Lake Goodwin Landfill Second Quarter 2016 Environmental Monitoring Report

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1.0 INTRODUCTION

The following report presents the second quarter 2016 groundwater monitoring results at the Lake Goodwin Landfill (*Landfill, Site*). The Site is located at 18520 Frank Waters Road, Stanwood, Washington, in northwestern Snohomish County, about 1.5 miles northwest of Lake Goodwin and approximately 5 miles south of the community of Stanwood, Washington (*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*). Compared with the previous SAP, the current 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.

1.1 Background

The Lake Goodwin Landfill is located within a former County gravel pit. Waste disposed at the landfill reportedly consisted of municipal waste including: garbage, some industrial waste and demolition debris. Waste was placed in the landfill starting in the early 1960s under the direction of the **Snohomish County Road Maintenance Division**. The landfill was closed in September 1982. A cover system was installed upon closure. The landfill is not lined. It does not 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 off of 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.

Surficial elevations in the immediate vicinity of the landfill range from approximately el. 320 to el. 380 (*feet above mean sea level - MSL*). 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 that have been 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 other perimeter Site explorations. Groundwater elevations beneath the landfill during the second quarter sampling event ranged from el. 152.72 to el. 153.92 with a north-northeasterly gradient within the unconfined Advance Outwash (*Qva*) aquifer.

1.5 Existing Monitoring Network

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

There are currently four-(*4*) groundwater monitoring wells (*LG-01 and LG-02, and LG-04 and LG-05*) at the 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, one (*designated LG-02*) is considered to be an upgradient well that characterizes background groundwater conditions in the immediate vicinity of the Site. The remaining three-(*3*) wells included in the current monitoring program (*LG-01, LG-04, and LG-05*) are located within and/or downgradient of the landfill and monitor groundwater zones that could be impacted by the landfill. Groundwater monitoring results are discussed in *Section 2.0* below.

There is no methane gas collection system at the landfill. A monthly methane gas monitoring program was initiated at the Lake Goodwin Landfill during the fourth quarter of 2011. Monitoring of methane gas production at the landfill is accomplished by a monthly 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 second quarter methane gas monitoring activities are discussed in *Section 3.0* below.

In addition, an annual settlement monitoring program was initiated during the fourth quarter of 2011. This is comprised of an annual topographic survey that is compared to previous recorded surveys to delineate any changes to the landfill cap. In 2014, a County survey crew installed a permanent 100-foot 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 settlement monitoring results 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 widespread areas of groundwater contamination. However, saltwater intrusion, agricultural, and septic system impacts occur locally. According to the 1996 United States Geological Survey (**USGS**) groundwater study, the most common water quality problems in Snohomish County are due to naturally-occurring minerals. High iron and manganese concentrations are fairly common throughout the County, and these minerals cause mostly nuisance issues (*such as objectionable odors and/or stained laundry and plumbing fixtures*). Another naturally-occurring water quality concern in Snohomish County is arsenic. Arsenic levels vary depending on the groundwater aquifer and the proximity to bedrock units. Arsenic concentrations in groundwater 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 United States **Environmental Protection Agency** (*USEPA*) Maximum Contaminant Level (*MCL*) reporting limits, but are not high enough to present health concerns.

The second quarter 2016 groundwater monitoring event was performed at the Site by **Snohomish County** personnel on April 14, 2016. Groundwater levels were 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 **Second Quarter Groundwater Measurements and Elevations** are shown in *Table 1* below. **Hydrographs** including the second quarter 2016 water level data are included in *Appendix A* of this report. As shown on *Table 1*, the groundwater elevations in all monitored wells increased from the previous quarter. The groundwater level data collected over the last six-(*6*) years indicate increasing groundwater elevations beneath the landfill and also confirm that the aquifer is unconfined in the immediate vicinity of the Site. The **Second Quarter Groundwater Contour Map** developed from the field data is included as *Figure 6* of this report.

The measured precipitation at the Stanwood Weather Station (*WA-SN-11, http://www.cocorahs.org/state.aspx?state=wa*) during the second quarter monitoring period (*from April 1 through June 30, 2016*) was 6.11 inches. This is a decrease of 4.10 inches compared to the previous quarter precipitation total of 10.21 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 – Second Quarter Groundwater Measurements and Elevations

Well ID	Casing Elevation (feet above MSL)	Groundwater Elevation (feet above MSL)	Change from Previous Quarter (feet)
LG-01	239.18	153.46	2.97
LG-02	268.67	153.92	1.09
LG-04	206.93	152.72	2.35
LG-05	235.00	152.89	1.84

2.2 Second Quarter Groundwater Sampling Event

Groundwater volumes ranging from approximately 5.4 to 10.2 gallons were purged from each of the four-(*4*) monitoring wells prior to sampling. Water samples were collected 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 preserve samples at approximately 4°C for delivery to the laboratory for testing. The 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*). The monitoring results are discussed below.

2.3 Evaluation of Second Quarter Groundwater Analytical Results

The Second Quarter 2016 Groundwater Test Results for each well are summarized in *Table 2* below. Comparison of results to the regulatory criteria indicates:

Second Quarter: Arsenic exceeded the groundwater standard of 0.05 µg/L in all wells, and pH exceeded the groundwater standard range of 6.5 to 8.5 pH units in downgradient wells LG-04 and LG-05. Additionally, the conductivity, nitrate, sodium, and total dissolved solids concentrations in well LG-05 each exceeded their respective groundwater standards. No other constituents exceeded the WAC groundwater or secondary drinking water standards during this sampling event.

Table 2 – Second Quarter 2016 Groundwater Test Results

Well	Groundwater Standard Exceedances
LG-01	Arsenic
LG-02	Arsenic
LG-04	pH, arsenic
LG-05	Conductivity, nitrate, pH, 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 performed 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 **USEPA** 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 (*from 1988 to present*), and the results of that analysis (*the presence of increasing or decreasing concentration trends*) are recorded on the spreadsheet in *Appendix B*. The trend analysis in *Appendix C* is performed on data from 2006 to present. This allows for placement of multiple constituents on a single graph to better see any potential correlation between the analyzed constituents. Per **Ecology** and Snohomish Health District request, the statistical prediction limits are 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 wells LG-01 and LG-05. The alkalinity, bicarbonate, conductivity, magnesium, potassium, sulfate, and barium concentrations in wells LG-01 and LG-05 exceeded their respective prediction limits. In addition, the calcium, nitrate, nitrite, sodium, TDS, cobalt, and manganese concentrations in well LG-05 exceeded their respective prediction limits. Downgradient well LG-04 appeared less impacted by leachate and contained only two-(*2*) exceedances to the calculated prediction limits (*chloride and barium*) during the second quarter sampling event. The sulfate and iron concentrations in upgradient well LG-02 exceeded their respective prediction limits. Overall, there were 26 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 second quarter are shown in *Table 3* below.

Table 3 – Second Quarter 2016 Statistical Summary Prediction Limit Exceedances

Well	Prediction Limit Exceedances
LG-01	Alkalinity, bicarbonate, conductivity, magnesium, potassium, sulfate, barium
LG-02	Sulfate, iron
LG-04	Chloride, barium
LG-05	Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrate, nitrite, potassium, sodium, sulfate, TDS, barium, cobalt, manganese

There were 19 increasing concentration trends noted during the current monitoring period (*mostly in wells LG-01 and LG-05*), and 9 decreasing trends, mostly found in well LG-04. **Statistical Analysis** 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-(*3*) 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 – Second Quarter Landfill Gas Monitoring Results

Probe	Date	% Methane	Oxygen	CO_2
LG-A1	4/8/16	13	0	16
	5/27/16	12	0	19
	6/10/16	13	0	20
LG-B2	4/8/16	27	0	12
	5/27/16	26	0	15
	6/10/16	22	0	16
LG-C2	4/8/16	21	0	14
	5/27/16	19	0	16
	6/10/16	17	0	16

No measurable oxygen concentrations were present during the monthly gas probe monitoring events during the second quarter of 2016, while methane concentrations decreased slightly and carbon dioxide increased slightly over the course of the quarter.

4.0 SUMMARY AND RECOMMENDATIONS

The groundwater data collected during the second quarter 2016 sampling event indicates the following:

- The precipitation totals for the second quarter 2016 were lower than those measured during previous quarter. Groundwater elevations increased in all wells by 1.09 to 2.97 feet compared to the previous quarter. Overall, the groundwater elevation trend of all wells has been steadily rising since 2005.
- The groundwater gradient and flow direction were generally consistent with historical Site groundwater flow data.
- All of the sampled wells contained arsenic concentrations that exceeded the arsenic groundwater standard.
- The concentrations of constituents of concern and the numbers of constituents that exceeded their applicable groundwater standard limits and/or prediction limits 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 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 (*9*) than increasing trends (*19*) during this sampling event.
- There were few dissolved metals impacts to the groundwater. Small exceedances to the calculated prediction limits for magnesium, potassium, and barium were noted in wells LG-01 and LG-05. In addition, the barium concentration in well LG-04 and the calcium, sodium, cobalt, and manganese concentrations in LG-05 also exceeded their respective prediction limits during the current monitoring period.
- Oxygen was consistently not detected at the monitored gas probe locations throughout the quarter, which is consistent with the previous quarter. Methane decreased slightly and carbon dioxide generally increased from the previous quarter to the current quarter.

4.1 *Conclusions/Recommendations*

The second 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, mostly in well LG-05, which is consistent with the last several groundwater sampling events.

Downgradient well LG-04 has shown a significant number of decreasing trends during this same time period.

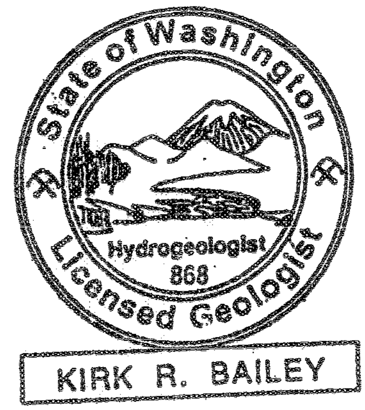
Interpretation of the data suggests that a leachate plume impacting groundwater could extend beyond the landfill boundaries downgradient to the north-northeast in the immediate vicinity of LG-05.

4.2 Signatures and Licenses

9/23/16

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

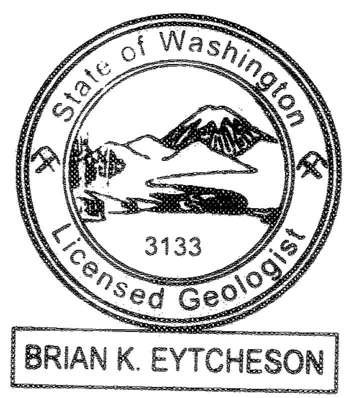
Date



9/23/16

Brian K. Eytcheson, LG
SCPW – Solid Waste Division

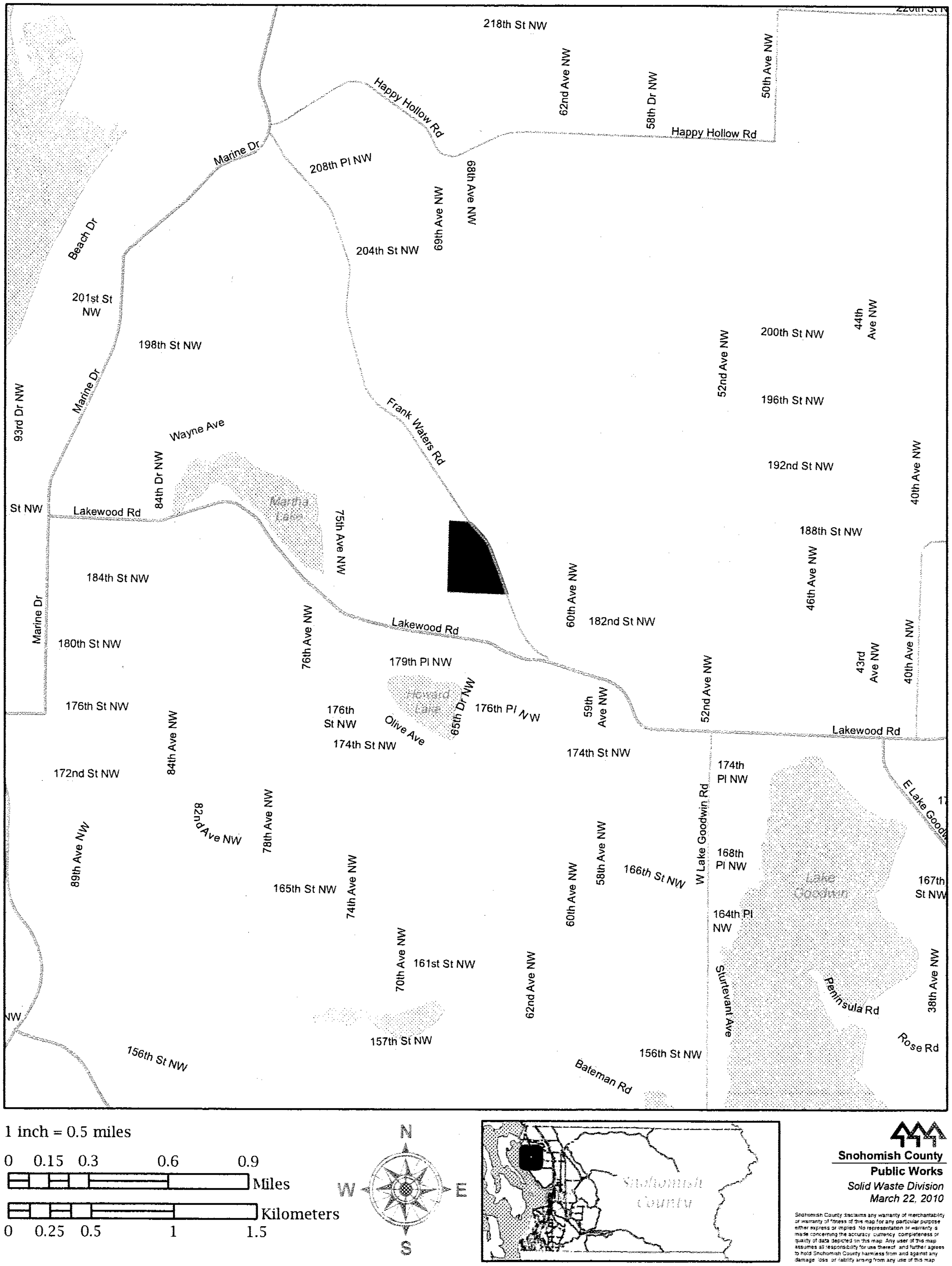
Date



Figures

Figure 1

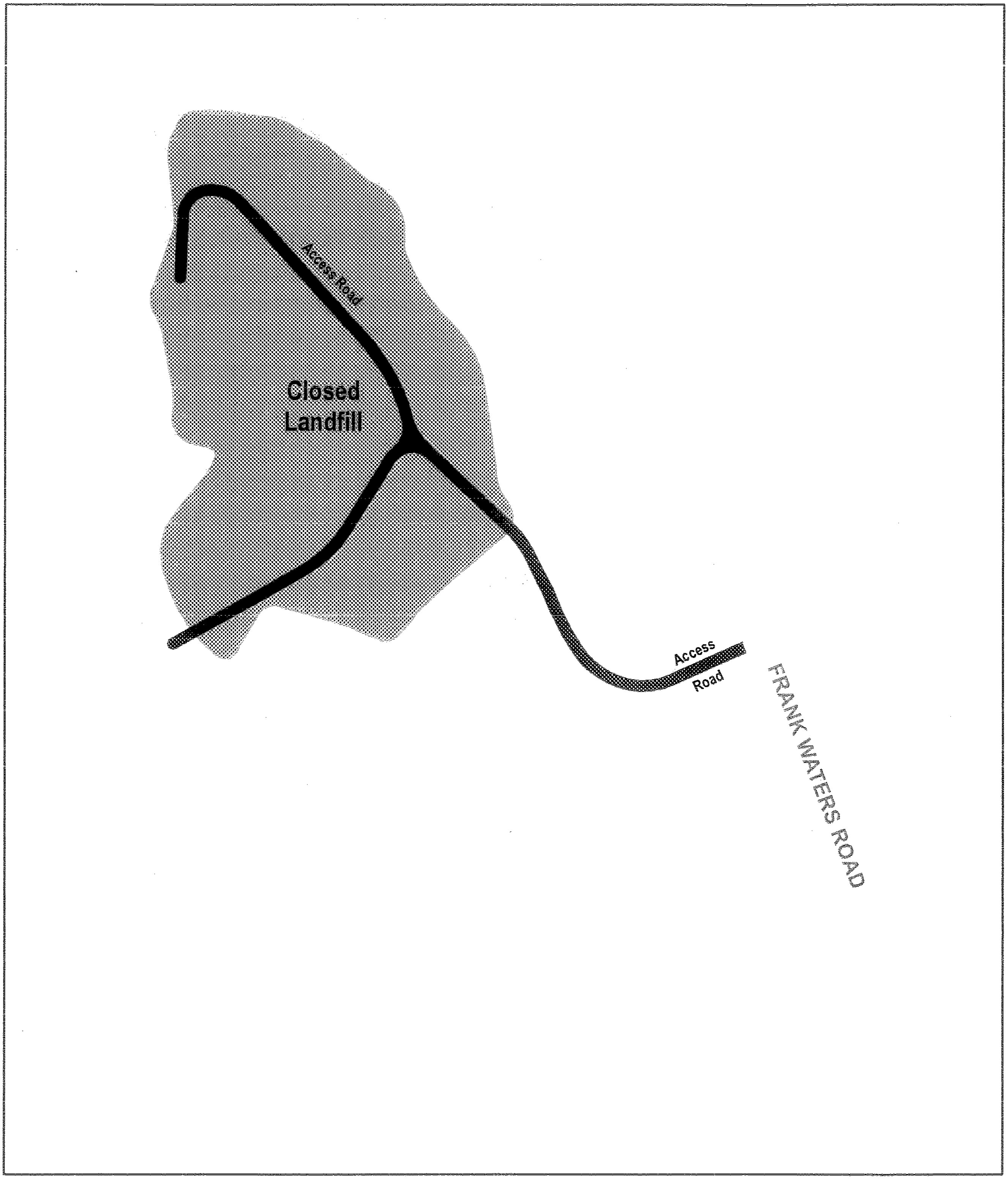
Lake Goodwin Landfill



Snohomish County
Public Works
Solid Waste Division
March 22, 2010

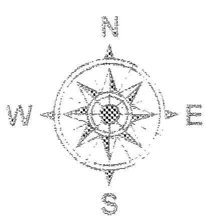
Figure 2

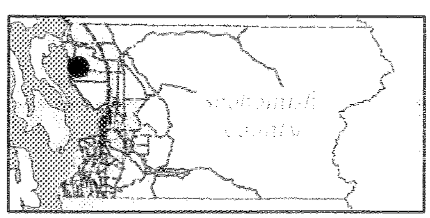
Lake Goodwin Landfill Site Map



0 0.015 0.03 0.06 Miles

0 70 140 280 420 Feet



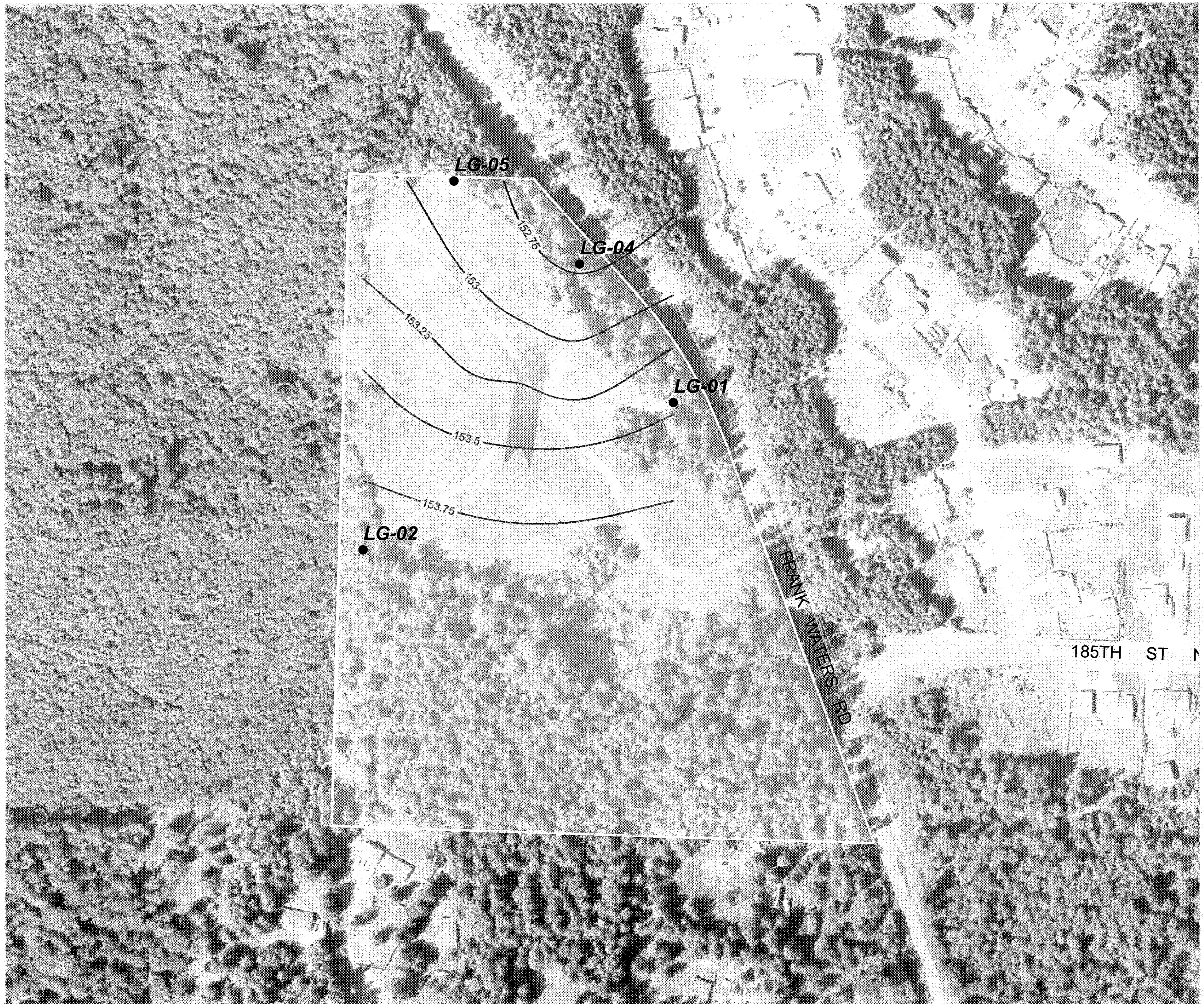


Snohomish County
Public Works
Solid Waste Division
March 25, 2010

Figure 6

Lake Goodwin Landfill

Groundwater Elevation Contours Second Quarter 2016



DIRECTION OF GROUNDWATER FLOW
.64 ft / day
235 ft / year
80.80 degrees to the positive x - axis

PARCEL BOUNDARY

SUBJECT PROPERTY BOUNDARY

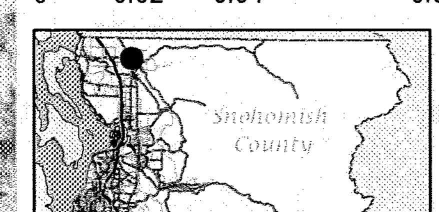
.25 FT CONTOUR

WELL LOCATION

WELL_ID	SAMP_DATE	MEAS_HEAD
LG-01	4/14/2016	153.46
LG-02	4/14/2016	153.92
LG-04	4/14/2016	152.72
LG-05	4/14/2016	152.89

0 85 170 340 510 680 Feet

0 0.02 0.04 0.08 0.12 Miles



N

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Public Works
Solid Waste Division
July 22, 2016

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

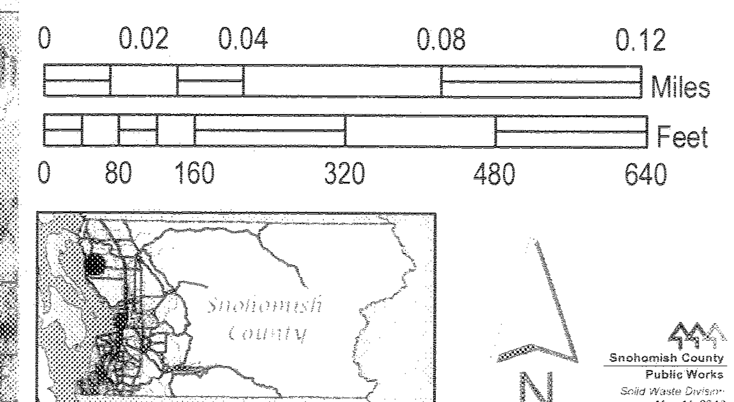

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Figure 4

Lake Goodwin Landfill

Geologic Map

Map Features

Parcel Boundary

Subject Property Boundary

Geologic Description

Vashon advance outwash (Qva)

Vashon recessional outwash

Vashon till (Qvt)

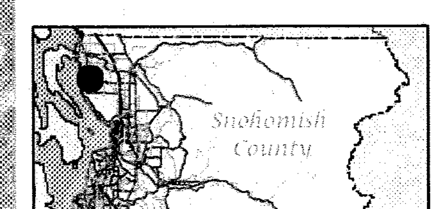
Water

Modified Land

1 inch = 600 feet

0 0.035 0.07 0.14 0.21 0.28 0.35 Miles

0 240 480 960 1,440 1,920 Feet



N W E S

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Solid Waste Division
May 6, 2010

Figure 3

Lake Goodwin Landfill

Topography

Map Features

Parcel Boundary

Subject Property Boundary

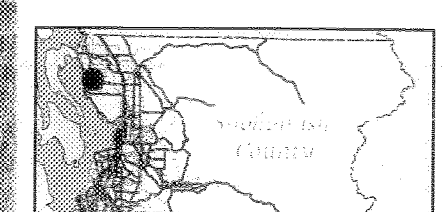
5 Foot Contours

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



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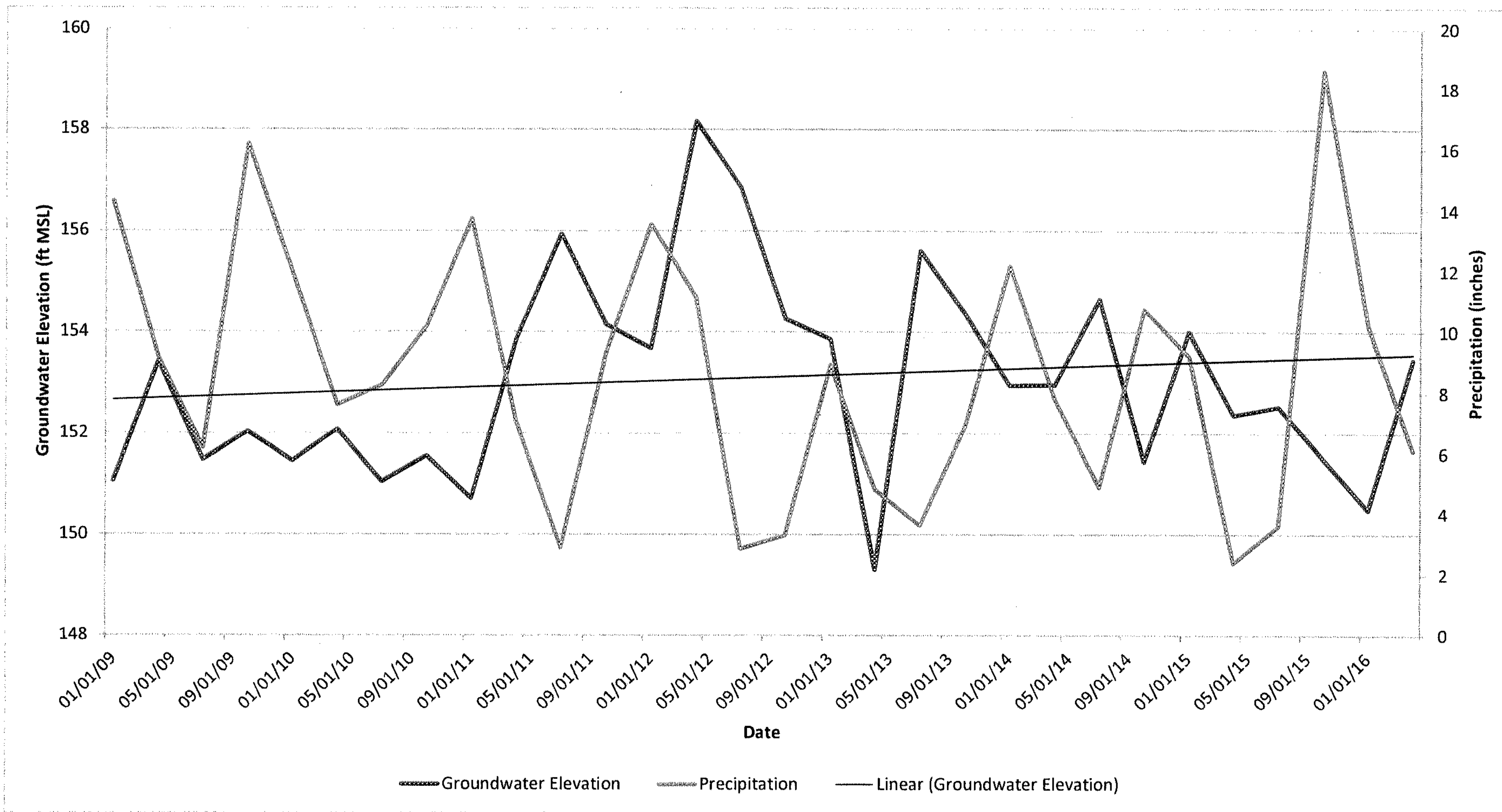
Solid Waste Division
March 23, 2010

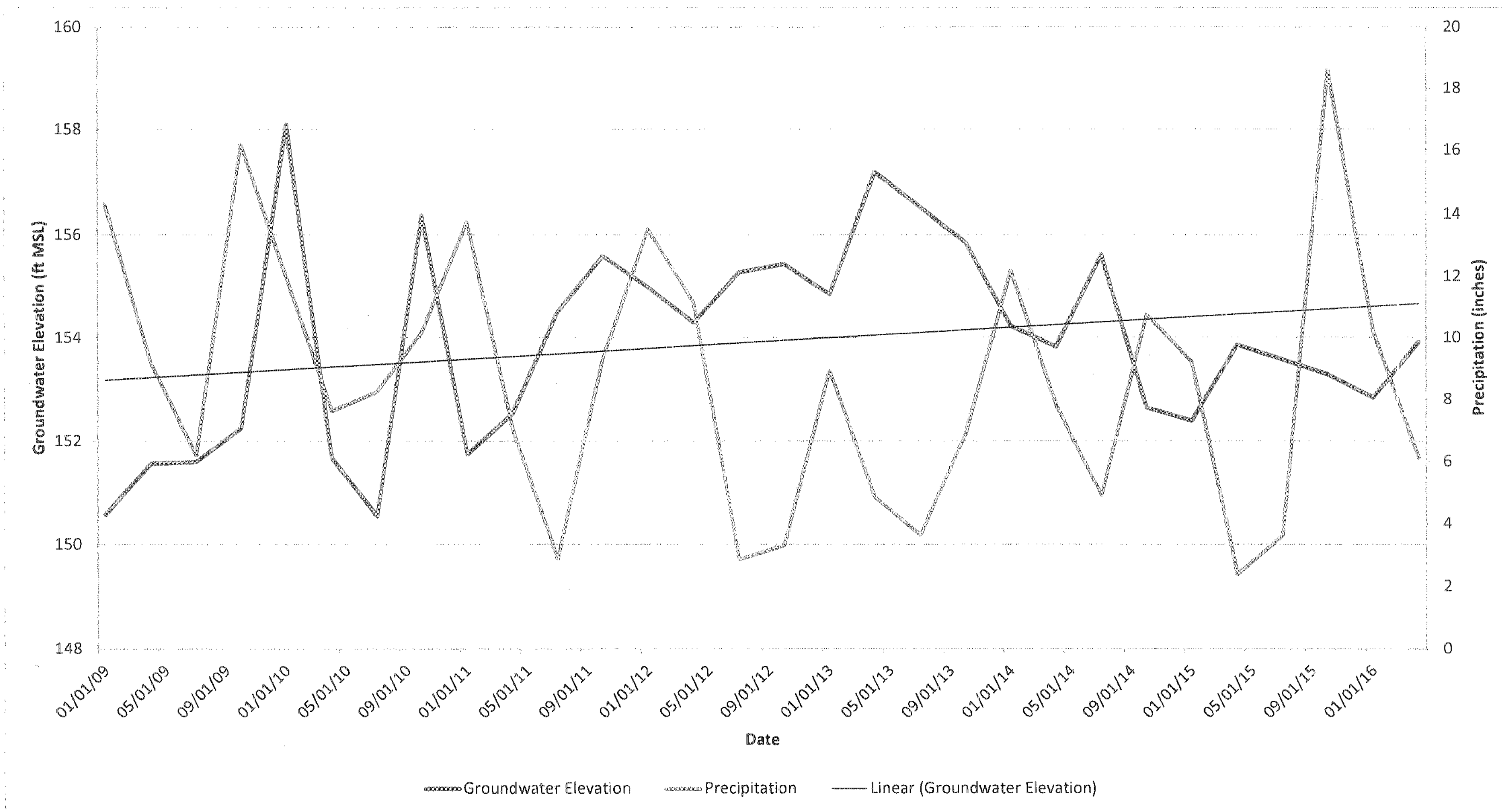
Appendix A

Well Hydrographs

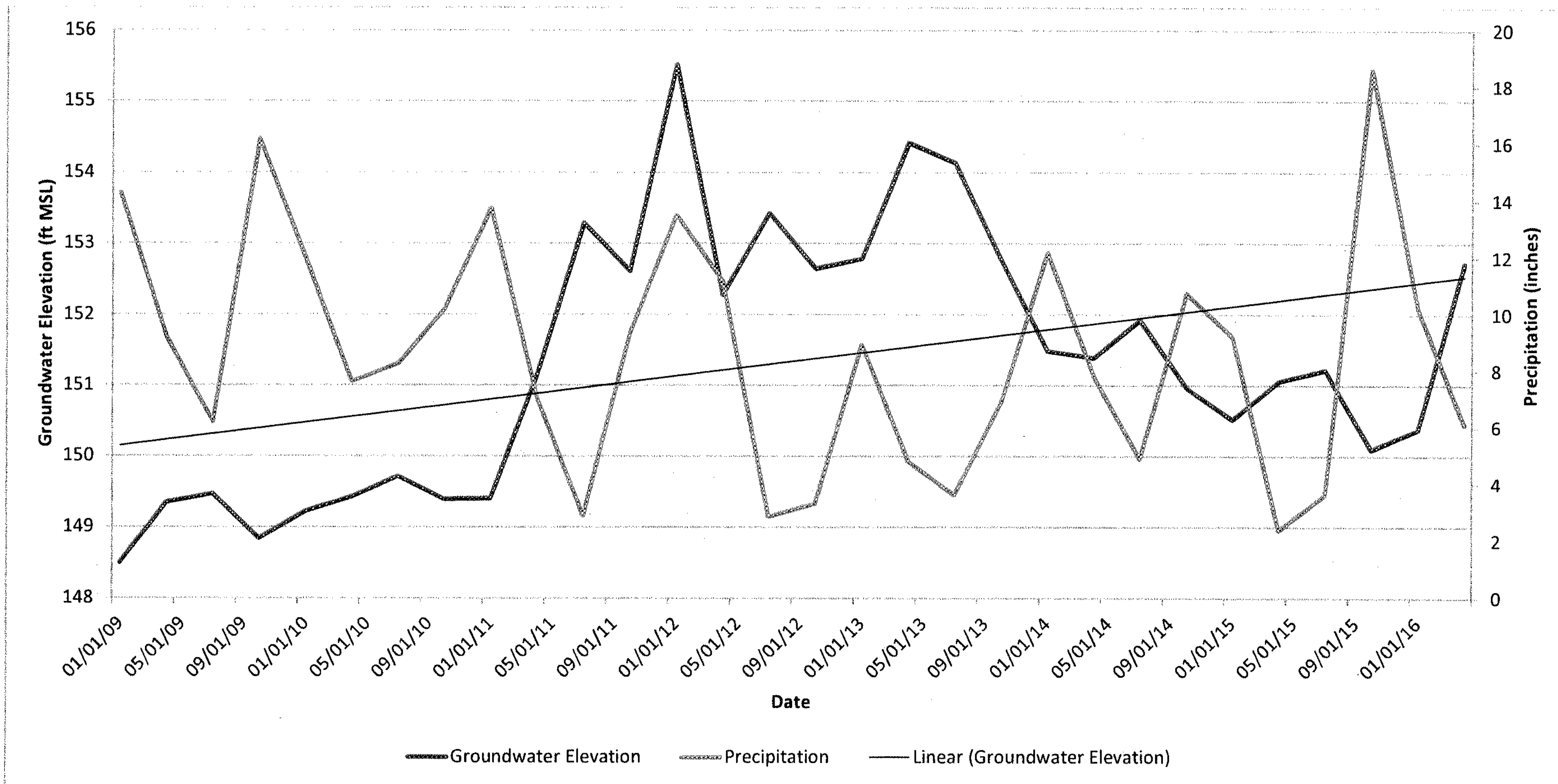
Hydrograph
Lake Goodwin Landfill
Well LG-01



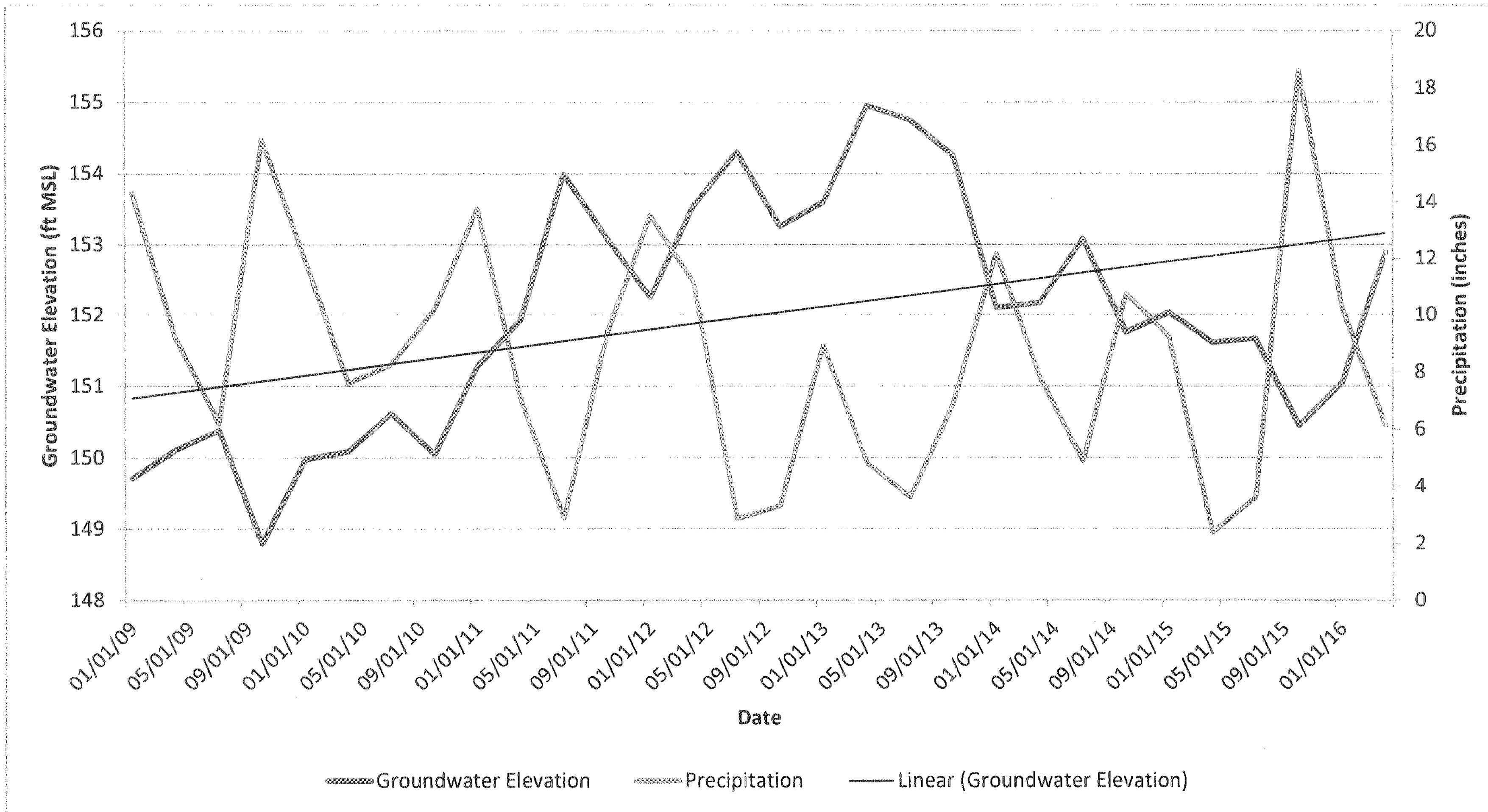
Hydrograph
Lake Goodwin Landfill
Well LG-02



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-04	D	4/14/2016	152.72
LG-02	D	4/14/2016	153.92
LG-05	D	4/14/2016	152.89
LG-01	D	4/14/2016	153.46

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 **4/14/2016**

		[X] matrix		[D] matrix
Well ID	**X-axis**	**Y-axis**	**GW Elev.**	D
LG-01	646.57	299.26	**153.46**	1
LG-02	21.47	2.50	**153.92**	1
LG-04	458.30	579.89	**152.72**	1
LG-05	205.32	748.45	**152.89**	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
153.46	153.92	152.72	152.89	0	0

{[P]t[P]}

670708.9182	612981.5542	203910.2454
612981.5542	986012.6122	249300.5609
203910.2454	249300.5609	93940.0885

{[P]t[P]}'

4.71288E-06	-1.04364E-06	-7.46033E-06
-1.04364E-06	3.3136E-06	-6.52835E-06
-7.46033E-06	-6.52835E-06	4.41639E-05

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

0.001590025	-0.001049718	0.000415374	-0.00095	0	0
-0.000685	-0.001018967	0.000446215	0.001268	0	0
9.00062E-08	0.006621211	-0.000460086	0.000334	0	0

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

A	1.60579E-06
B	9.91459E-06
C	0.006495532

Groundwater Gradient:	**0.0015**	
Conductivity (ft/day):	**83.3**	
Effective porosity:	**20%**	
GW velocity:	**0.64**	**ft/day**
	235	**ft/year**
Flow direction:	**80.80**	**degrees to the positive x-axis**

Appendix B

Analytical Data Summary Table

Groundwater Statistical Summary: Second Quarter 2016
Lake Goodwin Landfill, Snohomish County, WA

						Down Gradient Wells															Upgradient Well				
	Statistical Method	Number of Samples	Number of Detects	Prediction Limit (a)	GW Stds 173-200	LG-01					LG-04					LG-05					LG-02				
						4/14/16	D	V	Tr	Ch	4/14/16	D	V	Tr	Ch	4/14/16	D	V	Tr	Ch	4/14/16	D	V	Tr	Ch
CONVENTIONAL CHEMISTRY PARAMETERS (mg/L)																									
Alkalinity (as CaCO3)	lognor	43	43	183.2996	--	190		E	I	N	120					510		V	I	N	80				
Ammonia Nitrogen	nonpar	39	10	0.056	--	0.016					0.005	U				0.005	U				0.006				
Bicarbonate	lognor	43	43	160.1323	--	190		E			120			D	N	510		V	I	N	80				
Calcium, Dissolved	nonpar	43	43	31.2	--	23.9			I	N	19.3			D	N	51		V	I	N	14.4				
Chemical Oxygen Deman	nonpar	39	3	26	--	10	U				10	U				10	U				10	U			
Chloride	normal	43	43	9.69	250	7.35			I	N	9.9		E	I	N	25.7		V	I	N	6.93				
Conductivity (umhos/cm)	lognor	43	43	368.633	700	380		E	I	N	280			D	N	1000		V	I	N	190				
Magnesium, Dissolved	nonpar	43	43	25.15	--	34		V	I	N	19.3					71.5		V	I	N	12.3				
Nitrate Nitrogen (mg-N/L)	nonpar	43	43	6	10	2.7				Y	0.98					13		E	I	N	1.3				
Nitrite Nitrogen (mg-N/L)	nonpar	40	8	0.011	1	0.001	U				0.001	U				0.028		V			0.001	U			
pH (std units)	nonpar	43	43	5.99-7.51	6.5-8.5	6.52			D	N	6.26			D	N	6.37			D	N	6.93			D	N
Potassium, Dissolved	normal	43	43	3.5314	--	4.18		E			3.31					8.62		V	I	N	2.68				
Sodium, Dissolved	nonpar	42	42	13.8	20	10.7			D	N	9.73			D	N	54.1		V			7.94				
Sulfate	lognor	43	43	20.2636	250	27		V			14.3					51		V			20.4				
Total Dissolved Solids	nonpar	43	43	550	500	280			I	N	220					730		V	I	N	150				
Total Organic Carbon	nonpar	43	19	19	--	0.75					0.5	U				5.3			I	N	0.5	U			
DISSOLVED METALS EPA Methods 200.7/200.8 (mg/L)																									
Arsenic	nonpar	37	37	0.0078	0.00005	0.000546					0.000334					0.00118					0.00332				
Barium	nonpar	38	38	0.0193	1	0.0266		E	I	N	0.024		V			0.0838		V	I	N	0.0136				
Cadmium	nonpar	39	13	0.0002	0.005	0.000036					0.000025	U				0.000036					0.000025	U			
Chromium	normal	40	33	0.0091	0.05	0.005	U				0.006					0.005	U				0.005	U			
Cobalt	nonpar	43	8	0.008	--	0.008					0.008					0.009		E			0.006				
Copper	nonpar	39	11	0.005	1	0.005	U				0.005	U	P			0.005	U	P			0.005	U			
Iron	nonpar	43	7	0.031	0.3	0.01					0.005	U				0.008					0.042				
Manganese	nonpar	40	17	0.0061	0.05	0.006					0.0025					0.0166		V			0.002				
Nickel	nonpar	43	0	0.005	0.1	0.002	U				0.002	U				0.002	U				0.002	U			
TOTAL METALS EPA Methods 200.7/200.8 (mg/L)																									
Arsenic					0.00005	0.000542					0.000343					0.000807					0.00346				
Barium					1	0.025					0.0229					0.0915					0.0108				
Cadmium					0.005	0.000025	U				0.000025	U				0.000034					0.000025	U			
Chromium					0.05	0.0078					0.005	U				0.005	U				0.007				
Cobalt					--	0.007					0.005					0.009					0.007				
Copper					1	0.006					0.005	U				0.005	U				0.005	U			
Iron					0.3	0.029					0.031					0.068					0.011				
Manganese					0.05	0.0016					0.0021					0.0222					0.0013				
Nickel					0.1	0.002	U				0.002	U				0.002	U				0.002	U			

D: U = Indicates compound was not detected at the given reporting limit.
V: E= Exceedance, waiting verification based on subsequent lab data; V= Exceedance verified based on previous lab data; P=Passed, previous exceedance not verified based on current lab data.
Tr: I=increasing Trend, D=Decreasing Trend;
Ch: Y indicates a change in trend from previous quarter; N means no change in trend.
The groundwater standards listed are based on the Washington Administrative Code (WAC) 173-200 groundwater limits as modified by the TMS 91-11 standards - the most restrictive of the two is used.
* = Non-detect; exceedance due to elevated laboratory reporting limit

Table 2

Most Current Downgradient Monitoring Data

Constituent	Units	Well	Date		Result		Pred. Limit
Alkalinity (as caco3)	mg/L	LG-01	04/14/2016		190.0000	*	183.2996
Ammonia nitrogen	mg/L	LG-01	04/14/2016		0.0160		0.0560
Bicarbonate	mg/L	LG-01	04/14/2016		190.0000	*	160.1323
Chemical oxygen demand	mg/L	LG-01	04/14/2016	ND	10.0000		26.0000
Chloride	mg/L	LG-01	04/14/2016		7.3500		9.6900
Conductivity	umhos/cm	LG-01	04/14/2016		380.0000	*	368.6330
Dissolved antimony	U mg/l	LG-01	04/14/2016	ND	0.0002		0.0100
Dissolved arsenic	mg/L	LG-01	04/14/2016		0.0005		0.0078
Dissolved barium	mg/L	LG-01	04/14/2016		0.0266	*	0.0193
Dissolved beryllium	U mg/l	LG-01	04/14/2016	ND	0.0003		0.0005
Dissolved cadmium	U mg/l	LG-01	04/14/2016		0.0000		0.0002
Dissolved calcium	mg/L	LG-01	04/14/2016		23.9000		31.2000
Dissolved chromium	U mg/l	LG-01	04/14/2016	ND	0.0050		0.0091
Dissolved cobalt	U mg/l	LG-01	04/14/2016		0.0080		0.0080
Dissolved copper	mg/L	LG-01	04/14/2016	ND	0.0050		0.0050
Dissolved iron	U mg/l	LG-01	04/14/2016		0.0100		0.0310
Dissolved lead	U mg/l	LG-01	04/14/2016		0.0001		0.0010
Dissolved magnesium	mg/L	LG-01	04/14/2016		34.0000	***	25.1500
Dissolved manganese	U mg/l	LG-01	04/14/2016		0.0060		0.0061
Dissolved nickel	U mg/l	LG-01	04/14/2016	ND	0.0020		0.0050
Dissolved potassium	mg/L	LG-01	04/14/2016		4.1800	*	3.5314
Dissolved selenium	U mg/l	LG-01	04/14/2016		0.0008		0.0020
Dissolved silver	U mg/l	LG-01	04/14/2016	ND	0.0001		4.2501
Dissolved sodium	mg/L	LG-01	04/14/2016		10.7000		13.8000
Dissolved thallium	U mg/l	LG-01	04/14/2016	ND	0.0000		0.0010
Dissolved vanadium	U mg/l	LG-01	04/14/2016	ND	0.0100		0.0100
Dissolved zinc	mg/L	LG-01	04/14/2016		0.0080	*	0.0070
Nitrate nitrogen	mg-N/L	LG-01	04/14/2016		2.7000		6.0000
Nitrite nitrogen	mg-N/L	LG-01	04/14/2016	ND	0.0010		0.0110
pH	std units	LG-01	04/14/2016		6.5200		5.99 - 7.51
Sulfate	mg/L	LG-01	04/14/2016		27.0000	***	20.2636
Total dissolved solids	mg/L	LG-01	04/14/2016		280.0000		550.0000
Total organic carbon	U mg/l	LG-01	04/14/2016		0.7500		19.0000
Alkalinity (as caco3)	mg/L	LG-04	04/14/2016		120.0000		183.2996
Ammonia nitrogen	mg/L	LG-04	04/14/2016	ND	0.0050		0.0560
Bicarbonate	mg/L	LG-04	04/14/2016		120.0000		160.1323
Chemical oxygen demand	mg/L	LG-04	04/14/2016	ND	10.0000		26.0000
Chloride	mg/L	LG-04	04/14/2016		9.9000	*	9.6900
Conductivity	umhos/cm	LG-04	04/14/2016		280.0000		368.6330
Dissolved antimony	U mg/l	LG-04	04/14/2016	ND	0.0002		0.0100
Dissolved arsenic	mg/L	LG-04	04/14/2016		0.0003		0.0078
Dissolved barium	mg/L	LG-04	04/14/2016		0.0240	***	0.0193
Dissolved beryllium	U mg/l	LG-04	04/14/2016	ND	0.0003		0.0005
Dissolved cadmium	U mg/l	LG-04	04/14/2016	ND	0.0000		0.0002
Dissolved calcium	mg/L	LG-04	04/14/2016		19.3000		31.2000
Dissolved chromium	U mg/l	LG-04	04/14/2016		0.0055		0.0091
Dissolved cobalt	U mg/l	LG-04	04/14/2016		0.0080		0.0080
Dissolved copper	mg/L	LG-04	04/14/2016	ND	0.0050	**	0.0050
Dissolved iron	U mg/l	LG-04	04/14/2016	ND	0.0050		0.0310
Dissolved lead	U mg/l	LG-04	04/14/2016	ND	0.0001		0.0010
Dissolved magnesium	mg/L	LG-04	04/14/2016		19.3000		25.1500
Dissolved manganese	U mg/l	LG-04	04/14/2016		0.0025		0.0061
Dissolved nickel	U mg/l	LG-04	04/14/2016	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	04/14/2016		3.3100		3.5314
Dissolved selenium	U mg/l	LG-04	04/14/2016	ND	0.0003		0.0020
Dissolved silver	U mg/l	LG-04	04/14/2016	ND	0.0001		4.2501
Dissolved sodium	mg/L	LG-04	04/14/2016		9.7300		13.8000
Dissolved thallium	U mg/l	LG-04	04/14/2016	ND	0.0000		0.0010
Dissolved vanadium	U mg/l	LG-04	04/14/2016	ND	0.0100		0.0100
Dissolved zinc	mg/L	LG-04	04/14/2016	ND	0.0020		0.0070
Nitrate nitrogen	mg-N/L	LG-04	04/14/2016		0.9800		6.0000
Nitrite nitrogen	mg-N/L	LG-04	04/14/2016	ND	0.0010		0.0110
pH	std units	LG-04	04/14/2016		6.2600		5.99 - 7.51
Sulfate	mg/L	LG-04	04/14/2016		14.3000		20.2636
Total dissolved solids	mg/L	LG-04	04/14/2016		220.0000		550.0000
Total organic carbon	U mg/l	LG-04	04/14/2016	ND	0.5000		19.0000
Alkalinity (as caco3)	mg/L	LG-05	04/14/2016		510.0000	***	183.2996
Ammonia nitrogen	mg/L	LG-05	04/14/2016	ND	0.0050		0.0560
Bicarbonate	mg/L	LG-05	04/14/2016		510.0000	***	160.1323
Chemical oxygen demand	mg/L	LG-05	04/14/2016	ND	10.0000		26.0000
Chloride	mg/L	LG-05	04/14/2016		25.7000	***	9.6900
Conductivity	umhos/cm	LG-05	04/14/2016		1000.0000	***	368.6330
Dissolved antimony	U mg/l	LG-05	04/14/2016	ND	0.0002		0.0100
Dissolved arsenic	mg/L	LG-05	04/14/2016		0.0012		0.0078
Dissolved barium	mg/L	LG-05	04/14/2016		0.0838	***	0.0193
Dissolved beryllium	U mg/l	LG-05	04/14/2016	ND	0.0003		0.0005
Dissolved cadmium	U mg/l	LG-05	04/14/2016		0.0000		0.0002
Dissolved calcium	mg/L	LG-05	04/14/2016		51.0000	***	31.2000
Dissolved chromium	U mg/l	LG-05	04/14/2016	ND	0.0050		0.0091
Dissolved cobalt	U mg/l	LG-05	04/14/2016		0.0090	*	0.0080
Dissolved copper	mg/L	LG-05	04/14/2016	ND	0.0050	**	0.0050
Dissolved iron	U mg/l	LG-05	04/14/2016		0.0080		0.0310
Dissolved lead	U mg/l	LG-05	04/14/2016	ND	0.0001		0.0010
Dissolved magnesium	mg/L	LG-05	04/14/2016		71.5000	***	25.1500
Dissolved manganese	U mg/l	LG-05	04/14/2016		0.0166	***	0.0061
Dissolved nickel	U mg/l	LG-05	04/14/2016	ND	0.0020		0.0050
Dissolved potassium	mg/L	LG-05	04/14/2016		8.6200	***	3.5314
Dissolved selenium	U mg/l	LG-05	04/14/2016		0.0009		0.0020
Dissolved silver	U mg/l	LG-05	04/14/2016	ND	0.0001		4.2501
Dissolved sodium	mg/L	LG-05	04/14/2016		54.1000	***	13.8000
Dissolved thallium	U mg/l	LG-05	04/14/2016	ND	0.0000		0.0010
Dissolved vanadium	U mg/l	LG-05	04/14/2016	ND	0.0100		0.0100
Dissolved zinc	mg/L	LG-05	04/14/2016		0.0040		0.0070
Nitrate nitrogen	mg-N/L	LG-05	04/14/2016		13.0000	*	6.0000
Nitrite nitrogen	mg-N/L	LG-05	04/14/2016		0.0280	***	0.0110
pH	std units	LG-05	04/14/2016		6.3700		5.99 - 7.51
Sulfate	mg/L	LG-05	04/14/2016		51.0000	***	20.2636
Total dissolved solids	mg/L	LG-05	04/14/2016		730.0000	***	550.0000
Total organic carbon	U mg/l	LG-05	04/14/2016		5.3000		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

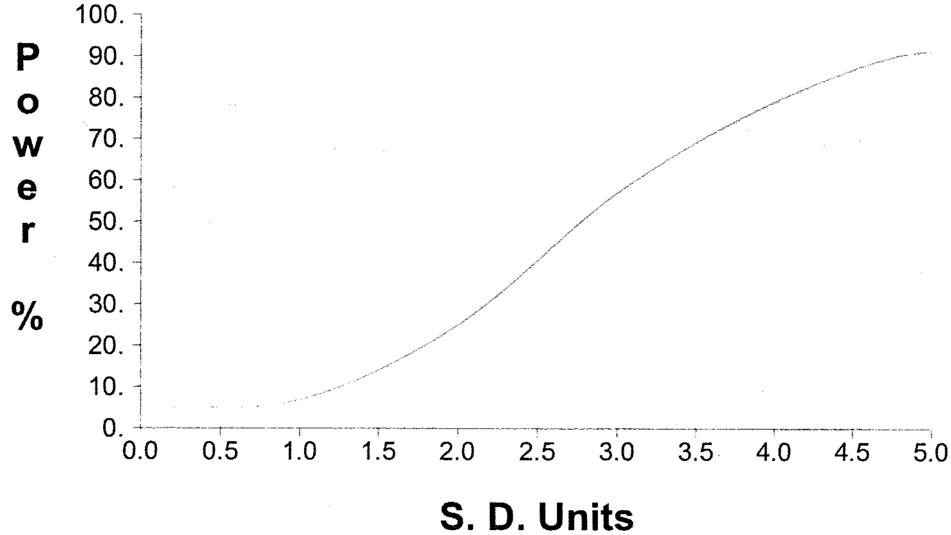
Constituent	Units	Model Type	N	Detect	Mean	SD	Pred Limit	Conf*
Alkalinity (as caco3)	mg/L	lognor	43	43	4.5156	0.2843	183.2996	
Ammonia nitrogen	mg/L	nonpar	39	10			0.0560	0.99
Bicarbonate	mg/L	lognor	43	43	4.5792	0.2031	160.1323	
Chemical oxygen demand	mg/L	nonpar	39	3			26.0000	0.99
Chloride	mg/L	normal	43	43	6.9577	1.1169	9.6900	
Conductivity	umhos/cm	lognor	43	43	5.5522	0.1462	368.6330	
Dissolved antimony	U mg/l	nonpar	33	10			0.0100	0.99
Dissolved arsenic	mg/L	nonpar	37	37			0.0078	0.99
Dissolved barium	mg/L	nonpar	38	38			0.0193	0.99
Dissolved beryllium	U mg/l	nonpar	43	0			0.0005	0.99
Dissolved cadmium	U mg/l	nonpar	39	13			0.0002	0.99
Dissolved calcium	mg/L	nonpar	43	43			31.2000	0.99
Dissolved chromium	U mg/l	normal	40	33	0.0038	0.0022	0.0091	
Dissolved cobalt	U mg/l	nonpar	43	8			0.0080	0.99
Dissolved copper	mg/L	nonpar	39	11			0.0050	0.99
Dissolved iron	U mg/l	nonpar	43	7			0.0310	0.99
Dissolved lead	U mg/l	nonpar	32	4			0.0010	0.99
Dissolved magnesium	mg/L	nonpar	43	43			25.1500	0.99
Dissolved manganese	U mg/l	nonpar	40	17			0.0061	0.99
Dissolved nickel	U mg/l	nonpar	43	0			0.0050	0.99
Dissolved potassium	mg/L	normal	43	43	2.8673	0.2715	3.5314	
Dissolved selenium	U mg/l	nonpar	32	10			0.0020	0.99
Dissolved silver	U mg/l	nonpar	32	3			4.2501	0.99
Dissolved sodium	mg/L	nonpar	42	42			13.8000	0.99
Dissolved thallium	U mg/l	nonpar	32	1			0.0010	0.99
Dissolved vanadium	U mg/l	nonpar	31	5			0.0100	0.99
Dissolved zinc	mg/L	nonpar	32	12			0.0070	0.99
Nitrate nitrogen	mg-N/L	nonpar	43	43			6.0000	0.99
Nitrite nitrogen	mg-N/L	nonpar	40	8			0.0110	0.99
pH	std units	nonpar	43	43			5.99- 7.51	0.99
Sulfate	mg/L	lognor	43	43	2.6152	0.1609	20.2636	
Total dissolved solids	mg/L	nonpar	43	43			550.0000	0.99
Total organic carbon	U mg/l	nonpar	43	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

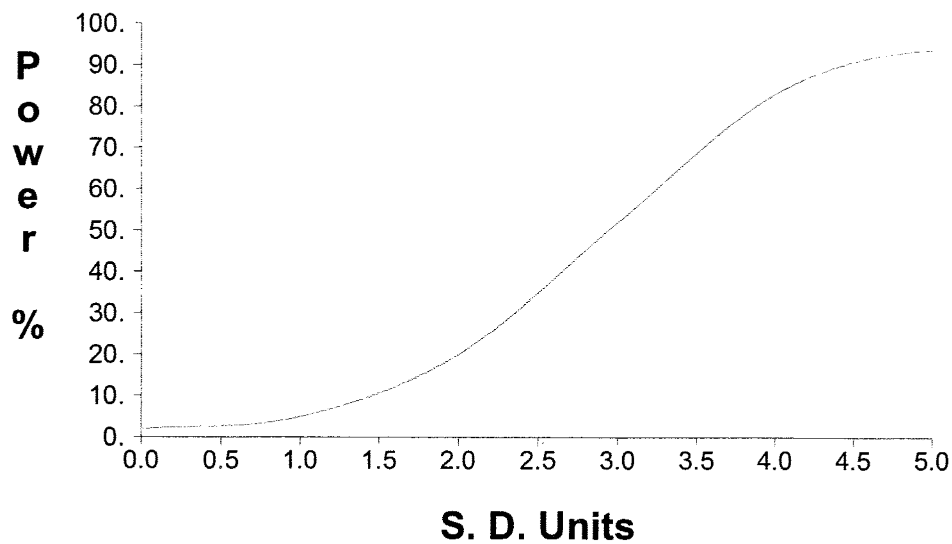
Groundwater Statistical Analyses

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



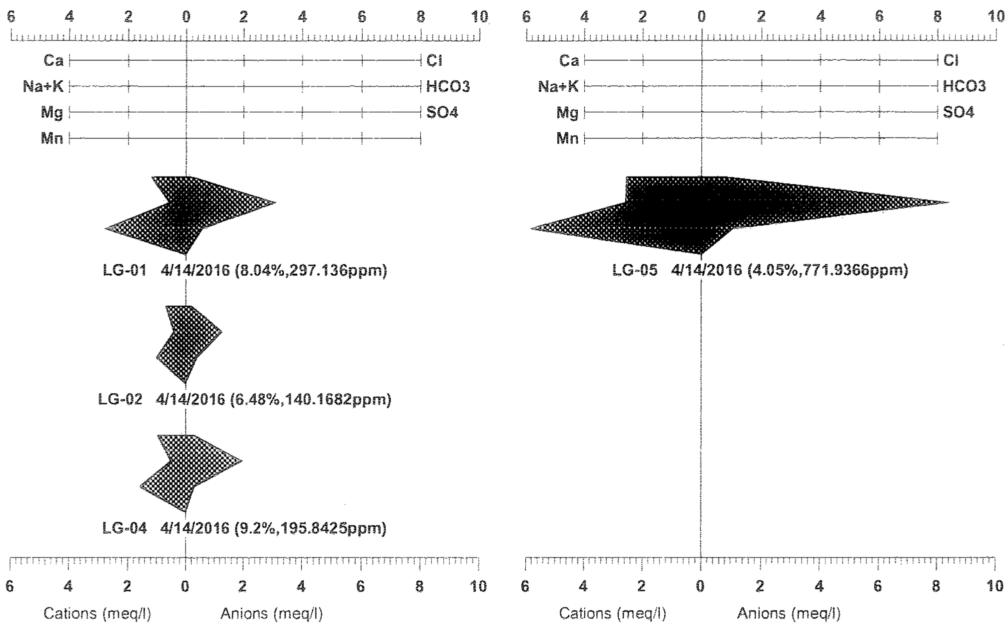
Goodwin Landfill
Analysis prepared on: 7/15/2016

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



1
Prepared by: Snohomish County Solid Waste

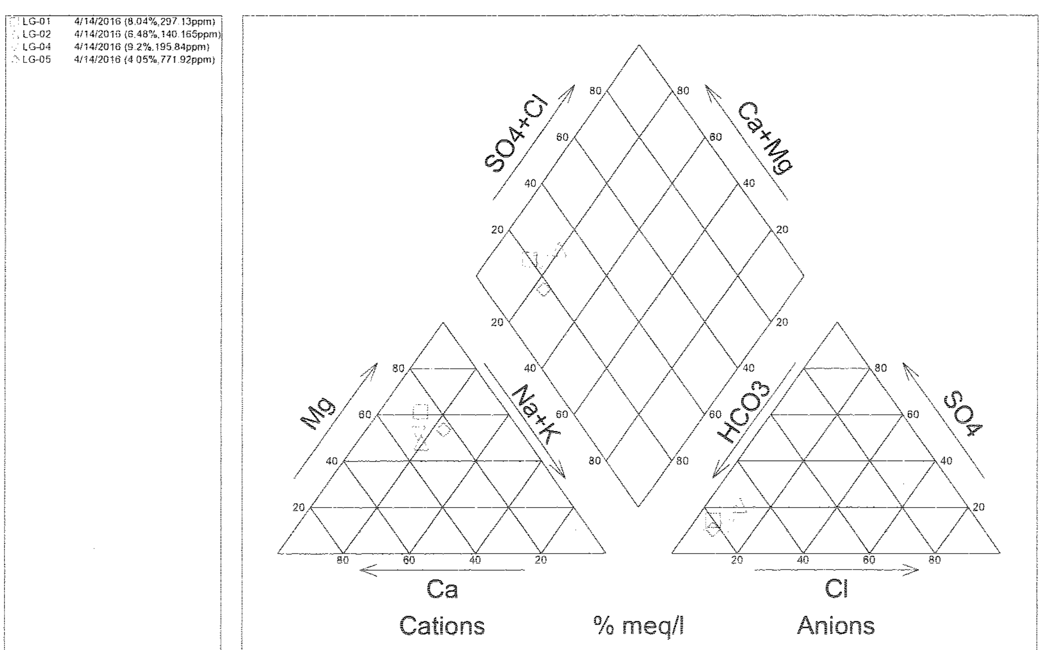
Goodwin Landfill



1

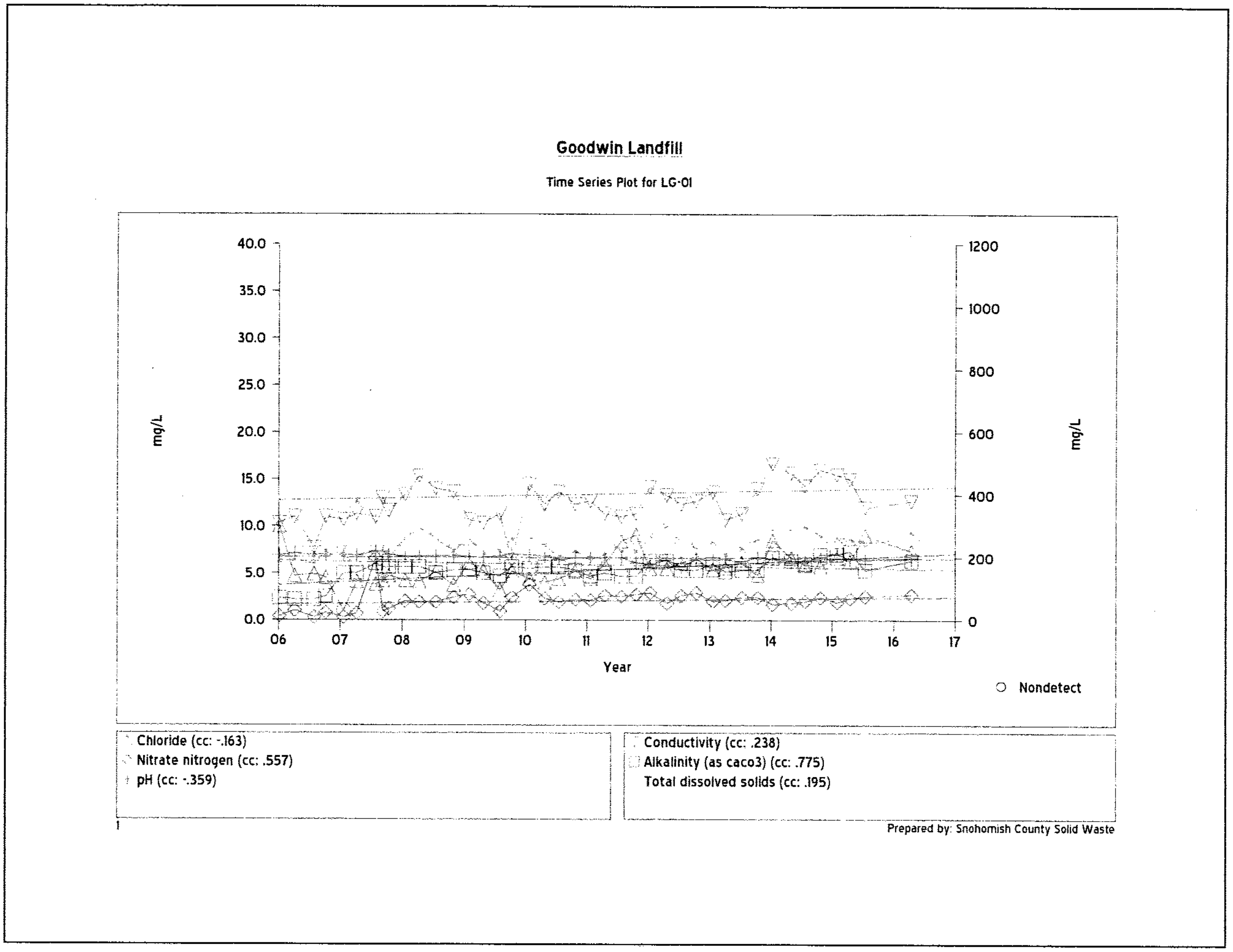
Prepared by: Snohomish County Solid Waste

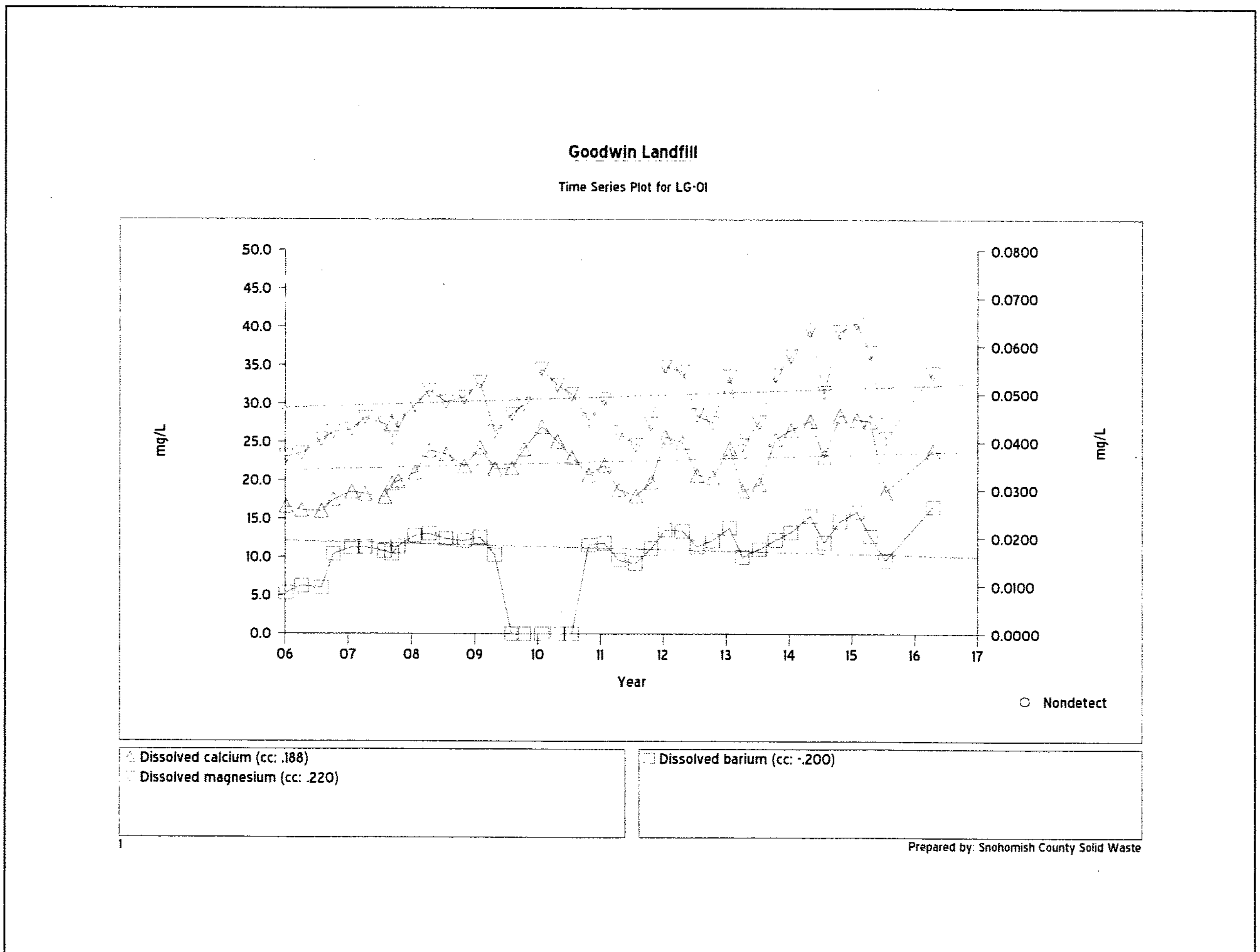
Goodwin Landfill



1

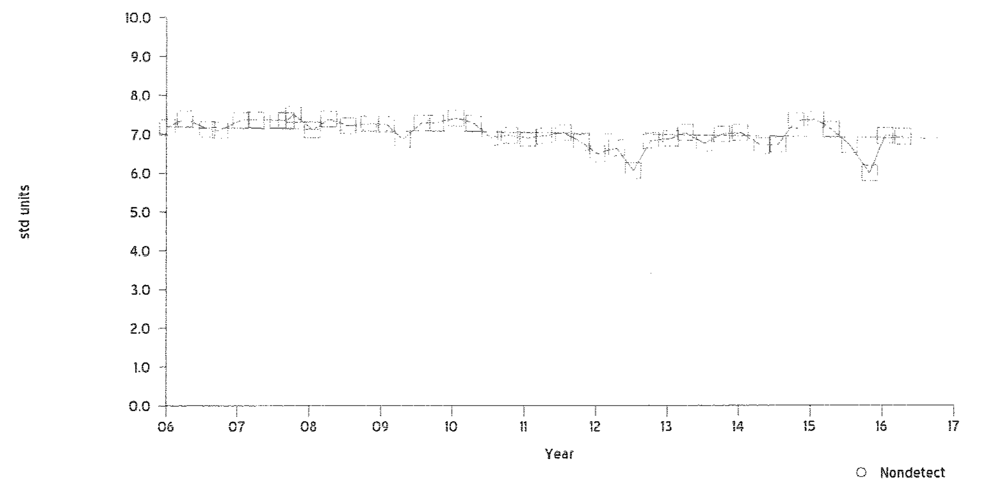
Prepared by: Snohomish County Solid Waste


Goodwin Landfill
Time Series Plot for LG-01
mg/L
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1200
1000
800
600
400
200
0
06
07
08
09
10
11
12
13
14
15
16
17
Year
Nondetect
Chloride (cc: -.163)
Nitrate nitrogen (cc: .557)
pH (cc: -.359)
Conductivity (cc: .238)
Alkalinity (as caco3) (cc: .775)
Total dissolved solids (cc: .195)
1
Prepared by: Snohomish County Solid Waste


Goodwin Landfill
Time Series Plot for LG-01
mg/L
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
06
07
08
09
10
11
12
13
14
15
16
17
Year
Nondetect
Dissolved calcium (cc: .188)
Dissolved magnesium (cc: .220)
Dissolved barium (cc: -.200)
1
Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-02

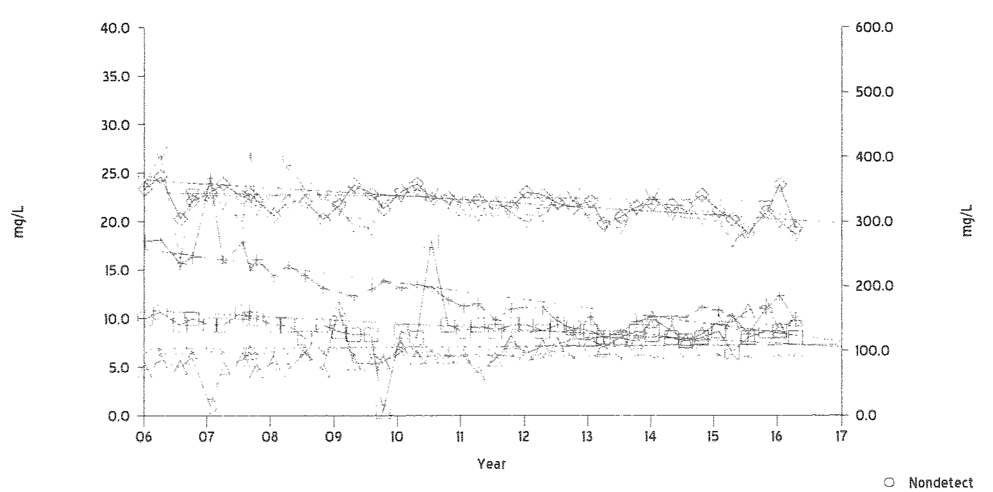


pH (cc: -.552)

1 Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-04

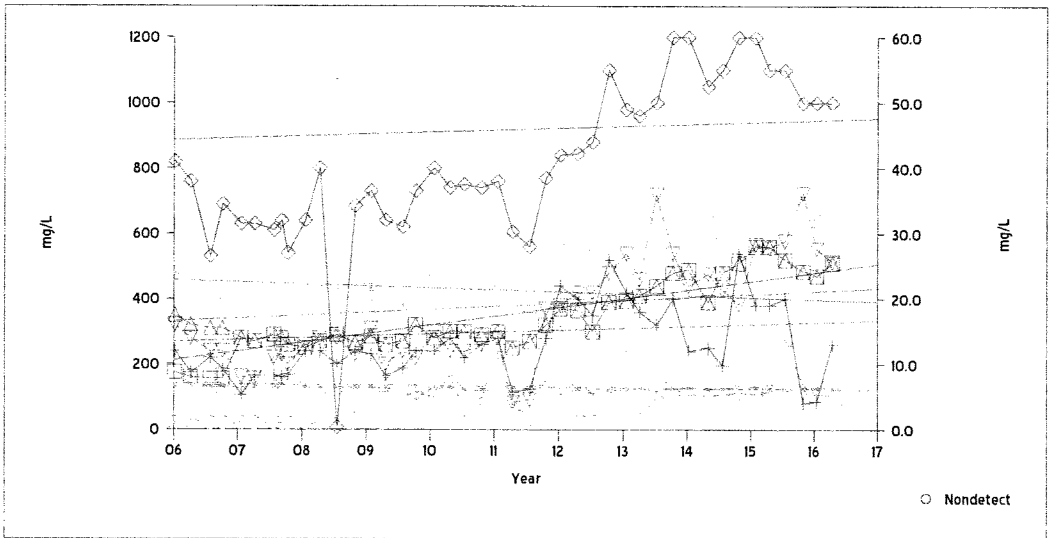


Chloride (cc: .157)
Dissolved calcium (cc: -.492)
Dissolved sodium (cc: -.816)
pH (cc: -.623)
Conductivity (cc: -.180)
Bicarbonate (cc: -.554)

1 Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-05



Alkalinity (as caco3) (cc: .904)
Bicarbonate (cc: .400)
Conductivity (cc: .184)
Total dissolved solids (cc: .427)
Chloride (cc: -.221)
Total organic carbon (cc: -.090)
pH (cc: -.507)
Nitrate nitrogen (cc: .315)

1

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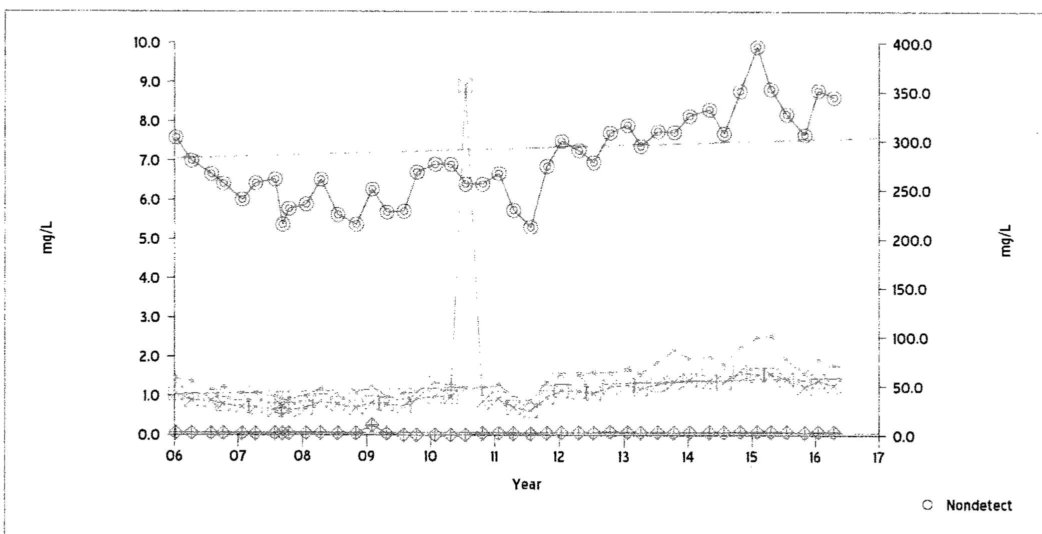
Time Series Plot for LG-05



Dissolved barium (cc: -.007)
Dissolved potassium (cc: .170)
Dissolved calcium (cc: .148)
Dissolved magnesium (cc: .388)

1

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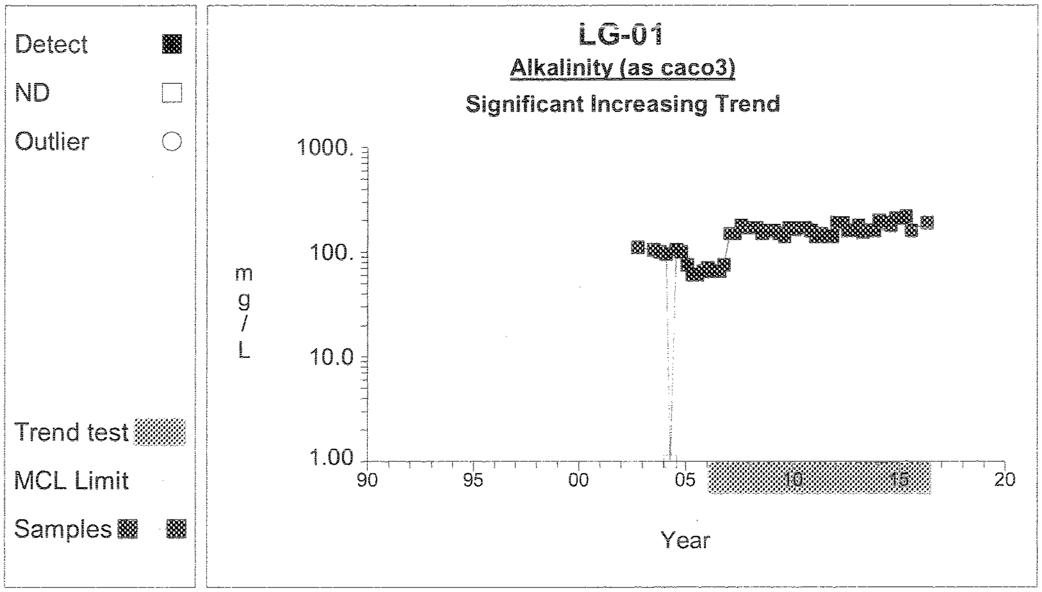
Analysis prepared on: 7/15/2016

Time Series



Graph 1

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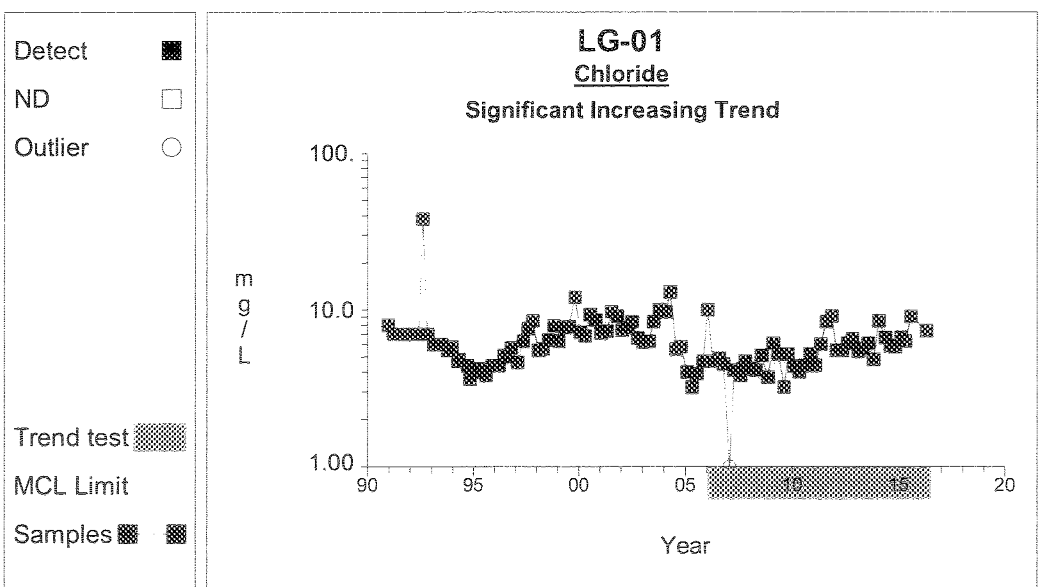
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 5

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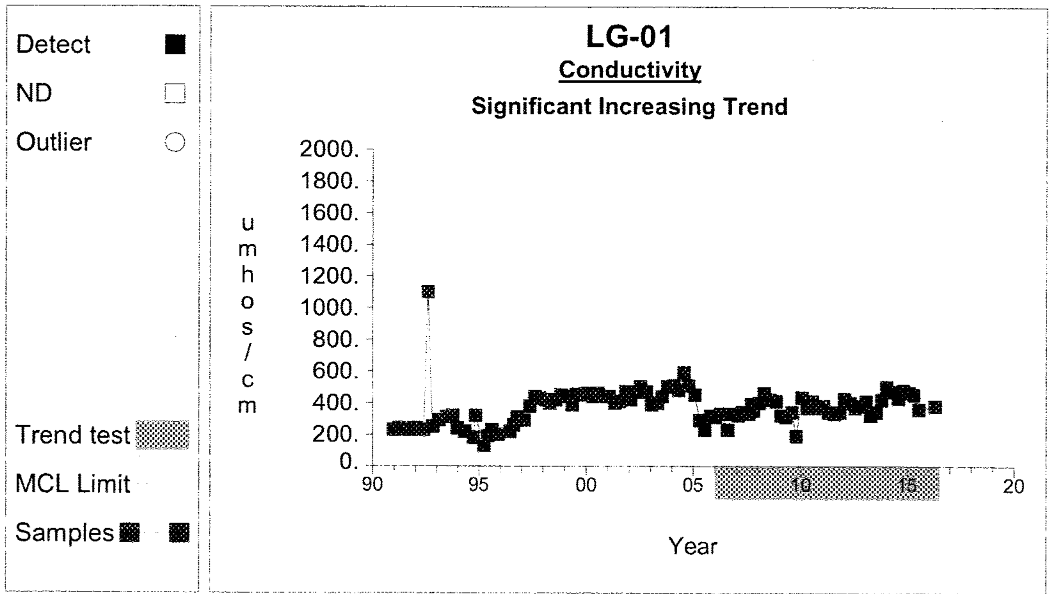
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 6

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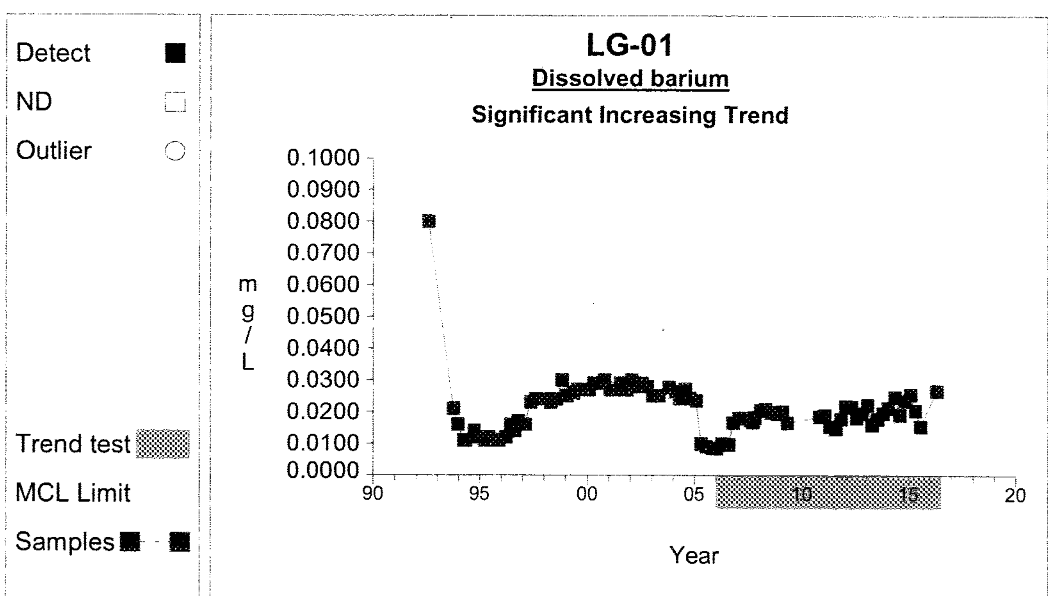
Analysis prepared on: 7/15/2016

Time Series



Graph 9

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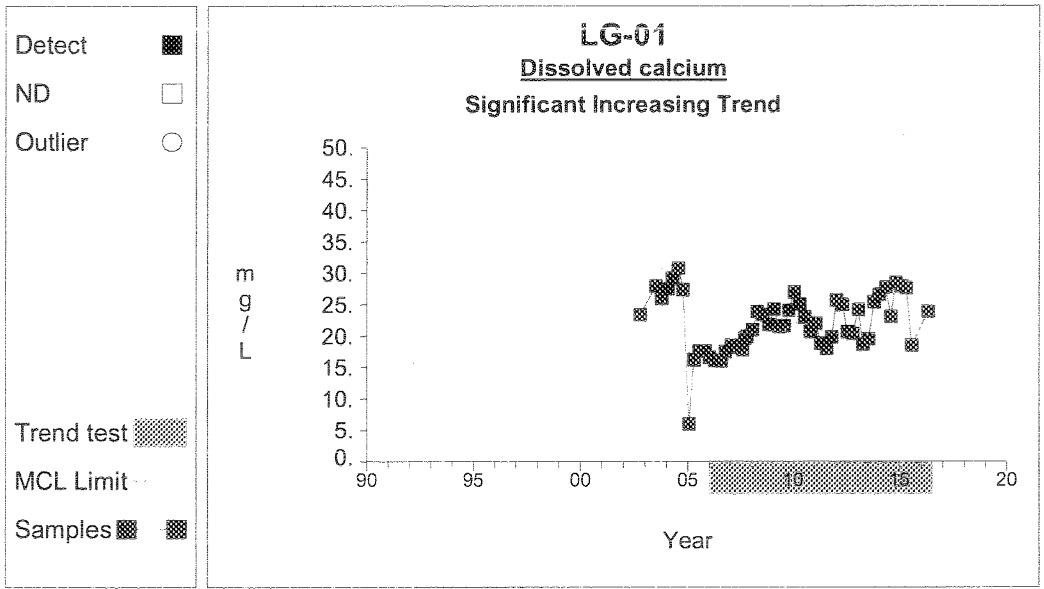
Time Series



Graph 12

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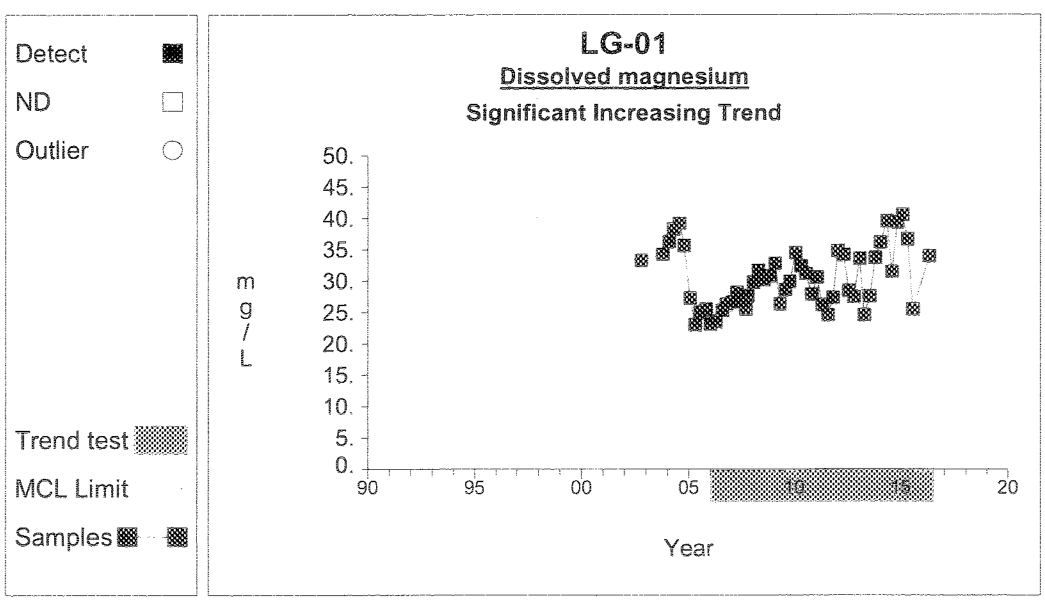
Analysis prepared on: 7/15/2016

Time Series



Graph 18

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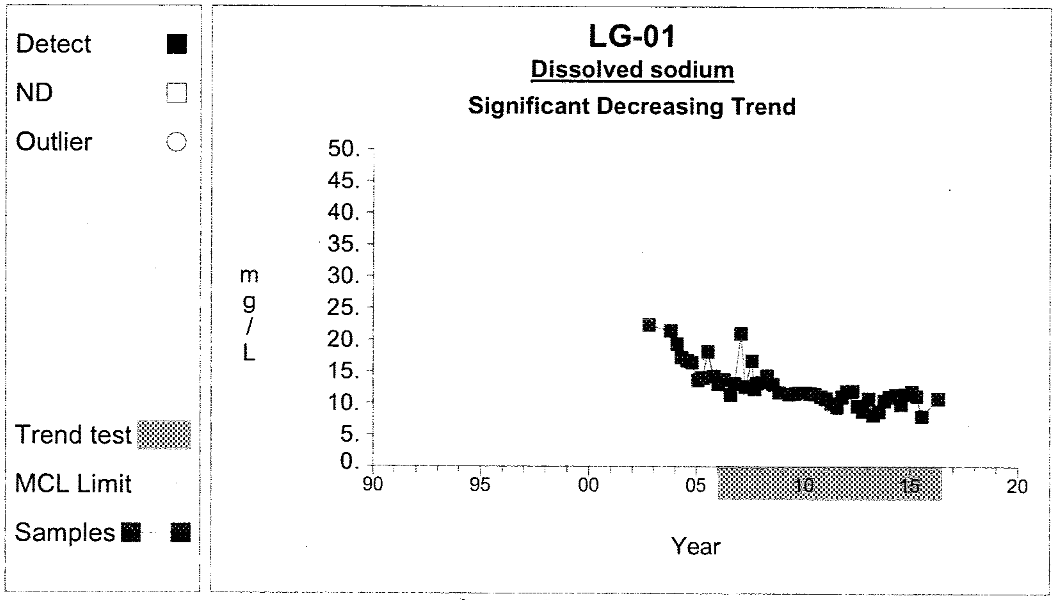
Analysis prepared on: 7/15/2016

Time Series



Graph 24

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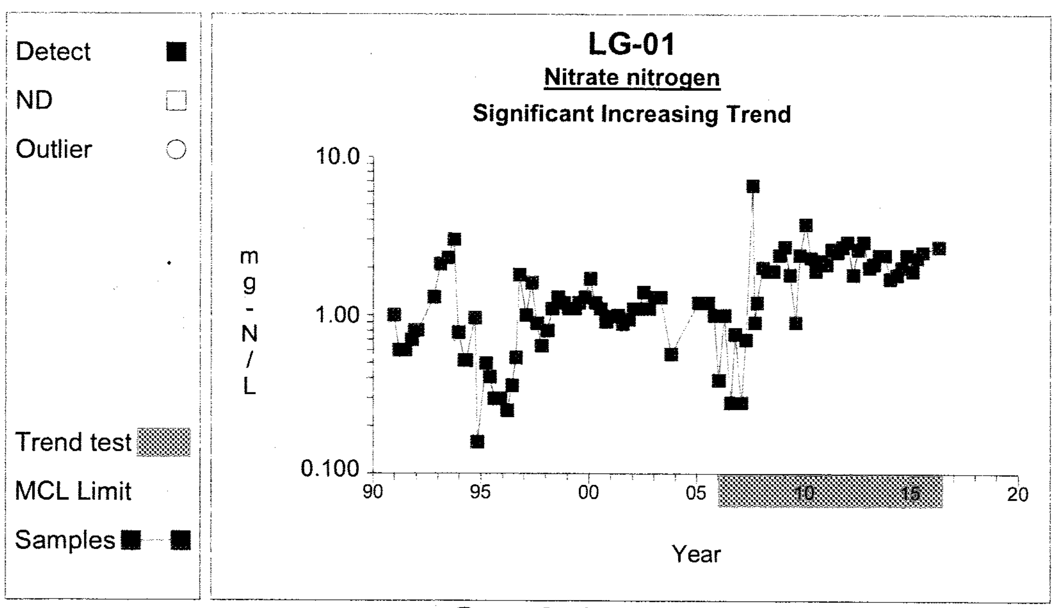
Analysis prepared on: 7/15/2016

Time Series



Graph 28

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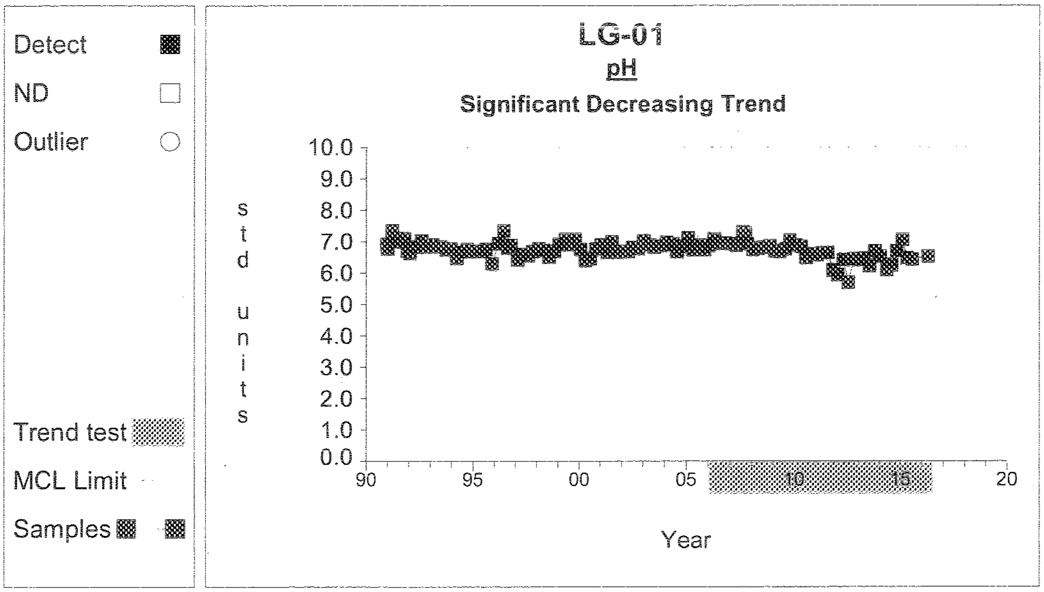
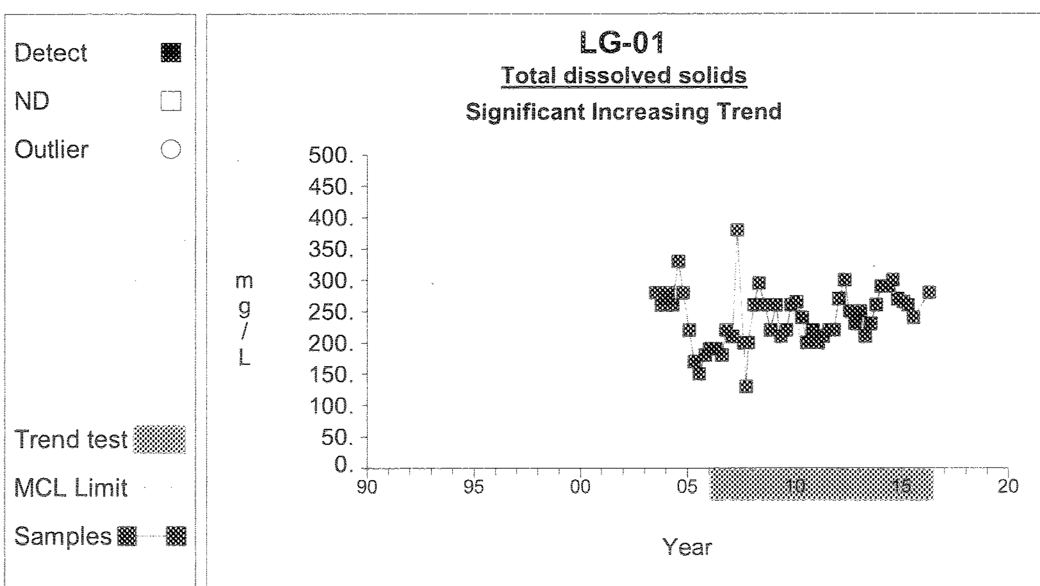
Time Series



Graph 30

Time Series

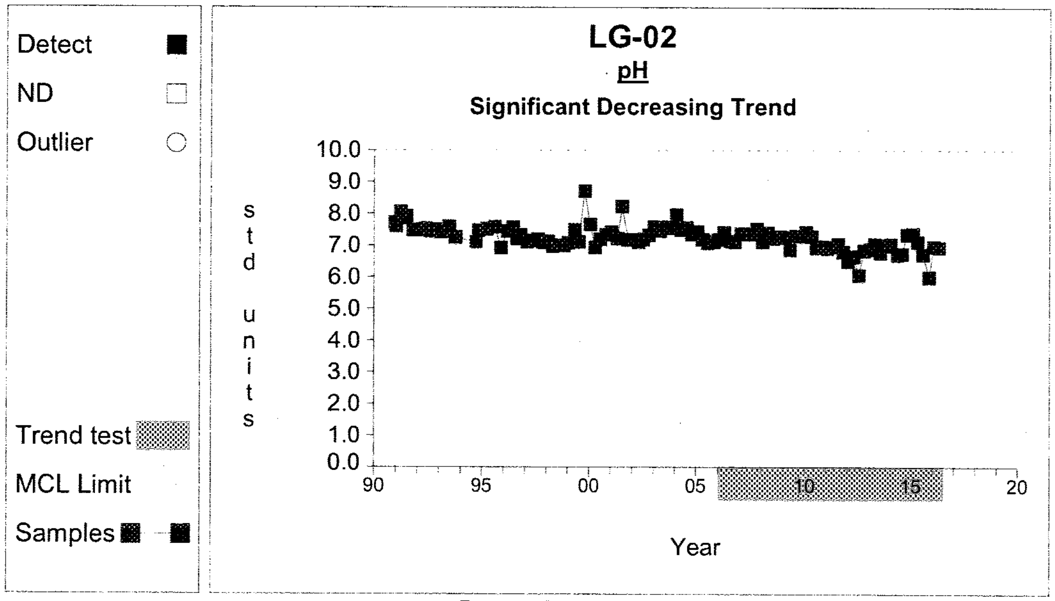


Graph 32

Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 63

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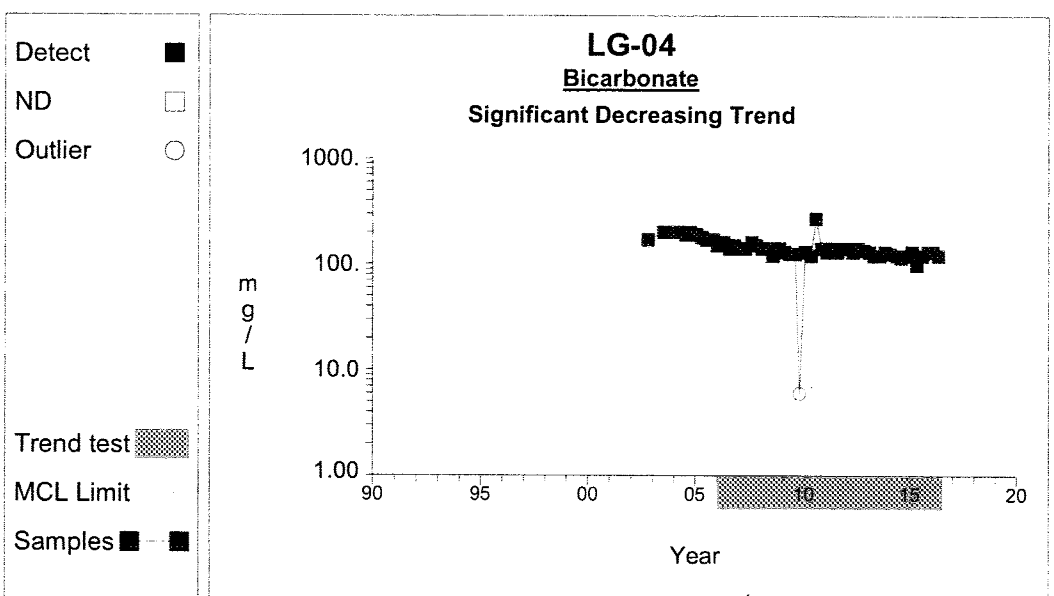
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 69

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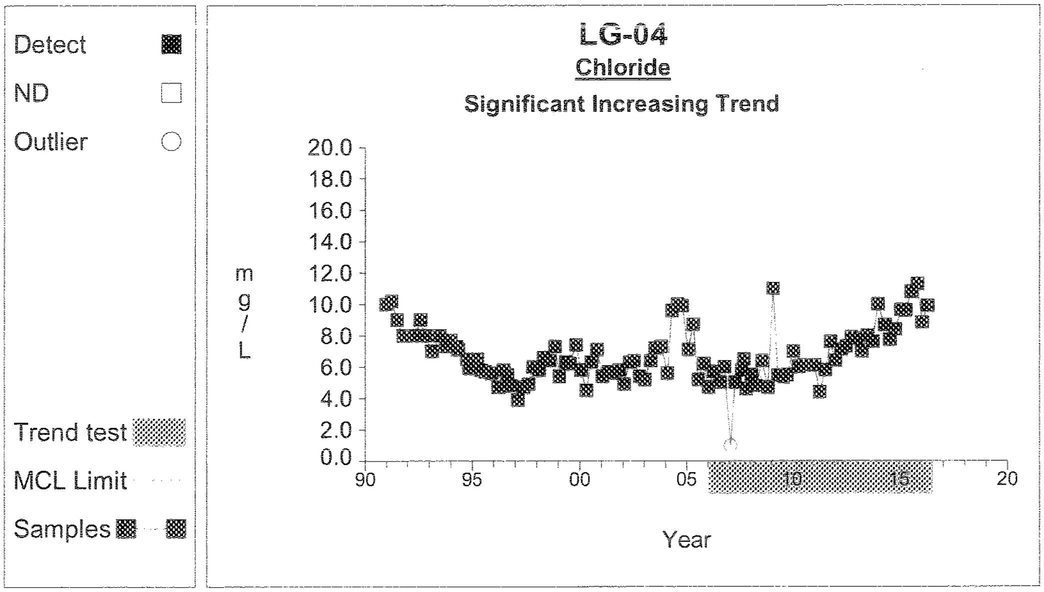
Analysis prepared on: 7/15/2016

Time Series



Graph 71

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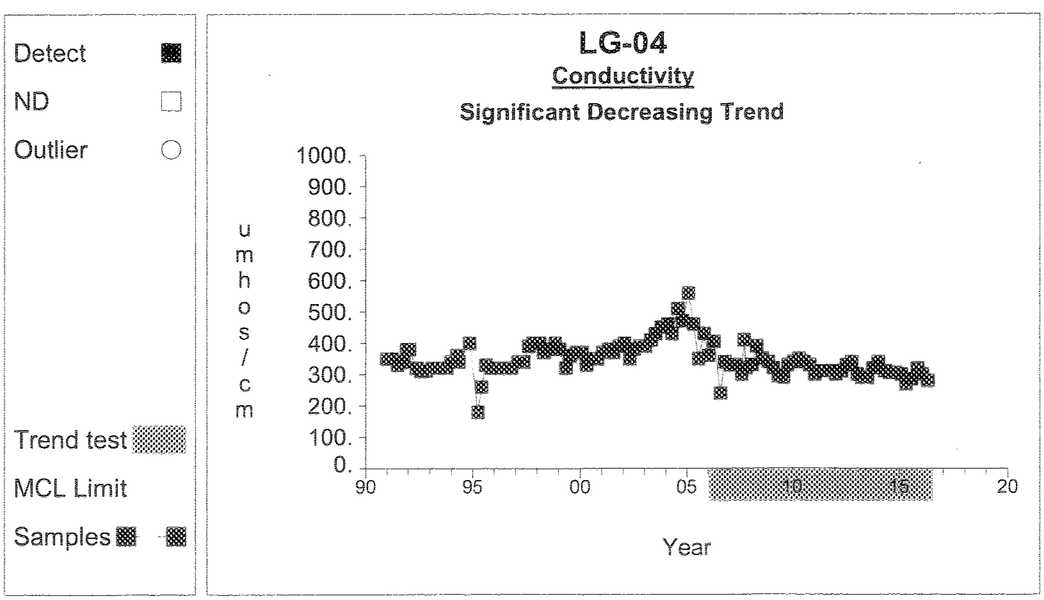
Analysis prepared on: 7/15/2016

Time Series



Graph 72

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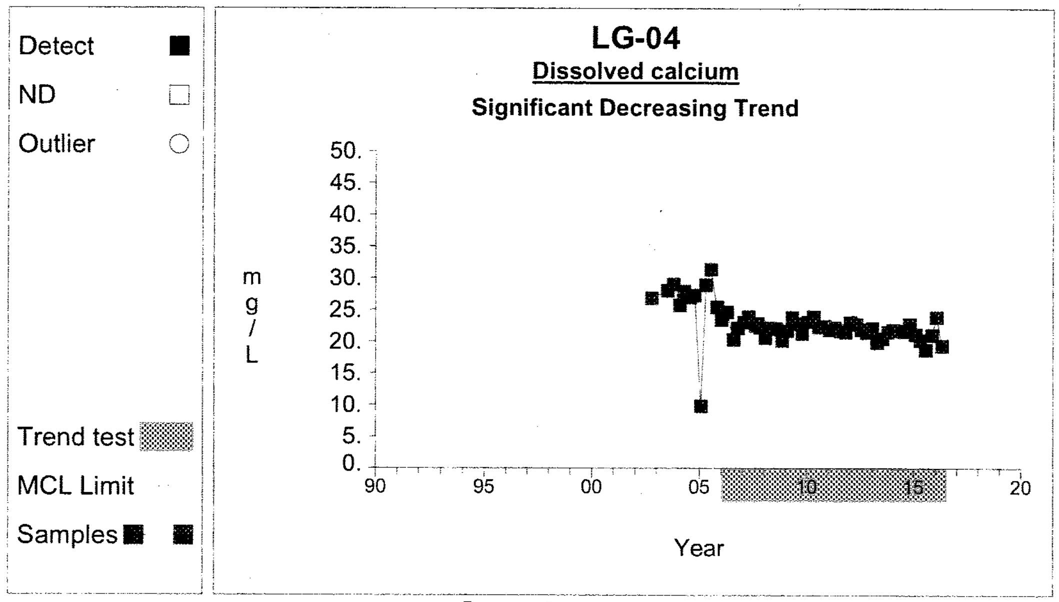
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 78

15

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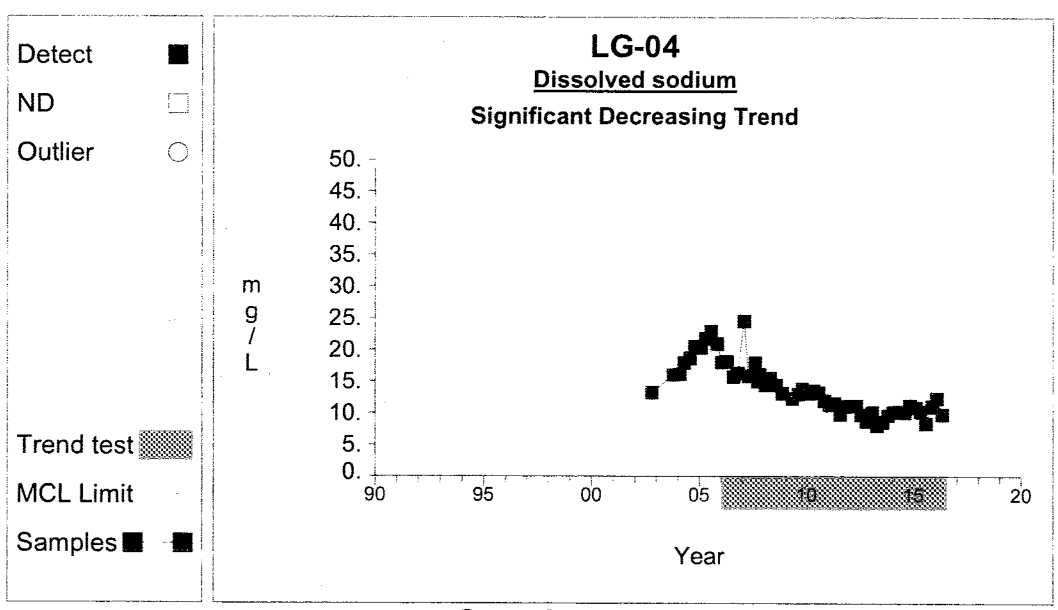
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 90

16

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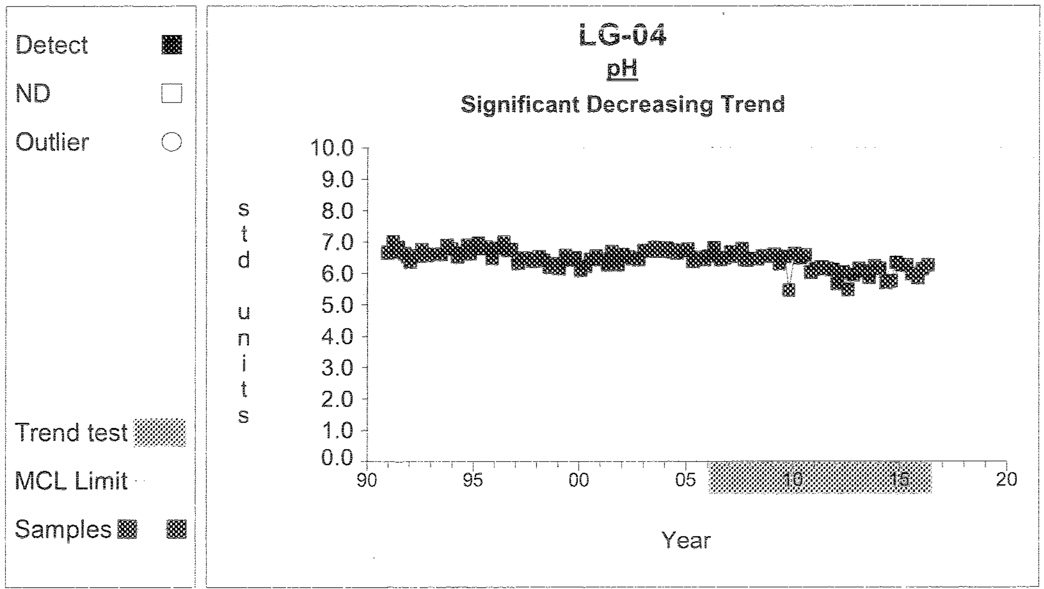
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 96

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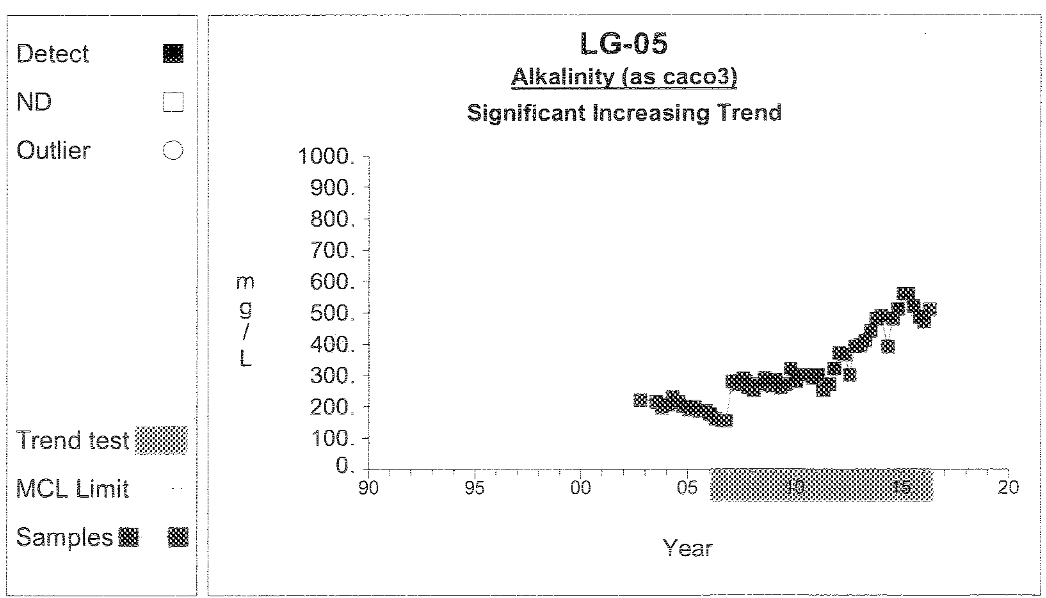
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 100

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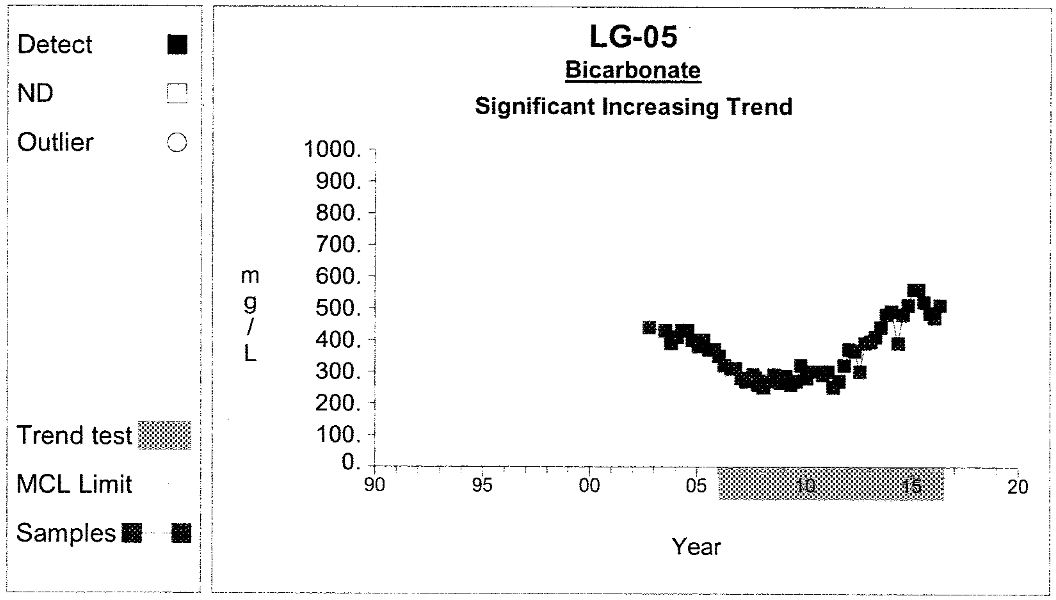
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 102

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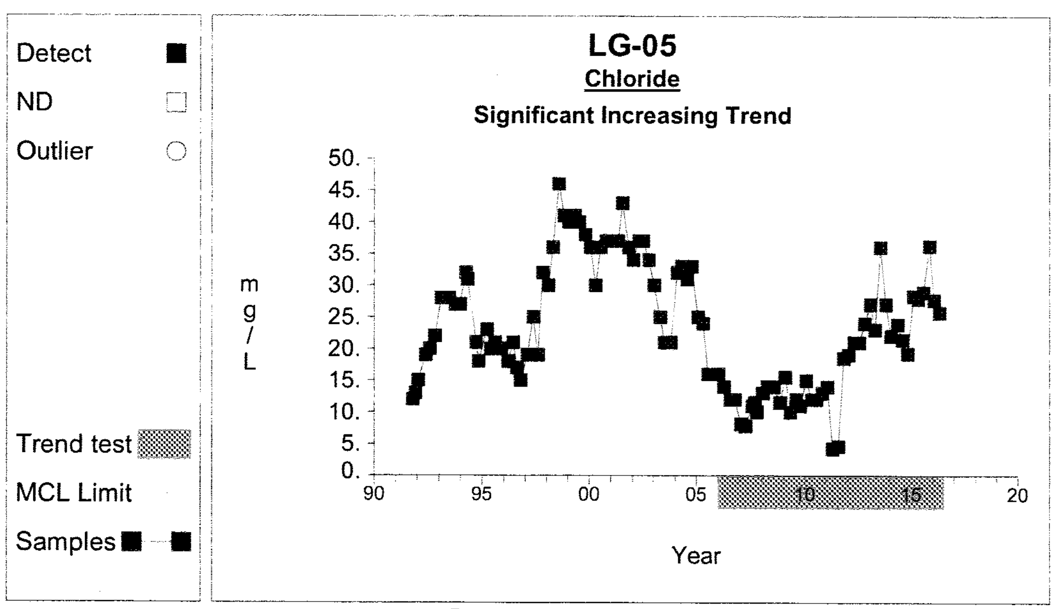
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 104

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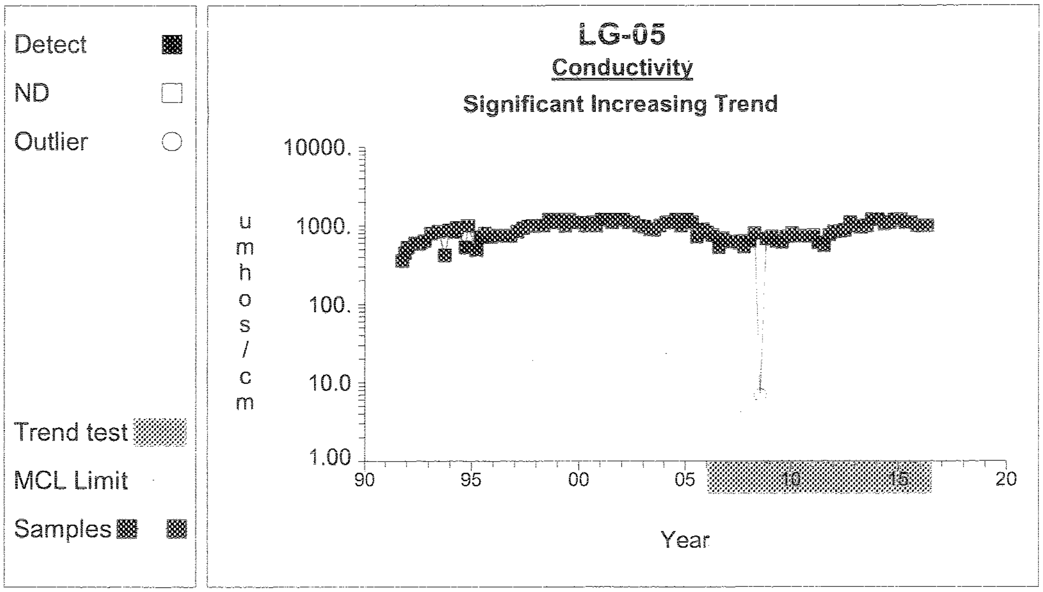
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 105

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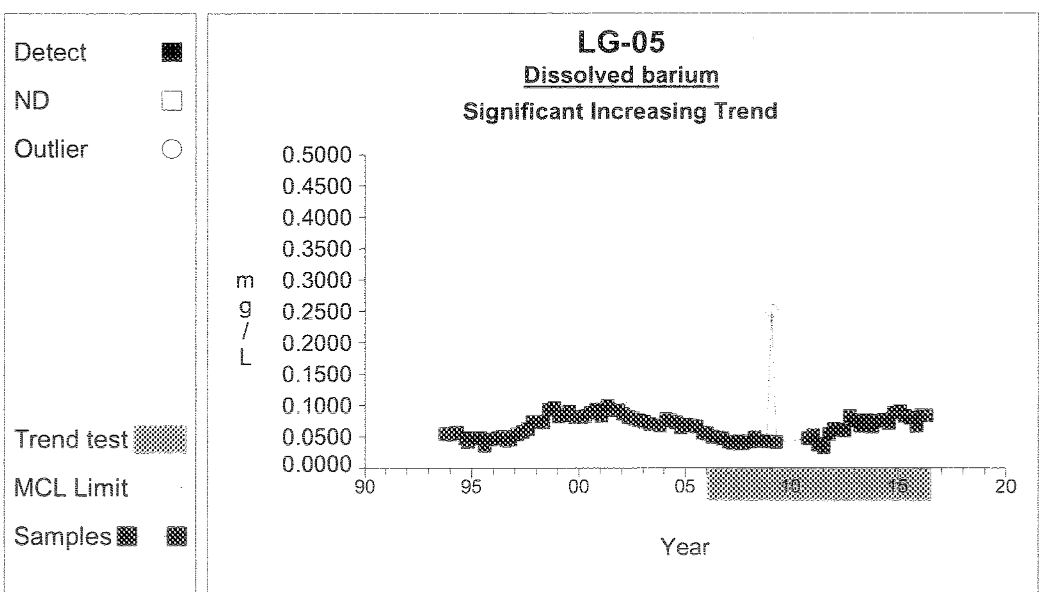
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 108

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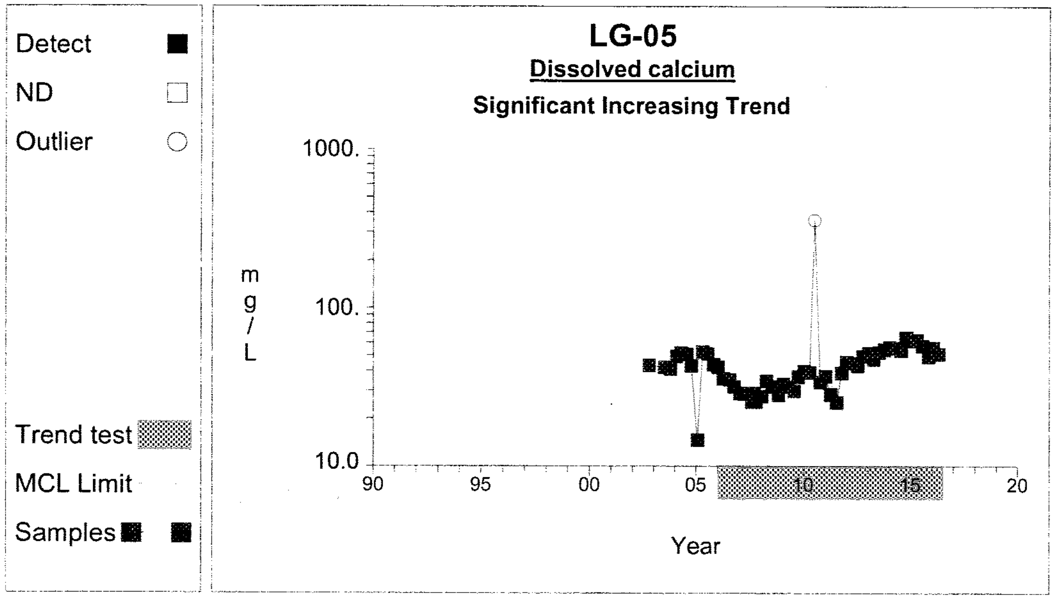
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series

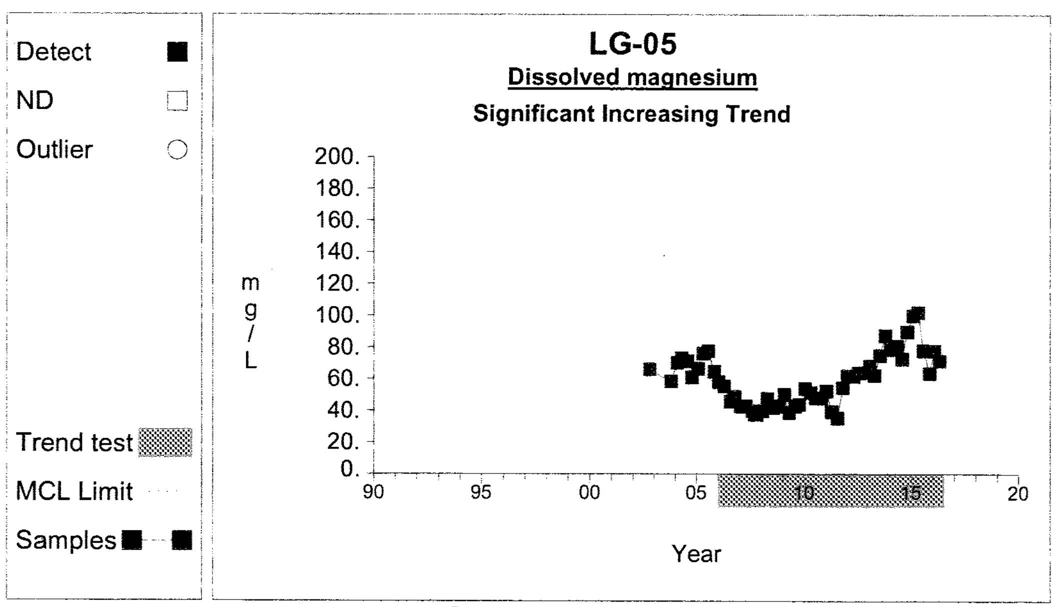


Graph 111

Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series

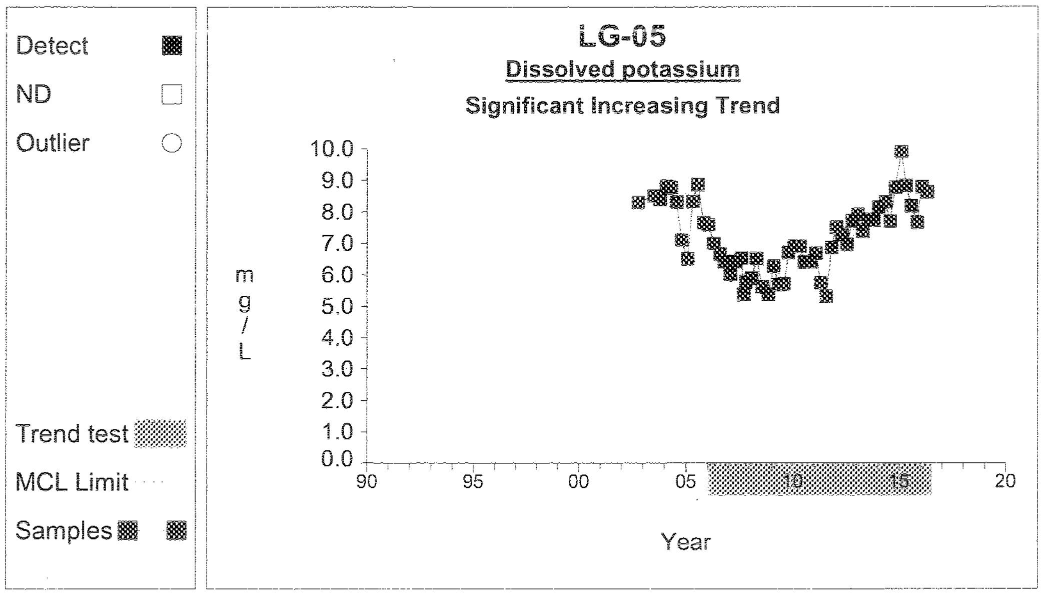


Graph 117

Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 120

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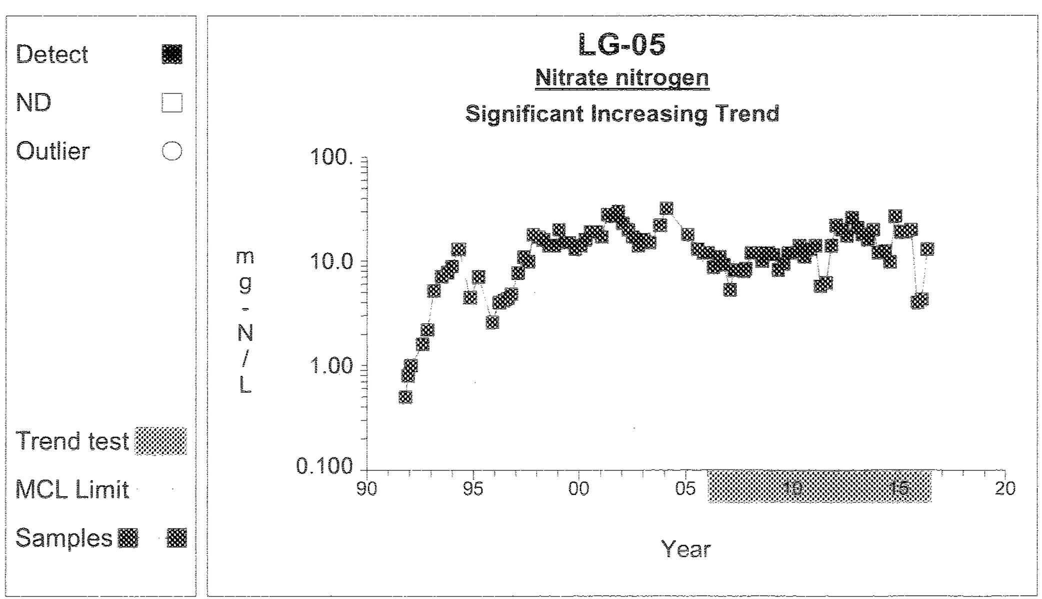
Goodwin Landfill

Analysis prepared on: 7/15/2016

Time Series



Graph 127

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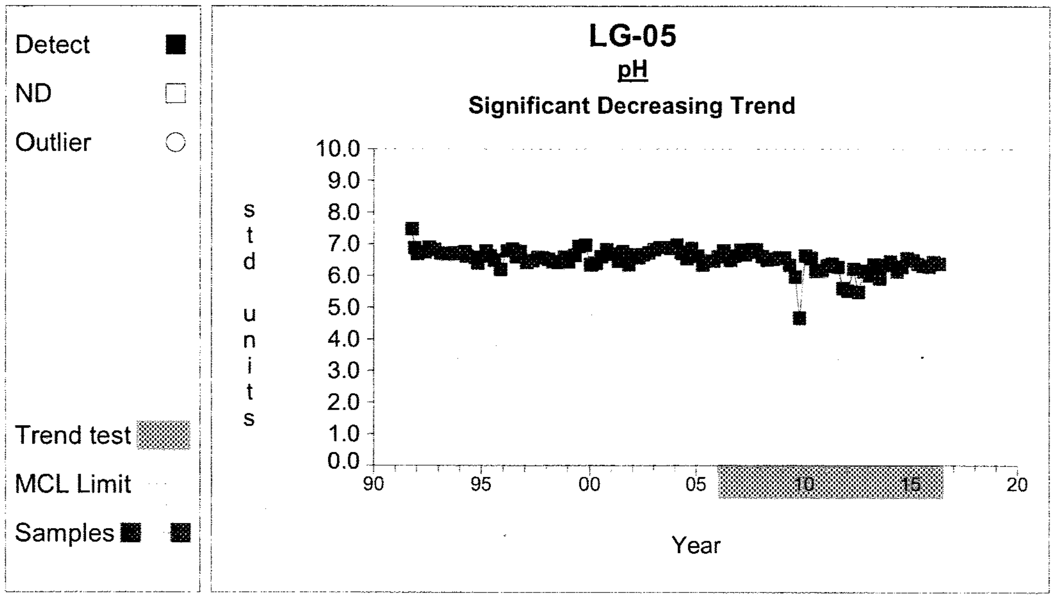
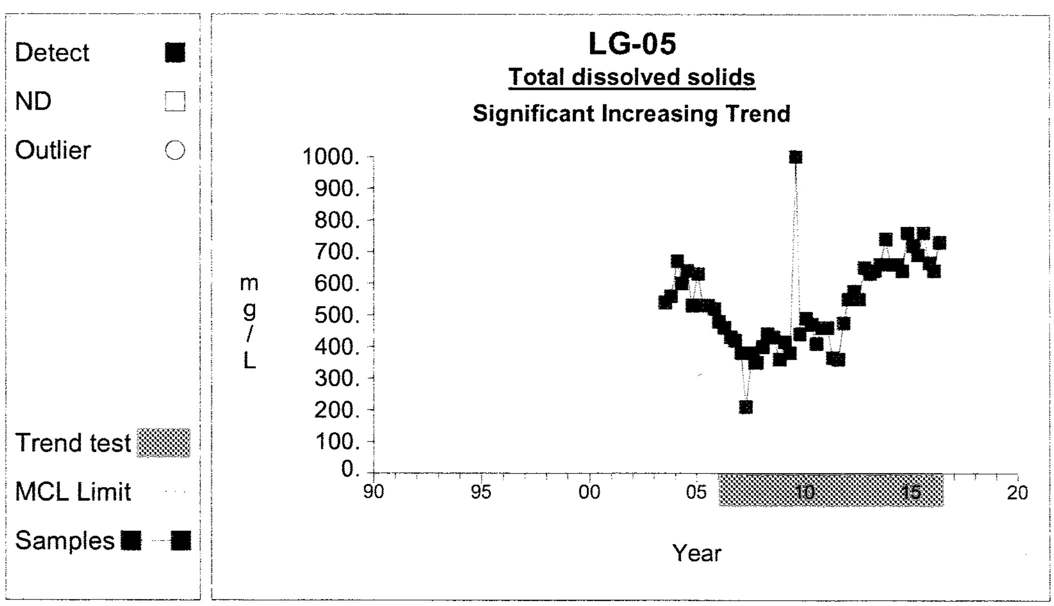
Time Series



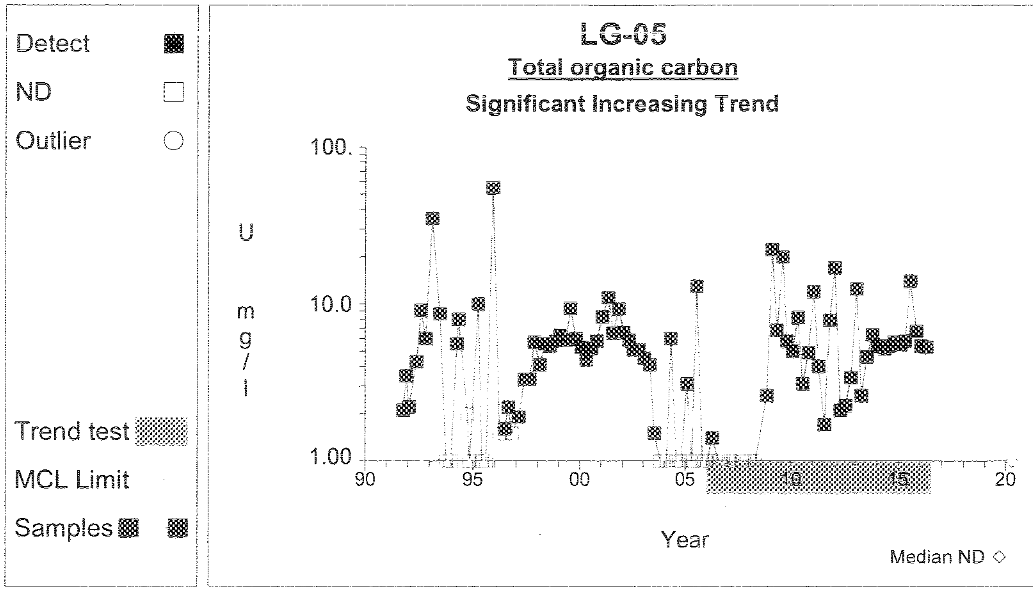
Graph 129

Time Series



Graph 131

Time Series



Graph 132