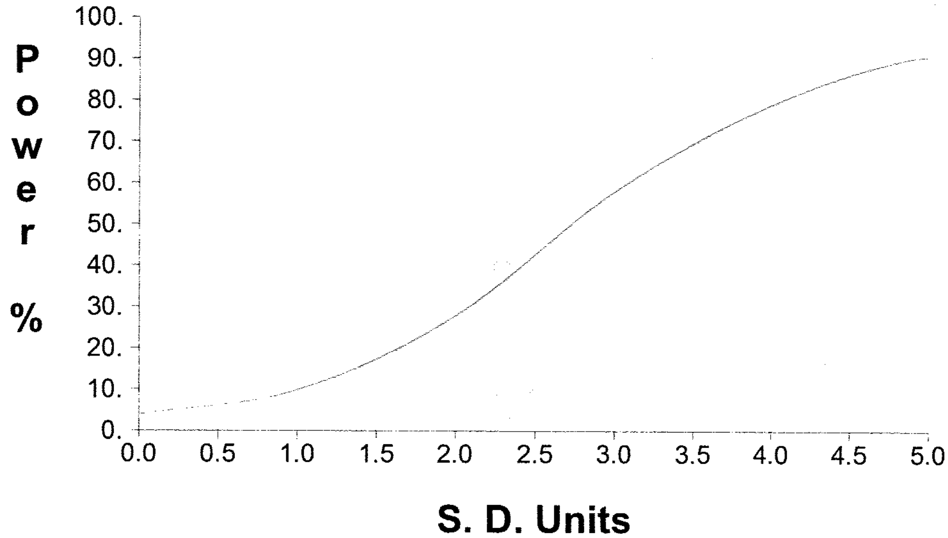
Constituent	Units	Model Type	N	Detect	Mean	SD	Pred Limit	Conf*
Alkalinity (as caco3)	mg/L	lognor	42	42	4.5194	0.2866	185.2145	
Ammonia nitrogen	mg/L	nonpar	38	9			0.0560	0.99
Bicarbonate	mg/L	lognor	42	42	4.5845	0.2025	160.8580	
Chemical oxygen demand	mg/L	nonpar	38	3			26.0000	0.99
Chloride	mg/L	normal	42	42	6.9627	1.1299	9.7304	
Conductivity	umhos/cm	lognor	42	42	5.5601	0.1384	364.6602	
Dissolved antimony	U mg/l	nonpar	32	10			0.0100	0.99
Dissolved arsenic	mg/L	nonpar	36	36			0.0078	0.99
Dissolved barium	mg/L	nonpar	37	37			0.0193	0.99
Dissolved beryllium	U mg/l	nonpar	42	0			0.0005	0.99
Dissolved cadmium	U mg/l	nonpar	38	13			0.0002	0.99
Dissolved calcium	mg/L	nonpar	42	42			31.2000	0.99
Dissolved chromium	U mg/l	normal	39	32	0.0037	0.0022	0.0091	
Dissolved cobalt	U mg/l	nonpar	42	7			0.0080	0.99
Dissolved copper	mg/L	nonpar	38	11			0.0050	0.99
Dissolved iron	U mg/l	nonpar	42	6			0.0310	0.99
Dissolved lead	U mg/l	nonpar	31	4			0.0010	0.99
Dissolved magnesium	mg/L	nonpar	42	42			25.1500	0.99
Dissolved manganese	U mg/l	nonpar	39	16			0.0061	0.99
Dissolved nickel	U mg/l	nonpar	42	0			0.0050	0.99
Dissolved potassium	mg/L	normal	42	42	2.8723	0.2728	3.5404	
Dissolved selenium	U mg/l	nonpar	31	9			0.0020	0.99
Dissolved silver	U mg/l	nonpar	31	3			4.2501	0.99
Dissolved sodium	mg/L	nonpar	41	41			13.8000	0.99
Dissolved thallium	U mg/l	nonpar	31	1			0.0010	0.99
Dissolved vanadium	U mg/l	nonpar	30	5			0.0100	0.99
Dissolved zinc	mg/L	nonpar	31	12			0.0070	0.99
Nitrate nitrogen	mg-N/L	nonpar	42	42			6.0000	0.99
Nitrite nitrogen	mg-N/L	nonpar	39	8			0.0110	0.99
pH	std units	nonpar	42	42			5.99- 7.51	0.99
Sulfate	mg/L	nonpar	42	42			24.0000	0.99
Total dissolved solids	mg/L	nonpar	42	42			550.0000	0.99
Total organic carbon	U mg/l	nonpar	42	19			19.0000	0.99

* - Confidence level for passing initial test or one verification resample at all downgradient wells for a single constituent (nonparametric test only).
Model Type refers to type of prediction limit.
For lognormal limit, mean and sd in natural log units and prediction limit in original units.
All sample sizes and statistics are based on outlier free data.
For nonparametric limits, median reporting limits are substituted for extreme reporting limit values.

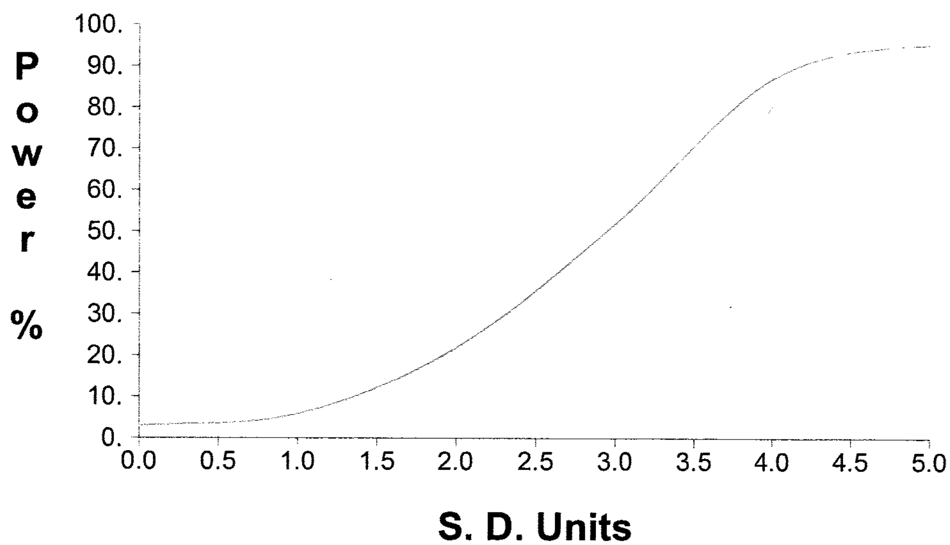
Appendix C

Statistical Analysis Plots

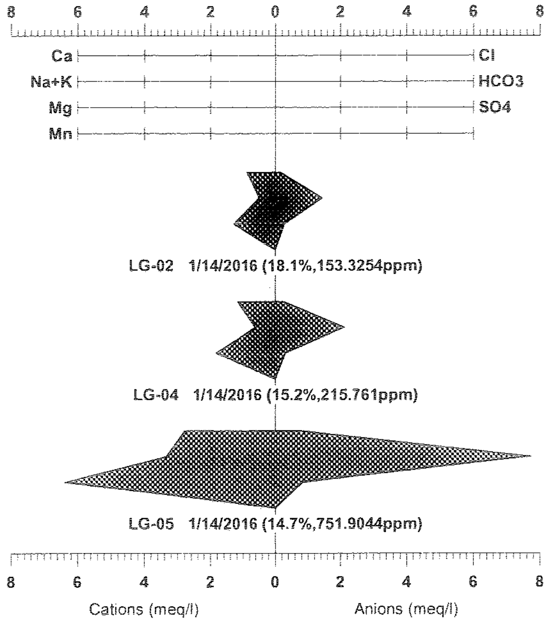
False Positive and False Negative Rates for Current Upgradient vs. Downgradient Monitoring Program



False Positive and False Negative Rates for Current Intra-Well Prediction Limits Monitoring Program



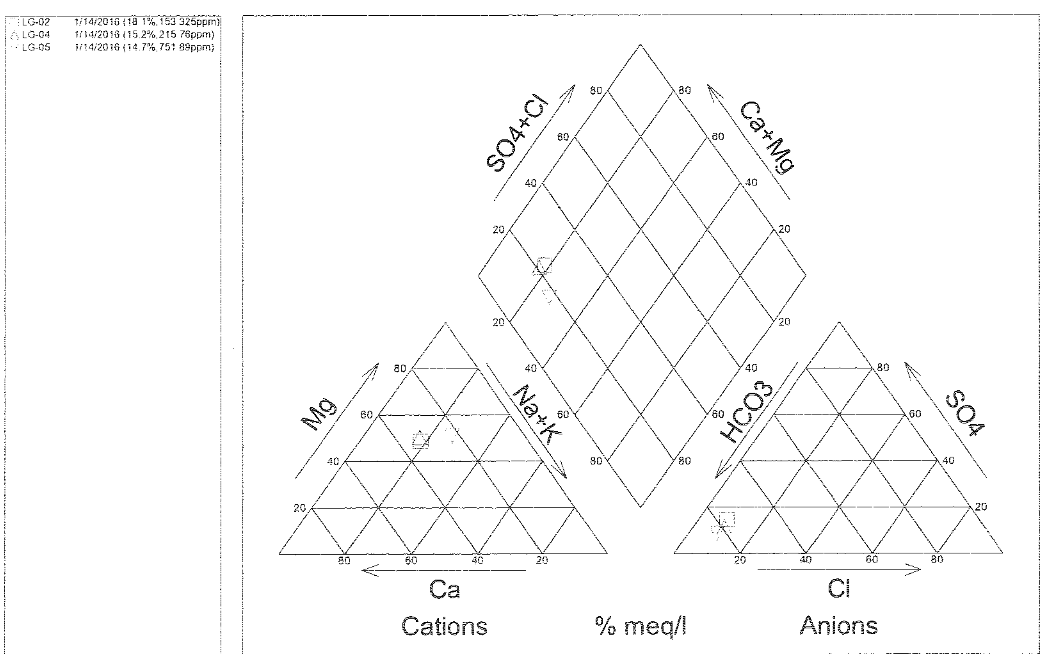
Goodwin Landfill



1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

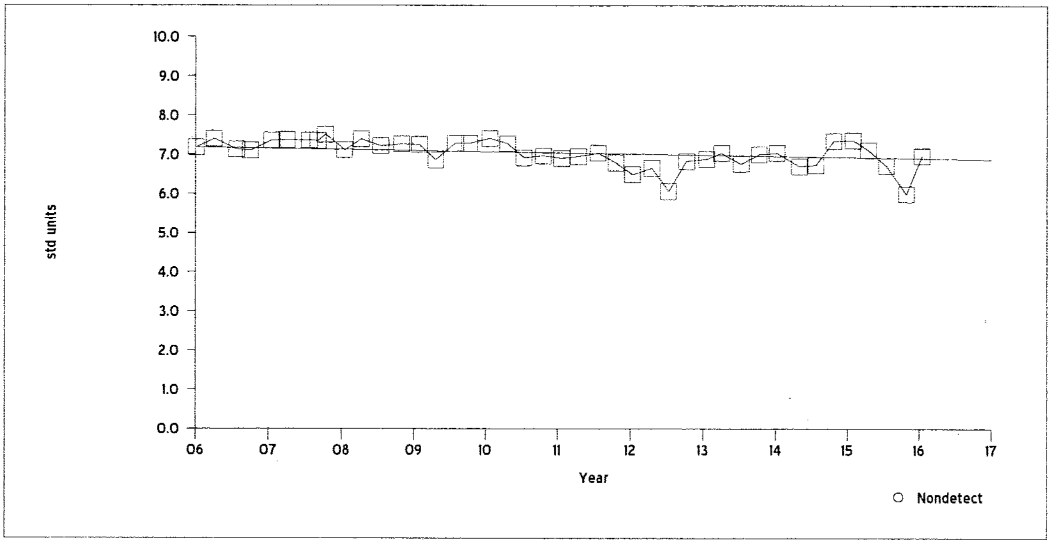


1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-02



□ pH (cc: -.547)

1

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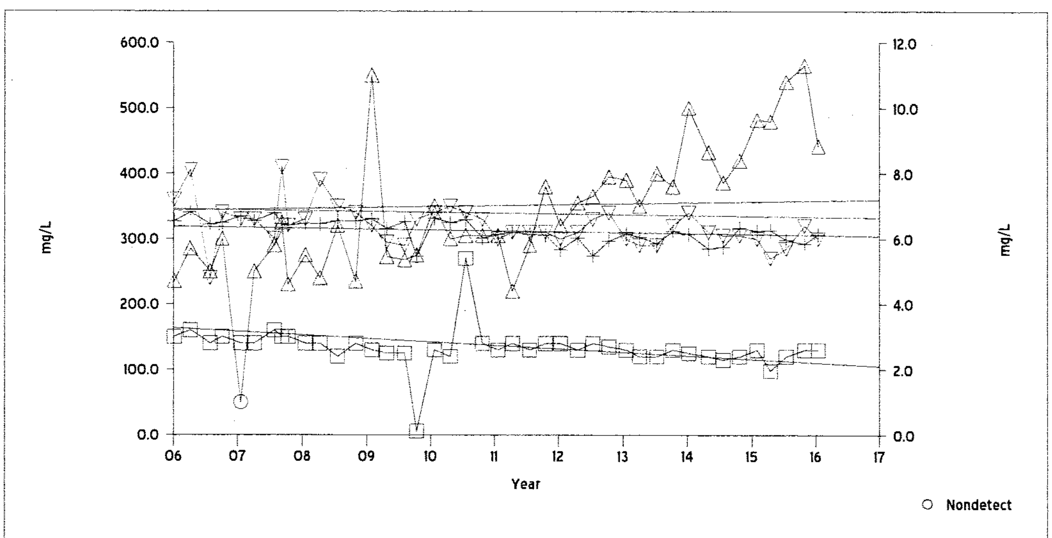
Goodwin Landfill

Time Series Plot for LG-04



□ Bicarbonate (cc: -.550)
▽ Conductivity (cc: -.163)

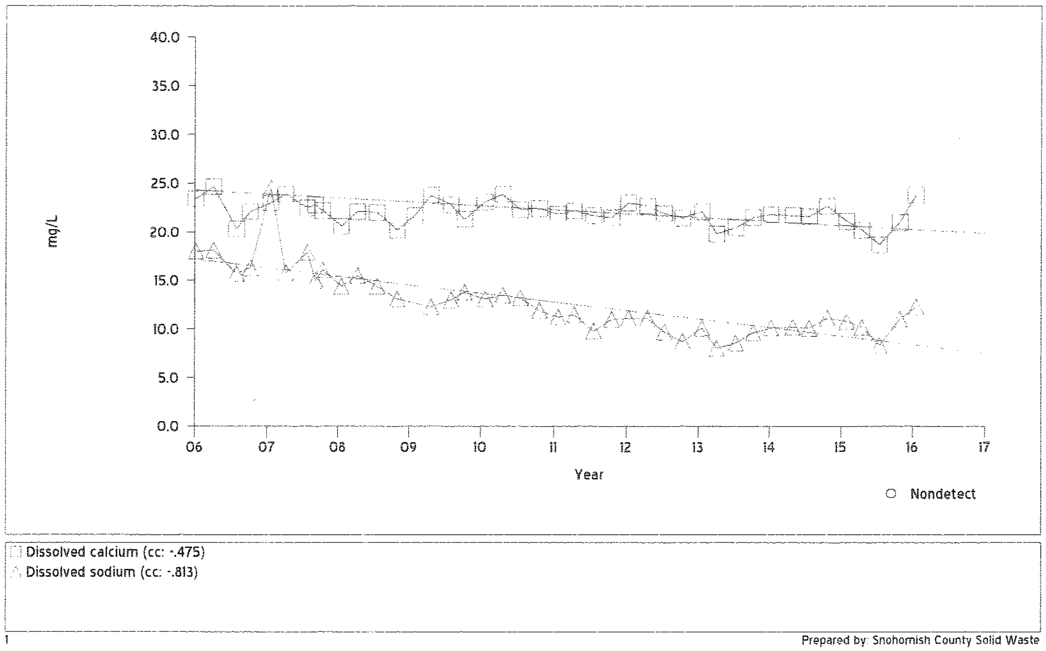
+ pH (cc: -.623)
△ Chloride (cc: .130)

1

Prepared by: Snohomish County Solid Waste

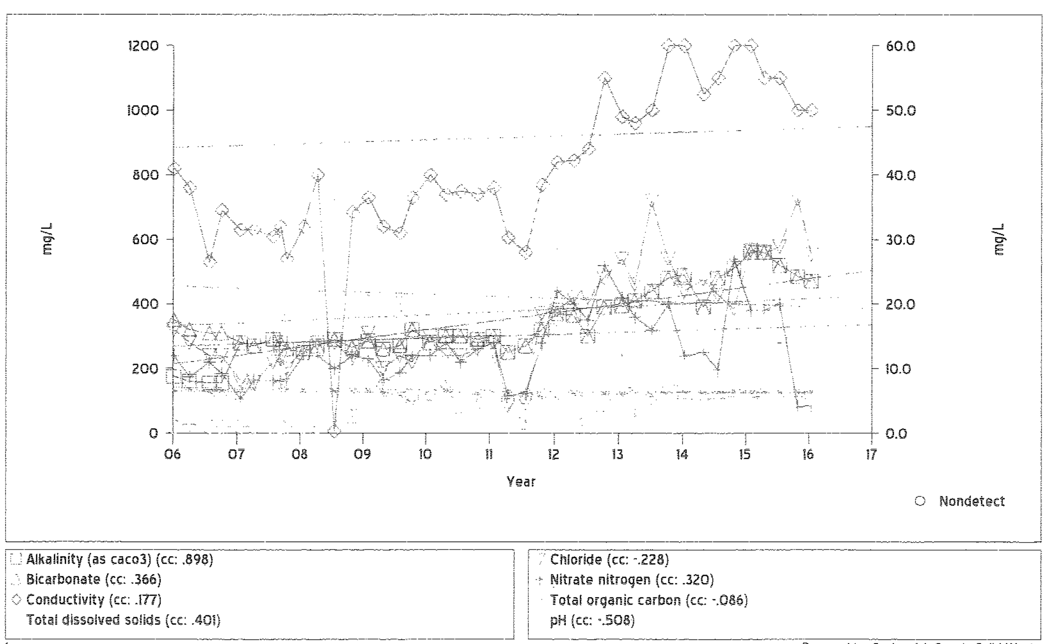
Goodwin Landfill

Time Series Plot for LG-04



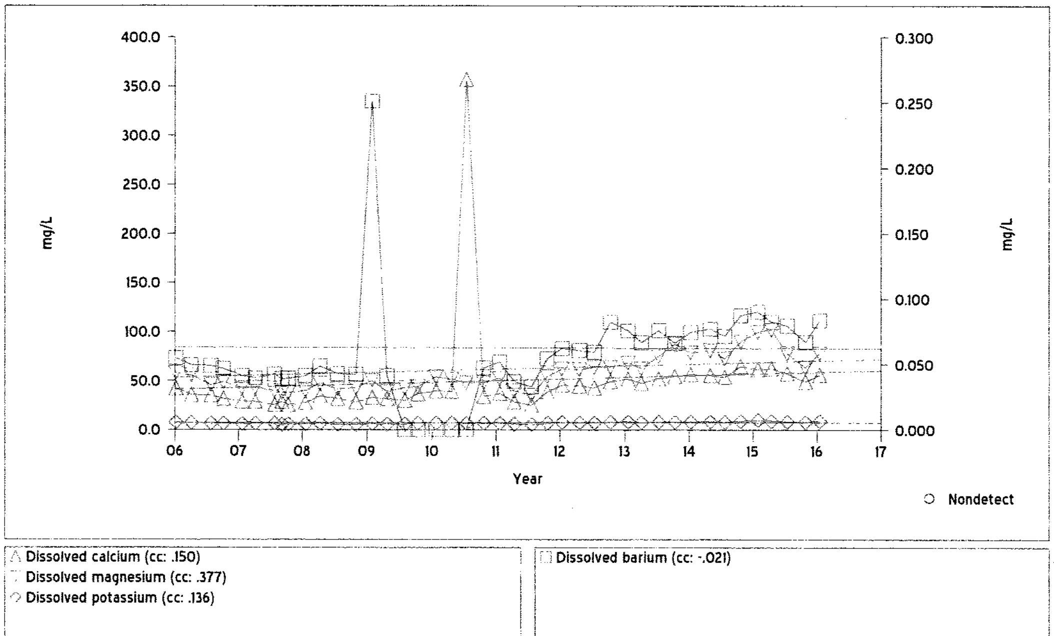
Goodwin Landfill

Time Series Plot for LG-05



Goodwin Landfill

Time Series Plot for LG-05

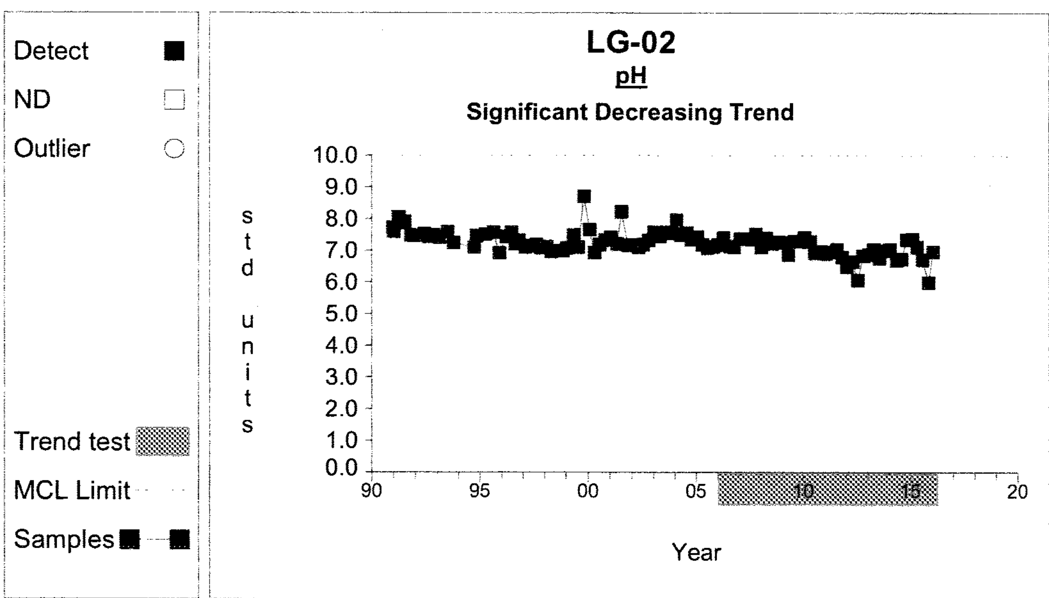


Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



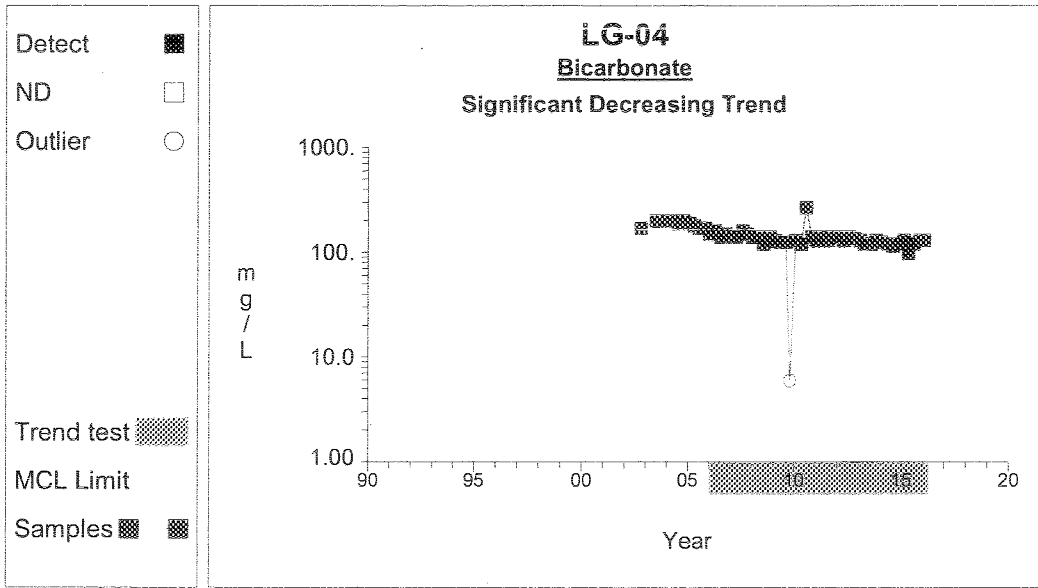
Graph 63

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



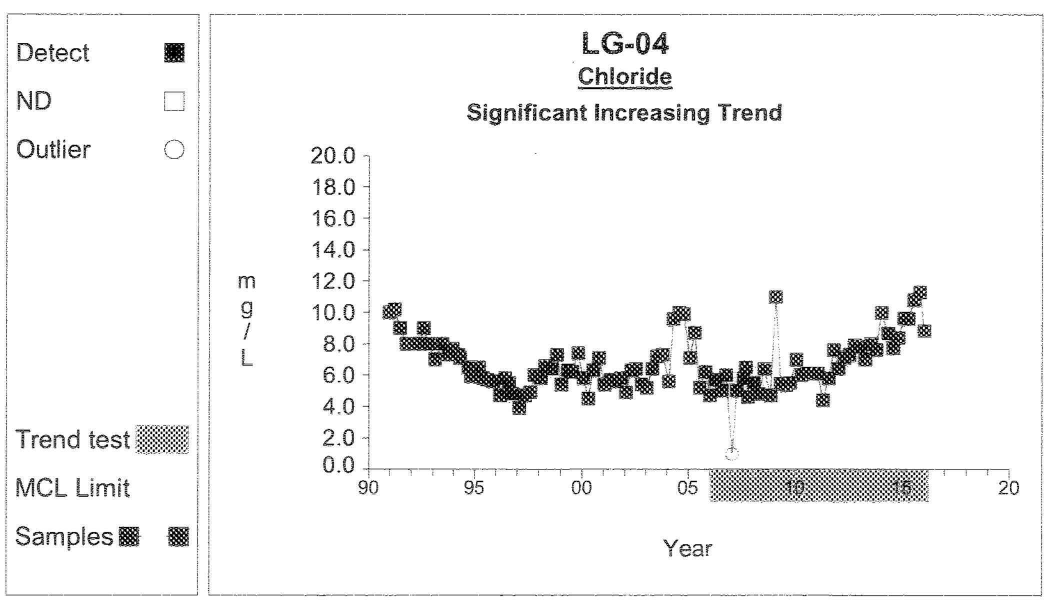
Graph 69

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



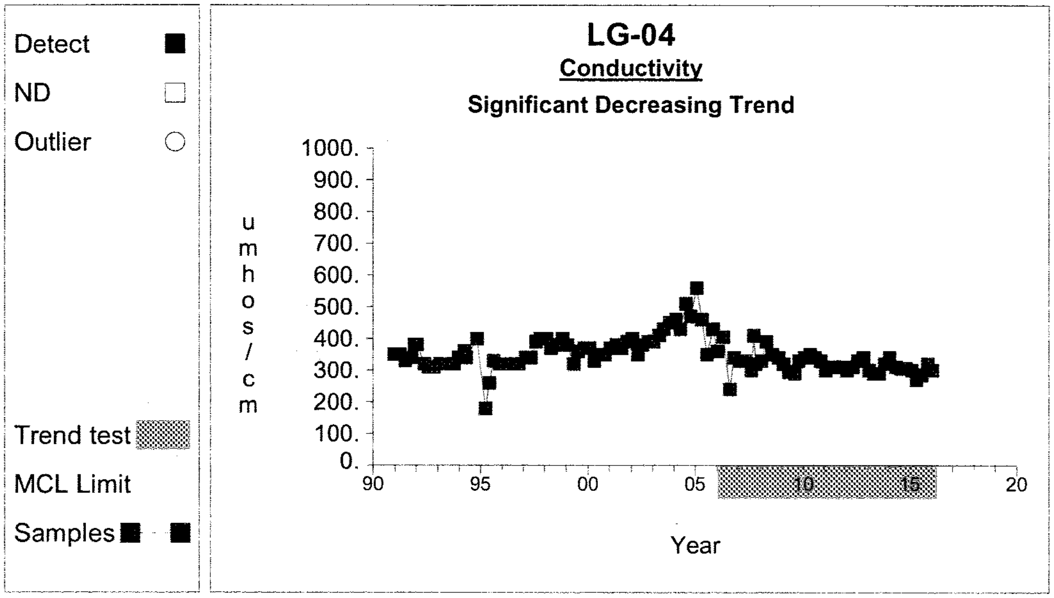
Graph 71

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



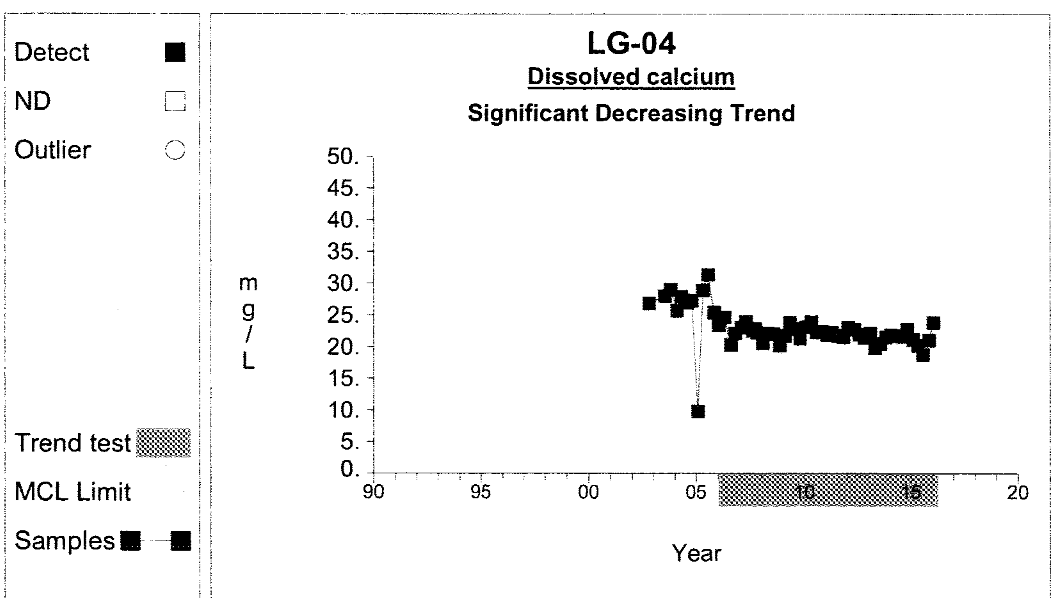
Graph 72

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

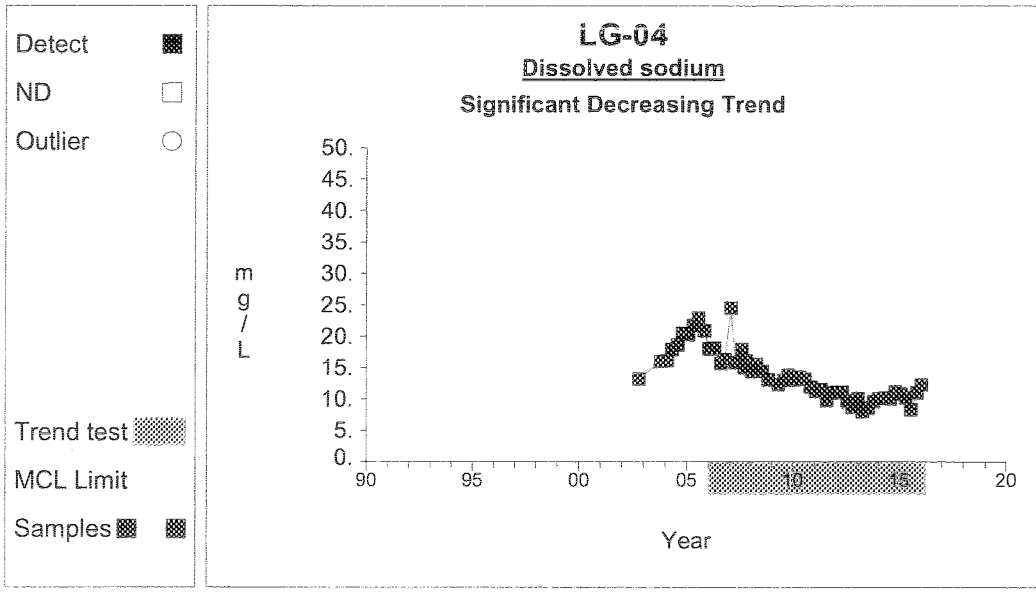
Time Series



Graph 78

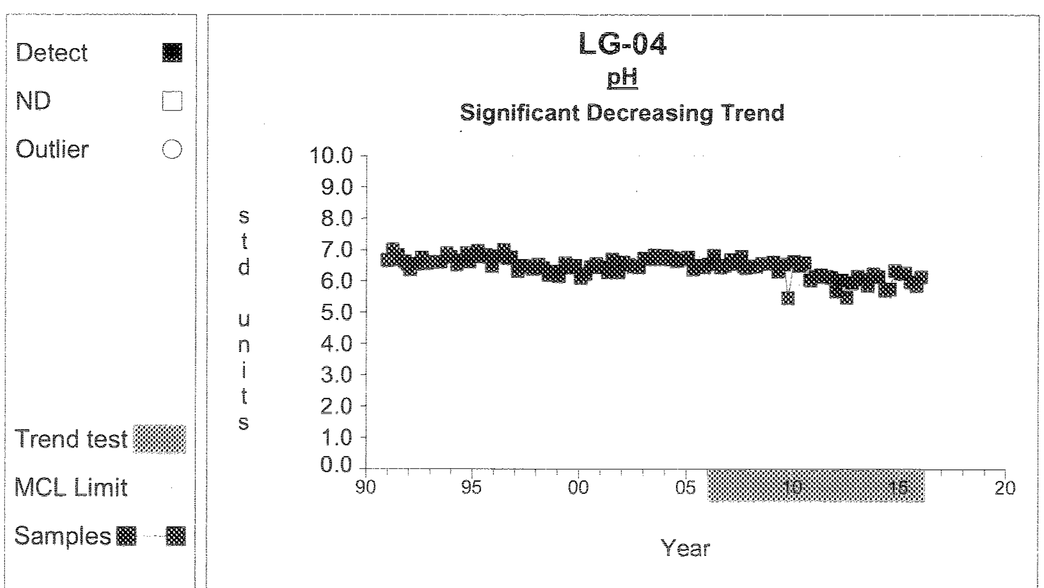
Prepared by: Snohomish County Solid Waste

Time Series



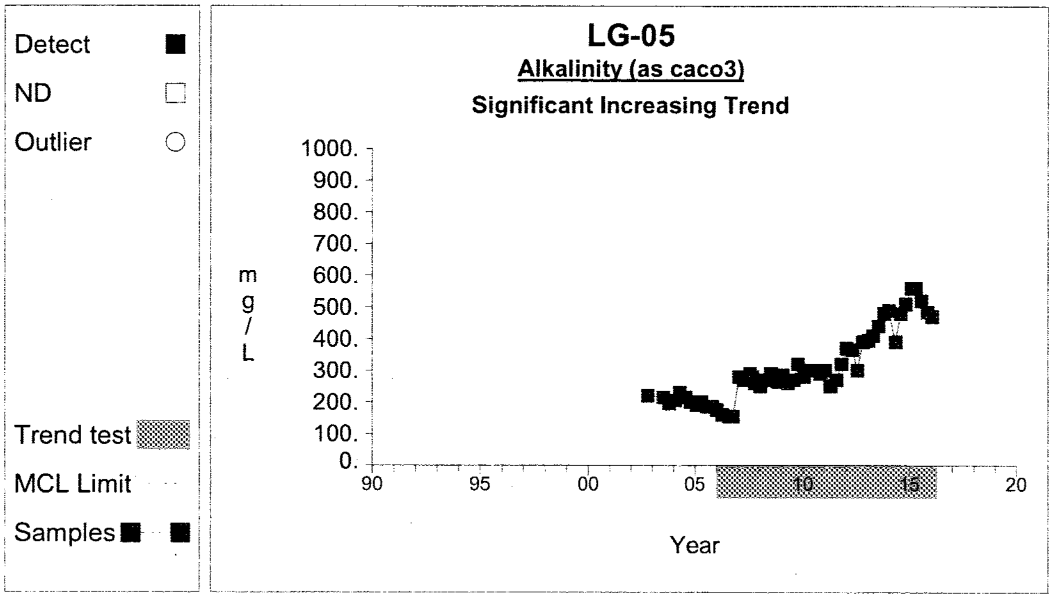
Graph 90

Time Series



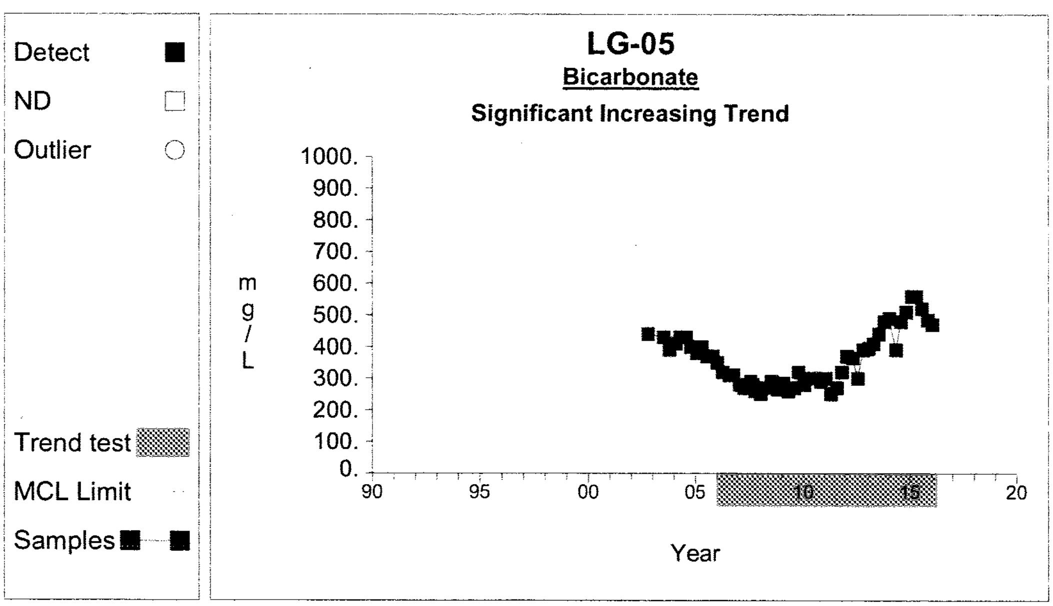
Graph 96

Time Series



Graph 100

Time Series

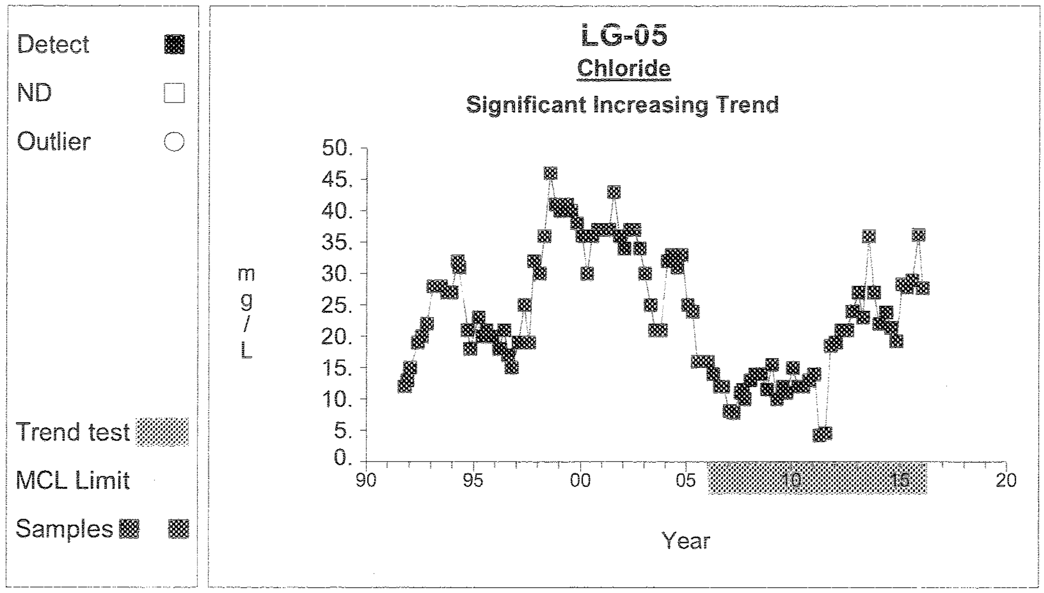


Graph 102

Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



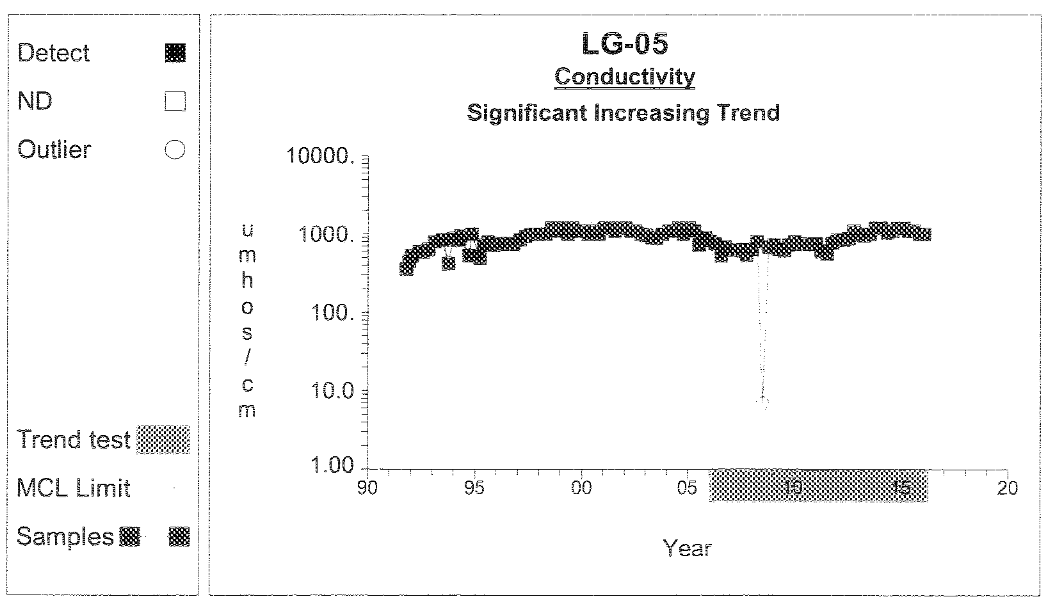
Graph 104

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

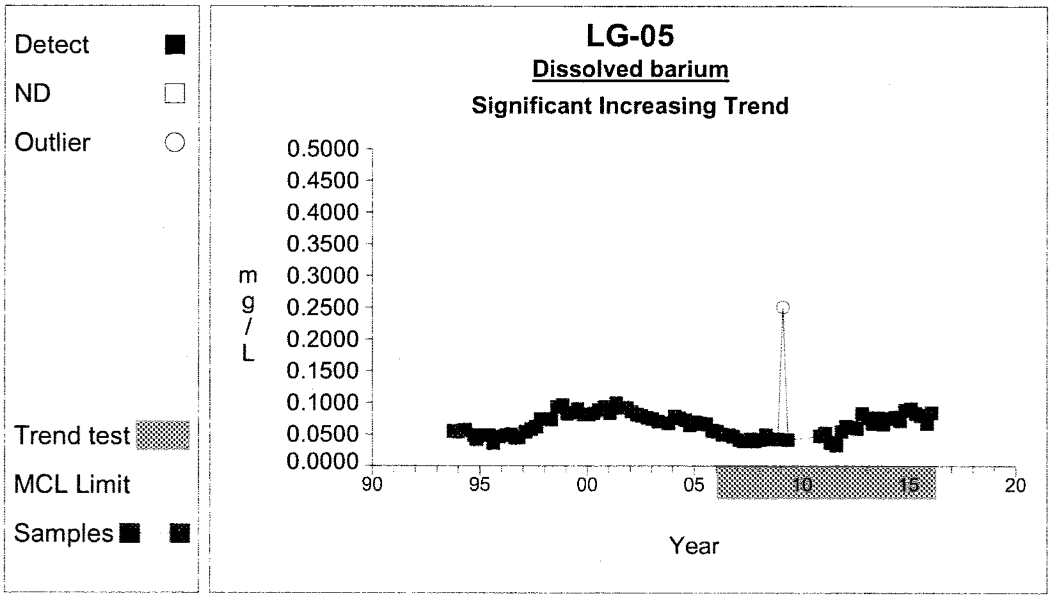
Time Series



Graph 105

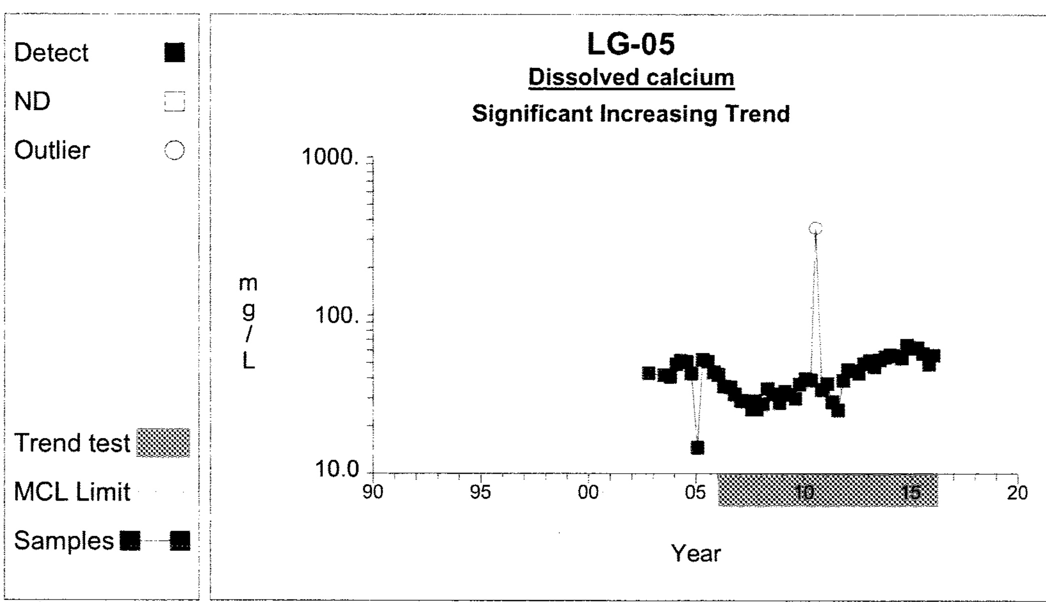
Prepared by: Snohomish County Solid Waste

Time Series



Graph 108

Time Series

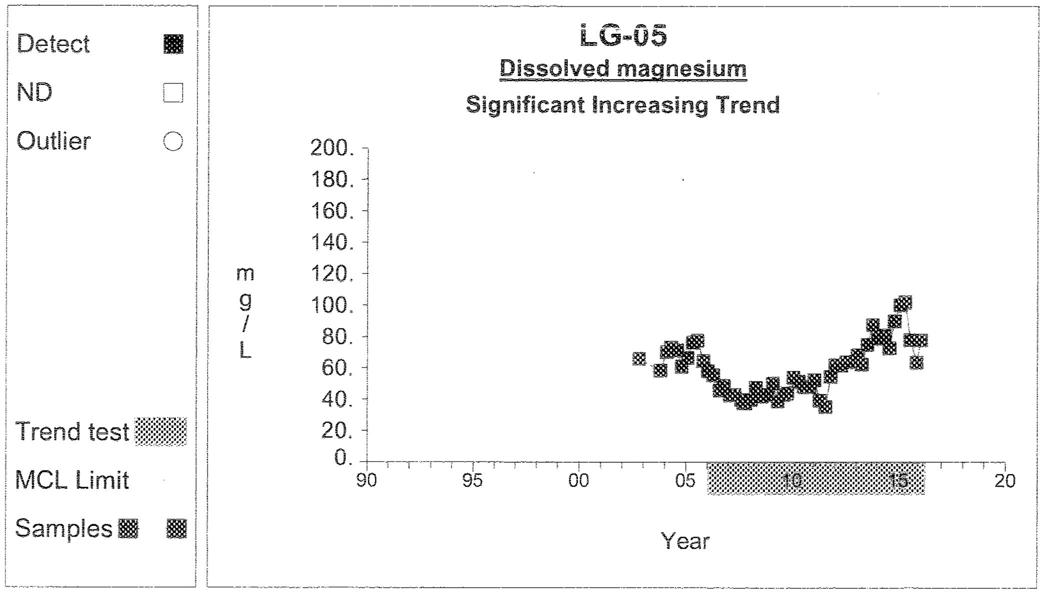


Graph 111

Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



Graph 117

23

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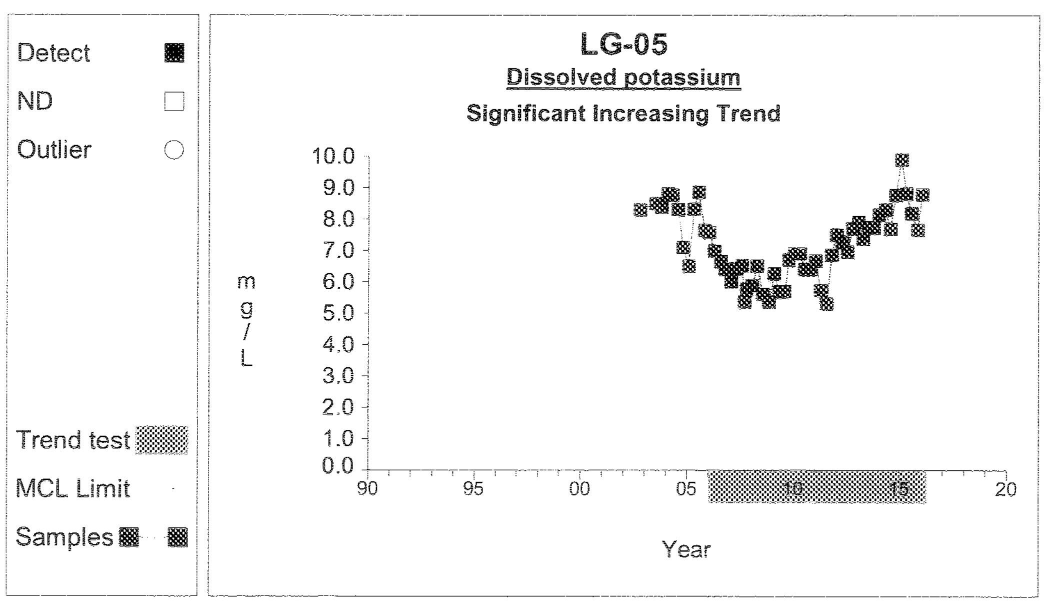
Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



Graph 120

24

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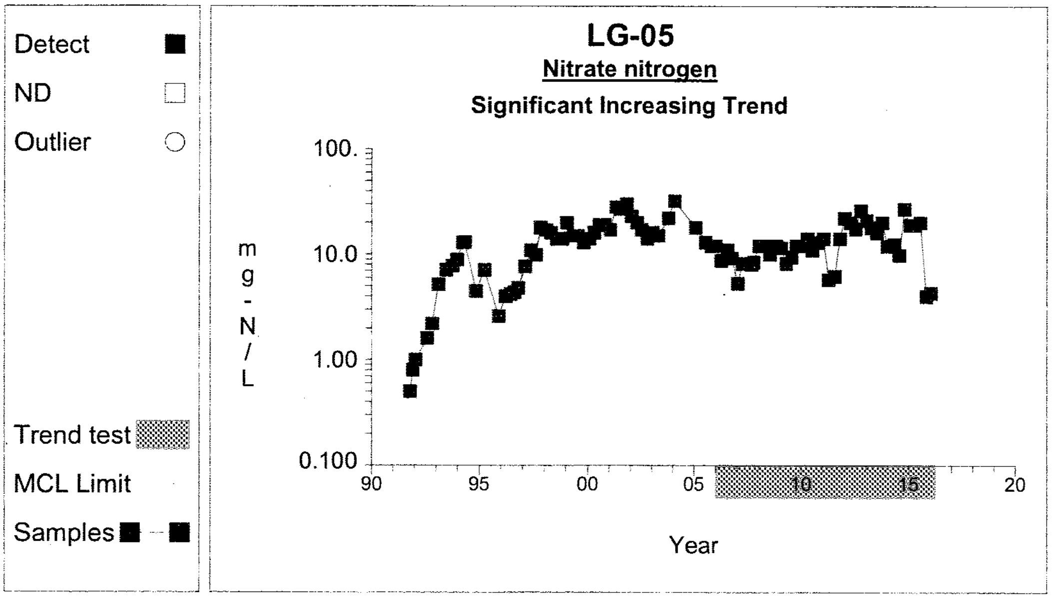
Goodwin Landfill

Analysis prepared on: 6/16/2016

Time Series



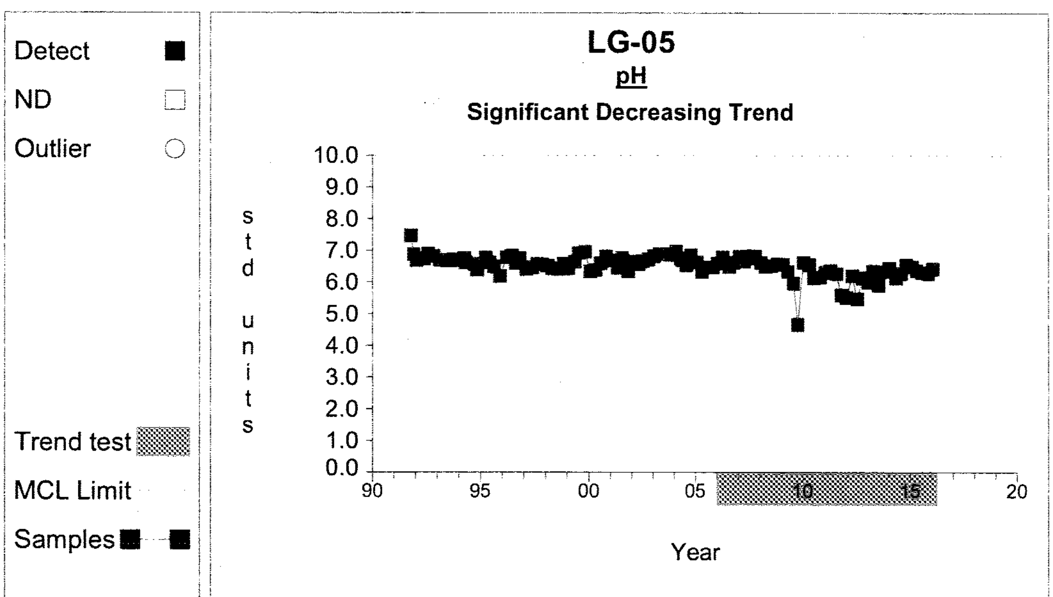
Graph 127

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/16/2016

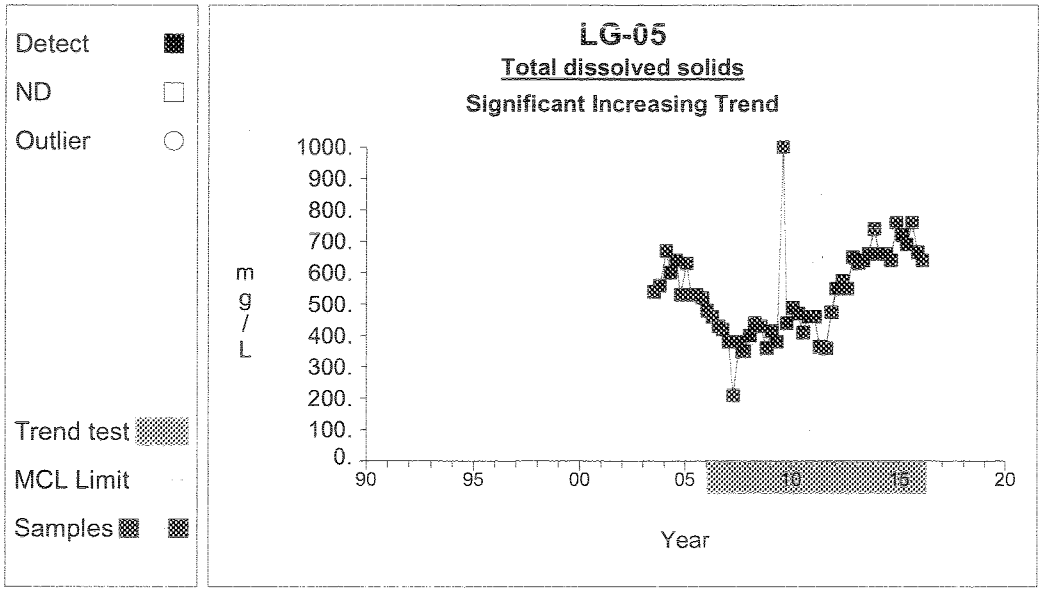
Time Series



Graph 129

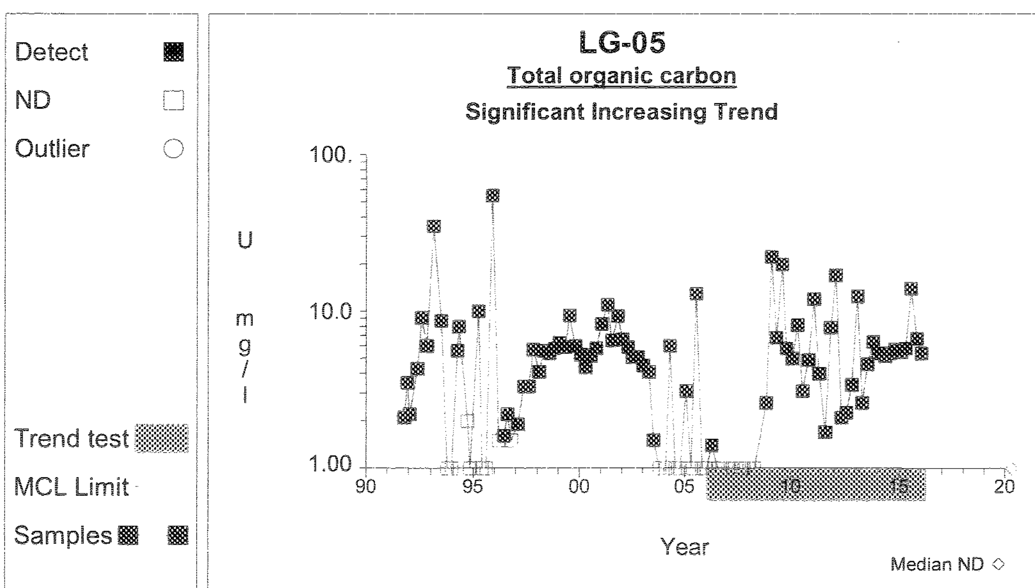
Prepared by: Snohomish County Solid Waste

Time Series



Graph 131

Time Series

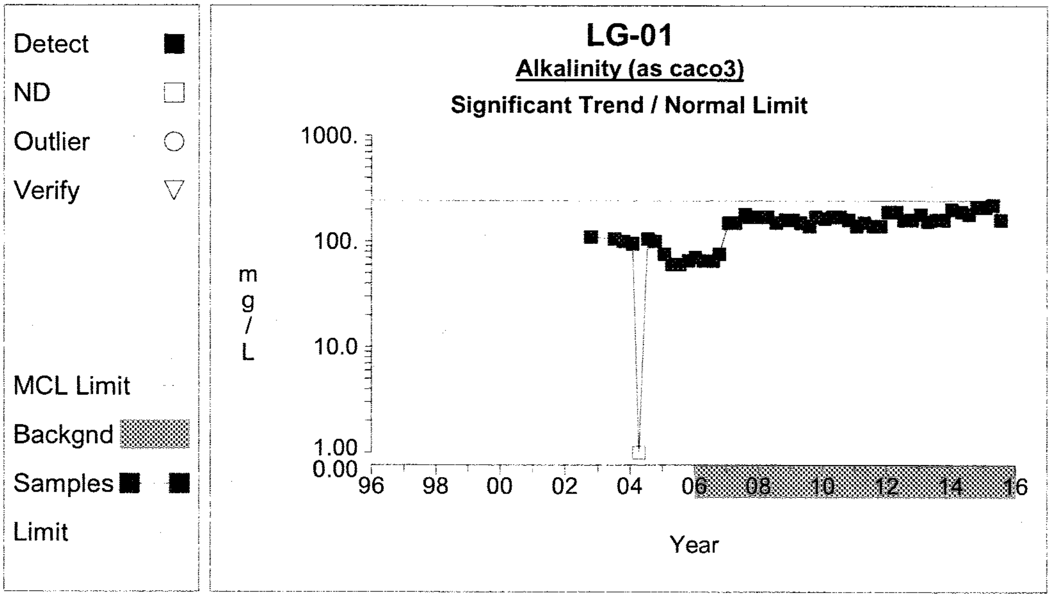


Graph 132

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



Graph 1

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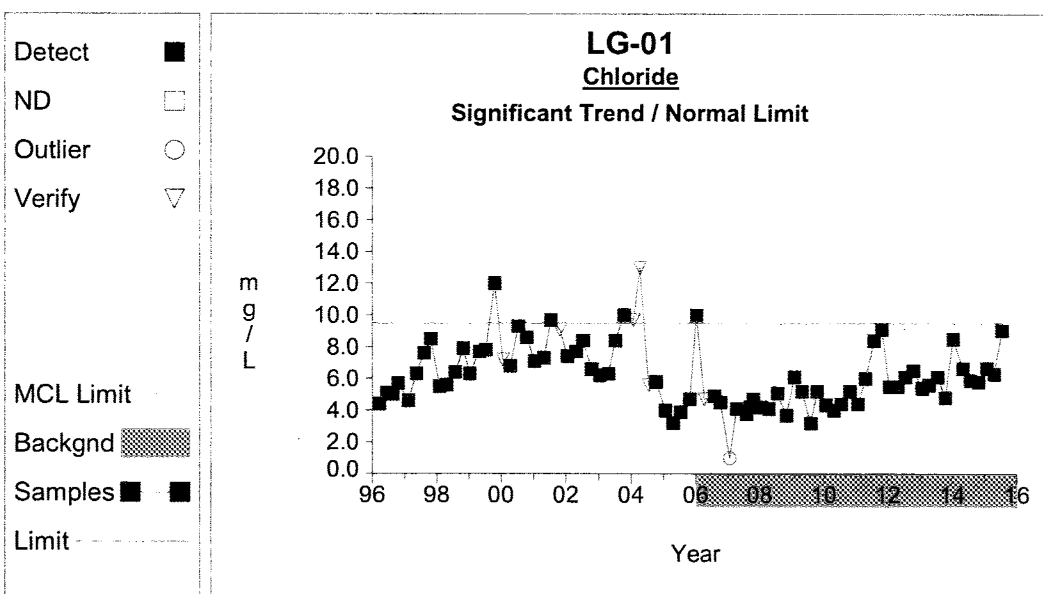
Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



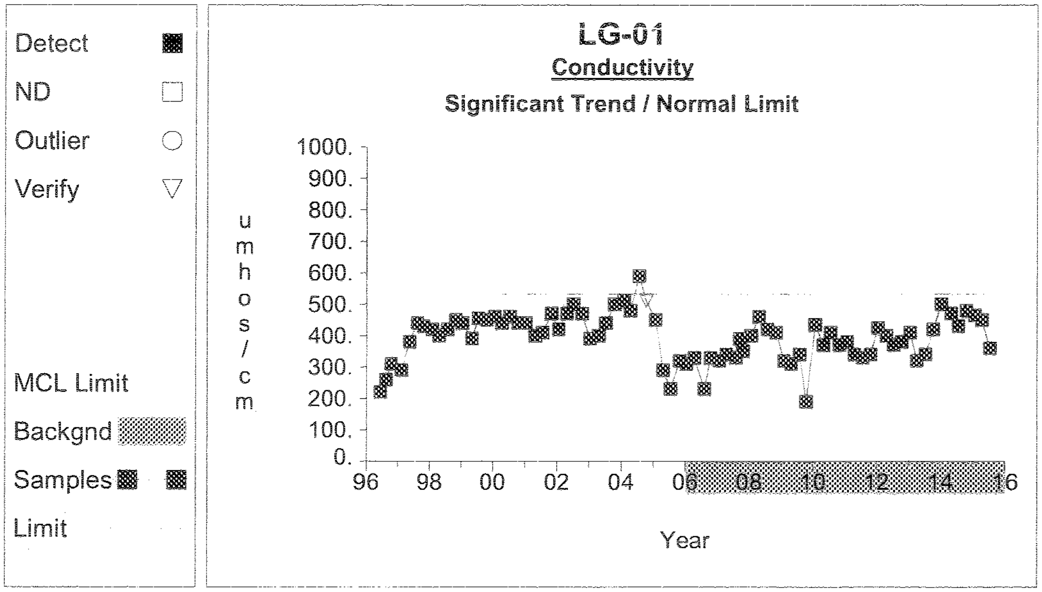
Graph 5

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



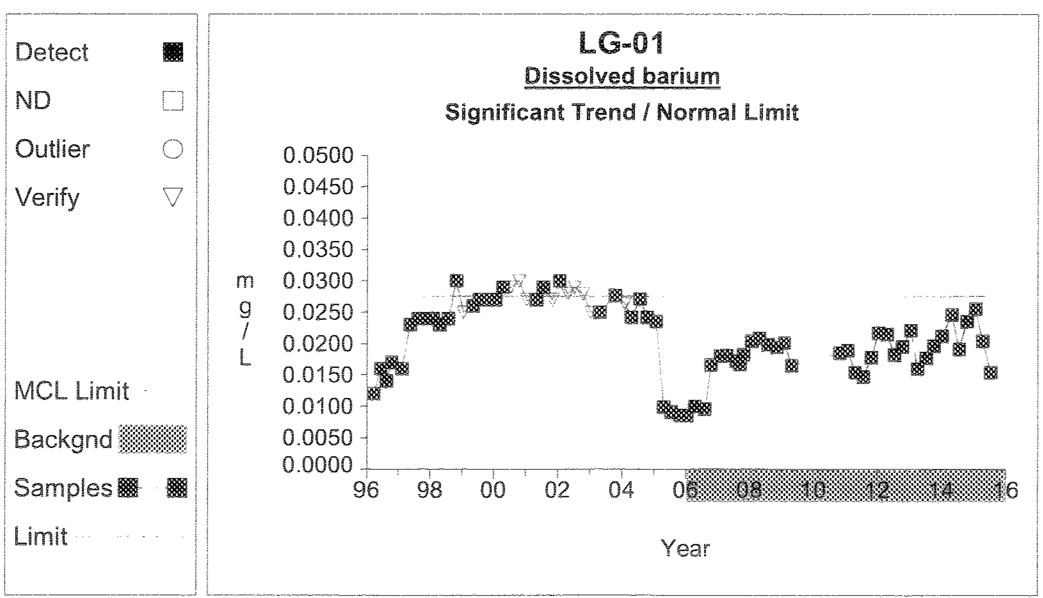
Graph 6

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

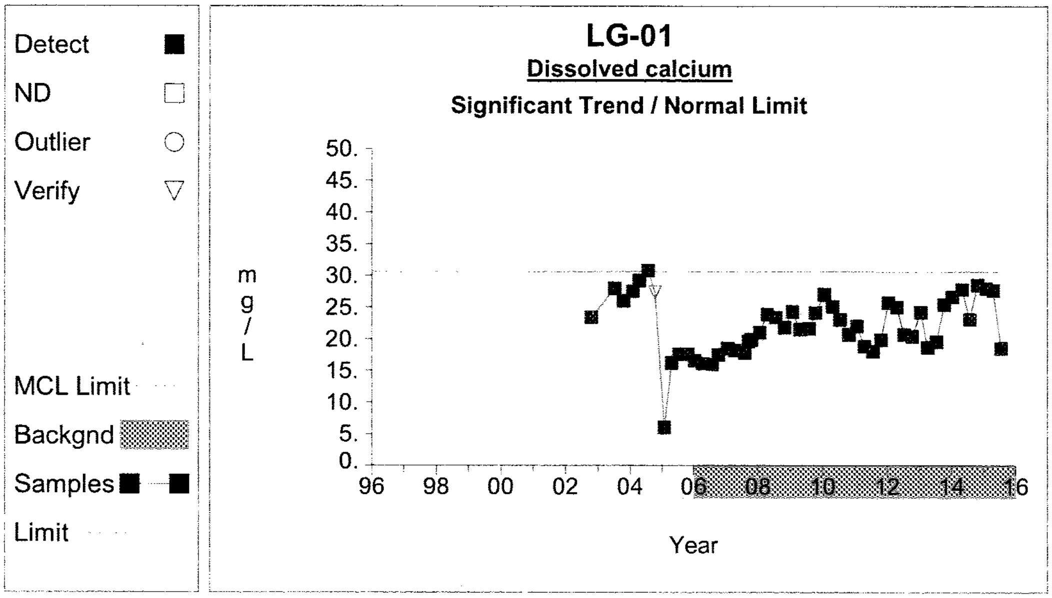
Intra-Well Prediction Limits



Graph 9

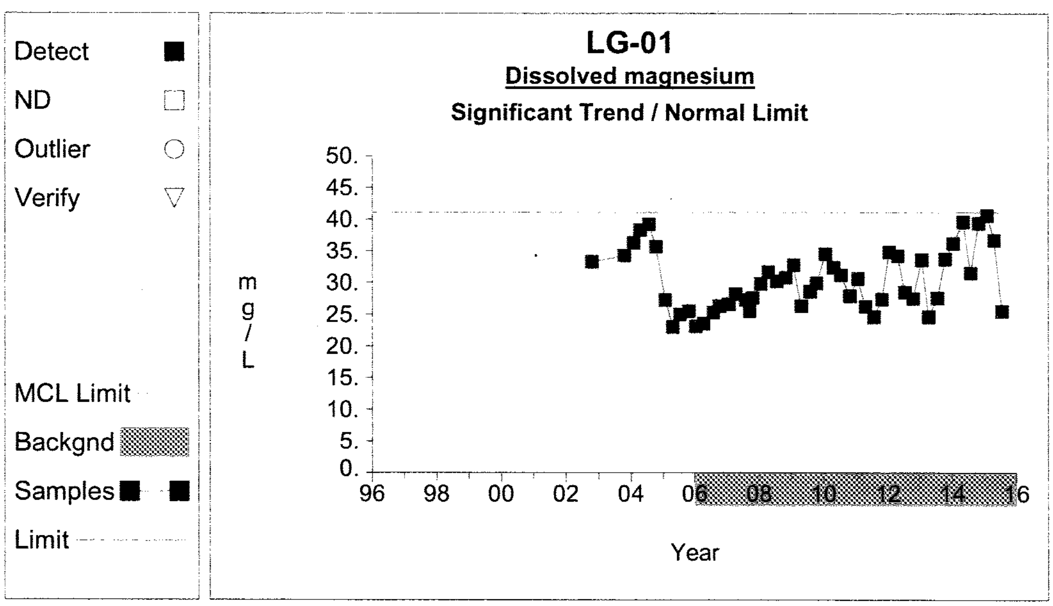
Prepared by: Snohomish County Solid Waste

Intra-Well Prediction Limits



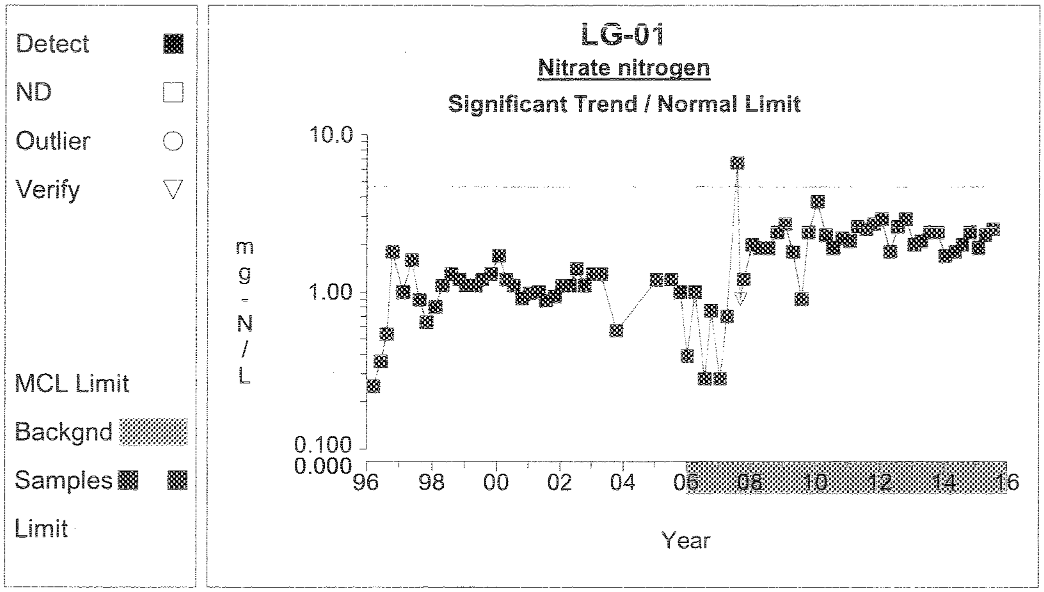
Graph 12

Intra-Well Prediction Limits



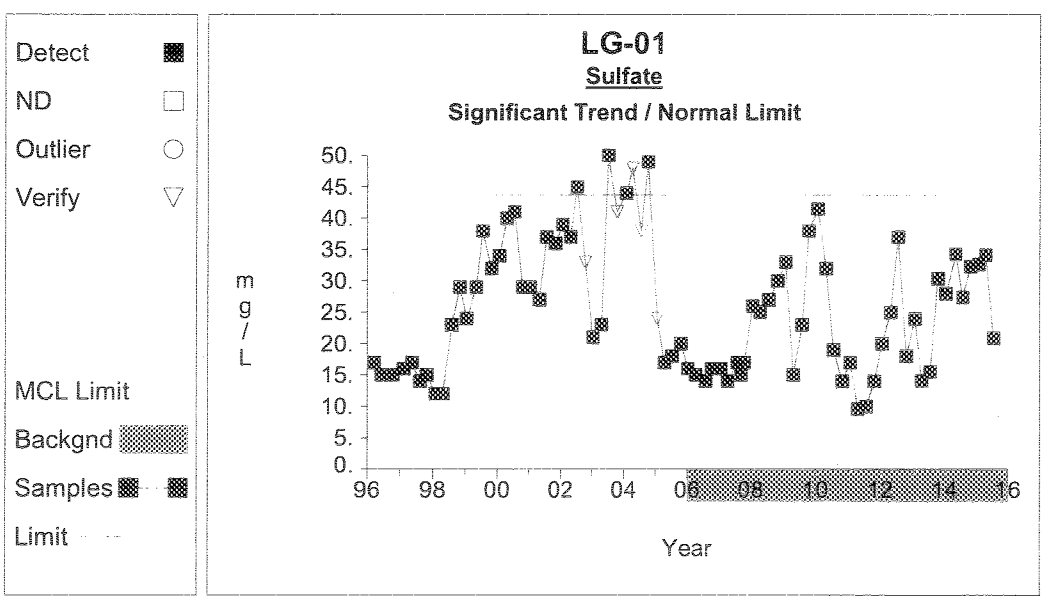
Graph 18

Intra-Well Prediction Limits



Graph 28

Intra-Well Prediction Limits

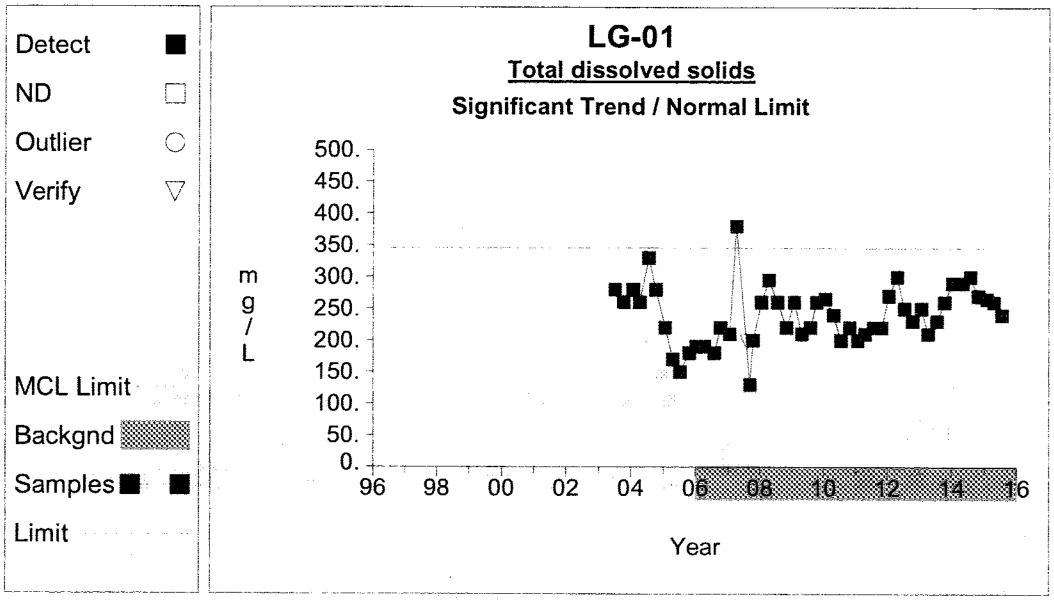


Graph 31

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



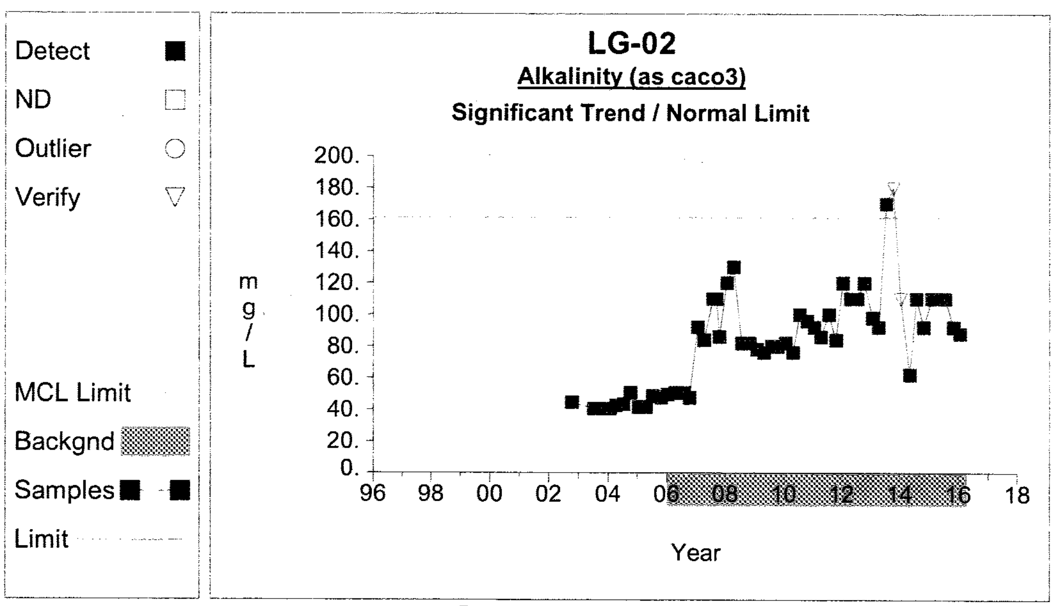
Graph 32

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

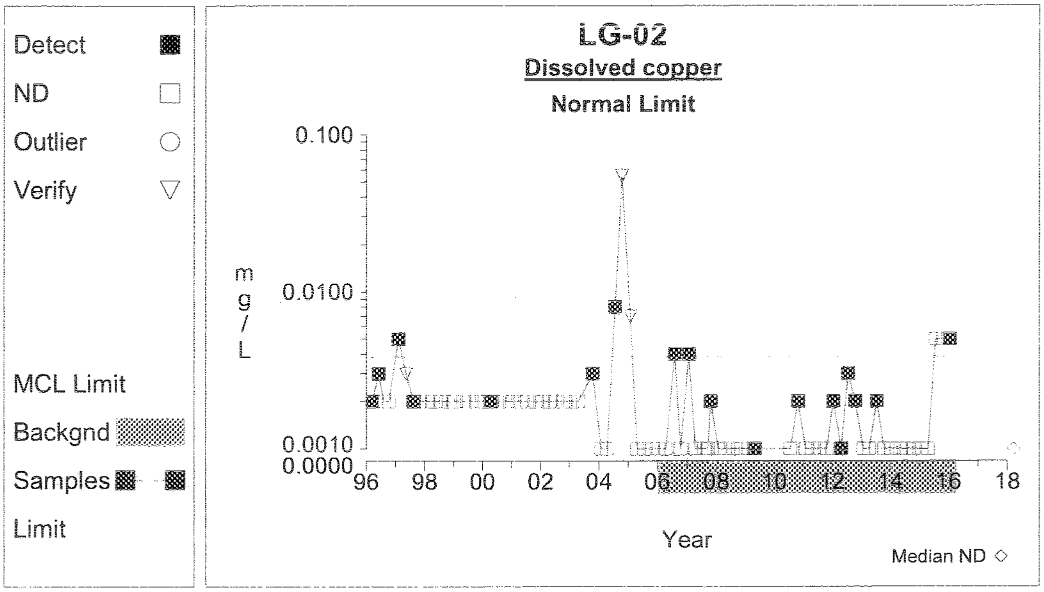
Intra-Well Prediction Limits



Graph 34

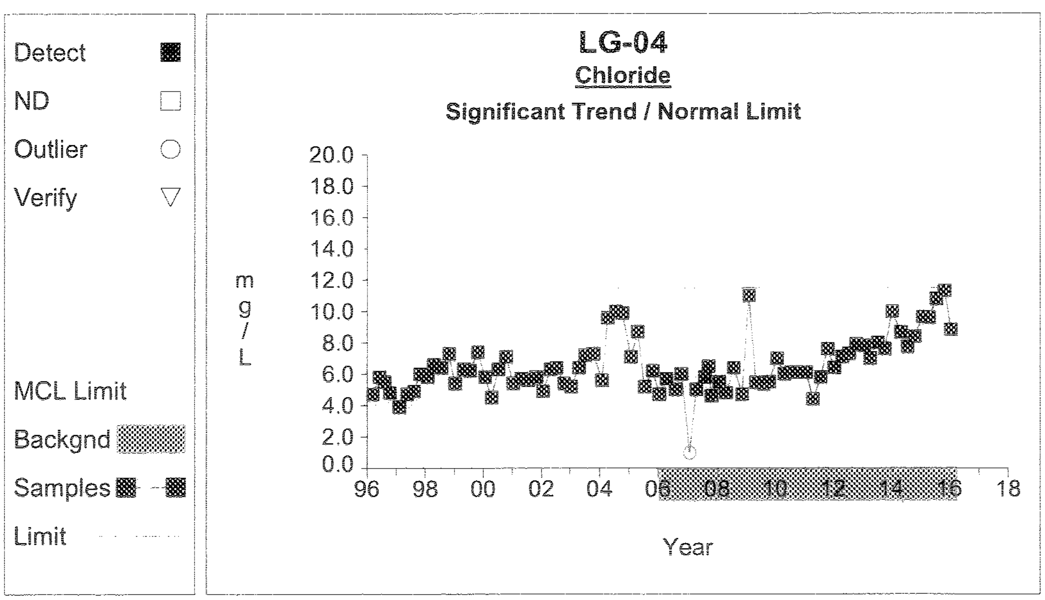
Prepared by: Snohomish County Solid Waste

Intra-Well Prediction Limits



Graph 48

Intra-Well Prediction Limits

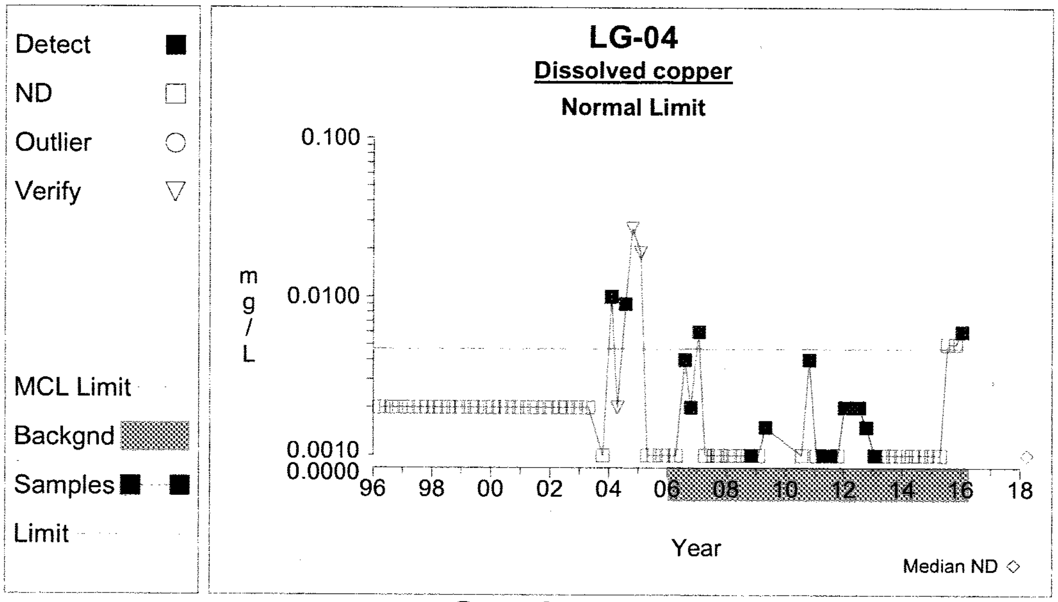


Graph 71

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



Graph 81

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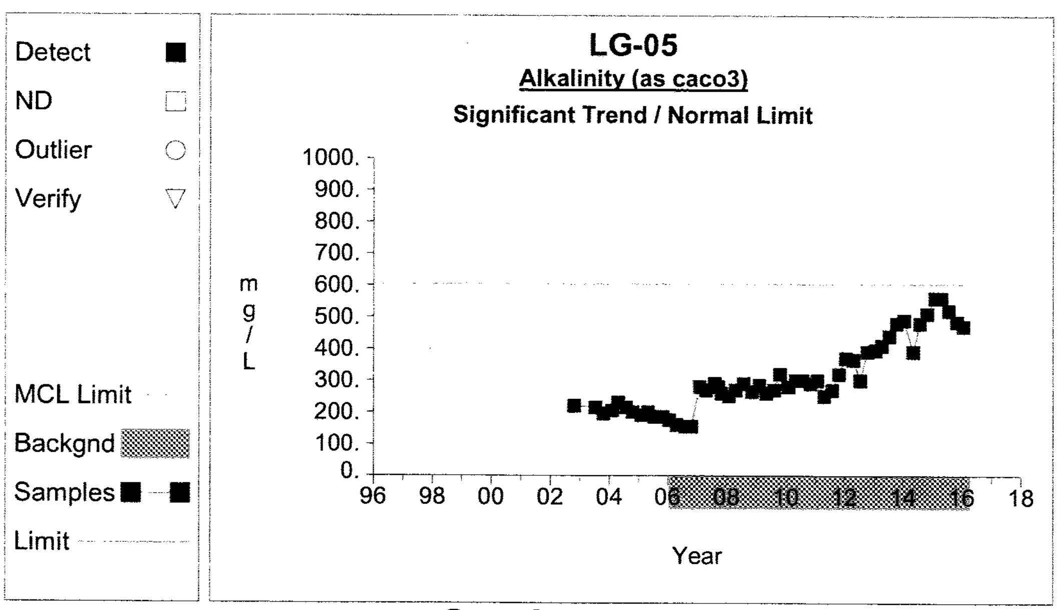
Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



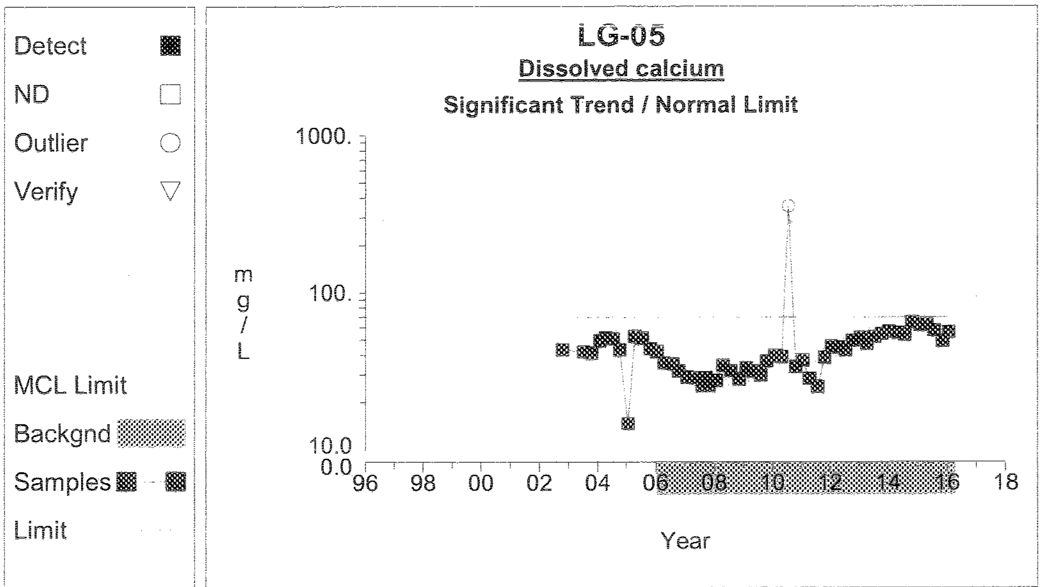
Graph 100

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



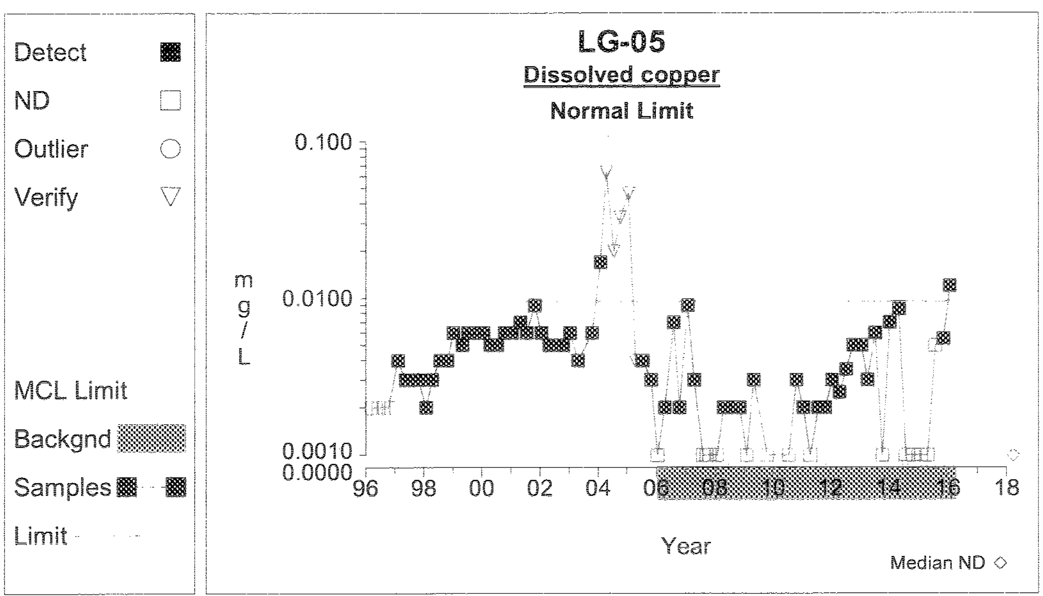
Graph 111

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



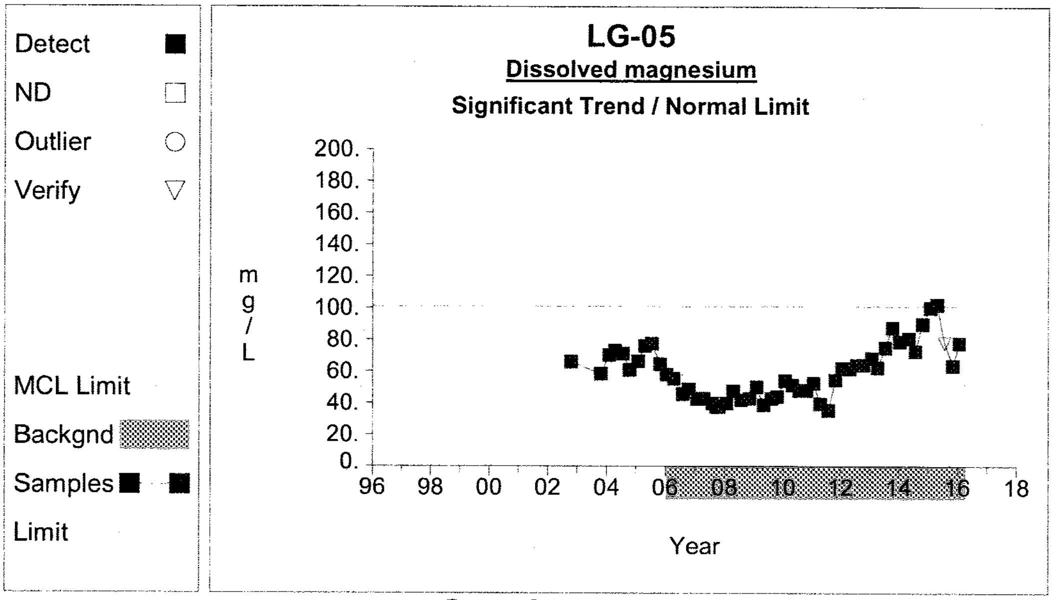
Graph 114

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



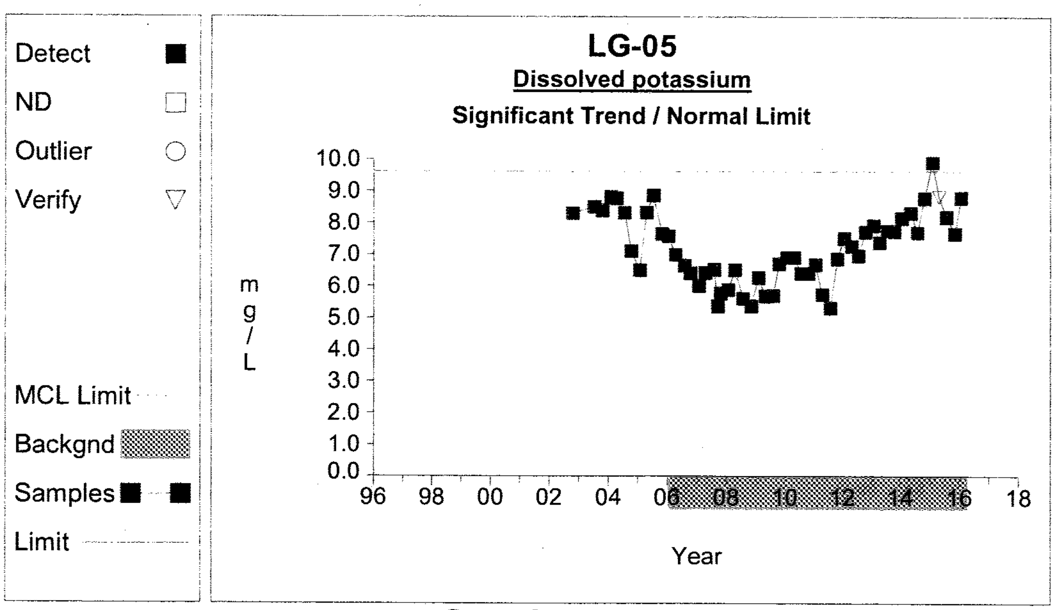
Graph 117

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



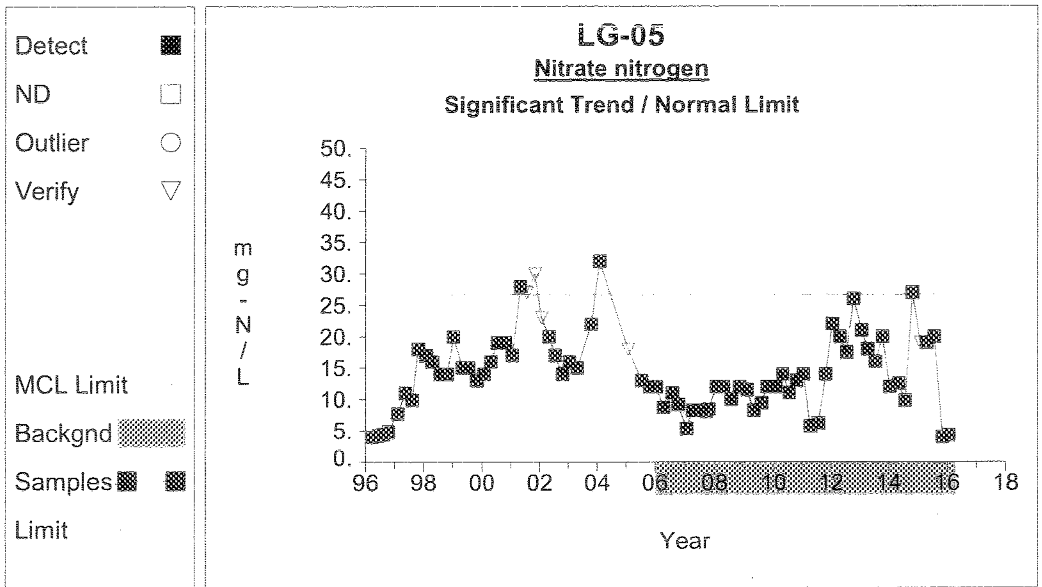
Graph 120

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



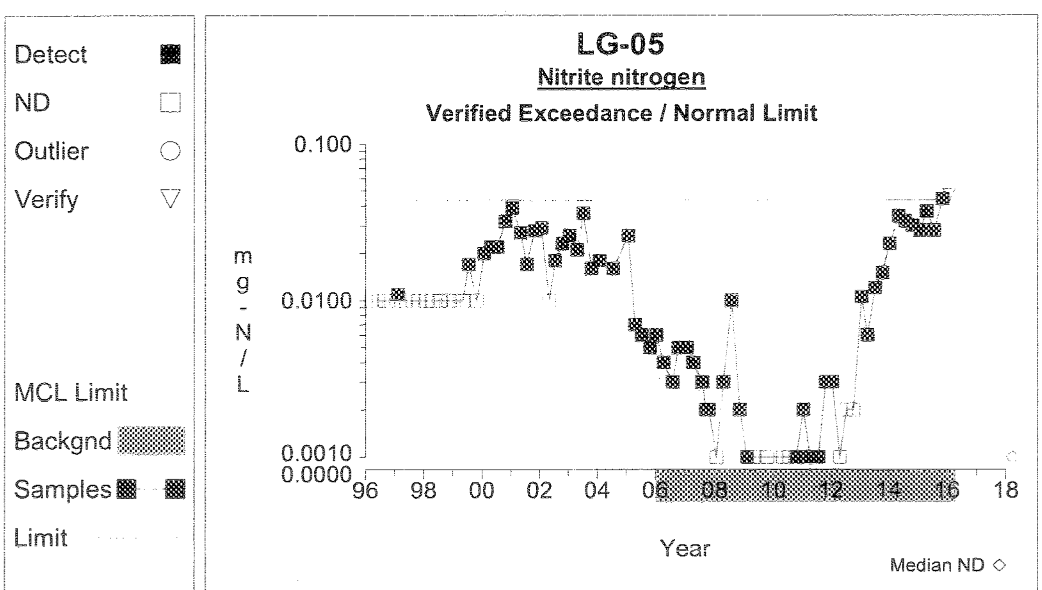
Graph 127

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



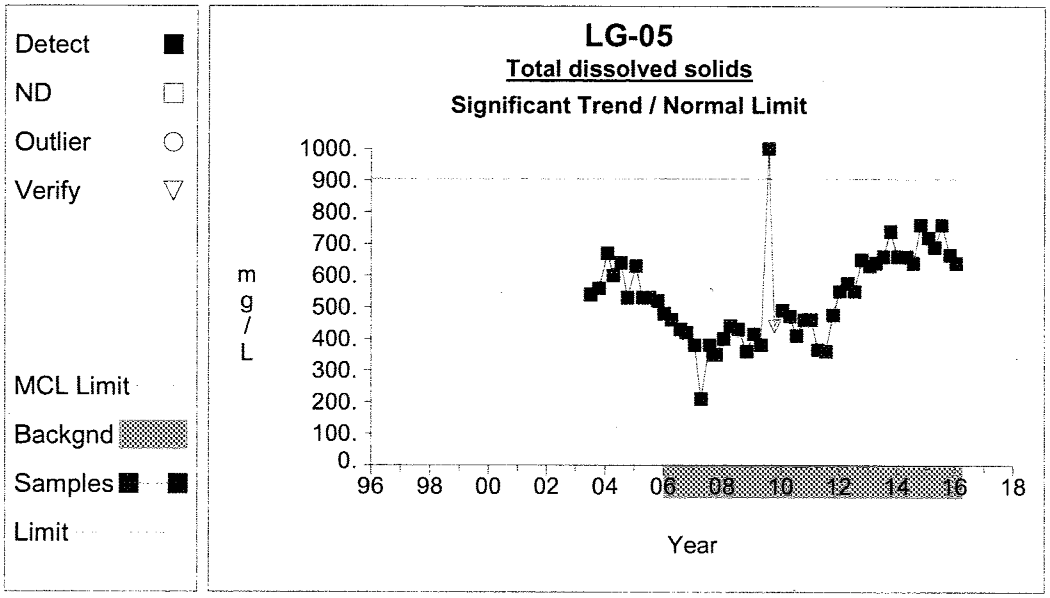
Graph 128

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



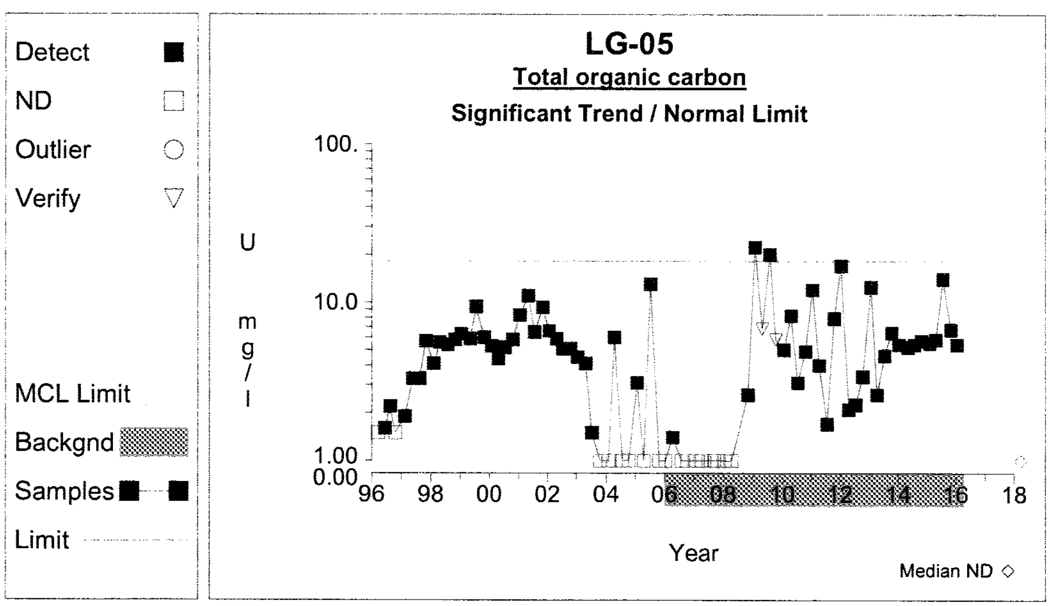
Graph 131

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 6/15/2016

Intra-Well Prediction Limits



Graph 132

Prepared by: Snohomish County Solid Waste