Lake Goodwin Landfill 2015 Annual Environmental Monitoring Report

Photo taken 8/1/08 J. Greninger

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1.0 INTRODUCTION

This report details the 2015 quarterly groundwater monitoring, monthly landfill gas monitoring and annual topographic survey results for the Lake Goodwin Landfill (*Lake Goodwin Landfill, Site*). The Site is located at 18520 Frank Waters Road in northwestern Snohomish County, approximately 1.5 miles northwest of Lake Goodwin and 5 miles south of the City 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*).

1.1 BACKGROUND

The Lake Goodwin Landfill was 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 the **Snohomish County 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 landfill gas collection systems. During 2015 the Lake Goodwin Landfill was permitted for post-closure monitoring by the **Snohomish Health District** (*SHD*) with a Solid Waste Facility Permit (*SW-085, 2015*). Monitoring results are reviewed by both the **SHD** and the **Department of Ecology (*DOE*)**.

1.2 PERMIT INFORMATION

Monitoring activities at the landfill during 2015 were governed by the Solid Waste Facility Permit SW-085 (*landfill permit, Snohomish Health District 2015*). 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 Lake Goodwin Landfill 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*. The Lake Goodwin Landfill has a current **Sampling & Analysis Plan** (*SAP,* *Snohomish County Public Works, 2013*) that was followed during all 2015 quarterly sampling events.

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 Lake Goodwin Landfill 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 Lake Goodwin Landfill is located on a topographic feature known as the Tulalip Plateau, a rolling upland area bounded by the Stillaguamish River to the north, 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 in the immediate vicinity of the Site - Lake Martha, Lake Howard and Lake Goodwin are all located within 1.5 miles of the Site. There are no named drainages, creeks or rivers located in the immediate vicinity of the Site. The Stillaguamish 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 ft. high. It has been graded and slopes gently to the north-northeast; the 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 GEOLOGY

The surficial geology of the Site area has been mapped by the USGS and is shown on the "Geologic Map of the Stanwood Quadrangle, Snohomish County, WA" by J.P. Minard, dated 1985. Surficial soil types mapped in the vicinity of the project Site are typical for glaciated landscapes throughout Snohomish County. As shown on the **Geologic Map** (*Figure 4*), Vashon Glacial Till (*Qvt*) and Vashon Advance Outwash (*Qva*) are the primary mapped surficial soil units in the immediate vicinity of the project Site.

The Glacial Till (*Qvt*) consists of a non-sorted mixture of silt, sand and gravel deposited as a lodgment till below the Vashon-aged glaciers as they advanced through this area. The deposits are generally very compact and where undisturbed will have a consistency similar to concrete. In this area, the Glacial Till (*Qvt*) is fairly sandy, with significant amounts of gravels and cobbles. Glacial Till (*Qvt*) is generally considered to be an aquiclude, not readily transmitting groundwater through it. Locally, groundwater may travel through and along discontinuous lenses of sand and gravel or through sandier portions of the Glacial Till (*Qvt*) within the upper few feet of the section. However, these discontinuous lenses of sand and gravel are difficult to characterize or quantify and are not considered to be reliable sources of groundwater.

The Advance Outwash (*Qva*) consists primarily of fine- to coarse-grained layers of sand and gravel deposited as the Vashon-aged glaciers advanced into this area. At depth, these deposits can contain significant amounts of silt and/or clay. There is a gradational contact with the underlying Transitional Beds (*Qtb*) found below this geologic unit, with the silt/clay beds becoming thicker and more predominant with depth. The Advance Outwash (*Qva*) sands and gravels are generally very compact, having been overridden by thousands of feet of glacial ice. Advance Outwash (*Qva*) sands and gravels contain significant amounts of groundwater and because of their relative shallow stratigraphic depth are the predominant source for groundwater throughout the County.

Glacial Till (*Qvt*) was encountered within one up-gradient test boring at the Site (*LG-02*). The Glacial Till (*Qvt*) was overlying basal Advance Outwash (*Qva*) sands and gravels at the LG-02 location. Glacial Till (*Qvt*) was not encountered at any of the other test boring locations across the site. These test borings (*LG-01, LG-03, LG-04 and LG-05*) encountered only the Advance Outwash (*Qva*) sands and gravels and were terminated in a gradational silt/clay zone at the base of the sands and gravels. This silt/clay layer has been interpreted as the top of the Transitional Beds (*Qtb*), a confining layer found below the Advance Outwash (*Qva*) throughout Snohomish County. Monitoring wells were installed at each of these test boring locations within the Advance Outwash (*Qva*) sands and gravels.

1.5 LOCAL HYDROGEOLOGY

Hydrogeologic conditions in the vicinity of the landfill have been studied by many including **EPA**, **USGS** and the **Army Corp of Engineers**. In the early to late 1980's, the **Seven Lakes Water Association** petitioned the **EPA** for consideration of a sole source aquifer area that included the landfill Site. This petition was made to protect their rapidly degrading groundwater quality, which was the only water source for the residences of the area at that time. The **EPA** consulted with the **USGS**, who, upon closer investigation, recommended that the boundaries of the proposed sole source aquifer be expanded to include a much larger area, which was named the **Tulalip Sole Source Aquifer**. The **USGS** expanded the boundaries of the Seven Lakes proposed sole source aquifer in order to protect the recharge source for a deeper aquifer found below the Tulalip Plateau and a larger area of Snohomish County. Recharge areas for this deep aquifer were determined to be located along the west margins of the Cascade Mountains. This deep aquifer is within pre-Glacial Undifferentiated Sands and Gravels (*Qu*) that are found stratigraphically lower than the Advance Outwash (*Qva*) aquifer. A thick sequence of Transitional Bed (*Qtb*) silts and clays act as an aquitard between the Advance Outwash (*Qva*) and Undifferentiated (*Qu*) aquifers. The petition for the **Tulalip Sole Source Aquifer** was eventually denied because other sources of water were available for domestic and commercial use over a large portion of the area.

Hydrogeologic conditions at the landfill were investigated by **Converse Consultants NW**. The results of their investigations were reported in their study titled "Hydrogeologic Study, Lake Goodwin Landfill" date July 1991. Subsequent Site explorations were completed by **Golder Associates** and were documented in their report titled "Snohomish County Lake Goodwin Landfill" dated December 1991.

Beneath the Tulalip Plateau (*a topographic feature upon on which the Site is situated*), the most productive aquifer 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 Lake Goodwin Landfill where Glacial Till (*Qvt*) is absent, groundwater 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 Site investigations. Groundwater elevations below the landfill range from 148 to 153 feet above mean sea level (*MSL*) with a north to northwest gradient within the unconfined Advance Outwash (*Qva*) aquifer. Estimated hydraulic conductivity of the Advance Outwash (*Qva*) aquifer is 50 to 200 ft/day (*E&E Services, Inc, 1991*). At the observed elevations, groundwater could be projected to discharge to the surface out of the exposed slopes above Puget Sound, north of Warm Beach or along the Stillaguamish River just south of Stanwood.

1.6 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-(*3*) bar hole punches.

There are currently four-(*4*) 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, one-(*1*) well (*designated LG-02*) characterizes upgradient background groundwater conditions in the immediate vicinity of the Site. The remaining three-(*3*) wells that are currently monitored per the SAP are located within and/or downgradient of the landfill (*LG-01, LG-04, and LG-05*) and monitor groundwater 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 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*). This survey was performed on a monthly basis through 2015. The results of 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. New topographic survey data was 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*". The **Annual Settlement Monitoring Program** is discussed in detail in *Section 4.0* of the report.

2.0 GROUNDWATER MONITORING

Quarterly monitoring of the groundwater wells at the Lake Goodwin Landfill was performed by **Snohomish County** personnel during 2015. During each monitoring event, the depths to water were measured and groundwater samples were collected following approved sampling protocols. The following sections describe field procedures used and analytical results derived from the sampling events. In addition, this report details groundwater data, figures, statistical summaries and charts from the first through fourth quarters of 2015. Details regarding the first and second quarter 2015 groundwater monitoring events are included in the **Environmental Monitoring Reports** that were submitted for those quarters.

2.1 GROUNDWATER LEVEL MEASUREMENTS

The depth to groundwater within each well was measured using an electronic water level indicator prior to groundwater sampling. Groundwater level measurements were recorded to the nearest 0.01 foot relative to a marked survey point on the top of each well casing.

Quarterly Groundwater Measurements are shown in *Table 1* below, and quarterly groundwater contour maps for the 2015 monitoring events are included as Figures 6a through 6d respectively. The general correlation between rainfall total trends and groundwater level fluctuations (*see hydrographs in Appendix A*) indicates that the aquifer is unconfined in the immediate vicinity of the Site.

The measured quarterly precipitation totals at the Stanwood Weather Station (*WA-SN-11, www.CoCoRaHS.org*) during the year were 11.25 inches (*first quarter*), 3.25 inches (*second quarter*), 4.60 inches (*third quarter*) and 19.69 inches (*fourth quarter*) for a total measured 2015 precipitation of 38.79 inches of rain. This is only 0.04 inches less measured precipitation than during 2014. The average yearly rainfall for the previous five years (*2010 thru 2014*) was 35.57 inches/year at this weather station.

Table 1 - Annual Groundwater Measurements and Elevations

Well Number	Casing Elevation	First Quarter Elevation	Second Quarter Elevation	Third Quarter Elevation	Fourth Quarter Elevation	Annual Trend*
LG-01	239.18	154.01	152.37	152.54	DRY	-2.11**
LG-02	268.67	152.38	153.86	153.58	153.28	0.65
LG-04	206.93	150.52	151.06	151.22	150.09	-0.88
LG-05	235.00	152.03	151.61	151.67	150.45	-1.30

* As measured from fourth quarter 2014 to fourth quarter 2015

** As measured from third quarter 2014 to third quarter 2015 due to dry well during the 4Q15 event

2.2 ANNUAL GROUNDWATER SAMPLING RESULTS

With the exception of well LG-01, which was dry during the fourth quarter event, purging and sampling of all four monitoring wells was performed during each quarterly event by Snohomish County personnel in accordance with the facilities closure permit and 2013 SAP. Groundwater samples were collected by slowly filling laboratory supplied containers in such a manner as to reduce aeration. Sample containers were filled so that no headspace remained within the container. Samples were placed in coolers and packed on ice to keep samples at approximately 4°C for delivery to the analytical laboratory. Samples were picked up by **Am Test, Inc.** and taken to their Kirkland, Washington laboratory for analysis of dissolved metals, volatile organic compounds (*VOCs*), and conventional chemistry parameters. The quarterly analytical data were compared to the groundwater standards. A complete statistical analysis of each quarterly data set was also performed utilizing **DUMPstat Software** (*version 2.1.9 by Robert D. Gibbons Ltd, 2000*). Sens Trend analyses were performed for the entire data set stretching back to 1988 and the results of these trend analyses are discussed below.

2.3 EVALUATION OF QUARTERLY GROUNDWATER ANALYTICAL RESULTS

Quarterly groundwater standard exceedances for each well are summarized as follows and in *Table 2* below.

Inorganics: Multiple exceedances to the groundwater standards during 2015 were observed in downgradient well LG-05, as shown on Table 2 above. The inorganic constituent exceedances in well LG-05 were generally consistent throughout the year, with the exception of nitrate, which decreased to below the groundwater standard of 6 mg/L during the fourth quarter 2015. As shown on the **Quarterly Groundwater Contour Map,** observation well LG-05 is located directly downgradient from the landfill.

Metals: Other than arsenic and sodium, there were no measured exceedances of dissolved metals during the 2015 sampling events at the Site. Arsenic levels were compared to the "Implementation Guidance for the Groundwater Quality Standards", and although the arsenic levels observed were not statistically anomalous, exceedances were noted when compared to the groundwater standards.

Table 2 - Summary of Groundwater Standard Exceedances

Well	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
LG-01	Arsenic	Arsenic, pH	Arsenic, pH	No sample
LG-02	Arsenic	Arsenic	Arsenic	Arsenic
LG-04	Arsenic, pH	Arsenic, pH	Arsenic, pH	Arsenic, pH
LG-05	Conductivity, nitrate nitrogen, pH, sodium, TDS, arsenic	Conductivity, nitrate nitrogen, pH, sodium, TDS, arsenic	Conductivity, nitrate nitrogen, pH, sodium, TDS, arsenic	Conductivity, pH, sodium, TDS, arsenic

2.4 STATISTICAL EVALUATION

The state health regulations under which the Lake Goodwin Landfill 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 state regulations is to limit the impact that a landfill will have on the surrounding groundwater resources. Groundwater samples are tested for primary and secondary drinking water standards constituents and selected dissolved metals, and the results 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 the 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 by **DUMPStat**. Printouts and tabulated statistical data for the first and second quarter were included in the respective environmental monitoring reports for those quarters. Statistical data tables and printouts for the third and fourth quarter 2015 monitoring events are included in Appendices B and C.

The quarterly trend analyses have been performed utilizing data sets from 2006 through 2015, allowing us to place multiple constituents on a single graph to better see potential correlations (*Appendix C*).

Per **DOE** and **Snohomish Health District** request, the prediction limit is updated in the first quarter of the year. Subsequent data sets are then compared against that prediction limit, which may or may not be lower than the groundwater standard. **Quarterly Statistical Summary Exceedances** are shown in *Table 3* below.

Table 3 – Quarterly Statistical Summary Exceedances for 2015

Well	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
LG-01	Alkalinity, bicarbonate, conductivity, magnesium, potassium, sulfate, barium	Alkalinity, bicarbonate, conductivity, magnesium, potassium, sulfate, barium	Bicarbonate, magnesium	No sample
LG-02	None	None	None	None
LG-04	pH, barium	pH, TOC	Chloride, pH, nickel	Chloride, pH
LG-05	Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrate, nitrite, potassium, sodium, sulfate, TDS, barium	Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrate, nitrite, potassium, sodium, sulfate, TDS, barium, iron,nickel	Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrate, nitrite, potassium, sodium, sulfate, TDS, barium, iron, nickel	Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrate, nitrite, potassium, sodium, sulfate, TDS, barium, iron,nickel

Statistical analysis indicates no statistical prediction limit concentration exceedances in upgradient well LG-02.

Increasing trends during the year included:

Downgradient Wells

- Well LG-01: Alkalinity, calcium, chloride, conductivity, magnesium, TDS, barium
- Well LG-04: Chloride
- Well LG-05: Alkalinity, bicarbonate, calcium, chloride, conductivity, magnesium, nitrate, TDS, potassium, TOC, barium

Upgradient Well

- LG-02: Alkalinity

Statistically-significant concentration trends were noted in all wells during 2015. Graphs showing these concentration trends over the last 10 years are included in Appendix C. Metals and inorganic constituent concentrations (*with the exception of chloride and TDS*) that exhibited significant trends generally decreased in well LG-01 in 2015. Bicarbonate and metals concentrations in well LG-04 that exhibited significant statistical trends generally decreased from the first to third quarters, then increased during the fourth quarter, while other inorganic constituents in that well (*chloride, conductivity, pH, and sulfate*) either remained generally stable or increased during the year. With the exception of chloride and TOC, concentrations of metals and inorganic constituents within downgradient well LG-05 generally decreased over the course of the year. Based on the groundwater statistical analyses for 2015, downgradient groundwater quality continues to be impacted by the landfill. Overall, concentration trends do not appear to correlate to precipitation trends.

Table 4 – Significant Trend Summary 2015

Well	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
LG-01	9-I, 2-D	10-I, 1-D	7-I, 2-D	No Sample
LG-02	2-I, 1-D	2-I, 1-D	1-I, 1-D	1-I, 1-D
LG-04	1-I, 7-D	1-I, 7-I	1-I, 5-D	1-I, 9-D
LG-05	6-I, 2-D	6-I, 2-D	11-I, 2-D	11-I, 1-D
Totals	18-I, 12-D	19-I, 11-D	20-I, 10-D	13-I, 11-D

I = increasing trend, D = decreasing trend

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 5* below.

Table 5 – 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 has been 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 LANDFILL GAS MONITORING PROCEDURES

Sampling of the three gas probes with a portable gas detector was initiated during the last quarter of 2011. These meters are designed to measure small concentrations of methane gas escaping through the probe monitoring ports. Methane concentrations are measured in parts per million (*ppm*) and recorded by field personnel. Twelve months of data were collected from the gas probes in 2015. The **Landfill Gas Monitoring Results** are included in *Table 6* below.

Table 6 – 2015 Landfill Gas Monitoring Results

Probe	Date	% Methane	Oxygen	CO2	Barometer
LG-A1	1/6/15	16	1	19	29.79
	2/8/15	13	0	17	29.05
	3/4/15	14	3	15	29.84
	4/23/15	14	0	18	29.32
	5/7/15	14	0	18	29.71
	6/18/15	14	0	20	29.64
	7/30/15	13	0	23	29.71
	8/7/15	15	0	23	29.59
	9/8/15	14	0	23	29.77
	10/20/15	17	0	22	29.93
	11/6/15	19	0	23	29.84
	12/31/15	15	0	16	30.18
LG-B2	1/6/15	28	0	12	29.79
	2/8/15	25	0	11	29.05
	3/4/15	30	0	12	29.84
LG-B2	4/23/15	28	0	13	29.32
	5/7/15	28	0	13	29.71
	6/18/15	22	0	15	29.64
	7/30/15	17	0	17	29.71
	8/7/15	17	0	17	29.59
	9/8/15	19	0	18	29.77
	10/20/15	13	0	16	29.93
	11/6/15	25	0	16	29.84
	12/31/15	28	0	11	30.18
LG-C2	1/6/15	19	0	13	29.79
	2/8/15	20	0	13	29.05
	3/4/15	20	2	12	29.84
	4/23/15	24	0	14	29.32
	5/7/15	24	0	14	29.71
	6/18/15	18	0	16	29.64
	7/30/15	8	0	17	29.71
	8/7/15	17	0	19	29.59
	9/8/15	14	0	20	29.77
	10/20/15	21	0	19	29.93
	11/6/15	20	0	18	29.84
	12/31/15	11	0	12	30.18

Methane gas levels measured during 2015 at the Lake Goodwin Landfill were consistent with those expected to be found in a 30+ year old landfill and are significantly less than those found in an active landfill environment.

4.0 SETTLEMENT MONITORING

Annual settlement monitoring was initiated by Snohomish County Solid Waste personnel in 2011 in order to establish landfill biomass stability for custodial care planning. In 2013, a County survey crew installed a permanent 100 foot grid over the top of the biomass, which will allow for compliance with the new Department of Ecology Guidance document.

4.1 SETTLEMENT MONITORING REQUIREMENTS

In order to comply with post closure requirements, cover surface slopes must remain between 2 and 5 percent grade, side slopes must remain below 33 percent slope and localized settlements must not impair cover drainage or cover integrity. Existing biomass stability will be determined based on these annual surveys.

4.2 SETTLEMENT MONITORING PROCEDURES

Settlement monitoring is performed on an annual basis by taking direct measurements through topographic surveys and comparing them to existing and previous topographic surveys. Survey crews perform a field survey of the side slopes, grade breaks and additional points necessary to prepare a topographic contour map with maximum 2-foot contours.

Topographic survey data is compared to previous and/or existing data for any changes, which includes historic topographic surveys. Existing surface slope grades are also analyzed. Areas exceeding the maximum percent slope grades given in *Section 4.1* above are shown on an annual contour topographic map of the Site.

The most recent Lake Goodwin Landfill survey was completed by the *Snohomish County Public Works Survey Group* in August 2015. Current survey results are shown on the **Vertical Movement Study of Monitoring Points**, *Figure 7* of this report. Survey results for 2015 indicate small amounts of settlement across the landfill mass that are within tolerance levels established in the Department of Ecology's Uniform Guidance document.

5.0 SUMMARY AND CONCLUSIONS/RECOMMENDATIONS

5.1 SUMMARY

The groundwater, methane gas and settlement data collected during the 2015 quarterly sampling events indicates the following:

- Overall groundwater elevation trends at each well indicate rising groundwater levels, which is a continuing trend that has been documented since 2005 (*Appendix A*). During 2015, groundwater elevations decreased in three downgradient wells (*LG-01, LG-04, and LG-05*) by 0.88 foot to 2.11 feet when compared to the previous year; the groundwater elevation in upgradient well LG-02 increased by 0.65 foot when compared to the previous year.
- Other than arsenic and sodium, there were no measured exceedances to the dissolved metals groundwater standards during the 2015 sampling events at the Lake Goodwin Landfill.
- Arsenic and pH were reoccurring exceedances to the groundwater standards in both upgradient and downgradient wells during 2015. Chloride, conductivity, magnesium, nitrate, and nitrite concentrations observed at well LG-05 were an order of magnitude higher than at the other three sampled wells.
- Statistical analysis indicated that significant impacts were present in the groundwater samples collected from well LG-05. Lesser impacts were indicated in wells LG-01 and LG-04. Time series plots based on the **DUMPStat** analysis indicates that there were more significant increasing trends (*13 to 20 per quarter*) than decreasing trends (*10 to 12 per quarter*) in 2015. The increasing trends were noted in LG-01 and LG-05 during the current monitoring year and consisted primarily of increases to inorganic constituents.
- Significant trends in metals (*barium, magnesium, potassium, sodium, nickel, and iron*) were also noted in wells LG-01, LG-04, and LG-05 during 2015.
- Due to the natural background levels of arsenic in the groundwater around the Lake Goodwin Landfill, it is difficult to determine the source of arsenic impacts to the groundwater. However, none of the arsenic detections during the 2015 monitoring events exceeded the statistical prediction limit for arsenic.
- The bar hole methane readings are within acceptable levels for the age of the Lake Goodwin Landfill. A trend analysis will be completed when enough data has been compiled to make a meaningful comparison.
- Annual settlement readings of the landfill cap were initiated during 2011. Initial readings indicate an overall stable landfill mass and cap. Measured settlements within

instrument tolerances with the highest observed delta of 0.04 foot between 2014 and 2015. This delta, measured at point 1602, may indicate a small amount of localized cap settlement during 2015.

5.2 CONCLUSIONS/RECOMMENDATIONS

Settlement surveys and landfill gas monitoring suggests that the landfill mass has stabilized. The 2015 data indicates a continued moderate leachate impact to the underlying Advance Outwash (*Qva*) aquifer below the Lake Goodwin Landfill. The monitoring data indicates that a leachate impacted groundwater plume extends beyond the landfill boundaries in the direction of groundwater flow to the north-northeast.

We recommend that monitoring of the Lake Goodwin Landfill continue through 2016 per the current approved SAP.

5.3 SIGNATURES

6/22/16
Date

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Date

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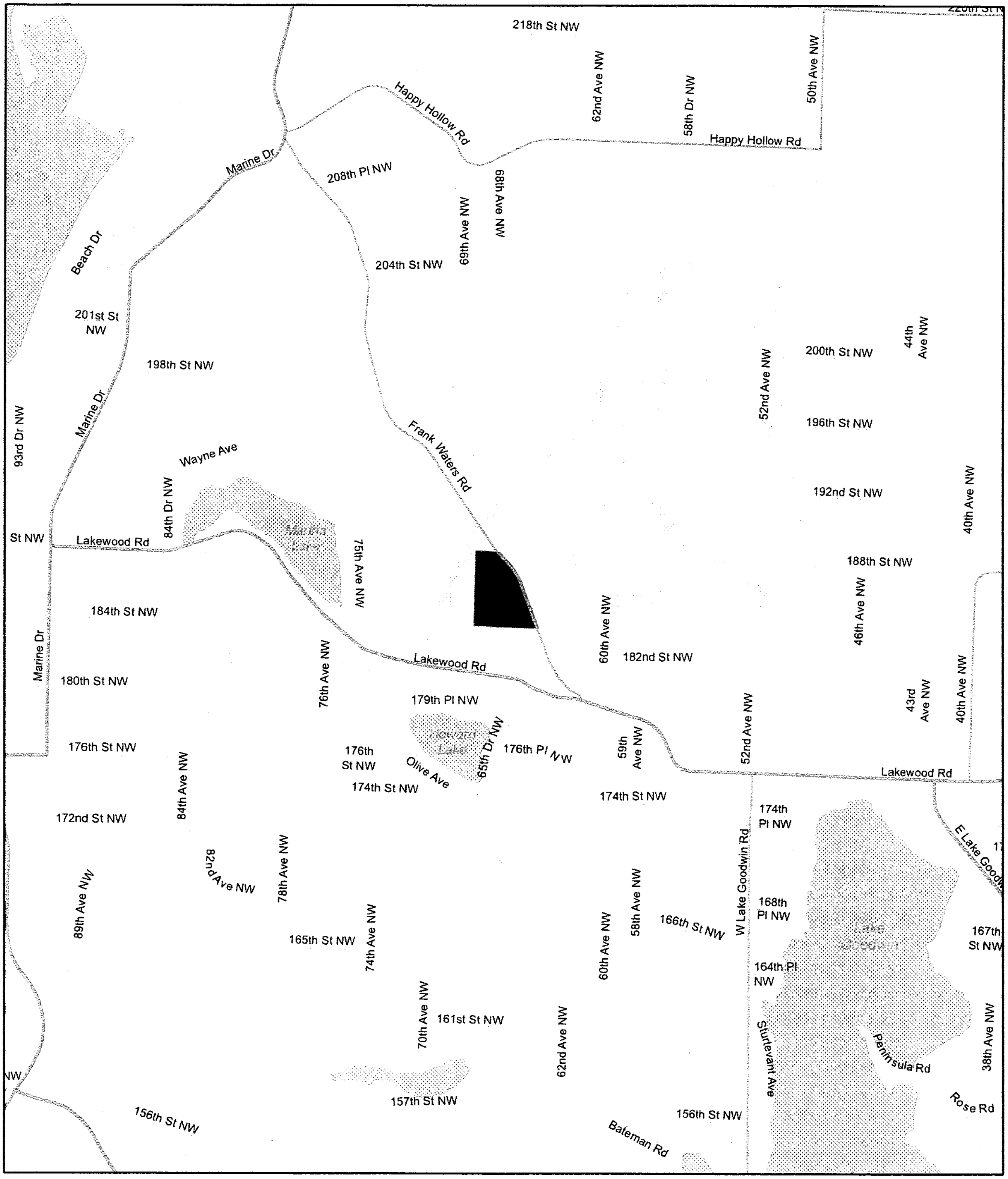
3133
Licensed Geologist
BRIAN K. EYTCHESON

Figure 1

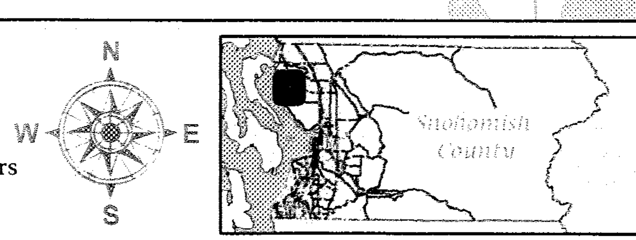
Lake Goodwin Landfill



1 inch = 0.5 miles

0 0.15 0.3 0.6 0.9 Miles

0 0.25 0.5 1 1.5 Kilometers



Snohomish County
Public Works
Solid Waste Division
March 22, 2010

Figure 2

Lake Goodwin Landfill Site Map

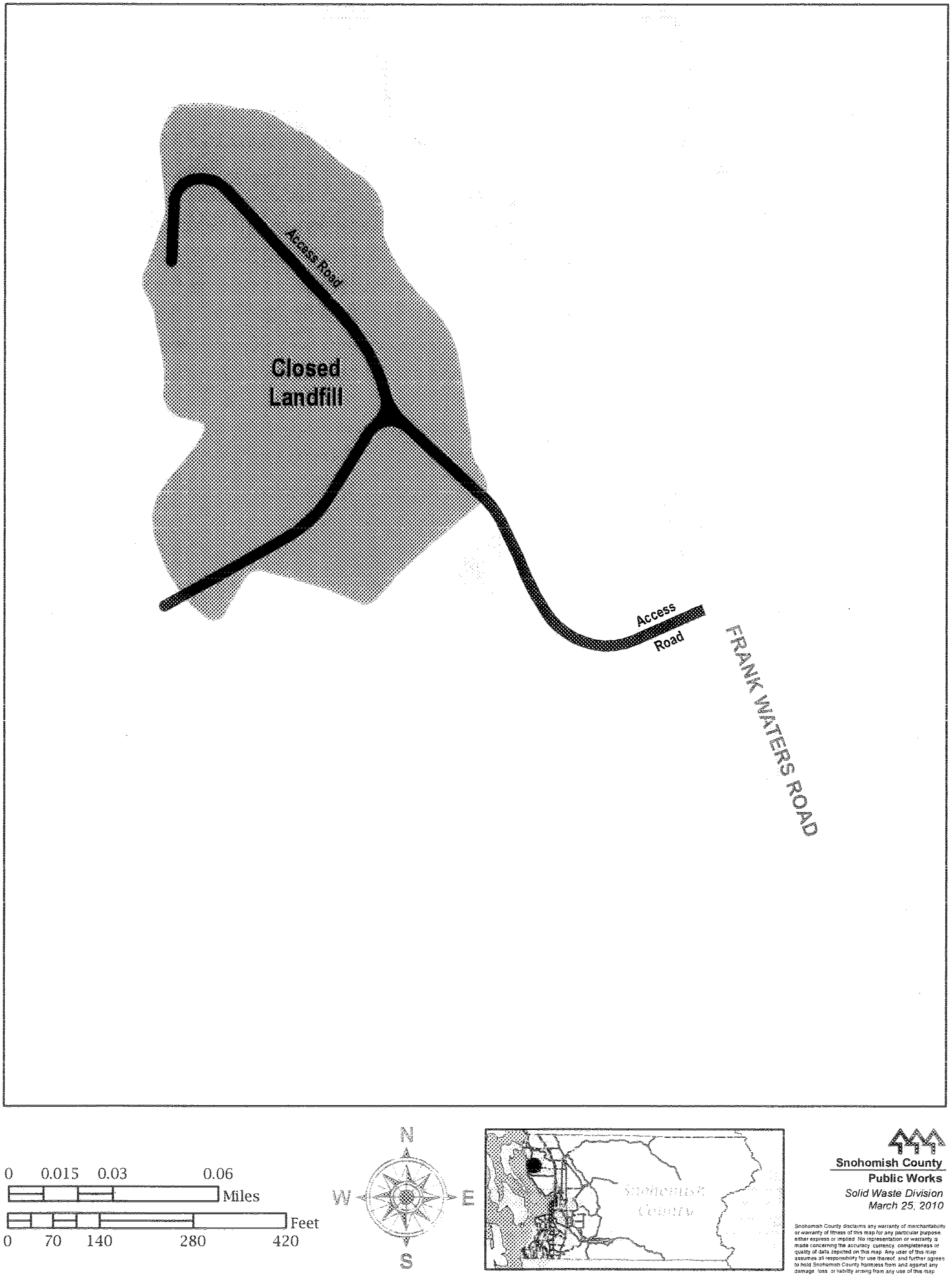


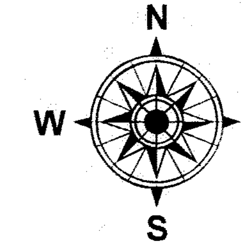
Figure 3

Lake Goodwin Landfill

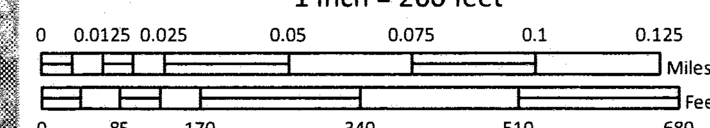
Topography

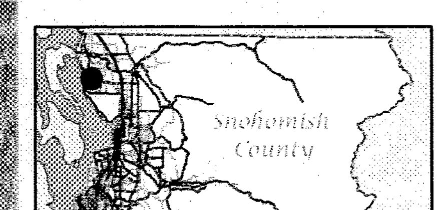
Map Features

- Parcel Boundary
- Subject Property Boundary
- 5 Foot Contours



1 inch = 200 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

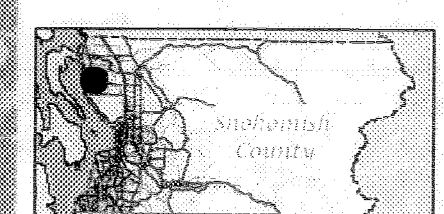
Geologic Description

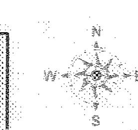
- Vashon advance outwash (Qva)
- Vashon recessional outwash
- Vashon till (Qvt)
- Water
- Modified Land

1 inch = 600 feet

0 0.035 0.07 0.14 0.21 0.28 0.35 Miles

0 240 480 960 1,440 1,920 Feet





Snohomish County
Public Works
Solid Waste Division
May 6, 2010

Figure 5

Lake Goodwin Landfill

Monitoring Network

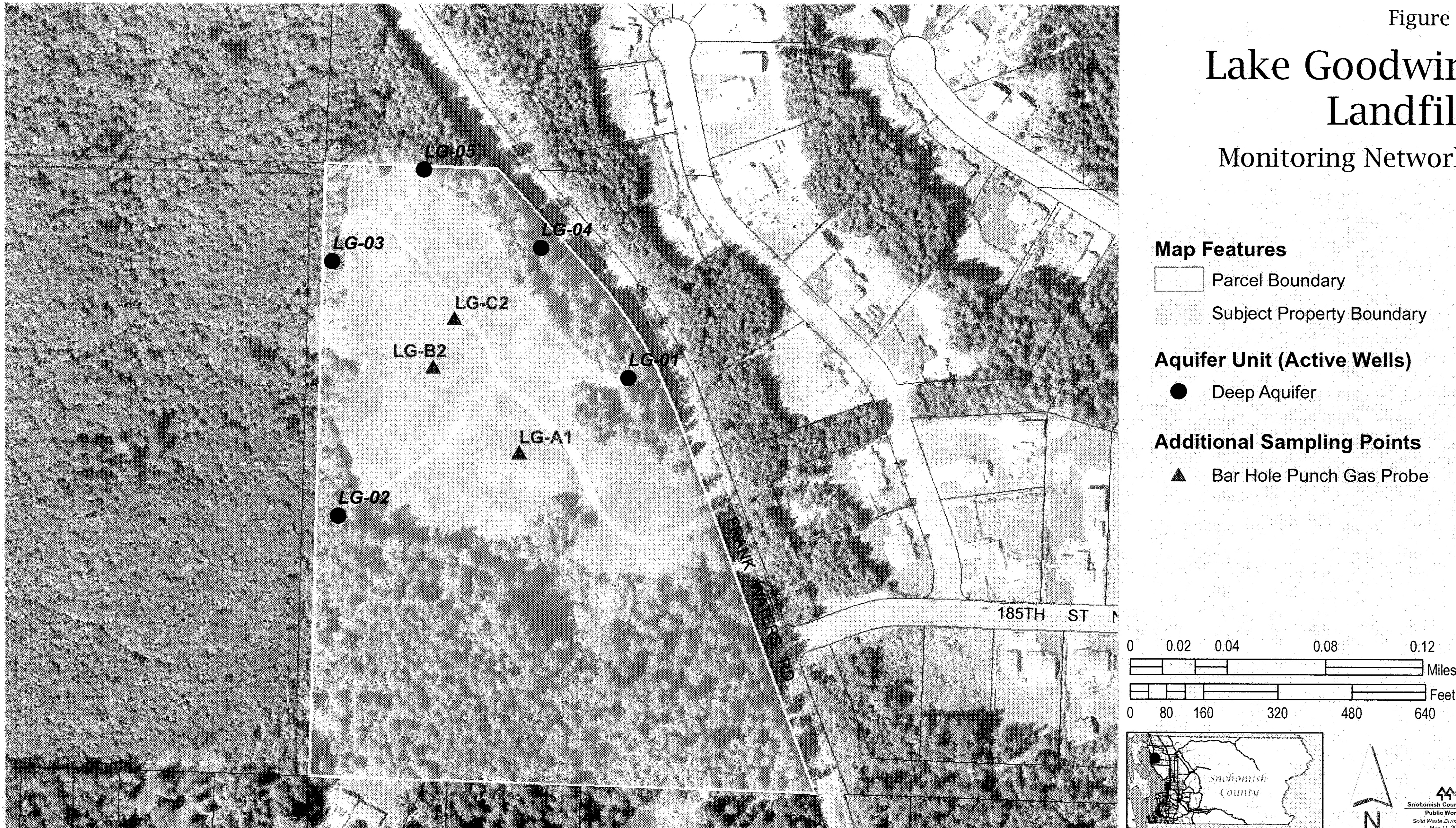


Figure 6a

Lake Goodwin Landfill

Water Elevation First Quarter 2015

DIRECTION OF GROUNDWATER FLOW
1.36 ft / day
497 ft / year
123.83 degrees to the positive x - axis

PARCEL BOUNDARY

SUBJECT PROPERTY BOUNDARY

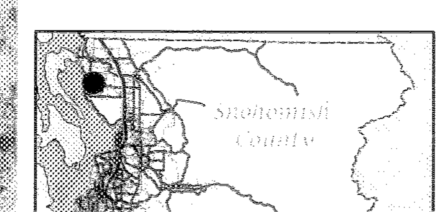
1 FT CONTOUR

WELL LOCATION

WELL_ID	SAMP_DATE	MEAS_HEAD
LG-01	1/28/2015	154.01
LG-02	1/28/2015	152.70
LG-04	1/28/2015	150.52
LG-05	1/28/2015	152.03

0 85 170 340 510 680 Feet

0 0.02 0.04 0.08 0.12 Miles



N

Snohomish County Public Works
Solid Waste Division
March 16, 2015

Figure 6b

Lake Goodwin Landfill

Water Elevation Contours
Second Quarter 2015

DIRECTION OF GROUNDWATER FLOW
1.59 ft / day
581 ft / year
63.22 degrees to the positive x - axis

PARCEL BOUNDARY

SUBJECT PROPERTY BOUNDARY

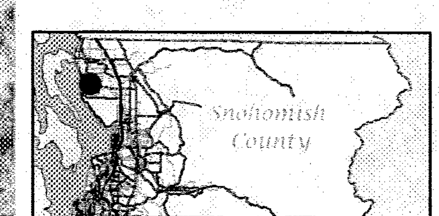
1 FT CONTOUR

WELL LOCATION

WELL_ID	SAMP_DATE	MEAS_HEAD
LG-01	4/15/2015	152.37
LG-02	4/15/2015	154.18
LG-04	4/15/2015	151.06
LG-05	4/15/2015	151.61

0 85 170 340 510 680 Feet

0 0.02 0.04 0.08 0.12 Miles



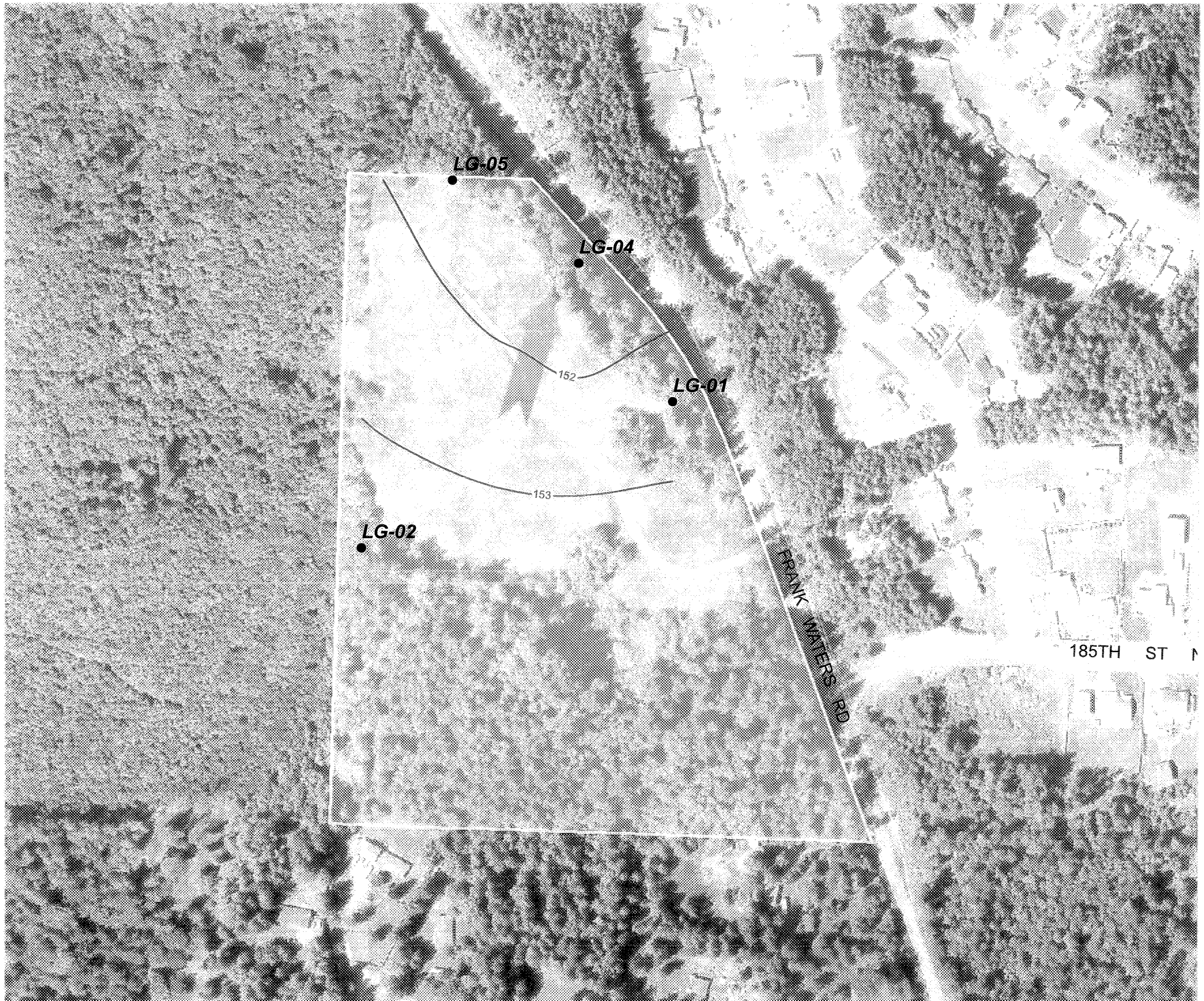
N

Snohomish County
Public Works
Solid Waste Division
June 15, 2015

Figure 6c

Lake Goodwin Landfill

Water Elevation Contours Third Quarter 2015



DIRECTION OF GROUNDWATER FLOW
1.20 ft / day
438 ft / year
73.61 degrees to the positive x - axis

PARCEL BOUNDARY

SUBJECT PROPERTY BOUNDARY

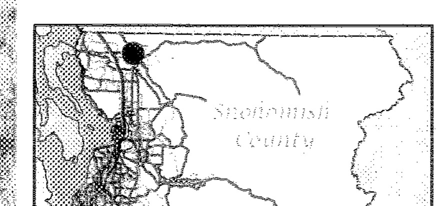
1 FT CONTOUR

WELL LOCATION

WELL_ID	SAMP_DATE	MEAS_HEAD
LG-01	7/15/2015	152.54
LG-02	7/15/2015	153.58
LG-04	7/15/2015	151.22
LG-05	7/15/2015	151.67

0 85 170 340 510 680 Feet

0 0.02 0.04 0.08 0.12 Miles



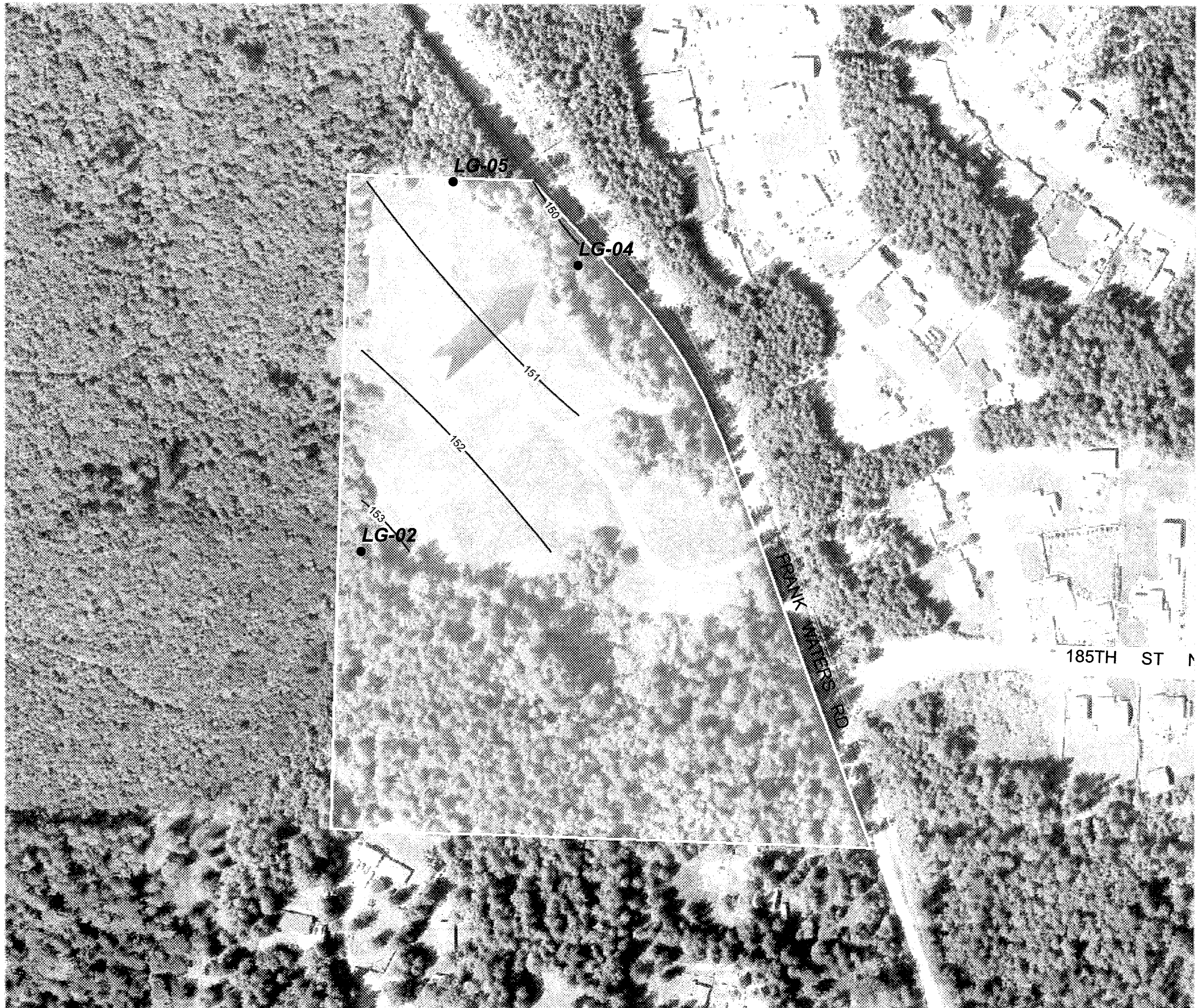
N

Snohomish County Public Works
Solid Waste Division
May 5, 2016

Figure 6d

Lake Goodwin Landfill

Water Elevation Contours Fourth Quarter 2015



DIRECTION OF GROUNDWATER FLOW
1.87 ft / day
684 ft / year
41.07 degrees to the positive x - axis

PARCEL BOUNDARY

SUBJECT PROPERTY BOUNDARY

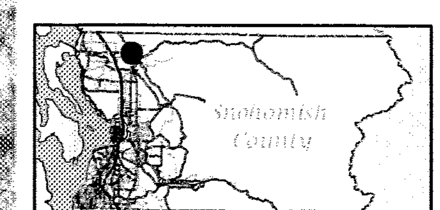
1 FT CONTOUR

WELL LOCATION

WELL_ID	SAMP_DATE	MEAS_HEAD
LG-02	10/27/2015	153.28
LG-04	10/27/2015	150.09
LG-05	10/27/2015	150.45

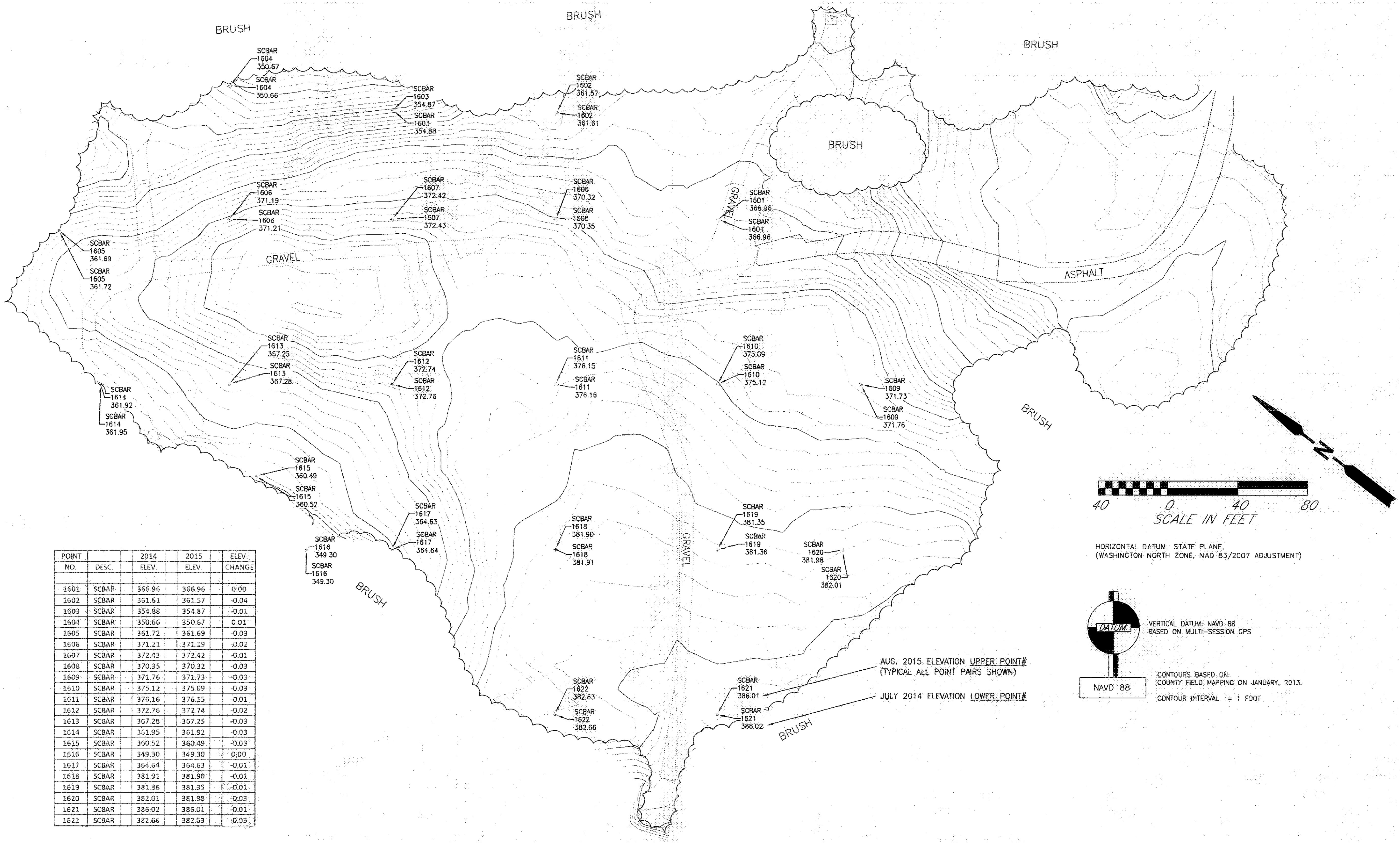
0 85 170 340 510 680 Feet

0 0.02 0.04 0.08 0.12 Miles



N

Snohomish County Public Works Solid Waste Division May 5, 2016



POINT NO.	DESC.	2014 ELEV.	2015 ELEV.	ELEV. CHANGE
1601	SCBAR	366.96	366.96	0.00
1602	SCBAR	361.61	361.57	-0.04
1603	SCBAR	354.88	354.87	-0.01
1604	SCBAR	350.66	350.67	0.01
1605	SCBAR	361.72	361.69	-0.03
1606	SCBAR	371.21	371.19	-0.02
1607	SCBAR	372.43	372.42	-0.01
1608	SCBAR	370.35	370.32	-0.03
1609	SCBAR	371.76	371.73	-0.03
1610	SCBAR	375.12	375.09	-0.03
1611	SCBAR	376.16	376.15	-0.01
1612	SCBAR	372.76	372.74	-0.02
1613	SCBAR	367.28	367.25	-0.03
1614	SCBAR	361.95	361.92	-0.03
1615	SCBAR	360.52	360.49	-0.03
1616	SCBAR	349.30	349.30	0.00
1617	SCBAR	364.64	364.63	-0.01
1618	SCBAR	381.91	381.90	-0.01
1619	SCBAR	381.36	381.35	-0.01
1620	SCBAR	382.01	381.98	-0.03
1621	SCBAR	386.02	386.01	-0.01
1622	SCBAR	382.66	382.63	-0.03

FIGURE 7

PLAN CHECK	BY	DATE				
		DATE	NO.	REVISION	BY	

Last Saved By: spwalj Sep 21, 2015 - 9:10am

REGION NO.	STATE	FED. AID PROJ. NO.	SURVEY NO.
10	WASH		3069

DESIGNED BY: DRAWN BY: ALJ

FIELD BOOK(S): 1848,1856,1875 UPI# 09-0064-1a

PRELIMINARY

SNOHOMISH COUNTY DEPARTMENT OF PUBLIC WORKS

FUNDING NO. RR8019

LAKE GOODWIN
LANDFILL MONITORING
VERTICAL MOVEMENT STUDY OF MONITORING POINTS

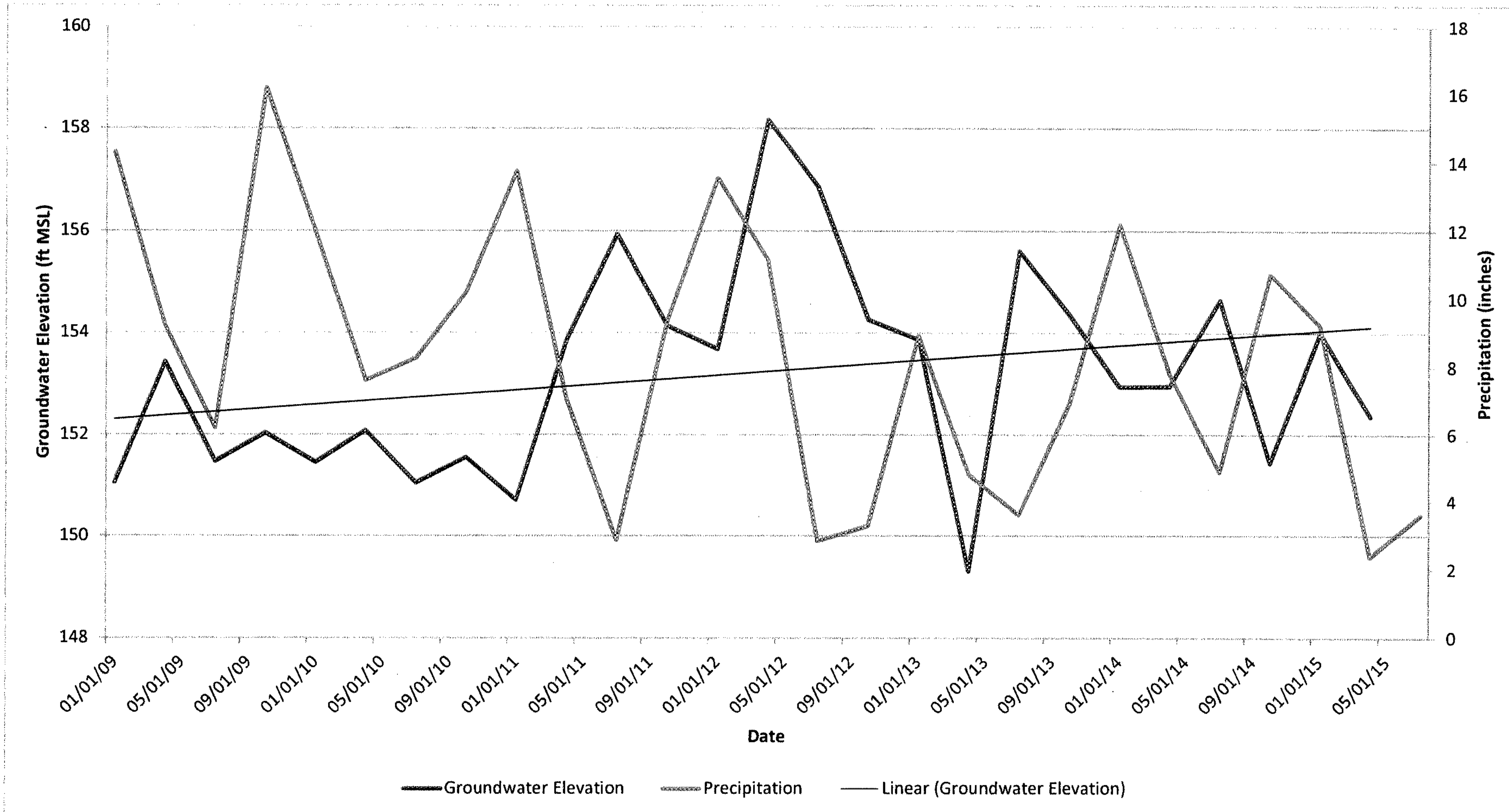
REFERENCE SHEET NO.

SHEET 1 OF 1 SHEETS

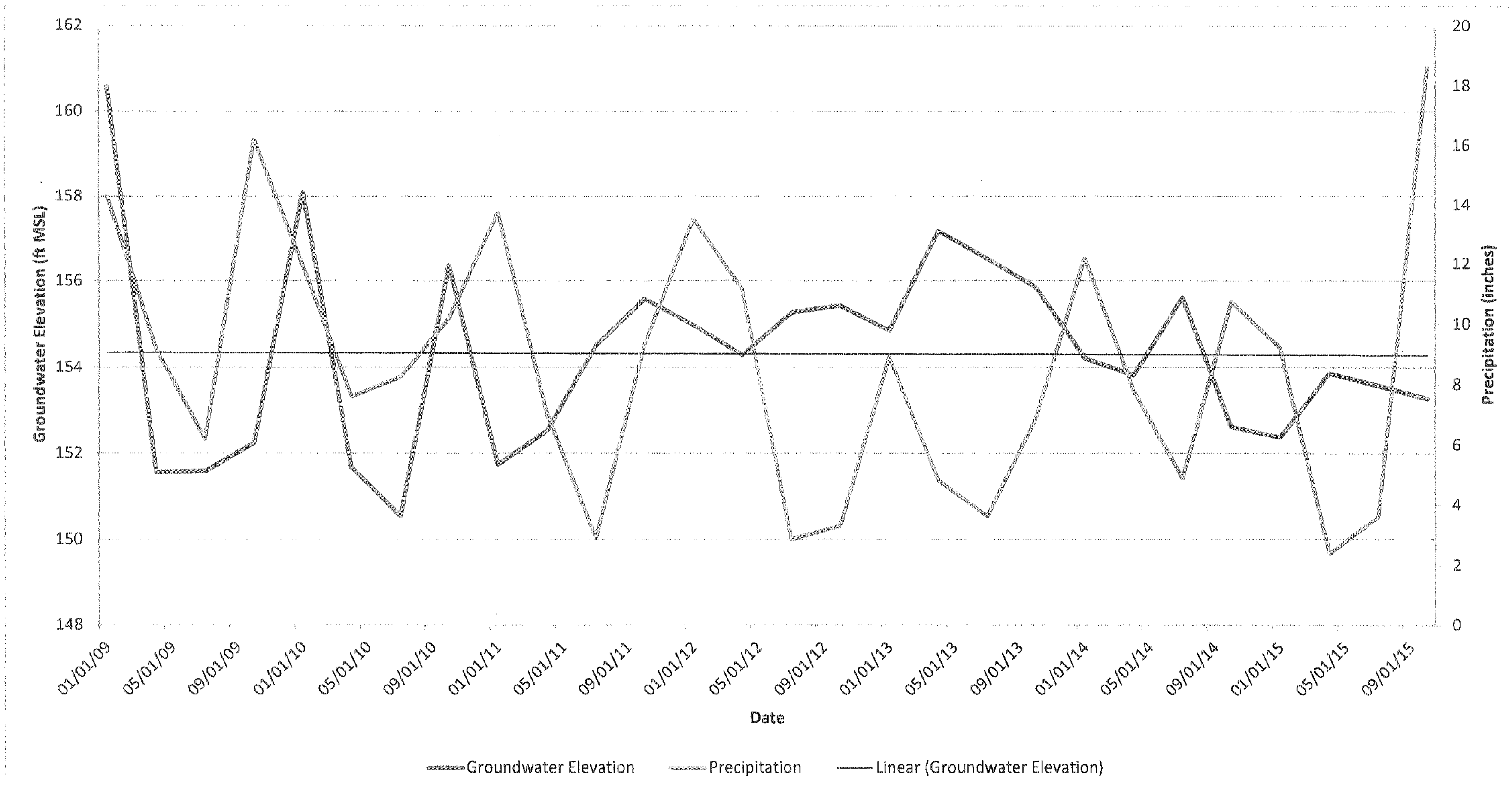
Appendix A

2015 Hydrographs

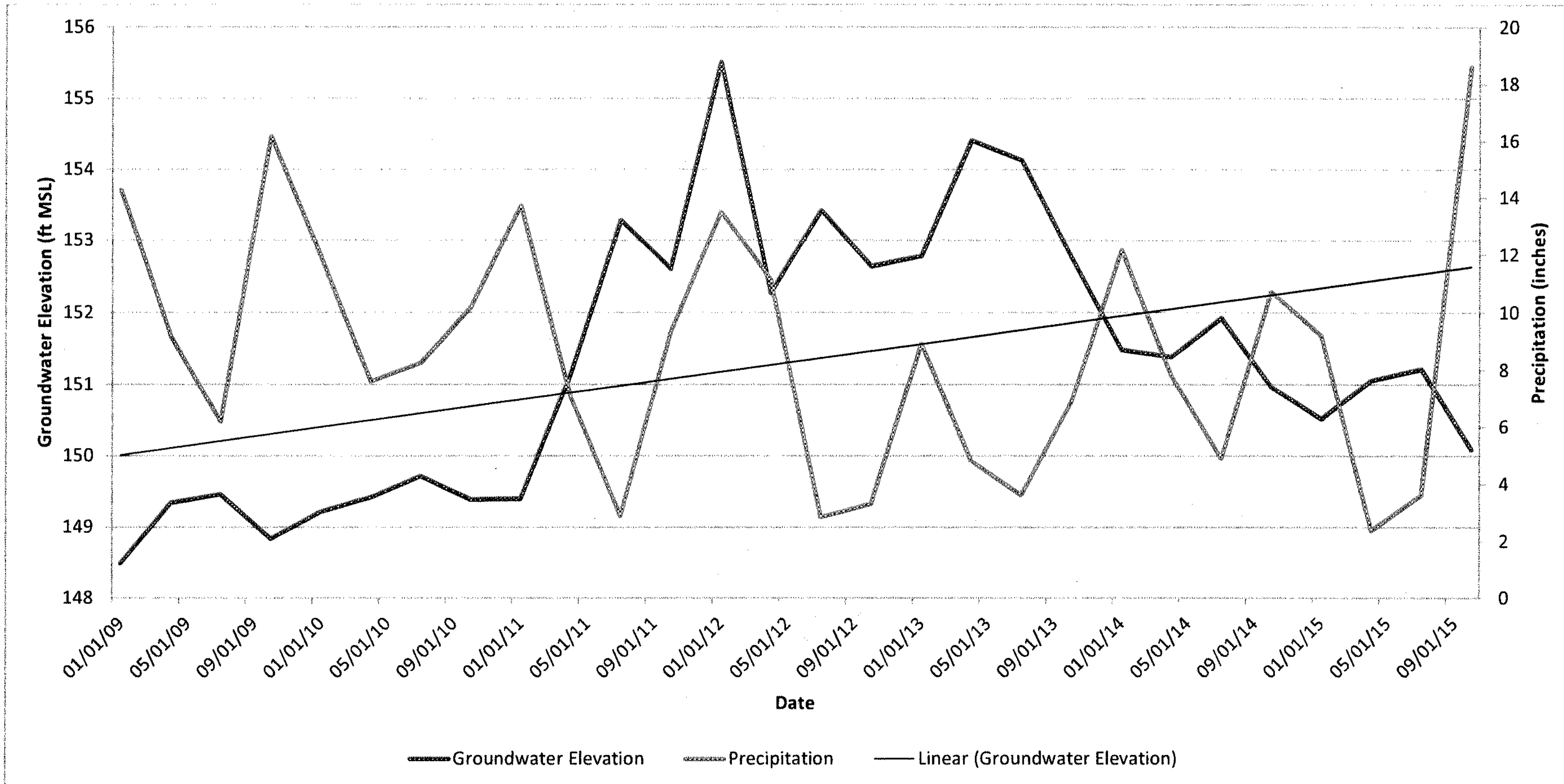
Hydrograph
Lake Goodwin Landfill
Well LG-01



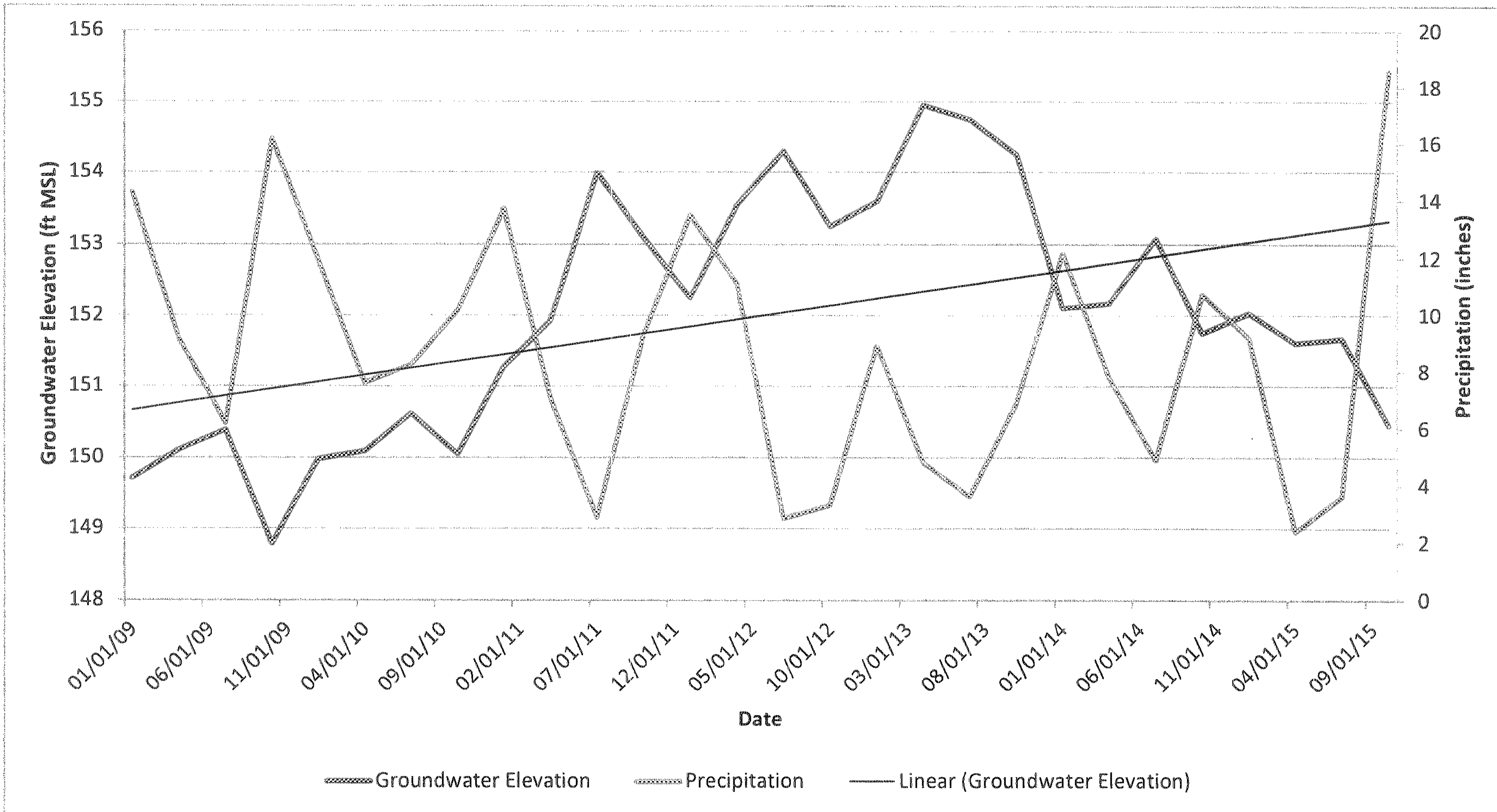
Hydrograph
Lake Goodwin Landfill
Well LG-02



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-01	D	1/28/2015	154.01
LG-02	D	1/28/2015	152.70
LG-04	D	1/28/2015	150.52
LG-05	D	1/28/2015	152.03

In-Situ Inc. Groundwater Velocity Program (V2.21)

Lake Goodwin Monitoring Wells First Quarter 2015

Output file is : h:\ess\modeling\watervel\LGDQ115.txt
Input file is : h:\ess\modeling\watervel\LGQ115D.txt

Isotropic hydraulic cond. = 83.30 ft/d
Effective porosity = 20.00 %

Least squares match to groundwater table:

N	X(ft)	Y(ft)	Meas. head (ft)	Calc. head (ft)
1	646.57	299.26	154.01	153.18
2	21.47	2.50	152.70	152.85
3	458.30	579.89	150.52	152.08
4	205.32	748.45	152.03	151.16

Calc. Head (ft) = 1.821E-03*X - 2.717E-03*Y + 1.528E+02

Natural groundwater flow = 1.36E+00 ft/day (4.97E+02 ft/yr)
at 123.83 deg to the positive X-axis

WATER-VEL COMPLETED.

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	4/15/2015	152.37
LG-02	D	4/15/2015	154.18
LG-04	D	4/15/2015	151.06
LG-05	D	4/15/2015	151.61

LGDQ215

In-Situ Inc. Groundwater Velocity Program (V2.21)

Lake Goodwin Monitoring Wells Second Quarter 2015

Output file is : h:\ess\modeling\watervel\LGDQ215.txt
Input file is : h:\ess\modeling\watervel\LGQ215.txt

Isotropic hydraulic cond. = 83.30 ft/d
Effective porosity = 20.00 %

Least squares match to groundwater table:

N	X(ft)	Y(ft)	Meas. head (ft)	Calc. head (ft)
1	646.57	299.26	152.37	152.13
2	21.47	2.50	154.18	154.22
3	458.30	579.89	151.06	151.50
4	205.32	748.45	151.61	151.36

Calc. Head (ft) = -1.721E-03*X - 3.410E-03*Y + 1.543E+02

Natural groundwater flow = 1.59E+00 ft/day (5.81E+02 ft/yr)
at 63.22 deg to the positive X-axis

WATER-VEL COMPLETED.

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	7/15/2015	151.22
LG-02	D	7/15/2015	153.58
LG-01	D	7/15/2015	152.54
LG-05	D	7/15/2015	151.67

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 **7/15/2015**

	[X] matrix			[D] matrix
Well ID	**X-axis**	**Y-axis**	**GW Elev.**	D
LG-01	646.57	299.26	**152.54**	1
LG-02	21.47	2.5	**153.58**	1
LG-04	458.3	579.89	**151.22**	1
LG-05	205.32	748.45	**151.67**	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
152.54	153.58	151.22	151.67	0	0

{[P]t[P]}

670708.9182	612981.5542	202370.1608
612981.5542	986012.6122	247241.4477
202370.1608	247241.4477	92726.5453

{[P]t[P]}'

4.70444E-06	-1.05657E-06	-7.44997E-06
-1.05657E-06	3.29746E-06	-6.48626E-06
-7.44997E-06	-6.48626E-06	4.43382E-05

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

0.001589143	-0.001045804	0.000416765	-0.00095	0	0
-0.000685767	-0.001010601	0.000447081	0.001267	0	0
5.33697E-06	0.006633289	-0.000470824	0.00034	0	0

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

A	5.29092E-06
B	1.79868E-05
C	0.0065083

gradient	0.0029	
Conductivity (ft/day)	83.3	
Effective porosity	20%	
GW velocity	**1.20**	ft/day
	438	ft/year
angle off x axis	**73.61**	degrees to the positive x-axis

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	10/27/2015	150.09
LG-02	D	10/27/2015	153.28
LG-05	D	10/27/2015	150.45
LG-05	D	10/27/2015	150.45

Groundwater Summary: First Quarter 2015 Lake Goodwin Landfill, Snohomish County WA

	Statistical Method	No. of Samples	No. of Detects	Prediction Limit (a)	Secondary Drinking	Ground Water	Downgradient LG-01 1/28/15	D V T C	Downgradient LG-04 1/28/15	D V T C	Downgradient LG-05 1/28/15	D V T C	Upgradient LG-02 1/28/15	D V T C
CONVENTIONAL CHEMISTRY PARAMETERS														
Alkalinity (as CaCO3)	normal	42	42	165.2534	--	--	210	V I	130		560	V I	110	I
Ammonia Nitrogen	nonpar	38	10	0.069	--	--	0.008		0.011		0.015		0.008	
Bicarbonate	lognor	42	42	159.4437	--	--	210	V I	130	D	560	V	110	
Calcium, Dissolved	nonpar	42	42	31.2	--	--	27.9	I	21.1	D	61.8	V I	19.3	
Chemical Oxygen Demand	nonpar	34	3	26	--	--	19		10 U		16	P	10 U	
Chloride	normal	42	42	9.7232	250	250	6.74	I	9.64	I	28.3	V	6.69	
Conductivity (umhos/cm)	normal	42	42	360.0914	--	700	460	V I	300	D	1200	V I	260	
Magnesium, Dissolved	nonpar	42	42	25.15	--	--	40.5	V I	20.8		100	V I	17.5	
Nitrate Nitrogen (mg-N/L)	nonpar	41	41	6	10	10	1.9	I	1.1		19	V I	1.7	
Nitrite Nitrogen (mg-N/L)	nonpar	39	8	0.011	1	1	0.002		0.001 U		0.028	V	0.001 U	
pH (std units)	normal	42	42	6.27-7.89	6.5-8.5	6.5-8.5	7.06	D	6.24	E D	6.48	D	7.36	D
Potassium, Dissolved	normal	42	42	3.6467	--	--	4.63	V	3.43		9.9	V	3.2	
Sodium, Dissolved	nonpar	41	41	13.8	--	20	11.8	D	10.8	D	63.4	V D	9.59	
Sulfate	nonpar	42	42	24	250	250	33.6	V	13.8	D	49.9	V	15.4	
Total Dissolved Solids	nonpar	42	42	550	500.0	500	270	I	180		720	V I	170	
Total Organic Carbon	nonpar	42	18	19	--	--	0.5 U		0.5 U		5.5		0.5 U	
DISSOLVED METALS (mg/L)														
Arsenic	nonpar	36	36	0.0078	0.01	0.00005	0.000755		0.000529		0.001200		0.00449	
Barium	nonpar	37	37	0.0193	2	2	0.0255	V I	0.0215	V D	0.0904	V	0.0123	I
Cadmium	nonpar	38	14	0.0002	0.005	0.005	0.000136 U		0.000025 U		0.000091		0.000025 U	
Chromium	normal	39	29	0.0091	0.1	0.1	0.0023		0.0027		0.001 U		0.0068	
Cobalt	nonpar	42	7	0.008	--	--	0.001 U		0.001 U		0.001 U		0.004	
Copper	nonpar	38	11	0.007	1	1.3	0.001 U		0.001 U		0.001 U		0.001 U	
Iron	nonpar	42	7	0.032	0.3	0.3	0.011		0.009 U		0.101	V	0.009 U	
Manganese	nonpar	39	16	0.0061	0.05	0.05	0.0005 U		0.0005 U		0.0005 U		0.0005 U	
Nickel	nonpar	42	0	0.005	--	0.1	0.005 U		0.005 U		0.005 U	P	0.005 U	

Groundwater Summary: Second Quarter 2015 Lake Goodwin Landfill, Snohomish County, WA

	Statistical Method	No. of Samples	No. of Detects	Prediction Limit (a)	Secondary Drinking	Ground Water	Downgradient LG-01 4/15/15	D	V	T	C	LG-04 4/15/15	D	V	T	C	LG-05 4/15/15	D	V	T	C	Upgradient LG-02 4/15/15	D	V	T	C
CONVENTIONAL CHEMISTRY PARAMETERS																										
Alkalinity (as CaCO3)	normal	43	43	165.2534	--	--	220		V	I	N	98					560		V	I	N	110			I	N
Ammonia Nitrogen	nonpar	39	10	0.069	--	--	0.005	U				0.005	U				0.005					0.005	U			
Bicarbonate	lognor	43	43	159.4437	--	--	220		V	I	N	98			D	N	560		V			110				
Calcium, Dissolved	nonpar	43	43	31.2	--	--	27.7			I	N	20.2			D	N	62.4		V	I	N	18.5				
Chemical Oxygen Demand	nonpar	35	3	26	--	--	10	U				10	U				10	U				10	U			
Chloride	normal	43	43	9.7232	250	250	6.29			I	N	9.59			I	N	27.8		V			6.74				
Conductivity (umhos/cm)	lognor	43	43	360.0914	--	700	450		V	I	N	270			D	N	1100		V	I	N	250				
Magnesium, Dissolved	nonpar	43	43	25.15	--	--	36.7		V	I	N	18.3					102		V	I	N	16				
Nitrate Nitrogen (mg-N/L)	nonpar	42	42	6	10	10	2.3			I	N	1.2					19		V	I	N	2.1				
Nitrite Nitrogen (mg-N/L)	nonpar	40	8	0.011	1	1	0.001					0.001	U				0.037		V			0.001	U			
pH (std units)	normal	43	43	6.27-7.89	6.5-8.5	6.5-8.5	6.47			D		6.26		V	D	N	6.36			D	N	7.11			D	N
Potassium, Dissolved	normal	43	43	3.6467	--	--	3.99		V			2.99					8.82		V			2.76				
Sodium, Dissolved	nonpar	42	42	13.8	--	20	11.1			I	Y	10.2			D	N	60		V	D	N	8.99				
Sulfate	nonpar	43	43	24	250	250	34.1		V			13			D	N	43.8		V			15.2				
Total Dissolved Solids	nonpar	43	43	550	500.0	500	260			I	N	170					690		V	I	N	140				
Total Organic Carbon	nonpar	43	19	19	--	--	0.91					20		E			5.8					0.5	U			
DISSOLVED METALS																										
Arsenic	nonpar	37	37	0.0078	0.01	0.00005	0.000596					0.000368					0.000898					0.00363				
Barium	nonpar	38	38	0.0193	2	2	0.0204		V	I	N	0.0166		P	D	N	0.0825		V			0.0087			I	N
Cadmium	nonpar	39	14	0.0002	0.005	0.005	0.000068					0.0005	U				0.000056	U				0.0005	U			
Chromium	normal	40	30	0.0091	0.1	0.1	0.001	U				0.000025	U				0.001	U				0.0046				
Cobalt	nonpar	43	7	0.008	--	--	0.001	U				0.001	U				0.001	U				0.001	U			
Copper	nonpar	39	11	0.007	1	1.3	0.001	U				0.001	U				0.001	U				0.001	U			
Iron	nonpar	43	7	0.032	0.3	0.3	0.009					0.009	U				0.038		V			0.009	U			
Manganese	nonpar	40	16	0.0061	0.05	0.05	0.0005	U				0.0005	U				0.0005	U				0.0005	U			
Nickel	nonpar	43	0	0.005	--	0.1	0.005	U				0.005	U				0.009		E			0.005	U			
TOTAL METALS																										
Arsenic					0.01	0.00005	0.000577					0.000358					0.000818					0.00361				
Barium					2	2	0.0232					0.018					0.0847					0.01				
Cadmium					0.005	0.005	0.000025	U				0.000025	U				0.000044					0.000025	U			
Chromium					0.1	0.1	0.0025	U				0.0025	U				0.0025	U				0.0036				
Cobalt					--	--																				
Copper					1	1.3	0.005	U				0.005	U				0.005	U				0.005				
Iron					0.3	0.3	0.038					0.022					0.207					0.023				
Manganese					0.05	0.05	0.0009	U				0.0009	U				0.0009	U				0.0009	U			
Nickel					--	0.1	0.005	U				0.005					0.013					0.005	U			

mg/L = milligrams per liter (ppm), µg/L = micrograms per liter (ppb).

D Column: U = Compound not detected in any sample. V Column: V = verified hit, E = exceedance, waiting verification; P = Passed, exceedance not verified

I means increasing trend, D means decreasing trend via Mann-Kendall Analysis. Ch? = a change in the trend analysis, N is no, Y is yes. Compared to previous quarter.

Groundwater Statistical Summary: Third Quarter 2015
Lake Goodwin Landfill, Snohomish County, WA

	Statistical Method	Number of Samples	Number of Detects	Prediction Limit (a)	Secondary Drinking Water	GW Stds 173-200	Down Gradient Wells															Upgradient Well				
							LG-01					LG-04					LG-05					LG-02				
							7/15/15	D	V	Tr	Ch	7/15/15	D	V	Tr	Ch	7/15/15	D	V	Tr	Ch	7/15/15	D	V	Tr	Ch
CONVENTIONAL CHEMISTRY PARAMETERS (mg/L)																										
Alkalinity (as CaCO3)	normal	44	44	165.2534	--	--	160		P	I	N	120					520		V	I	N	110			I	
Ammonia Nitrogen	nonpar	40	10	0.069	--	--	0.005	U				0.005	U				0.005	U				0.005	U			
Bicarbonate	lognor	44	44	159.4437	--	--	160		V		Y	120			D	N	520		V	I	Y	110				
Calcium, Dissolved	nonpar	44	44	31.2	--	--	18.5			I	N	18.2			D	N	57.4		V	I	N	16.3				
Chemical Oxygen Demand	nonpar	36	3	26	--	--	10	U				10	U				16					10	U			
Chloride	normal	44	44	9.7232	250	250	9.05			I	N	11.0		E	I	N	28.9		V	I	Y	7.15				
Conductivity (umhos/cm)	lognor	44	44	360.0914	--	700	360		P	I	N	280			D	N	1100		V	I	N	250				
Magnesium, Dissolved	nonpar	44	44	25.15	--	--	25.5		V	I	N	16.1					77.9		V	I	N	14.4				
Nitrate Nitrogen (mg-N/L)	nonpar	43	43	6	10	10	2.5				Y	1.2					20		V	I	N	1.9				
Nitrite Nitrogen (mg-N/L)	nonpar	41	8	0.011	1	1	0.001	U				0.001	U				0.028		V			0.001	U			
pH (std units)	normal	44	44	6.27-7.89	6.5-8.5	6.5-8.5	6.43			D	N	6.11		V	D	N	6.30			D	N	6.89			D	
Potassium, Dissolved	normal	44	44	3.6467	--	--	3.24		P			2.61					8.18		V	I	Y	2.47				
Sodium, Dissolved	nonpar	43	43	13.8	--	20	7.94			D	Y	8.18			D	N	50.1		V	D		7.66				
Sulfate	nonpar	44	44	24	250	250	20.9		P			15.0				Y	60.2		V			14.5				
Total Dissolved Solids	nonpar	44	44	550.0000	500	500	240			I	N	190					760		V	I	N	150				
Total Organic Carbon	nonpar	44	19	19	--	--	2.9					0.52		P			14			I	Y	0.5	U			
DISSOLVED METALS EPA Methods 200.7/200.8 (mg/L)																										
Arsenic	nonpar	38	38	0.0078	0.01	0.00005	0.000563					0.000367					0.000853					0.00360				
Barium	nonpar	39	39	0.0193	2	1	0.0154		P	I	N	0.0163				Y	0.0796		V	I	Y	0.0098				Y
Cadmium	nonpar	40	15	0.0002	0.005	0.005	0.000055					0.000025	U				0.000102					0.000097				
Chromium	normal	41	31	0.0091	0.1	0.05	0.001	U				0.0068					0.001	U				0.0039				
Cobalt	nonpar	44	7	0.008	--	--	0.001	U				0.001	U				0.001	U				0.001	U			
Copper	nonpar	40	11	0.007	1.3	1	0.001	U				0.001	U				0.001	U				0.001	U			
Iron	nonpar	44	7	0.032	0.3	0.3	0.009	U				0.009	U				0.088		V			0.009	U			
Manganese	nonpar	41	16	0.0061	0.05	0.05	0.0005	U				0.0005	U				0.0005	U				0.0005	U			
Nickel	nonpar	44	0	0.005	--	0.1	0.005	U				0.006		E			0.013		V			0.005	U			
TOTAL METALS EPA Methods 200.7/200.8 (mg/L)																										
Arsenic					0.01	0.00005	0.000504					0.000297					0.00140					0.00320				
Barium					2	1	0.0177					0.0188					0.0948					0.0115				
Cadmium					0.005	0.005	0.000025	U				0.000025	U				0.00025	U				0.000033				
Chromium					0.1	0.05	0.0025	U				0.0025	U				0.0141					0.0060				
Cobalt					--	--	0.001	U				0.001	U				0.005					0.001	U			
Copper					1.3	1	0.005	U				0.005	U				0.005					0.005	U			
Iron					0.3	0.3	0.029					0.009	U				3.07					0.028				
Manganese					0.05	0.05	0.0009	U				0.0009	U				0.0510					0.0009	U			
Nickel					--	0.1	0.005	U				0.005	U				0.033					0.005	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

Groundwater Statistical Summary: Fourth Quarter 2015
Lake Goodwin Landfill, Snohomish County, WA

	Statistical Method	Number of Samples	Number of Detects	Prediction Limit (a)	Secondary Drinking Water	GW Stds 173-200	Down Gradient Wells															Upgradient Well				
							LG-01					LG-04					LG-05					LG-02				
							10/27/15	D	V	Tr	Ch	10/27/15	D	V	Tr	Ch	10/27/15	D	V	Tr	Ch	10/27/15	D	V	Tr	Ch
CONVENTIONAL CHEMISTRY PARAMETERS (mg/L)																										
Alkalinity (as CaCO3)	normal	45	45	165.2534	--	--	No sample - insufficient water					130					490		V	I	N	92			I	N
Ammonia Nitrogen	nonpar	41	10	0.069	--	--						0.01					0.005	U				0.005	U			
Bicarbonate	lognor	45	45	159.4437	--	--						130			D	N	490		V	I	N	92				
Calcium, Dissolved	nonpar	45	45	31.2	--	--						21			D	N	48.7		V	I	N	15.6				
Chemical Oxygen Demand	nonpar	37	3	26	--	--						10	U				10	U				10	U			
Chloride	normal	45	45	9.7232	250	250						11.3		V	I	N	36.2		V	I	N	7.27				
Conductivity (umhos/cm)	lognor	45	45	360.0914	--	700						320			D	N	1000		V	I	N	220				
Magnesium, Dissolved	nonpar	45	45	25.15	--	--						20.8			D	Y	63.5		V	I	N	13.7				
Nitrate Nitrogen (mg-N/L)	nonpar	44	44	6	10	10						1.3					4		P		Y	1.5				
Nitrite Nitrogen (mg-N/L)	nonpar	42	9	0.011	1	1						0.002					0.044		V	I	Y	0.002				
pH (std units)	normal	45	45	6.27-7.89	6.5-8.5	6.5-8.5						6.26		V	D	N	6.35			D	N	7.06			D	N
Potassium, Dissolved	normal	45	45	3.6467	--	--						3.16			D	Y	7.78		V	I	N	2.57				
Sodium, Dissolved	nonpar	44	44	13.8	--	20						11			D	N	63.7		V		Y	7.93				
Sulfate	nonpar	45	45	24	250	250						21.3			D	Y	39.6		V			16.8				
Total Dissolved Solids	nonpar	45	45	550.0000	500	500						240					670		V	I	N	180				
Total Organic Carbon	nonpar	45	20	19	--	--						0.61					6.8			I	N	0.62				
DISSOLVED METALS EPA Methods 200.7/200.8 (mg/L)																										
Arsenic	nonpar	39	39	0.0078	0.01	0.00005	No sample - insufficient water					0.000353					0.000742					0.00353				
Barium	nonpar	40	40	0.0193	2	1						0.0203		E	D	Y	0.0677		V	I	N	0.0092				
Cadmium	nonpar	41	15	0.0002	0.005	0.005						0.000025	U				0.000042					0.000025	U			
Chromium	normal	42	32	0.0091	0.1	0.05						0.0025	U				0.0025	U				0.0058				
Cobalt	nonpar	45	7	0.008	--	--						0.001	U				0.001	U				0.001	U			
Copper	nonpar	41	11	0.007	1.3	1						0.005	U				0.006					0.005	U			
Iron	nonpar	45	7	0.032	0.3	0.3						0.009	U				0.009	U	P			0.009	U			
Manganese	nonpar	42	16	0.0061	0.05	0.05						0.0009	U				0.0009	U				0.0009	U			
Nickel	nonpar	45	0	0.005	--	0.1						0.005	U	P			0.012		V			0.005	U			
TOTAL METALS EPA Methods 200.7/200.8 (mg/L)							No sample - insufficient water																			
Arsenic					0.01	0.00005						0.000434					0.000893					0.00407				
Barium					2	1						0.0214					0.0893					0.0096				
Cadmium					0.005	0.005						0.000025	U				0.000032					0.000059				
Chromium					0.1	0.05						0.0025	U				0.0025	U				0.0065				
Cobalt					--	--						0.001	U				0.001	U				0.001	U			
Copper					1.3	1						0.005	U				0.005	U				0.005	U			
Iron					0.3	0.3						0.064					0.191					0.057				
Manganese					0.05	0.05						0.0009	U				0.0009	U				0.0009	U			
Nickel					--	0.1						0.005	U				0.005	U				0.005	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.

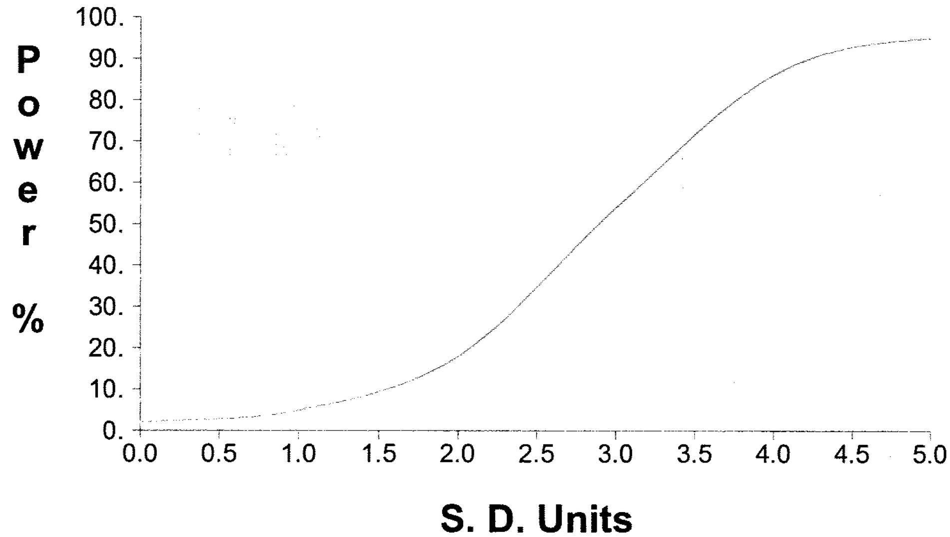
The groundwater standards listed are based on the Washington Administrative Code (WAC) 173-200 groundwater limits as modified by the TMS 91-11 standards - the most restrictive of the two is used.

* = Non-detect; exceedance due to elevated laboratory reporting limit

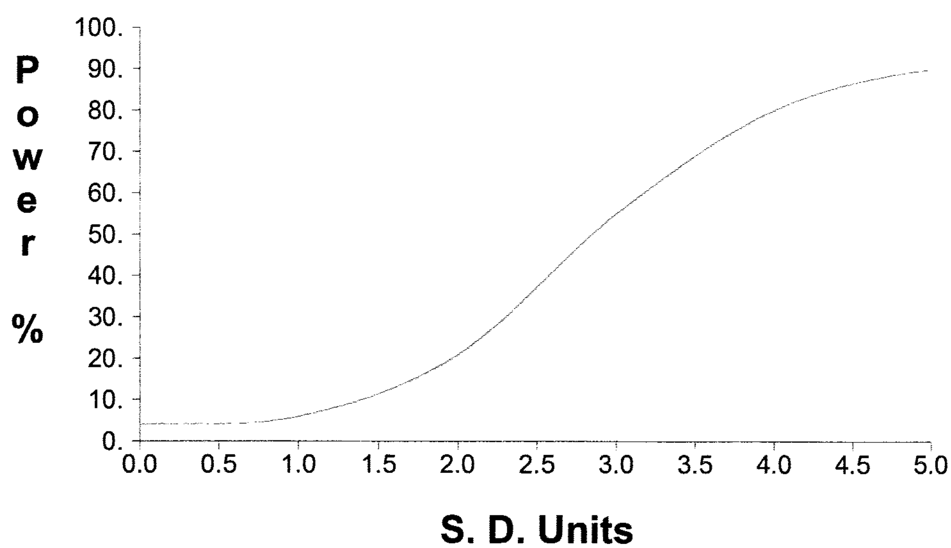
Appendix C

2015 Groundwater Statistical Analyses

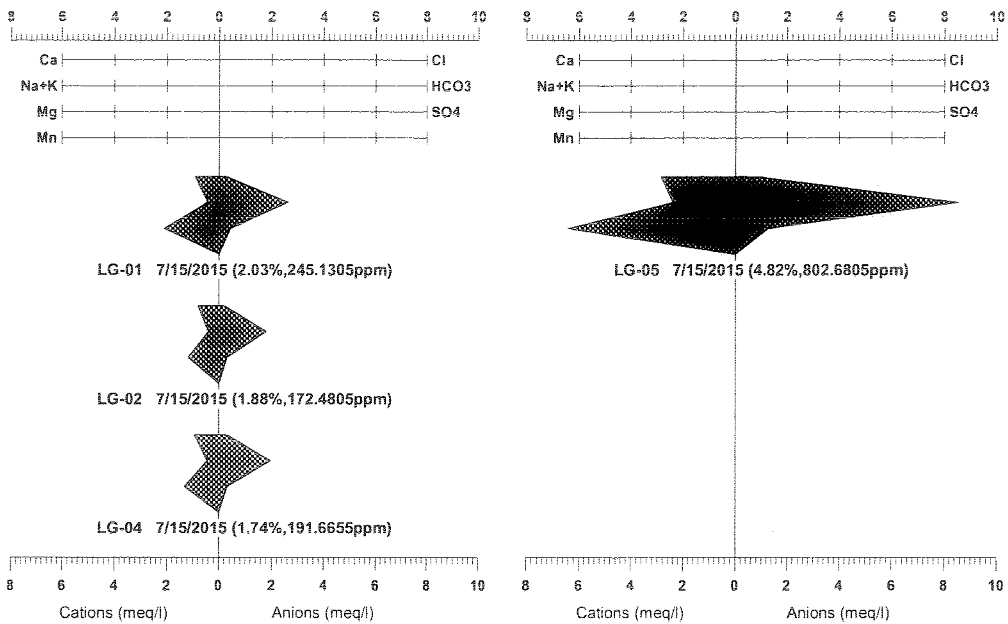
False Positive and False Negative Rates for Current Intra-Well Prediction Limits Monitoring Program



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



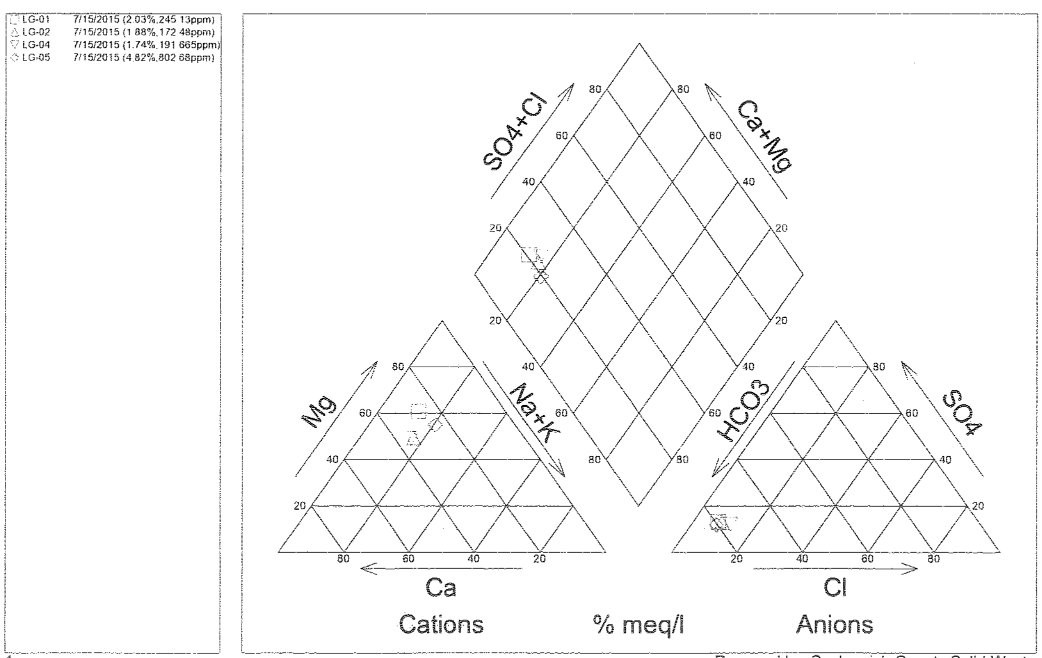
Goodwin Landfill



1

Prepared by: Snohomish County Solid Waste

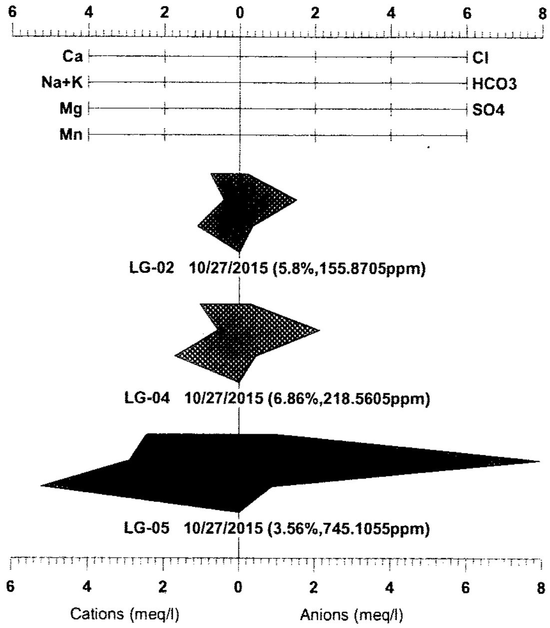
Goodwin Landfill



1

Prepared by: Snohomish County Solid Waste

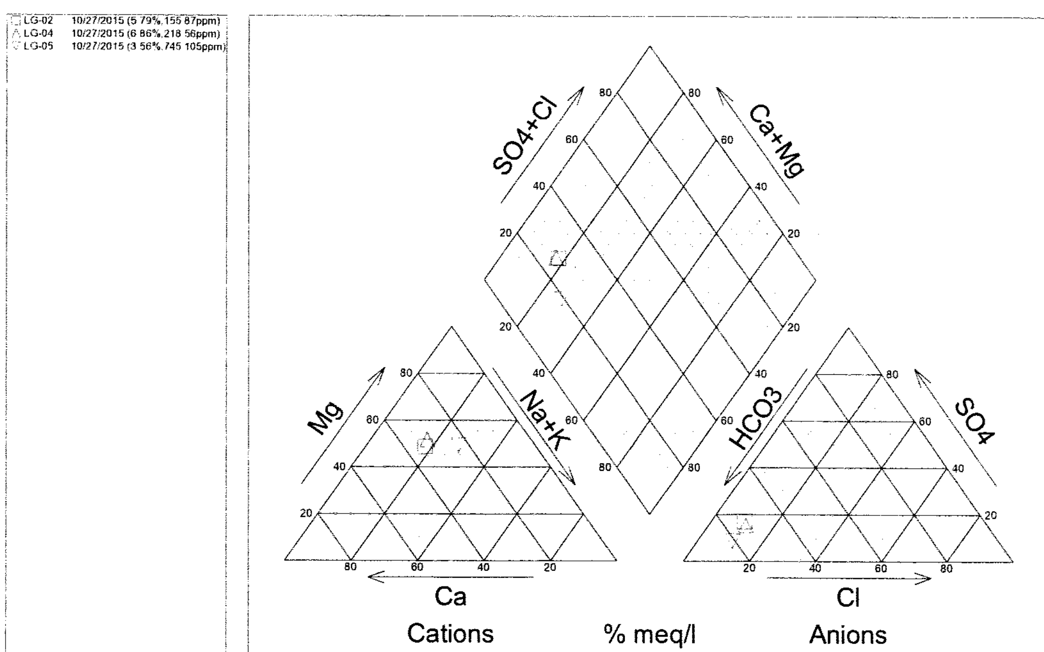
Goodwin Landfill



1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

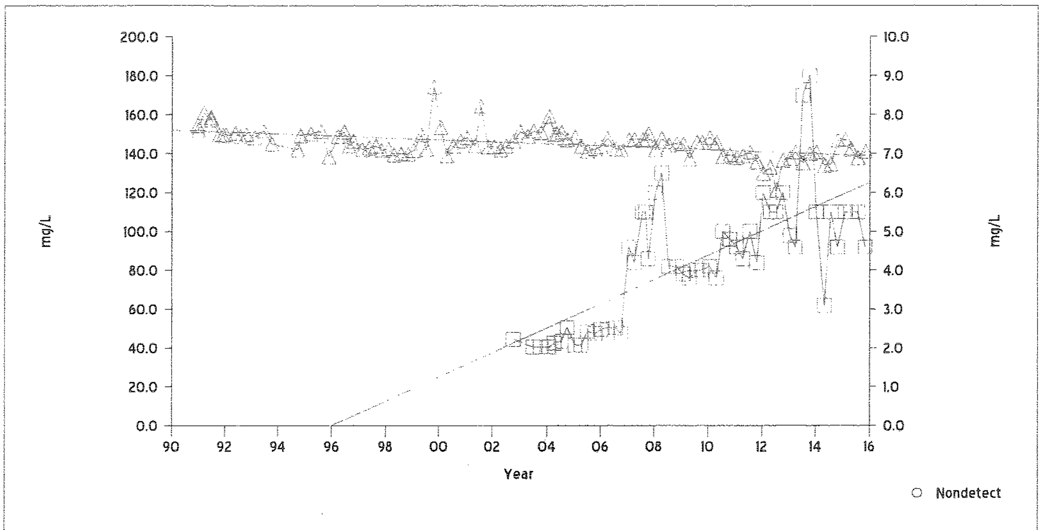


1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-02



Alkalinity (as caco3) (cc: .719)

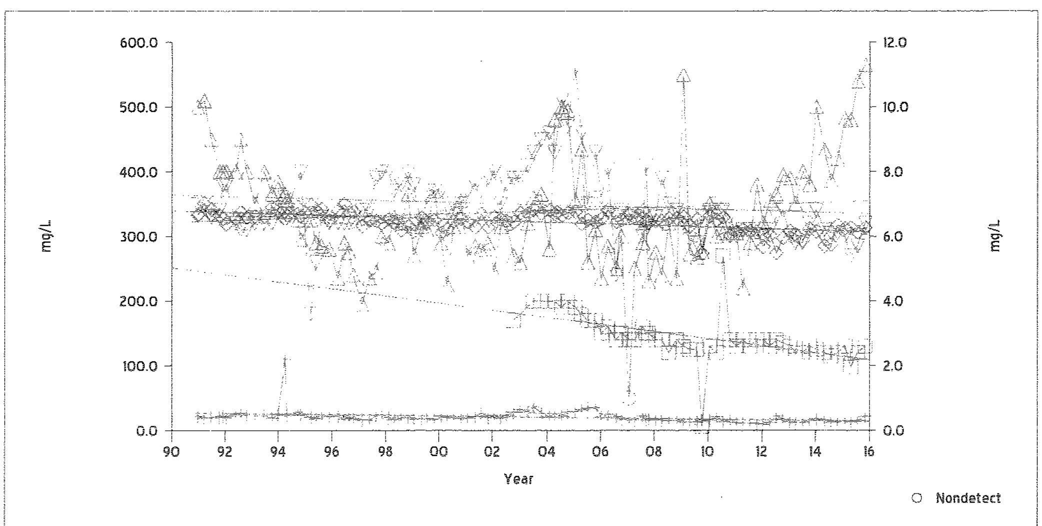
pH (cc: -.520)

1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-04



Bicarbonate (cc: -.554)
Conductivity (cc: -.150)
Sulfate (cc: -.338)

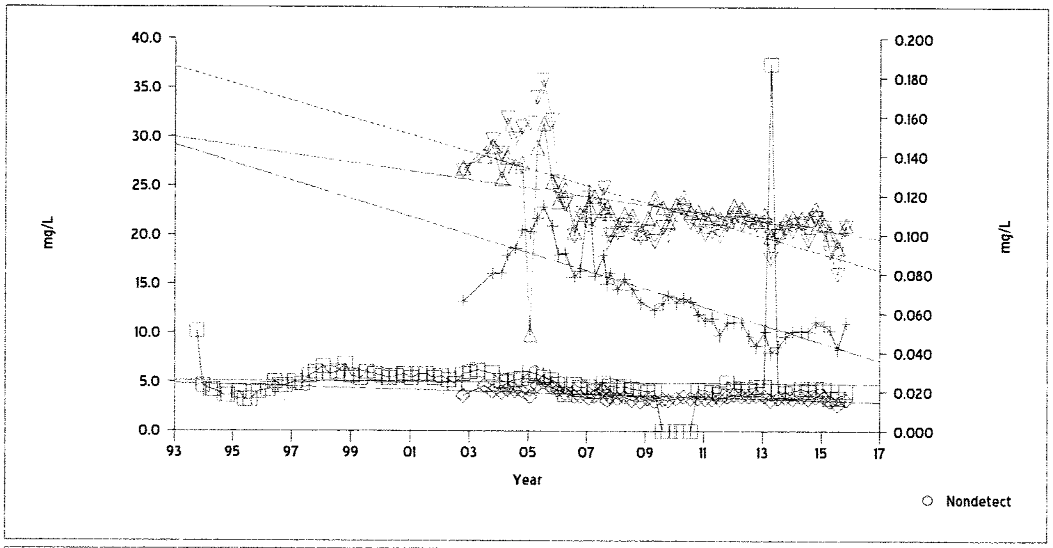
pH (cc: -.602)
Chloride (cc: .112)

1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-04



Dissolved calcium (cc: -.499)
Dissolved magnesium (cc: -.701)
Dissolved potassium (cc: -.642)
Dissolved sodium (cc: -.825)

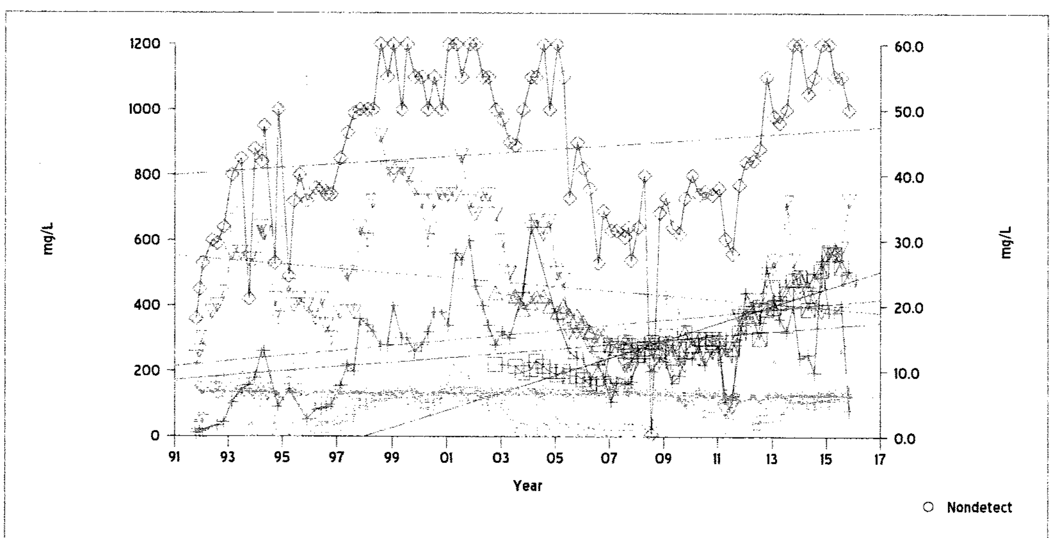
Dissolved barium (cc: -.028)

1

Prepared by Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-05



Alkalinity (as caco3) (cc: .893)
Bicarbonate (cc: .340)
Total dissolved solids (cc: .389)
Conductivity (cc: .171)

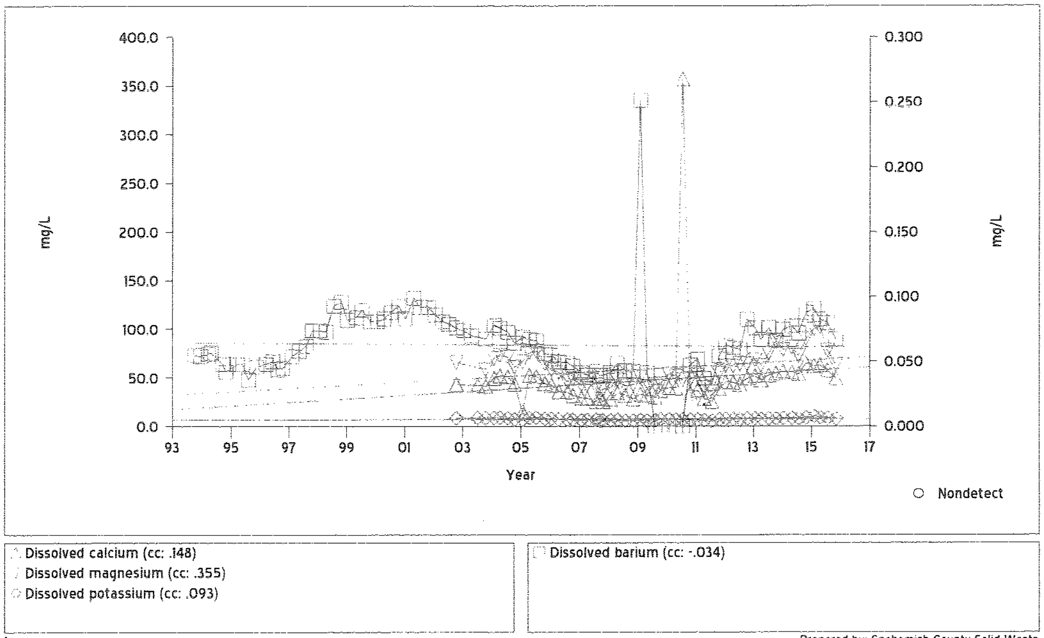
Chloride (cc: -.239)
Nitrate nitrogen (cc: .352)
pH (cc: -.508)
Total organic carbon (cc: -.083)

1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Time Series Plot for LG-05



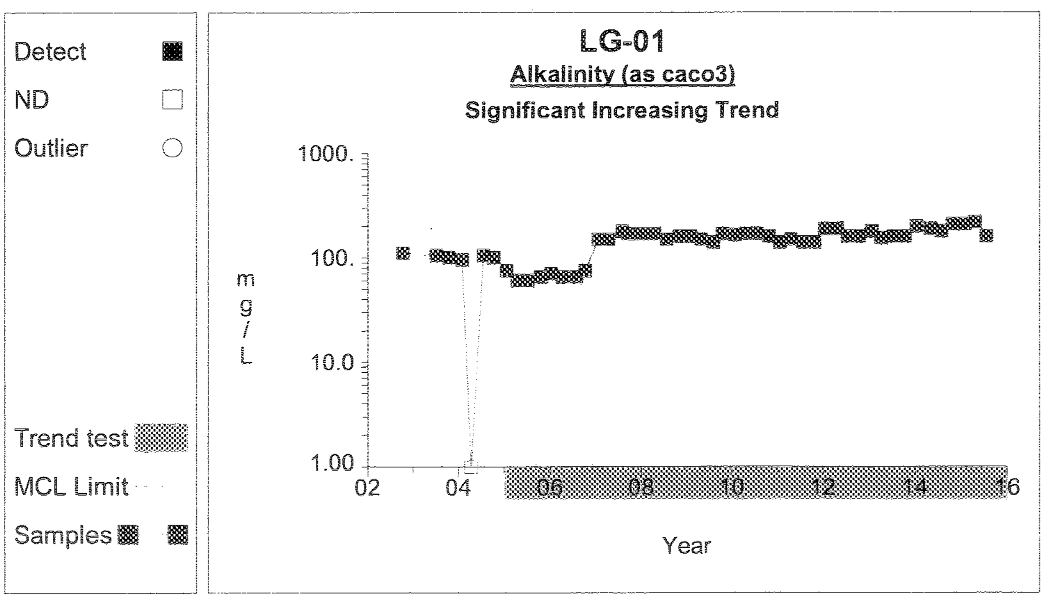
1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



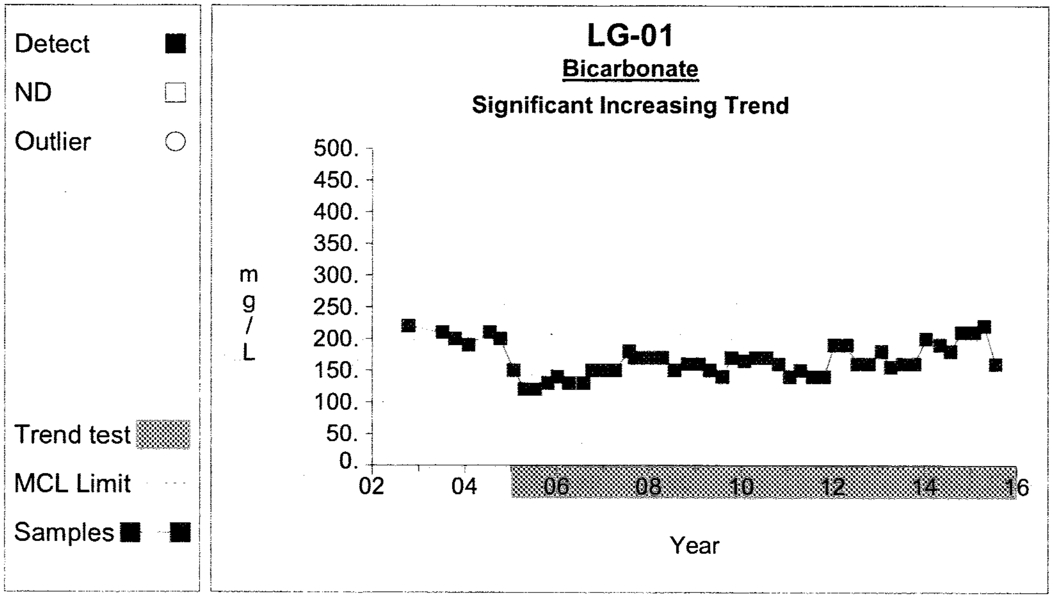
Graph 1

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



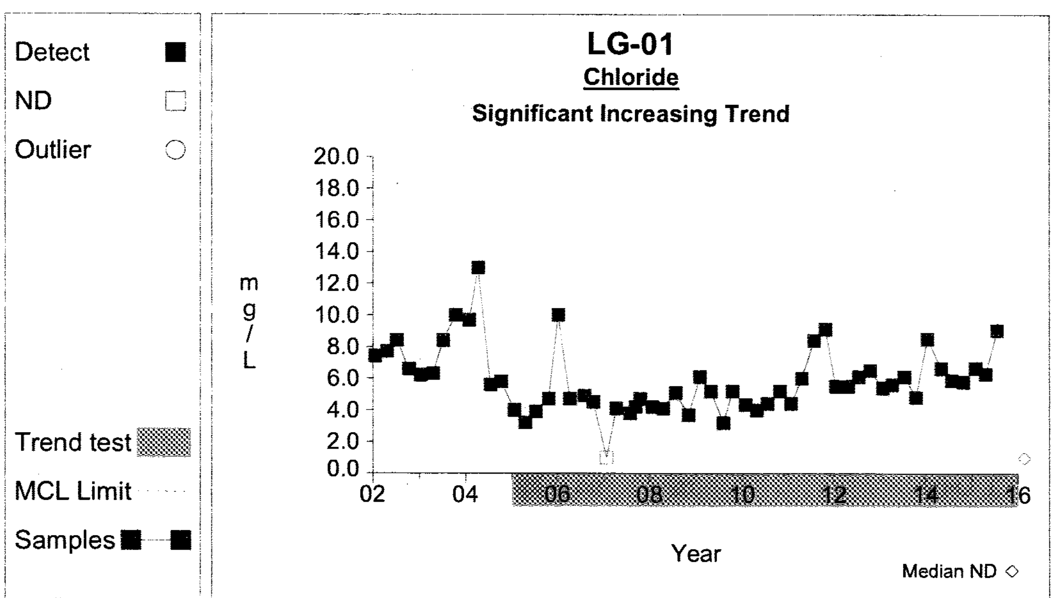
Graph 3

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



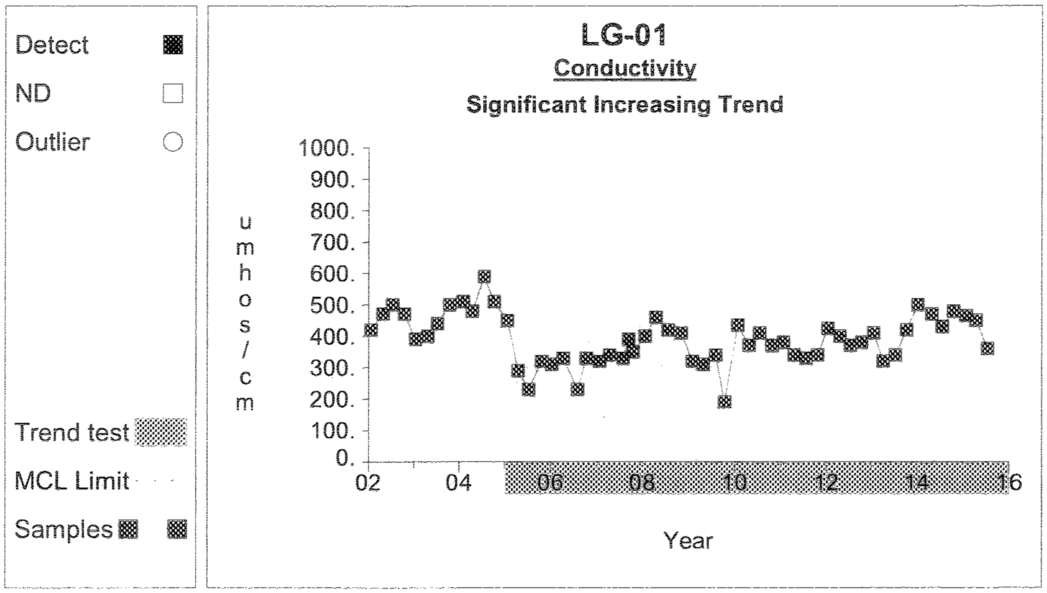
Graph 5

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



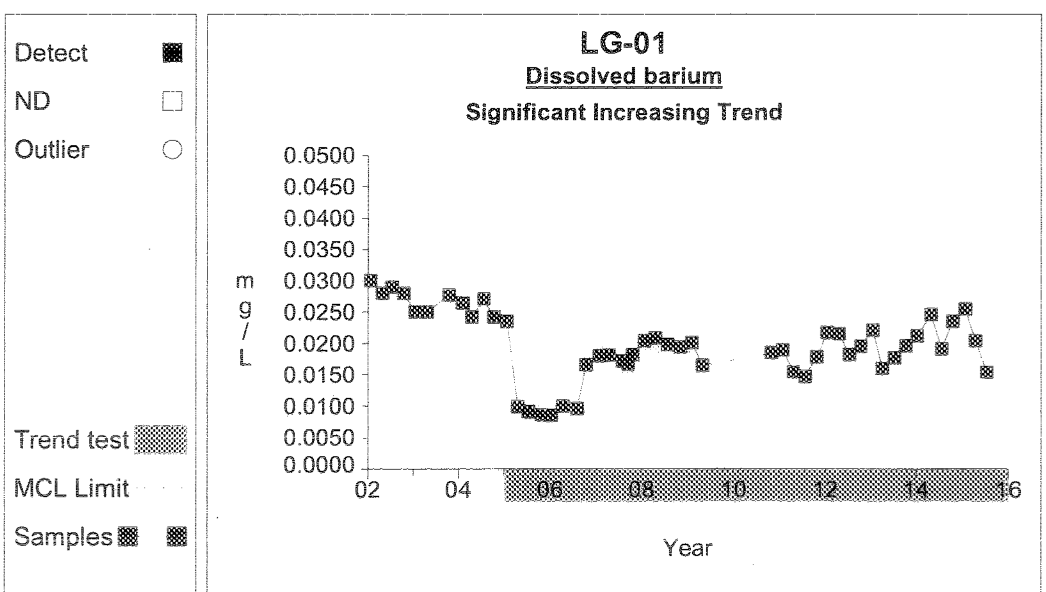
Graph 6

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



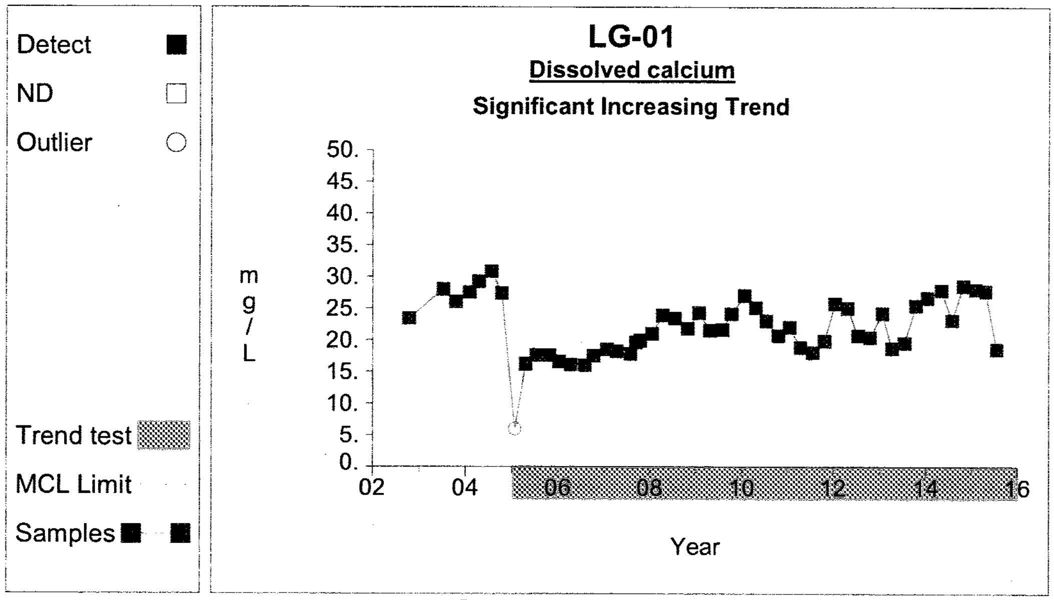
Graph 9

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



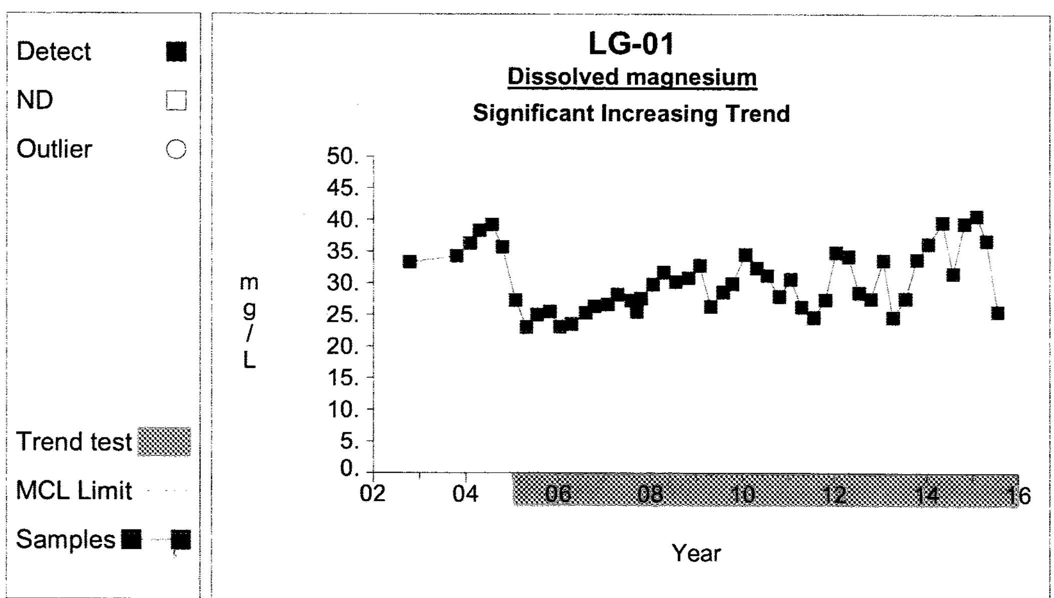
Graph 12

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

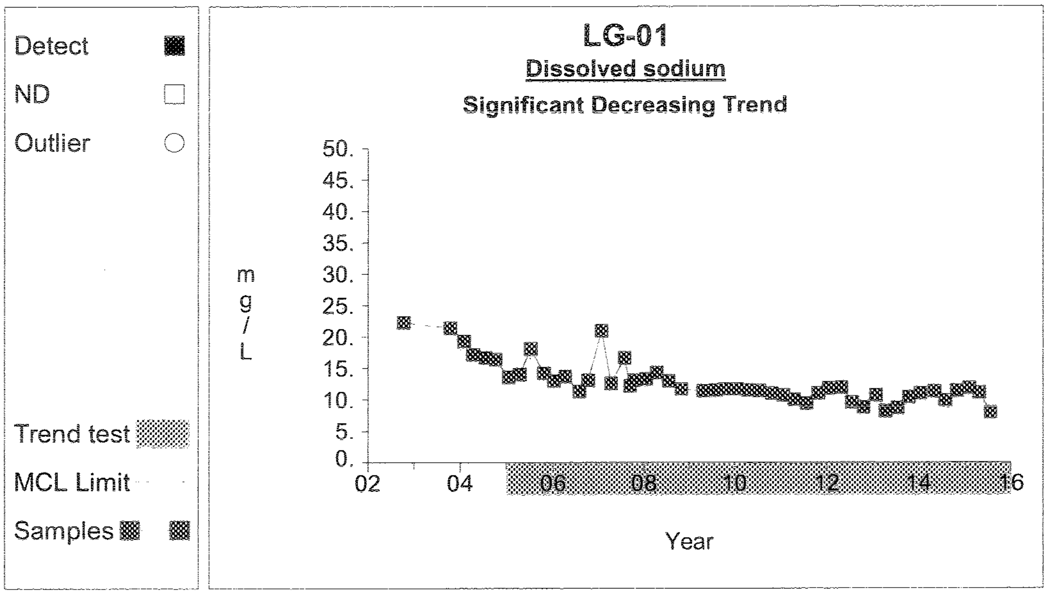
Time Series



Graph 18

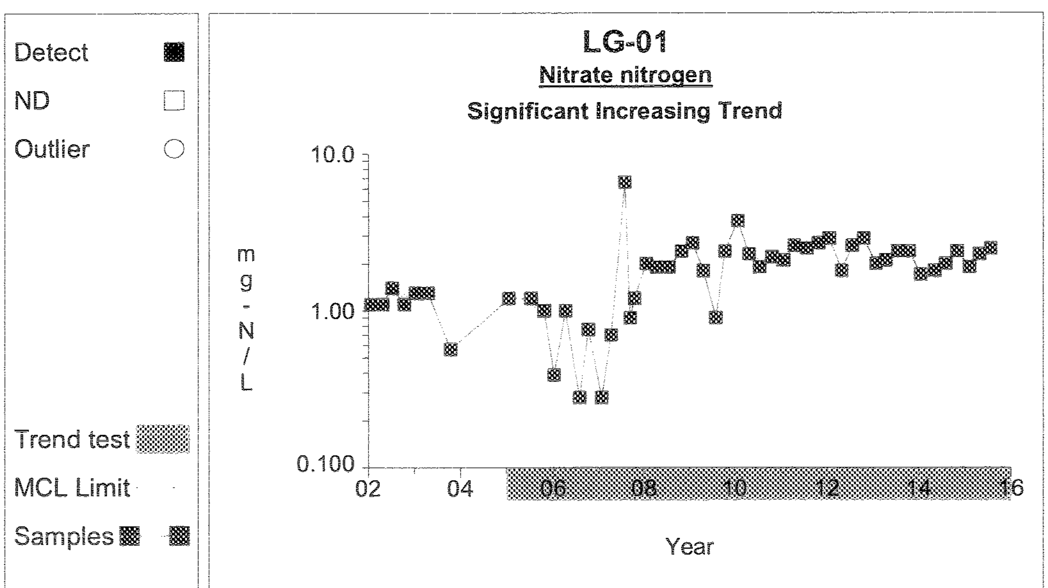
Prepared by: Snohomish County Solid Waste

Time Series



Graph 24

Time Series

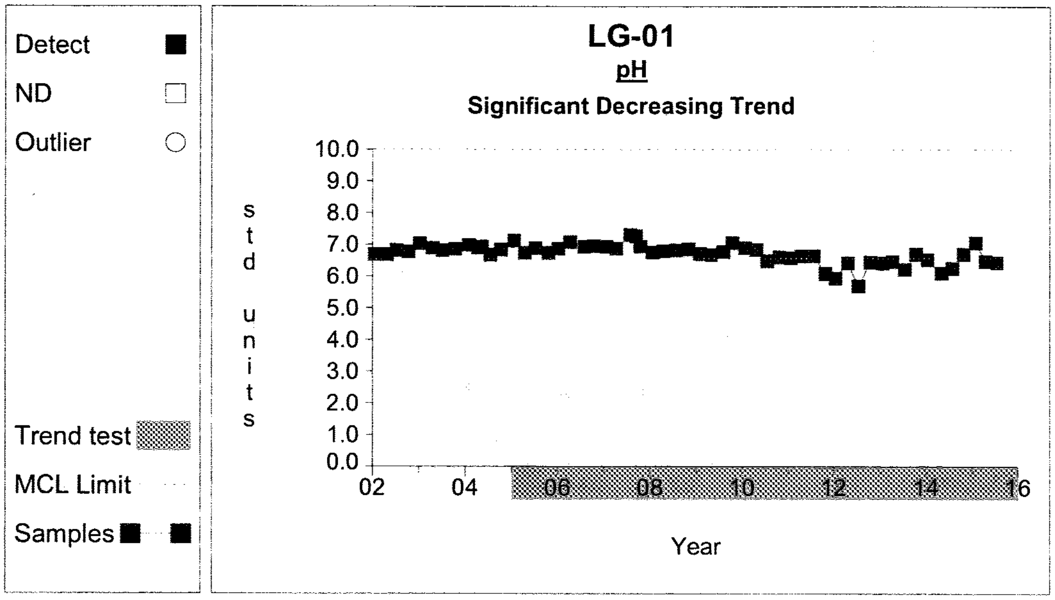


Graph 28

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



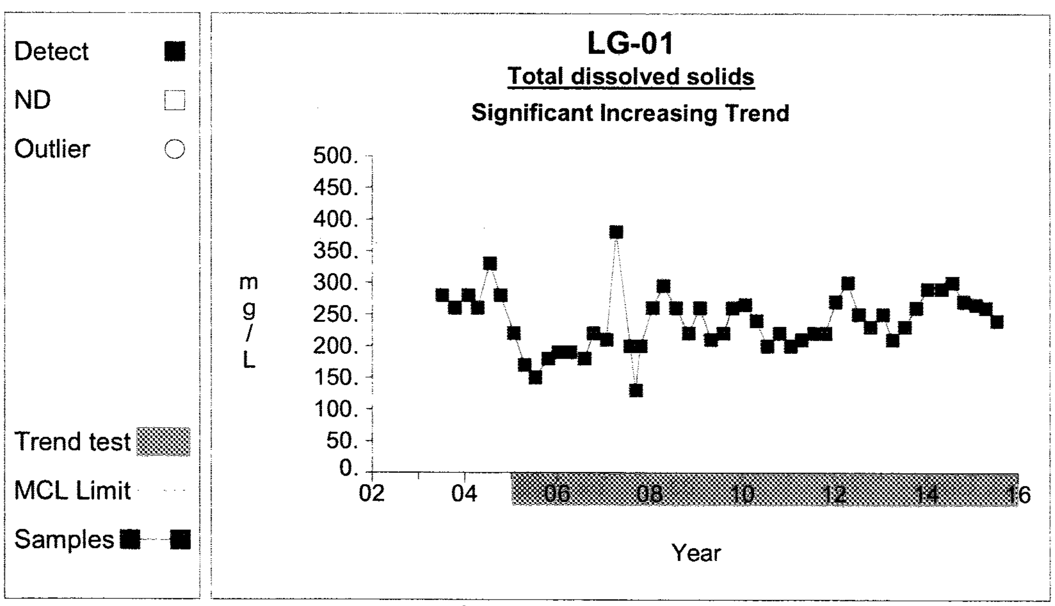
Graph 30

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



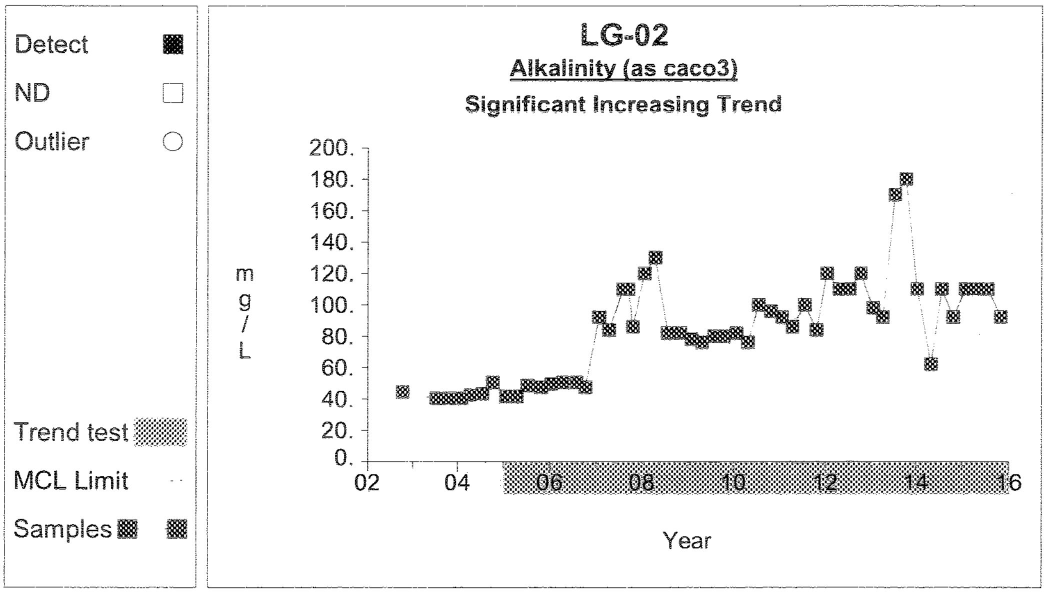
Graph 32

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



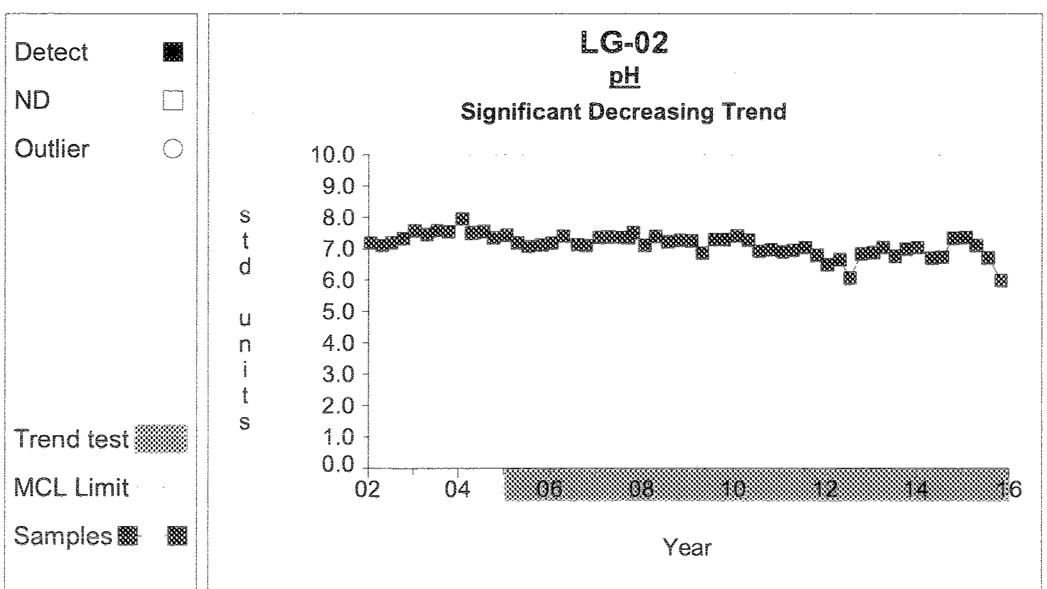
Graph 34

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



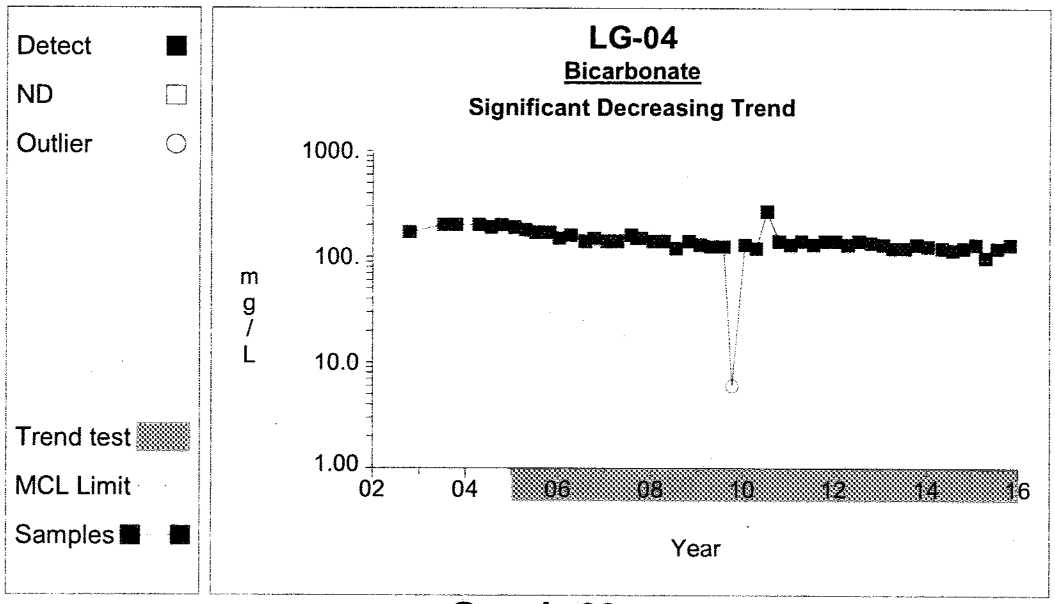
Graph 63

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



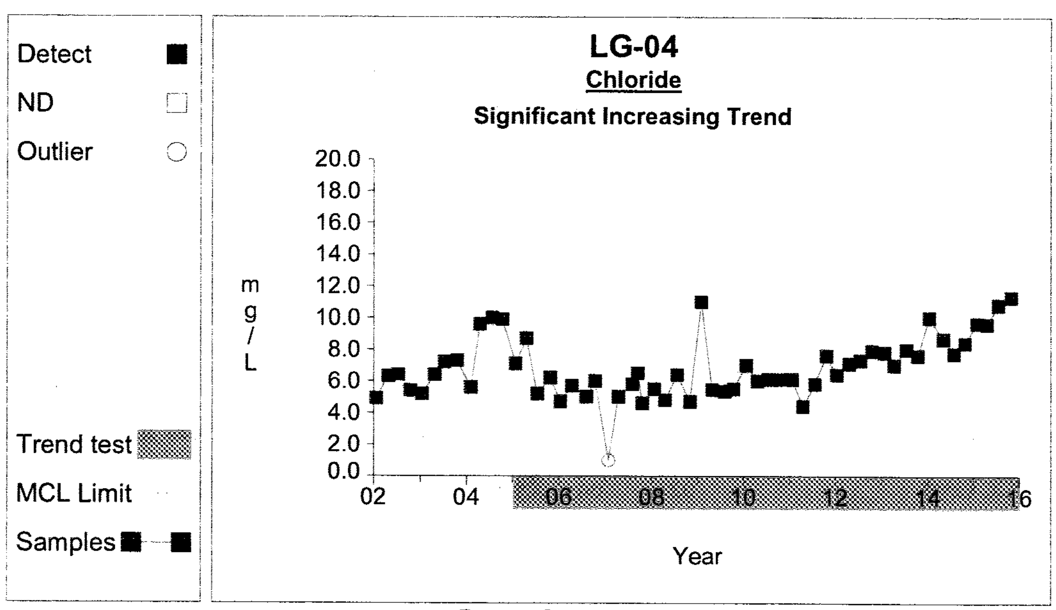
Graph 69

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



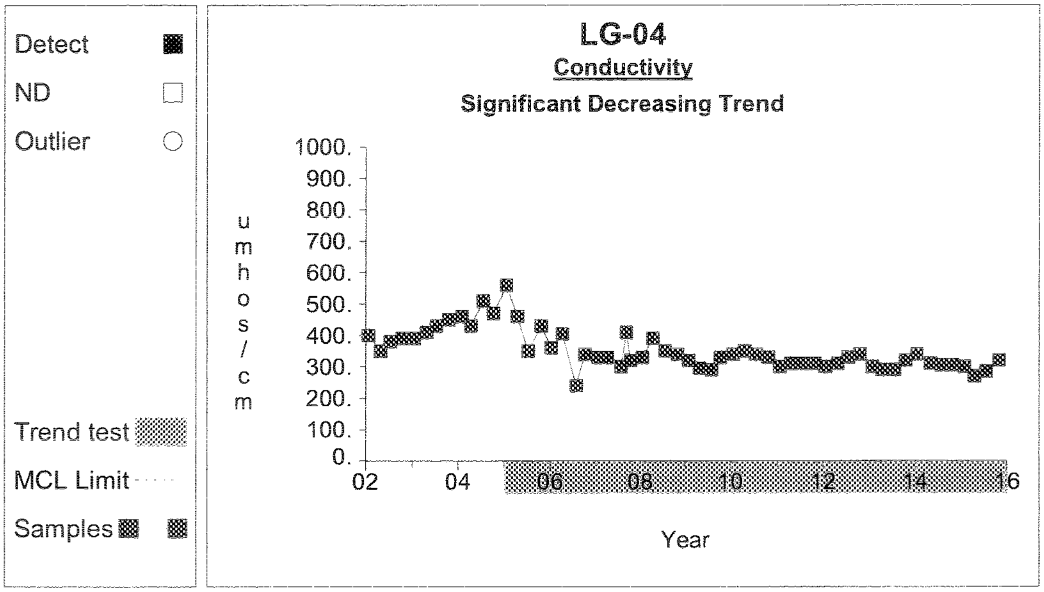
Graph 71

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



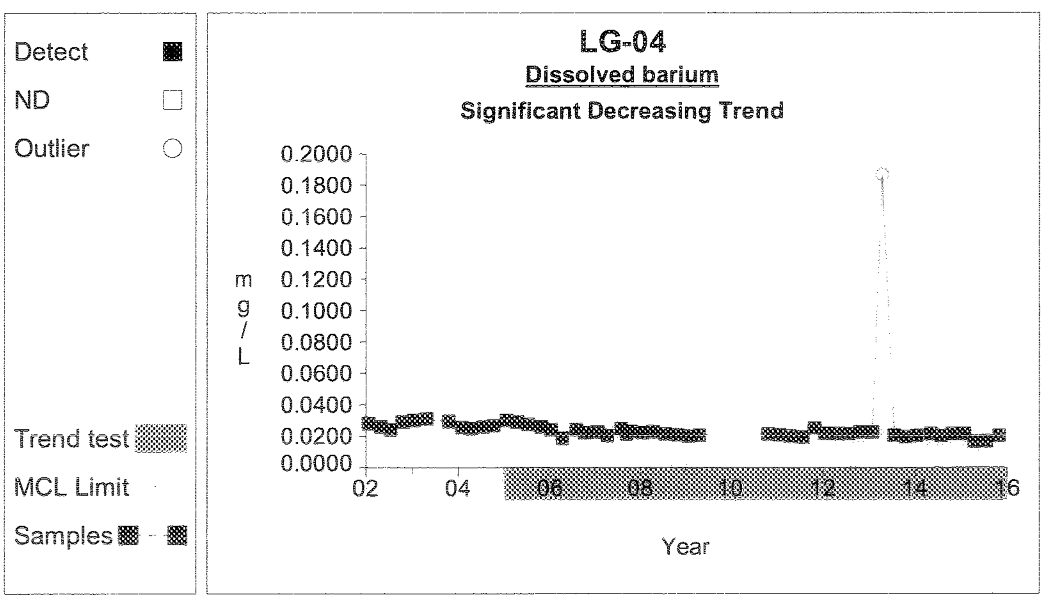
Graph 72

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



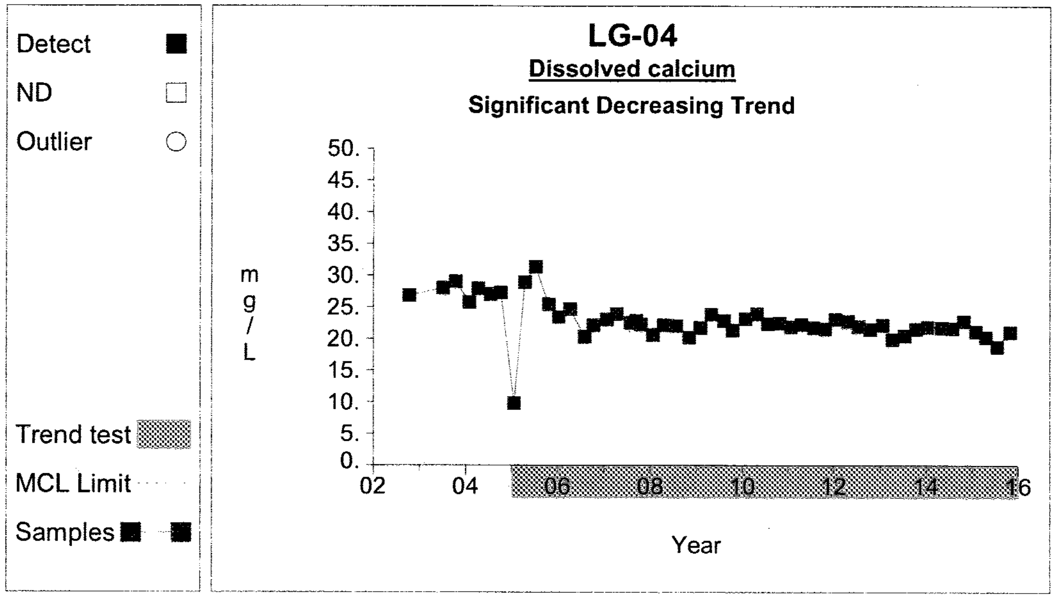
Graph 75

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series

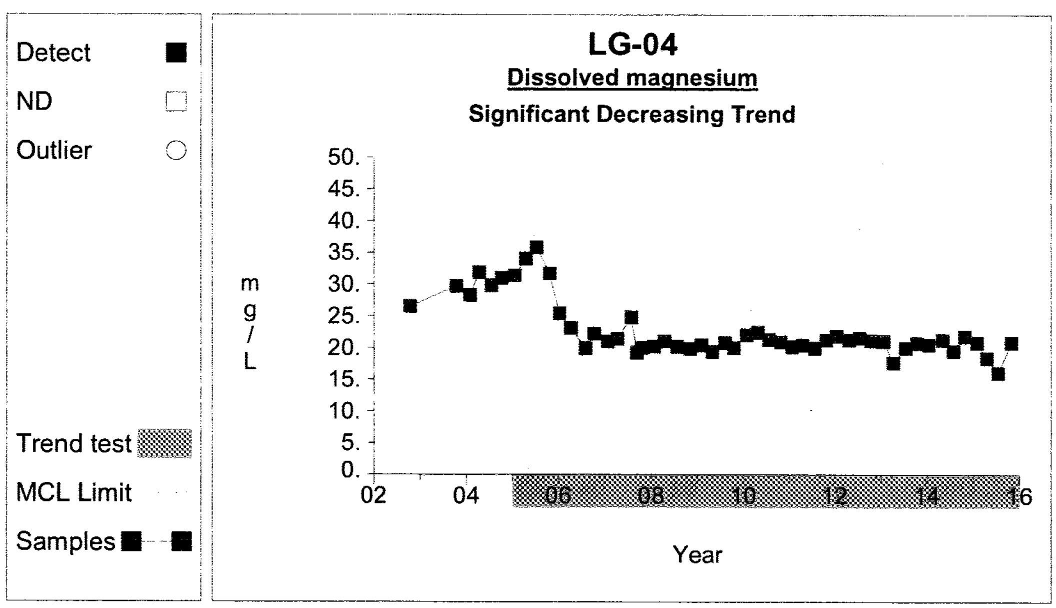


Graph 78

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series

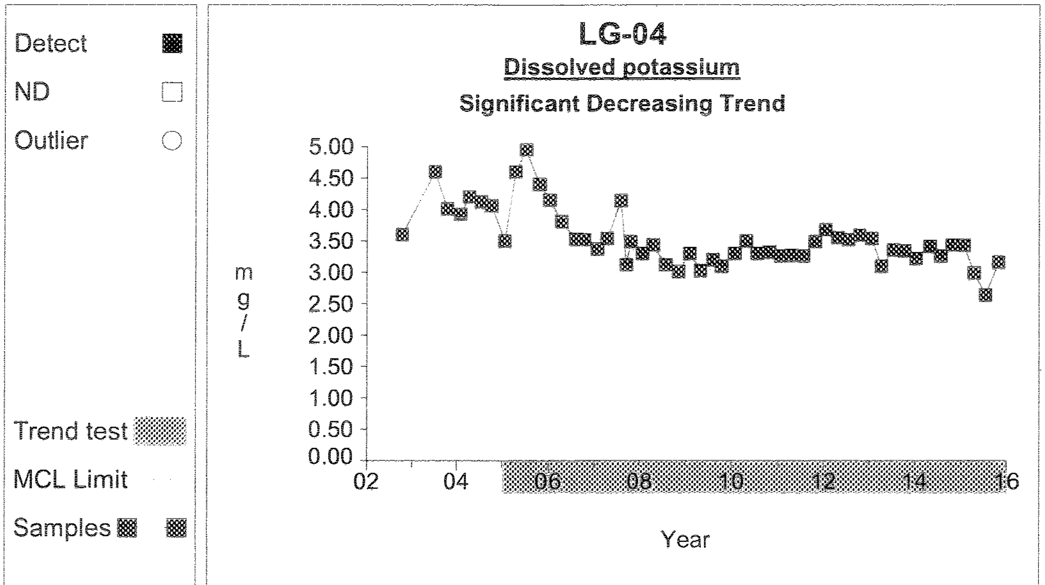


Graph 84

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



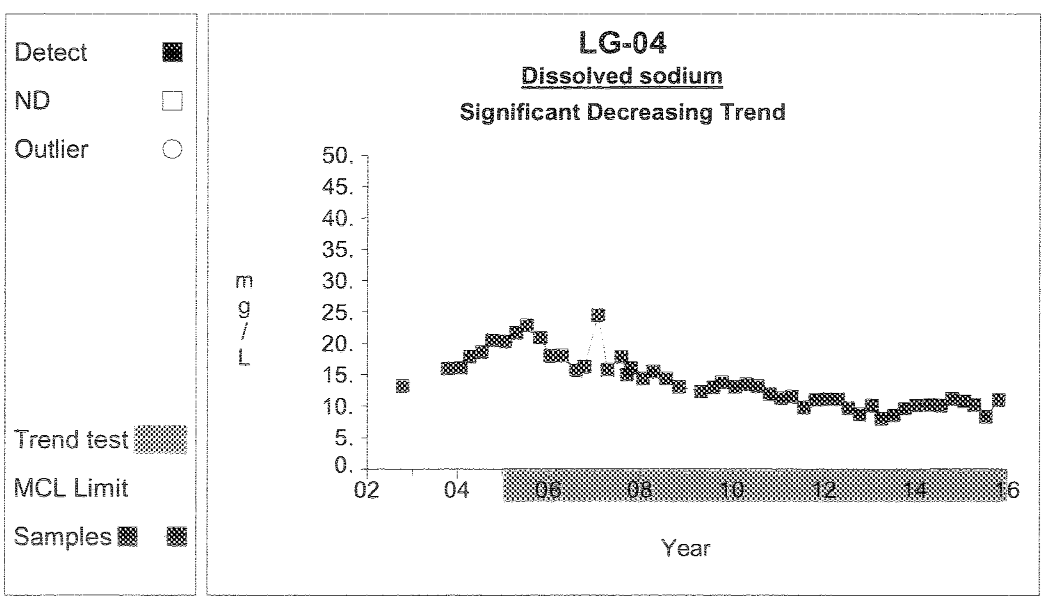
Graph 87

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



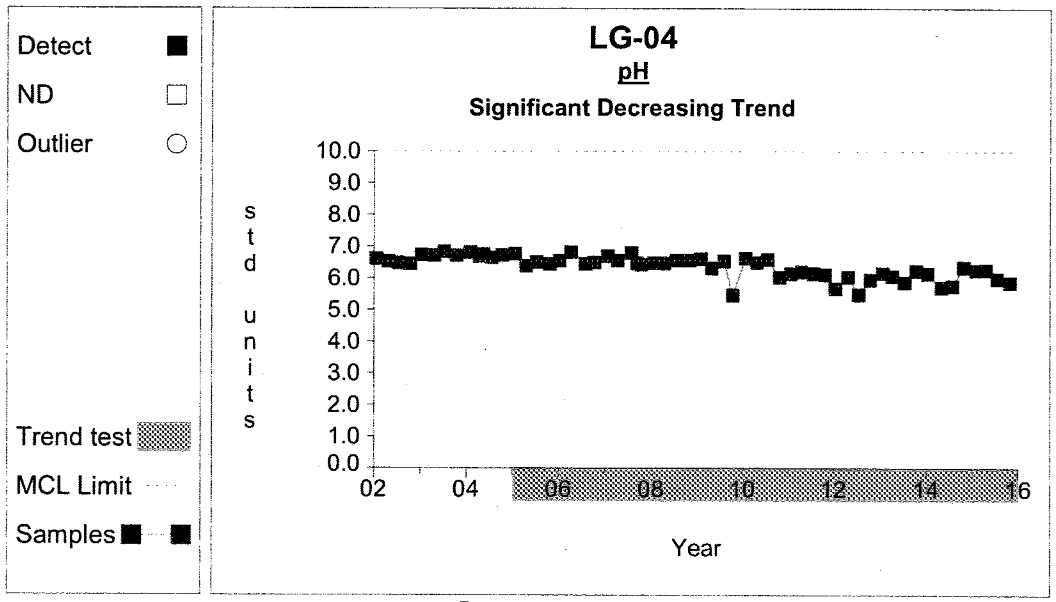
Graph 90

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



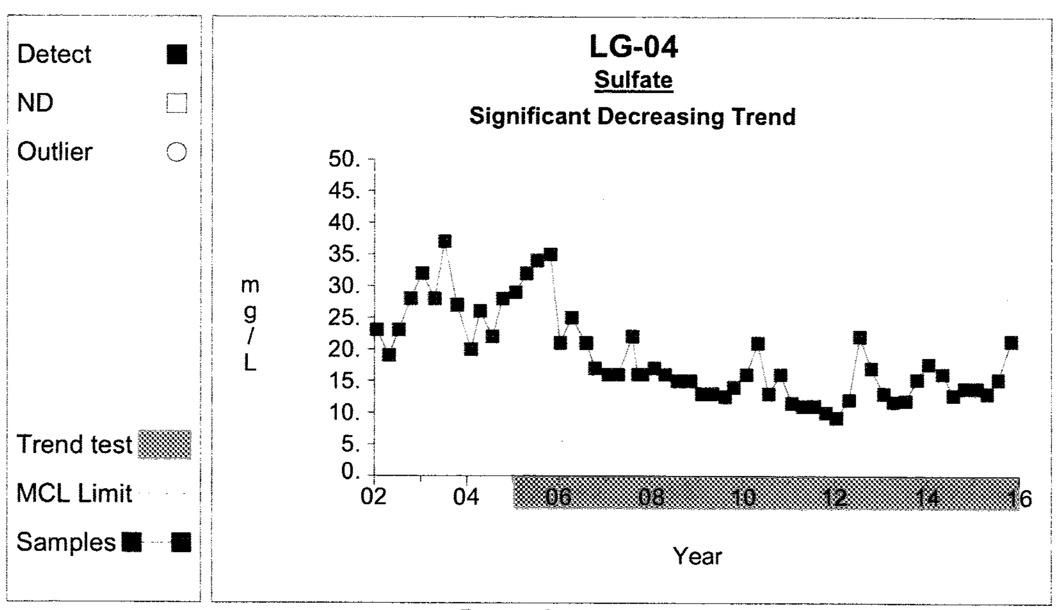
Graph 96

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



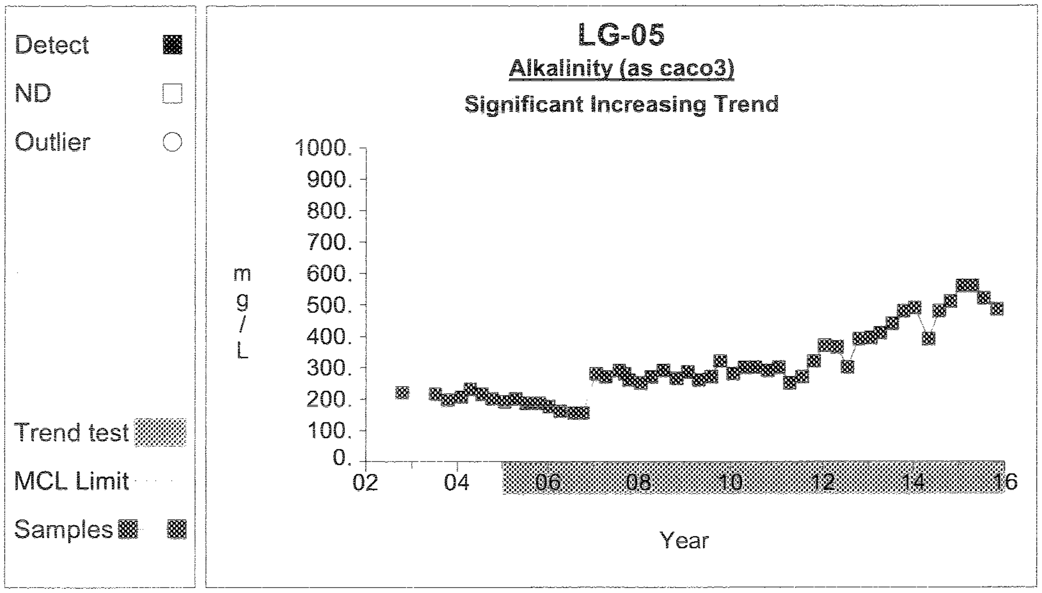
Graph 97

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



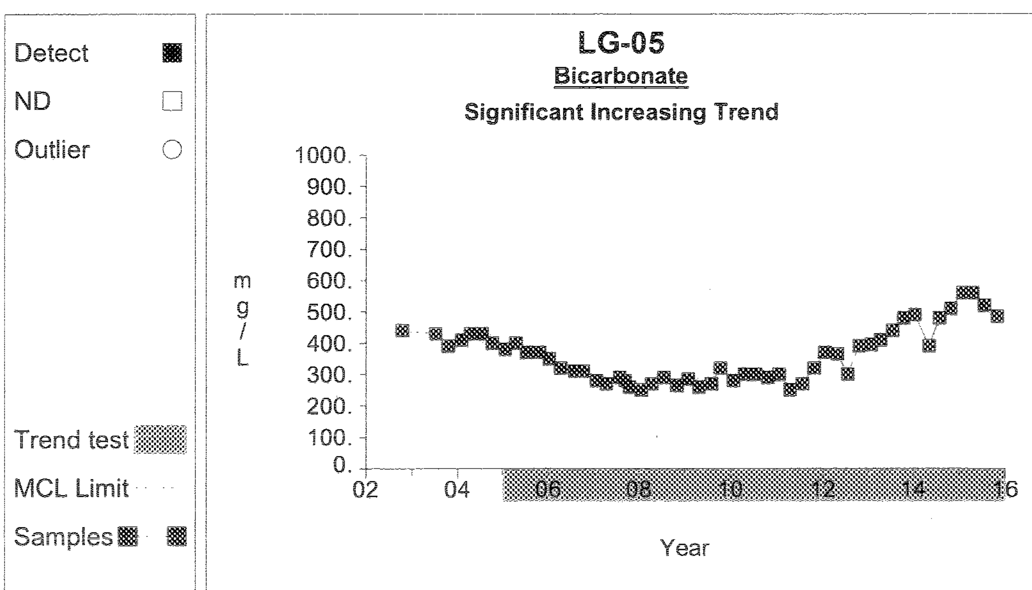
Graph 100

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



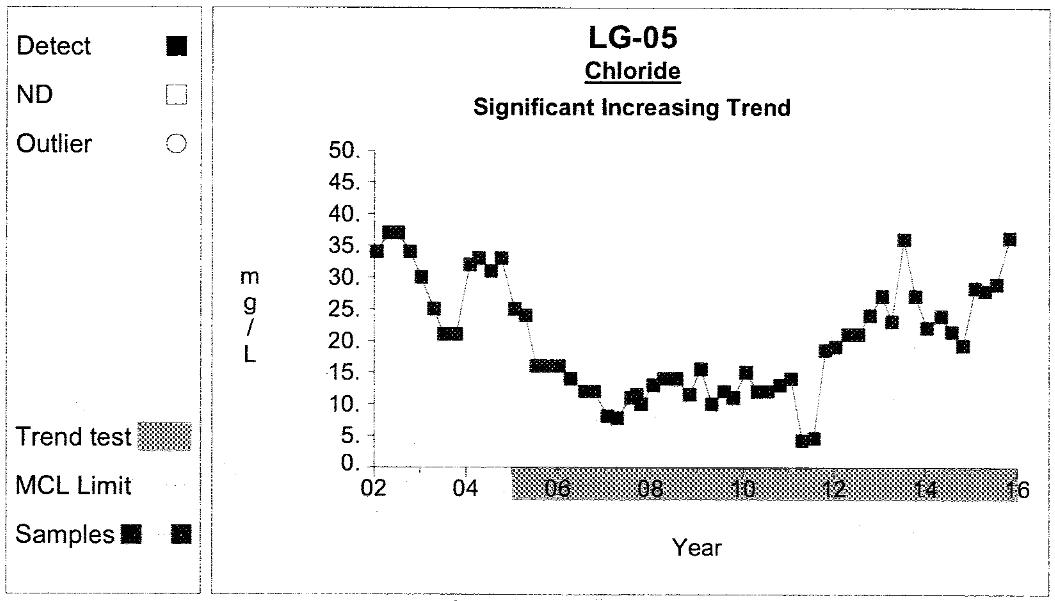
Graph 102

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



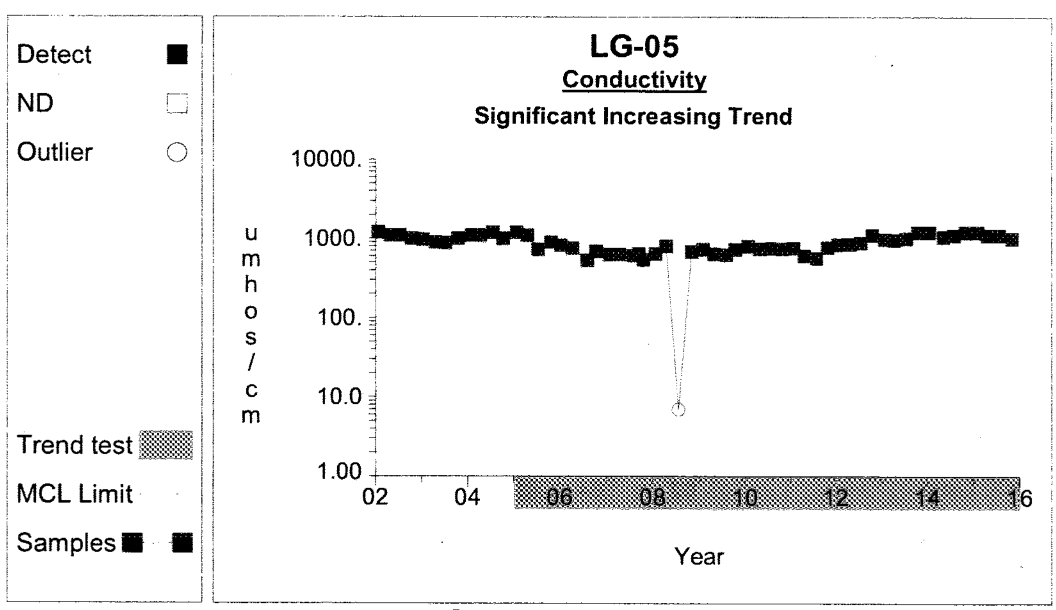
Graph 104

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



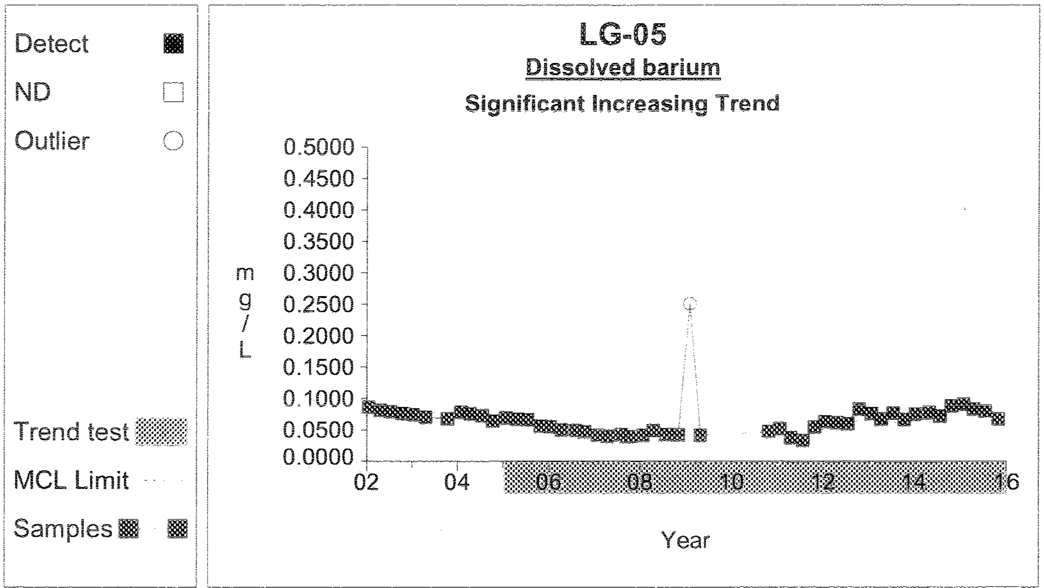
Graph 105

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



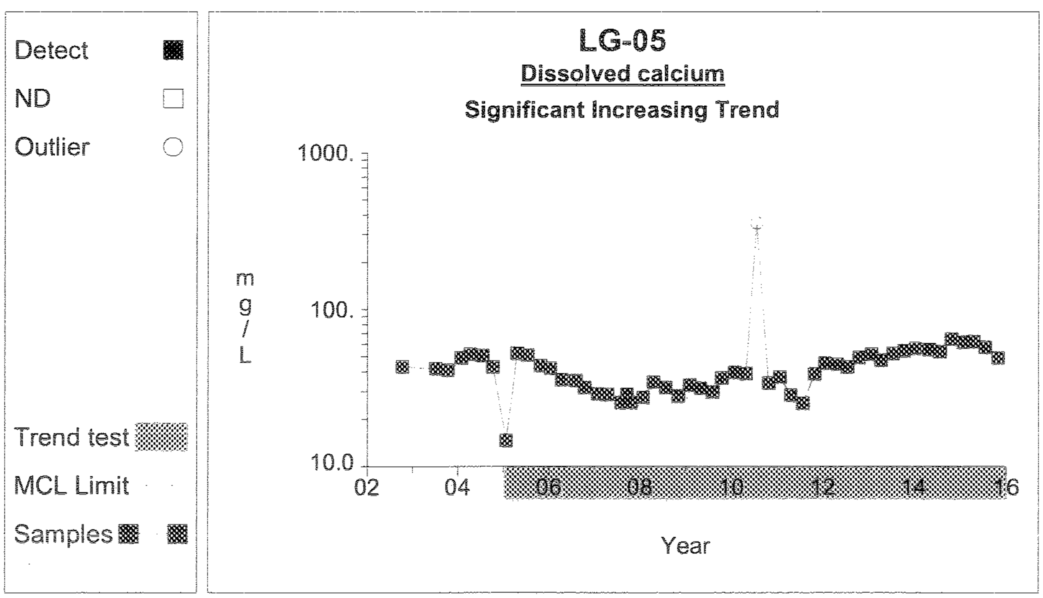
Graph 108

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



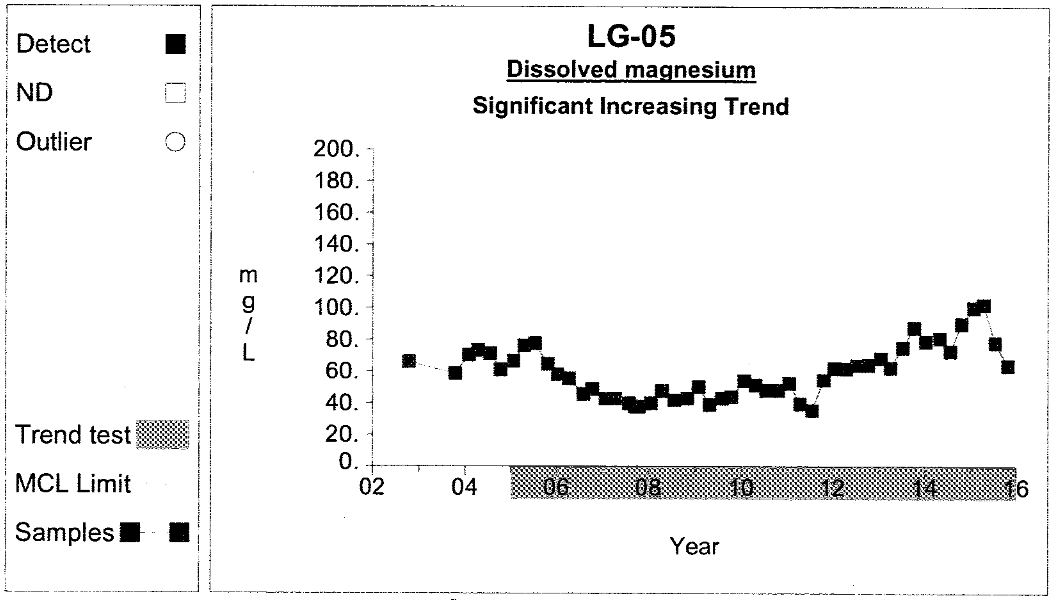
Graph 111

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



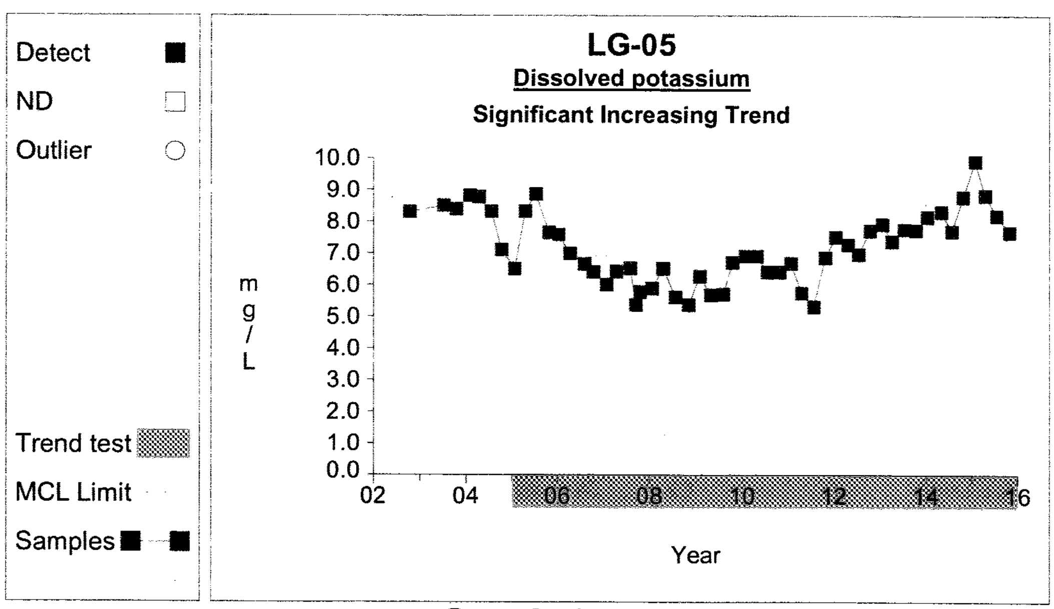
Graph 117

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



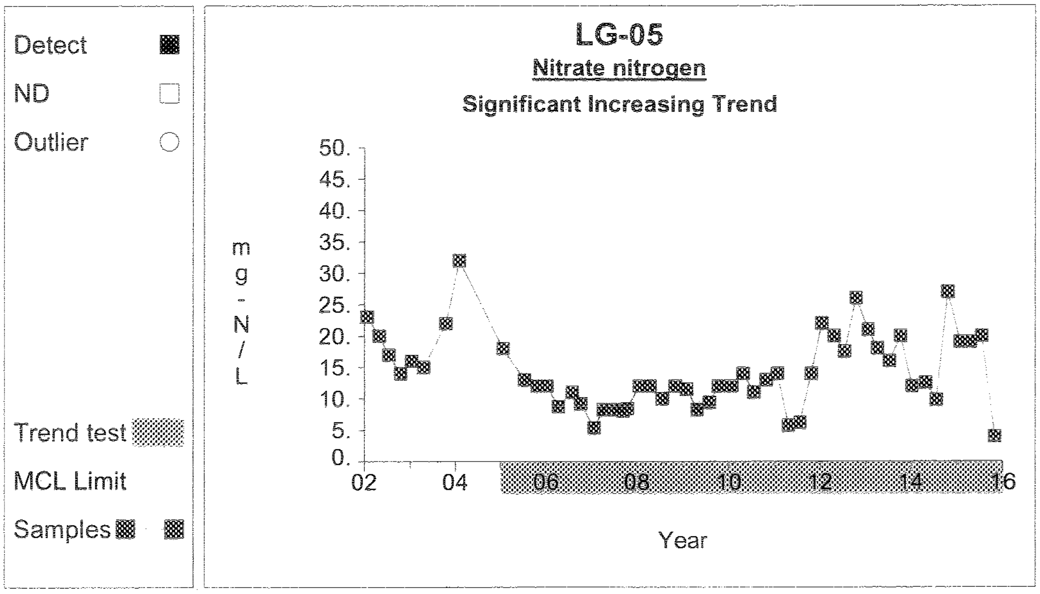
Graph 120

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



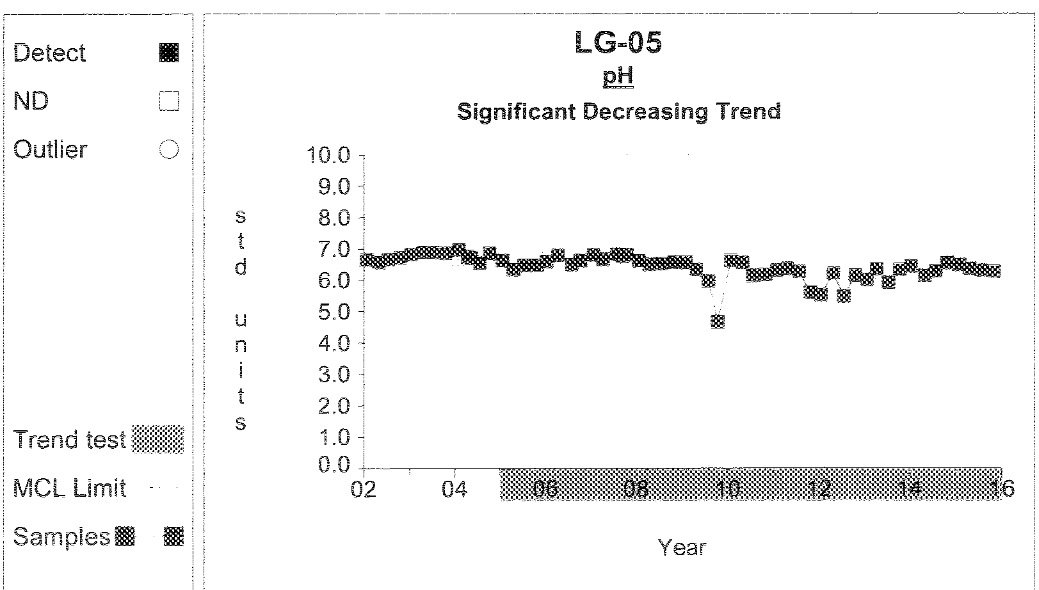
Graph 127

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



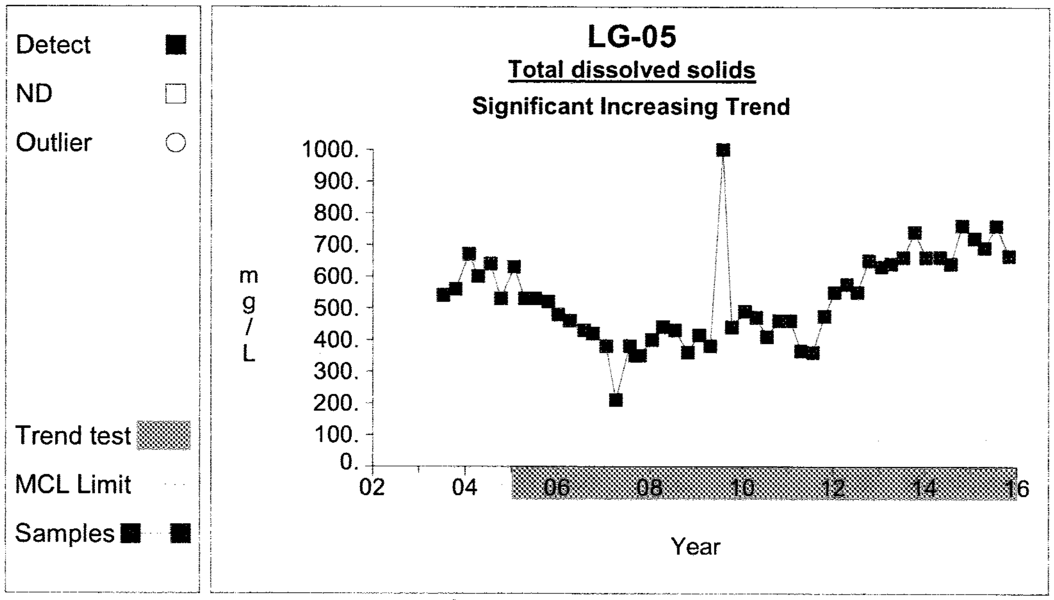
Graph 129

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Time Series



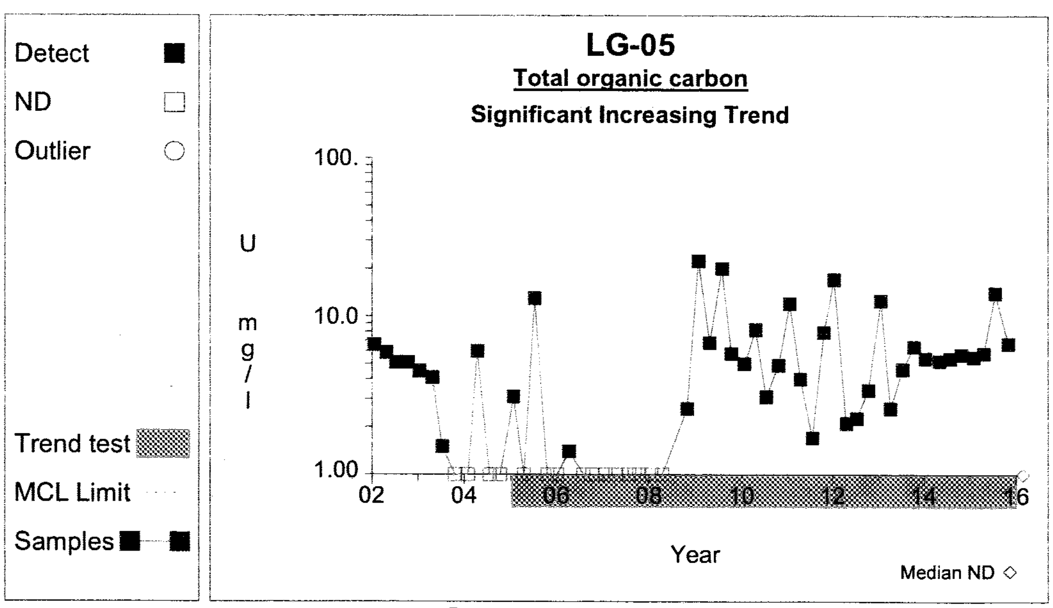
Graph 131

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

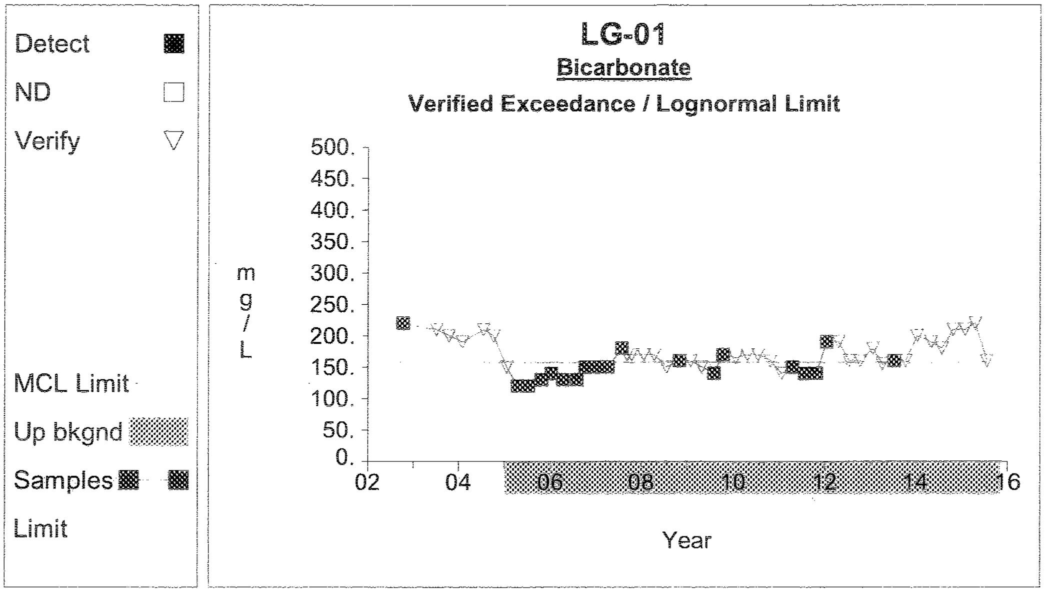
Time Series



Graph 132

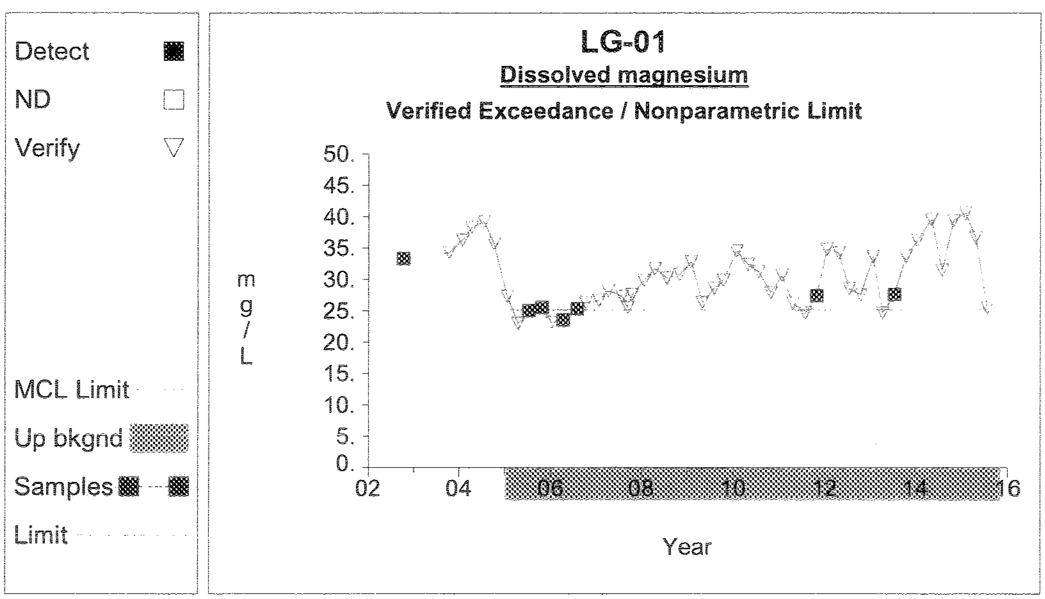
Prepared by: Snohomish County Solid Waste

Up vs. Down Prediction Limits



Graph 3

Up vs. Down Prediction Limits

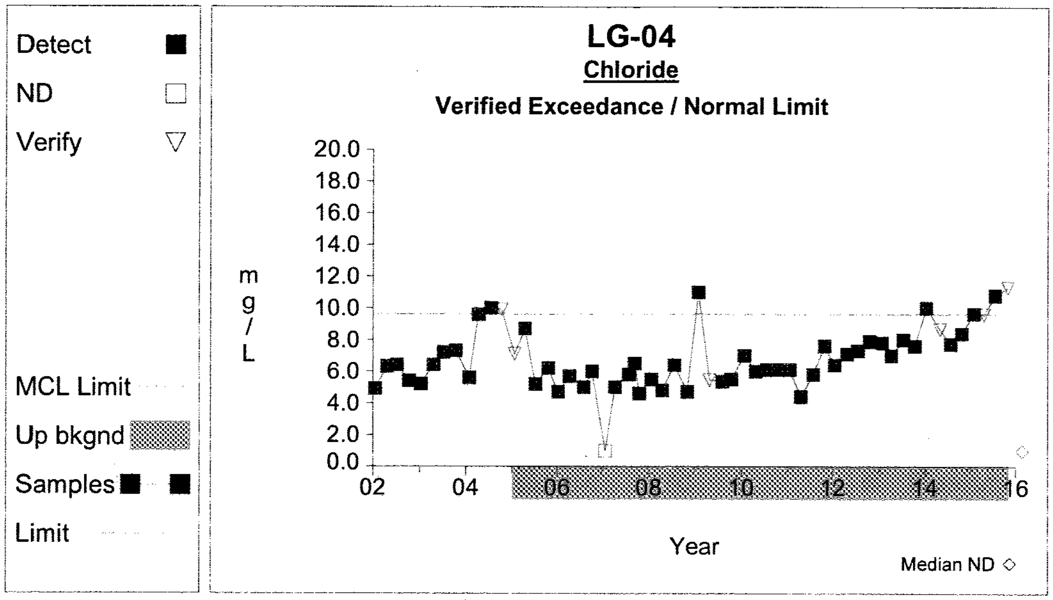


Graph 18

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 38

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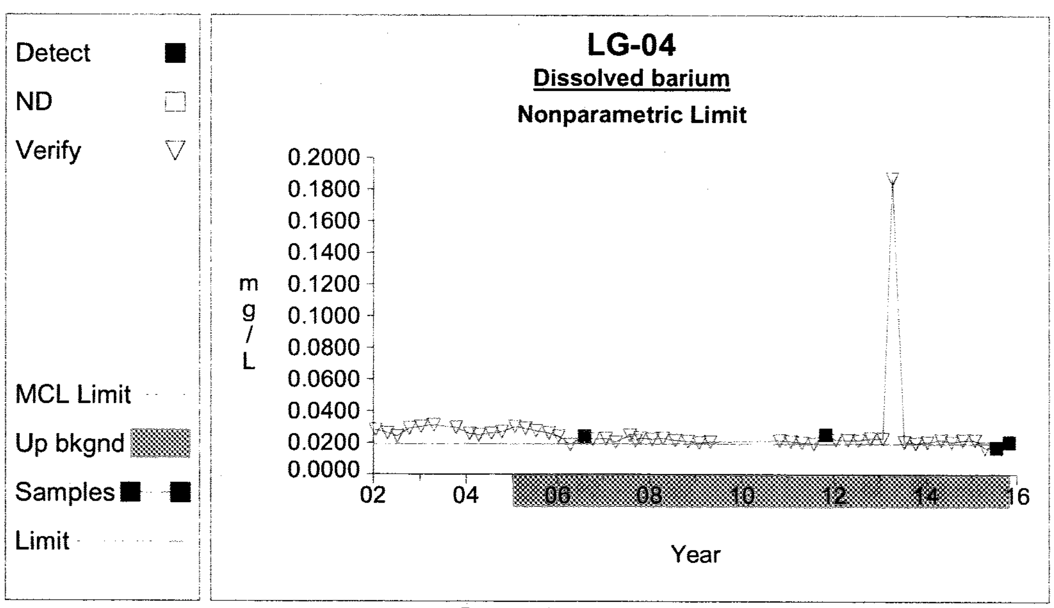
Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



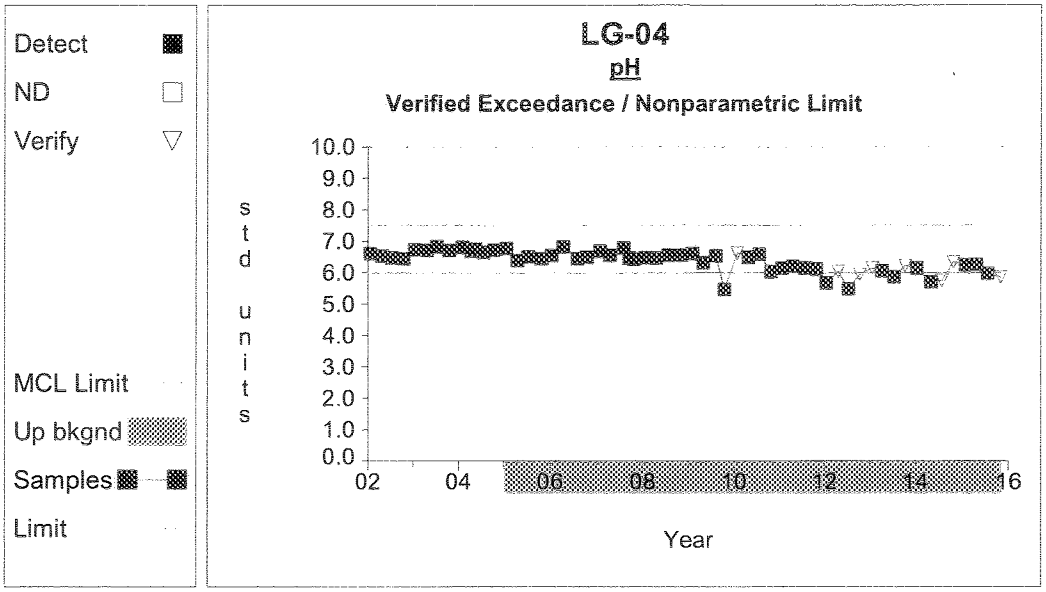
Graph 42

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



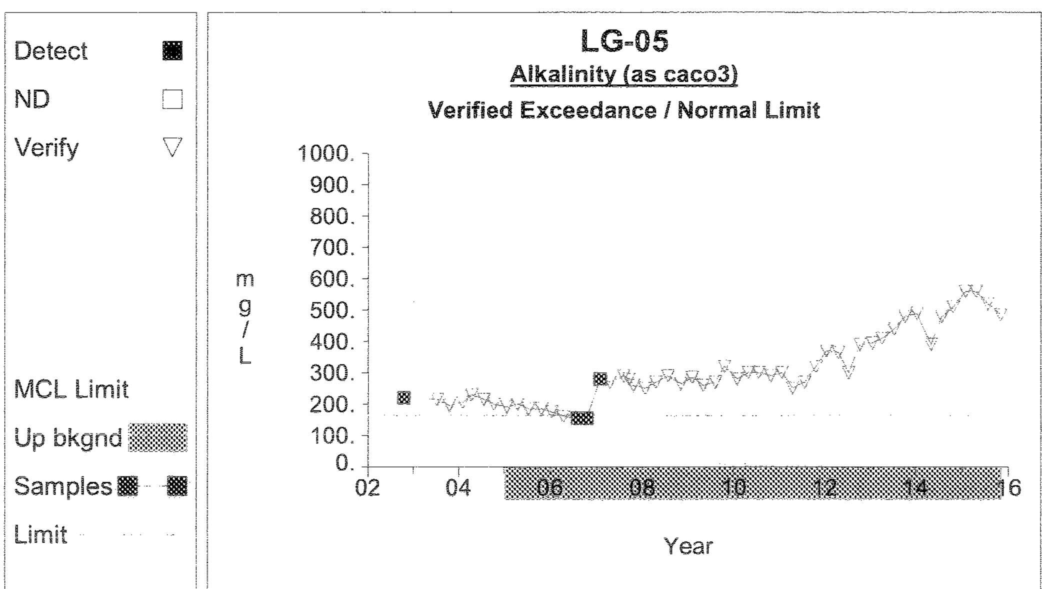
Graph 63

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 67

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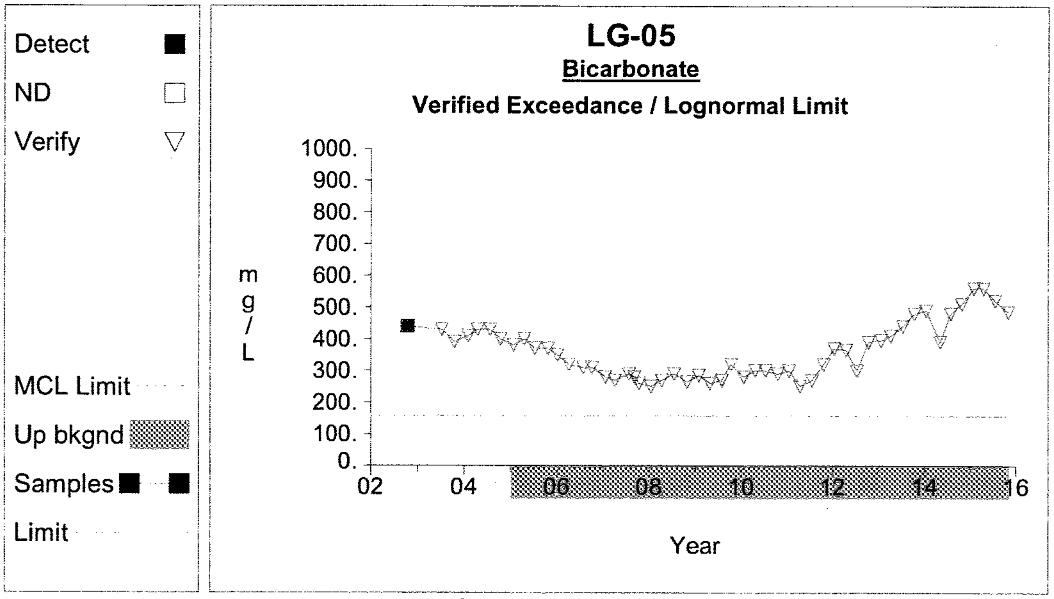
Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 69

7

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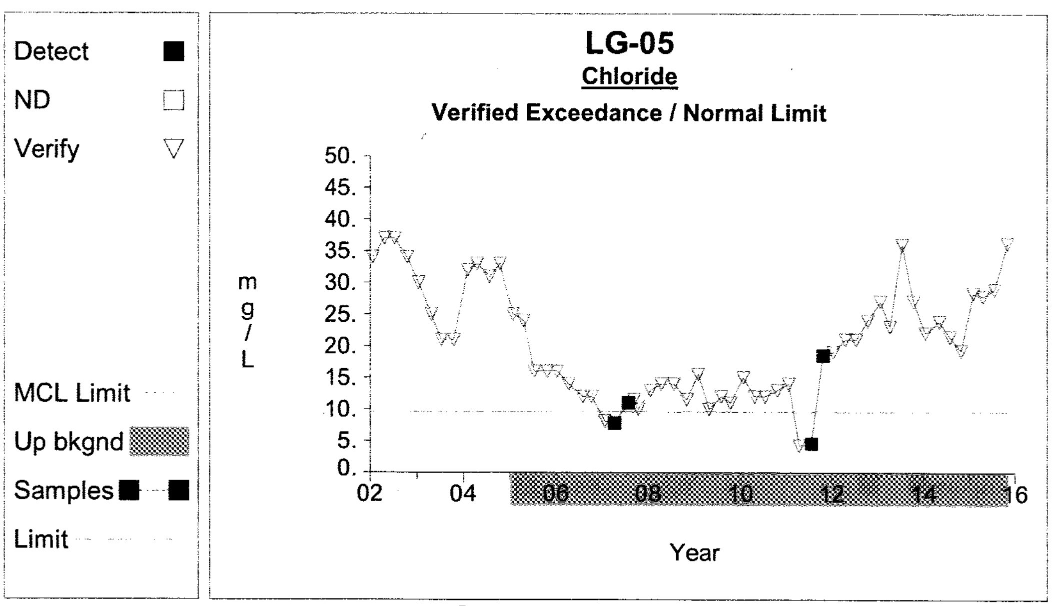
Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 71

8

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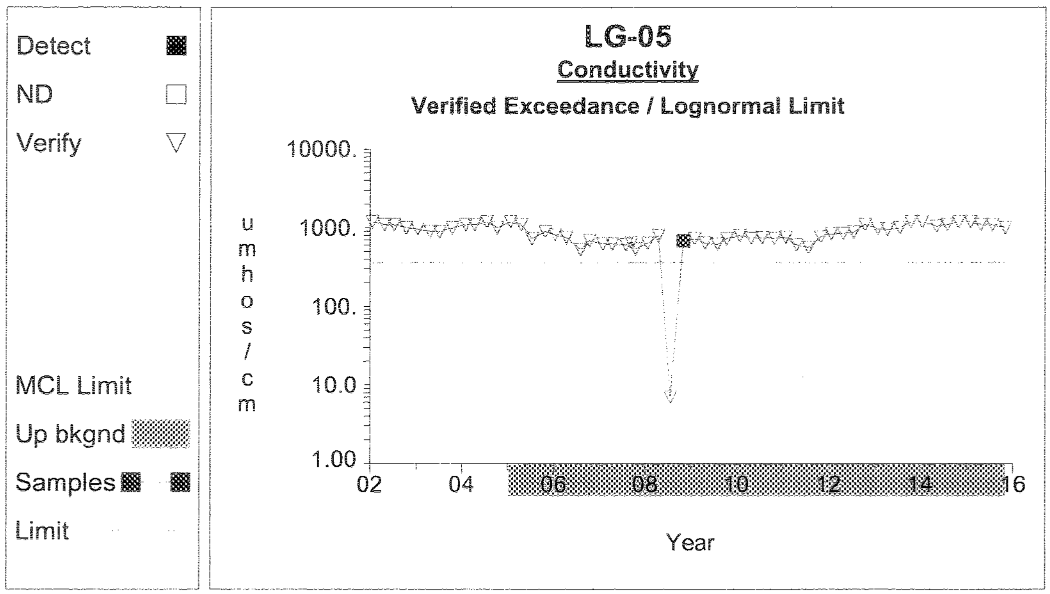
Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



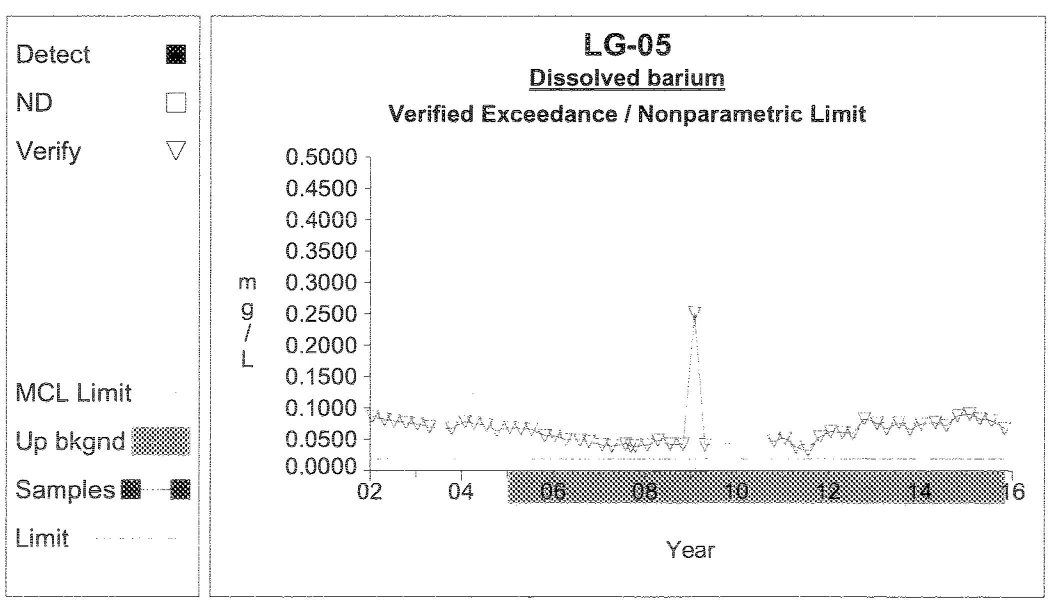
Graph 72

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



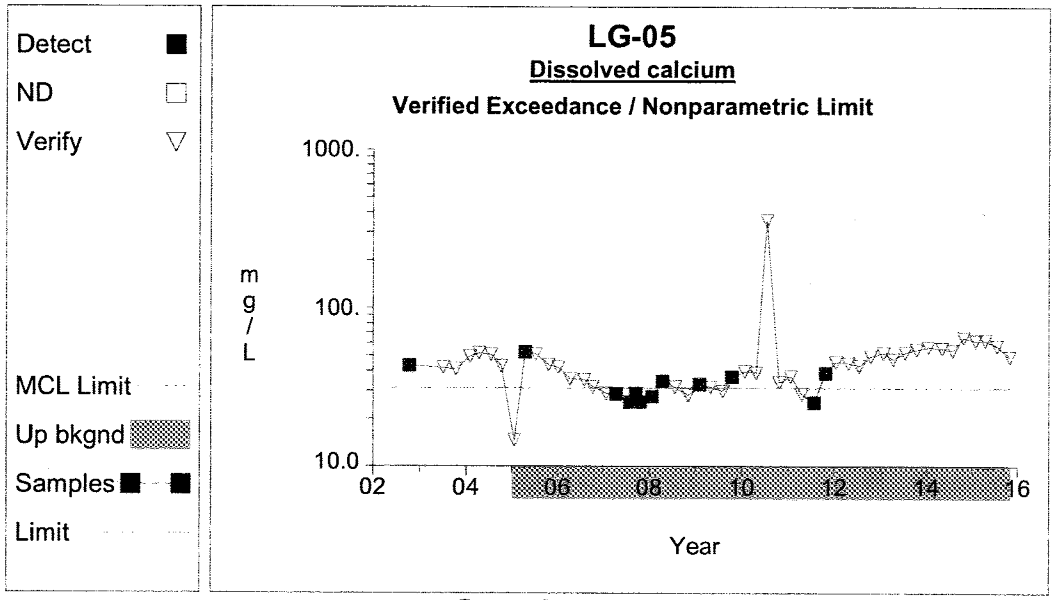
Graph 75

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



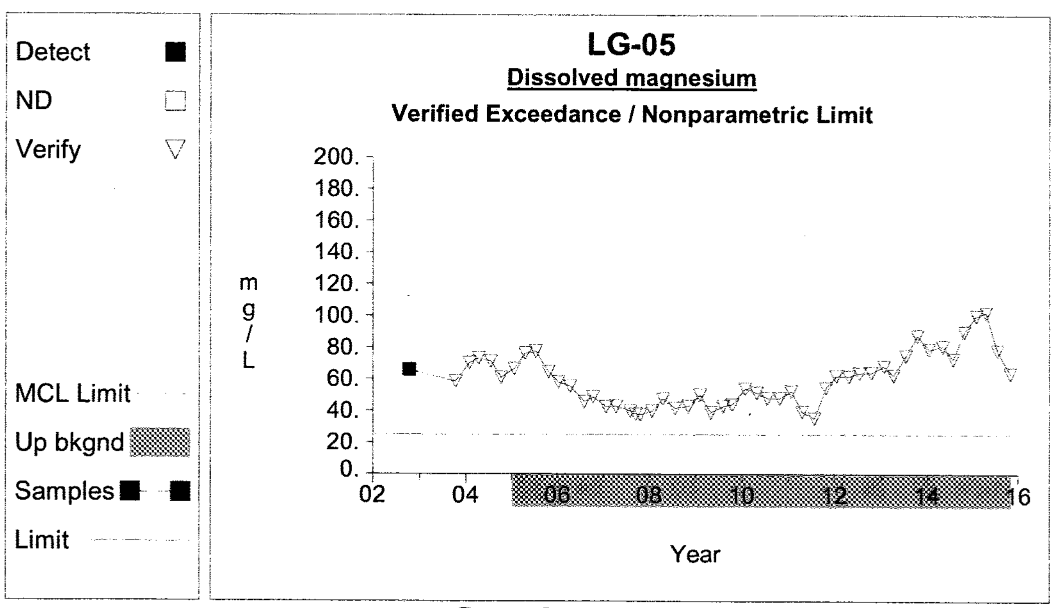
Graph 78

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



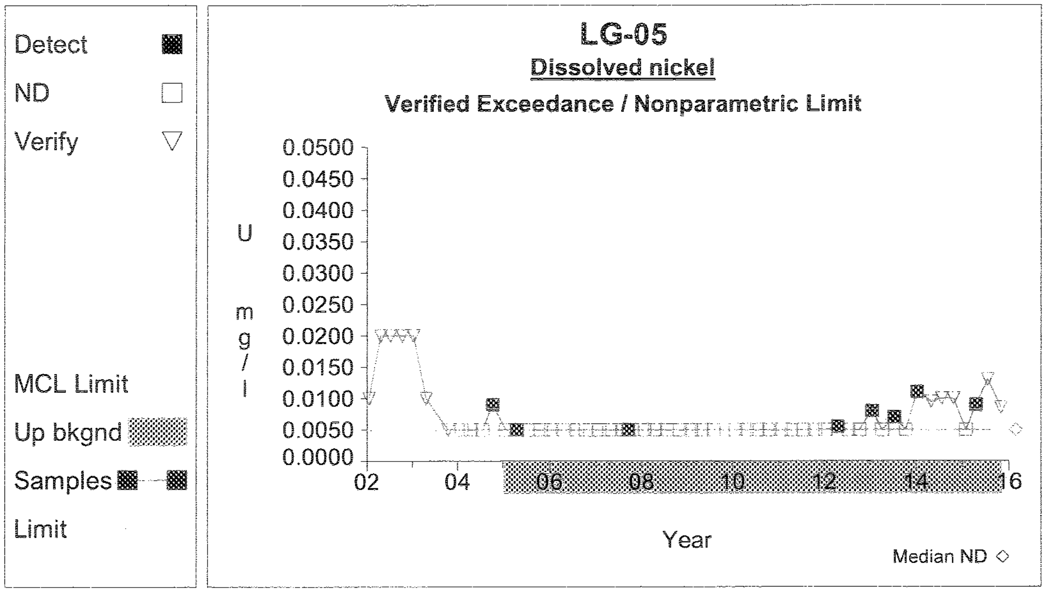
Graph 84

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 86

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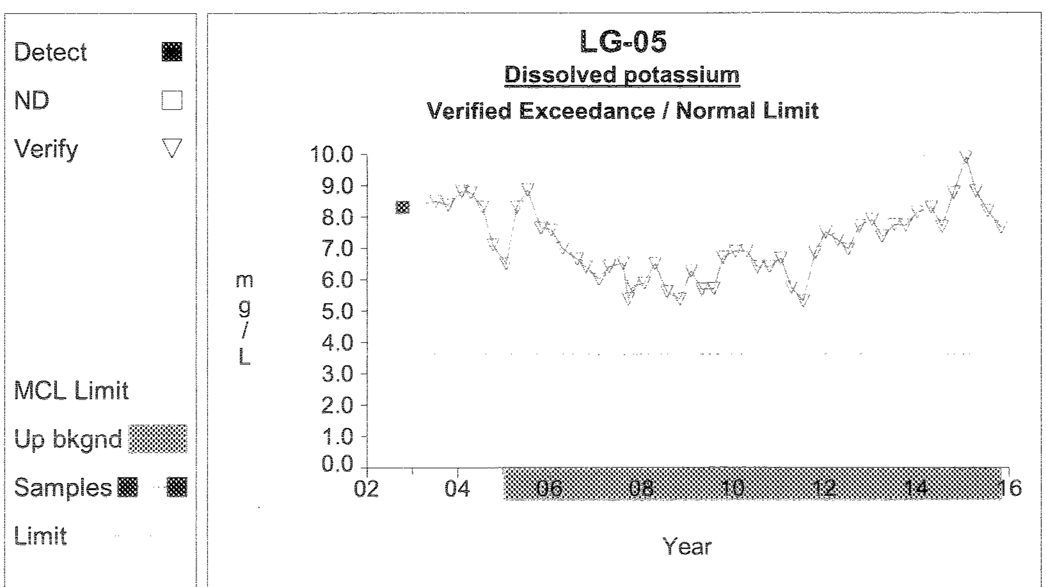
Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



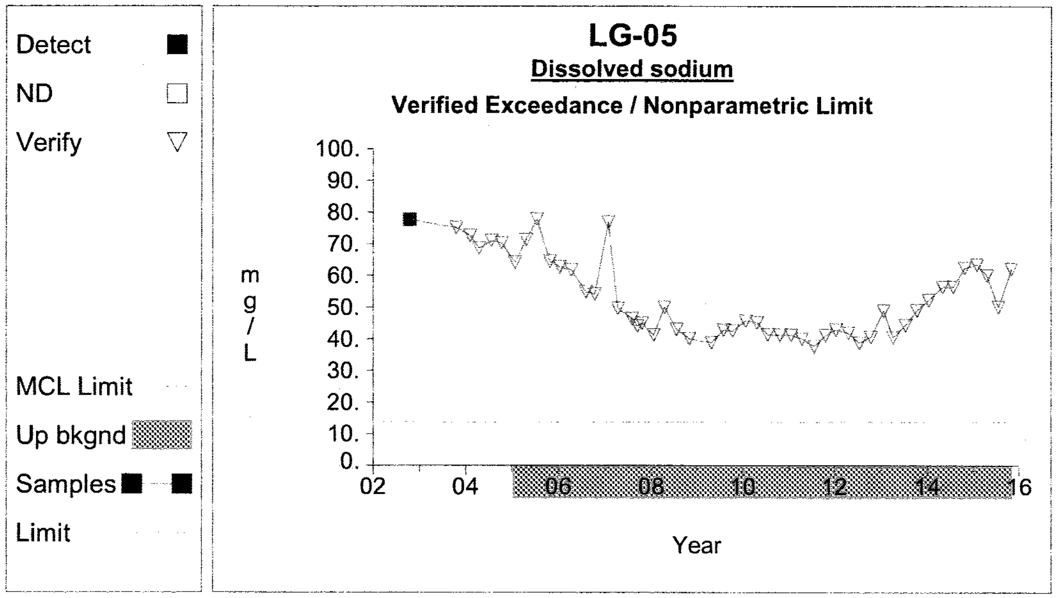
Graph 87

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 90

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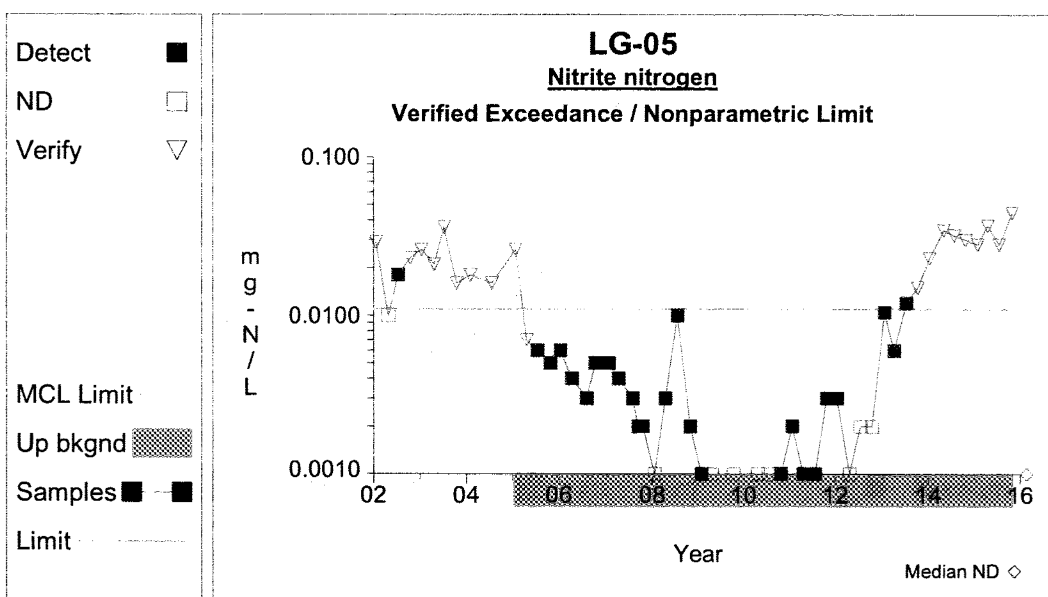
Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



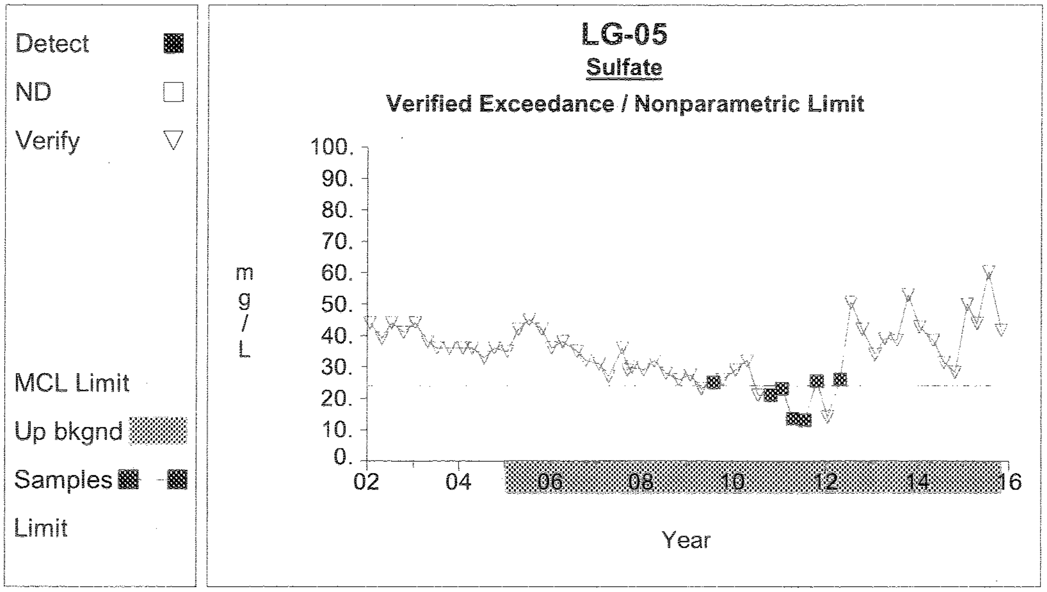
Graph 95

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



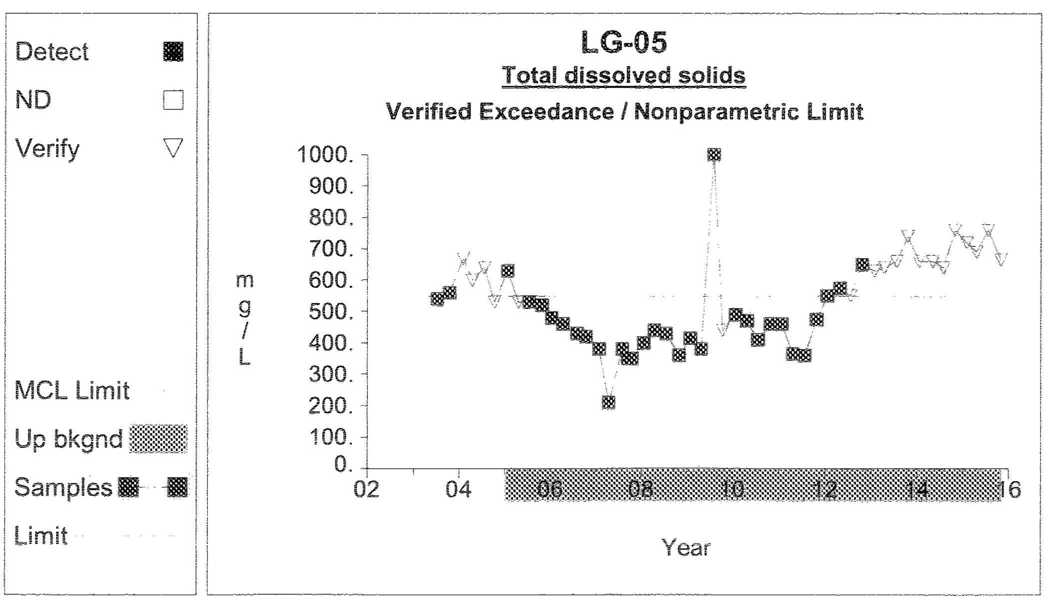
Graph 97

Prepared by: Snohomish County Solid Waste

Goodwin Landfill

Analysis prepared on: 5/10/2016

Up vs. Down Prediction Limits



Graph 98

Prepared by: Snohomish County Solid Waste