May 17, 2022

Ana Cortez
City of Carnation
P.O. Box 1238
4621 Tolt Avenue
Carnation, Washington 98104-1238

Jeromeo Cruz
Solid Waste, Rodents, and Zoonotics Program
Public Health Seattle & King County
401 5th Ave Ste 1100
Seattle, Washington 98104

Attn: Ana Cortez & Jeromeo Cruz
Re: Groundwater and Methane Monitoring Results, 2021 Annual Report
Carnation Landfill

Dear Ana and Jeromeo:

This letter summarizes groundwater chemistry, groundwater flow, and landfill gas data for 2021 at the closed Carnation landfill. This report is consistent with requirements set forth in WAC 173-304. Groundwater sample collection occurred quarters 1, 2, 3, and 4 during 2021, with analytical services provided by Analytical Resources Incorporated of Tukwila, WA and Edge Analytical of Burlington, WA, both Washington State Certified Laboratories. For Quarter 1 (Q1) and Quarter 3 (Q3) of 2021, sampling only occurred at MW-2D rather than all wells (which occurs in Q2 and Q4), which is consistent with the Sampling and Analysis Plan (SAP) (PGG, 2019). During each quarter field parameters (pH, specific conductance, and temperature), VOCs, and select metals (arsenic, iron, and manganese) were monitored. In Q2 nitrate and sulfate are also monitored, while in Q4 multiple natural attenuation parameters (dissolved oxygen, oxidation reduction potential, alkalinity, ferrous iron, nitrate, and sulfate) are sampled from all wells, as specified in the SAP.

Methane monitoring results from 2021 are also summarized in this report, with methane concentrations measured in the field using a landfill gas meter.

SUMMARY

Sampling results indicate some impact due to the landfill in downgradient monitoring wells. Five compounds exceeded their respective GWCLs during 2021 including dissolved arsenic, dissolved iron, dissolved manganese, pH, and vinyl chloride.

Confidence intervals (CIs) were calculated for current well-constituent pairs which have had multiple historical exceedances, with the CIs constructed around the average, geometric mean, or median concentration of each population (depending on the distribution) and compared to GWCLs. In cases where background concentrations consistently exceed a GWCL (as with arsenic), non-parametric prediction limits were calculated, with downgradient concentrations compared to the prediction limit. Out of the 31 well-constituent pairs tested, 17 pairs significantly differ from GWCLs or background concentrations. MW-2D has the greatest number (five) of significantly different well-constituent combinations.

Trend analyses found one statistically significant increasing trend out of 187 well-constituent combinations analyzed, and five significant decreasing trends were detected. Out of the 40 well-constituent pairs that have historically exceeded GWCLs, no increasing trends were detected and one decreasing trend was detected. However, when all trend test p-values are adjusted for the number of tests performed, no well-constituent pair had a statistically significant trend.

Groundwater flow directions and horizontal gradients remained relatively consistent throughout the year, with flow generally to the west-northwest in the shallow aquifer and north in the deep aquifer. Gradients ranged from 0.026 to 0.033 in the shallow aquifer zone and were 0.028 to 0.029 in the deep aquifer zone. Based on these gradients and existing hydraulic conductivity data, groundwater flow underneath the landfill has an expected velocity of approximately 4.4 ft/day and 1.2 ft/day for the shallow and deep aquifer zones.

Landfill gas sampling indicates that exceedances of the LEL occurred in landfill gas vents V-1, V-3, and V-4, while no exceedances occurred in landfill gas wells.

DEVIATIONS FROM THE SAMPLING AND ANALYSIS PLAN

All groundwater samples were collected in accordance with the SAP (PGG, 2019), except for MW-6S (which was dry or nearly dry all quarters). For landfill gas monitoring, all samples were collected according to the SAP except for that wells M-3 and M-4 were not sampled in 2021 Q2 due to health and safety concerns (hornet nests were present inside the well monuments).

COMPOUNDS DETECTED IN GROUNDWATER

A summary of Ground Water Contaminant Level (GWCL) exceedances is presented in Table 1, while Table 2 tabulates detections of volatile organic compounds. Figures 1 through 11 present time series plots of frequently detected VOCs, field parameters, dissolved metals (arsenic, iron, manganese), nitrate, and sulfate. Concentrations of VOCs in Figures 1 through 3 generally have a long-term decreasing trend or no apparent trend. The metals, field parameters, and conventional parameter plots indicate that most constituents were within their historical ranges during 2021 (historical high concentrations are mentioned below).

GWCL Exceedances

Constituents which exceeded their GWCLs in 2021 include vinyl chloride (VC), dissolved arsenic, dissolved iron, dissolved manganese, and pH. Exceedances are discussed below:

- **VC** at MW-2D and MW-5S exceeded the GWCL (0.02 ug/L) during Q4, with exceedance concentrations ranging from 0.027 to 0.036 ug/L. During the first three quarters VC was not detected. Figure 3 is a time series plot of VC data.
- **Dissolved arsenic** was detected and exceeded the GWCL (0.05 ug/L) in ten of the 11 monitoring wells sampled. The presence of arsenic in up-gradient background wells (MW-1S and MW-1D) indicates that it is naturally elevated in the aquifer. However, highly elevated arsenic concentrations in well MW-2D (frequently one to two times higher than any other well), suggests that the landfill likely affects metals concentrations. Elevated arsenic is not likely derived from landfill waste, but from reducing conditions caused by the landfill that result in dissolution of metals from aquifer material. A historical high dissolved arsenic concentration was detected at MW-5S in 2021 Q2 (6.1 ug/L).
- **Dissolved iron and manganese** have been detected above their respective GWCLs (300 ug/L and 50 ug/L) consistently in down-gradient wells MW-2D and MW-6D. Additionally, cross-gradient monitoring well MW-3S consistently exceeds the manganese GWCL and frequently exceeds the iron GWCL. The elevated metals concentrations are likely due to reducing conditions imposed by the landfill at MW-2D and MW-6D, and local reducing conditions at MW-3S.

  Downgradient well MW-2S also exceeded the iron and manganese GWCLs in 2021. At MW-2S metals concentrations (including arsenic) have frequently exceeded their GWCLs since 2017 Q4. These concentration spikes are potentially tied to root matter observed growing into the well via the screen (which was confirmed with a downhole video survey in 2019 Q4). It is thought that the addition of organic carbon from the root matter has caused geochemical conditions to become reducing at MW-2S, thus mobilizing metals from the aquifer material surrounding the well.

- Multiple wells had **pH** values outside of the GWCL pH range (6.5 - 8.5 standard units) during one or more quarters. Wells in this category had the following exceedance ranges in 2021: MW-1S (6.41 - 6.43), MW-2D (6.19 – 6.40), MW-2S (5.74 - 5.76), MW-3S (6.05), MW-5S (6.26 – 6.48), MW-7D (5.82 - 6.11), and MW-8D (6.43).

Other Detected VOCs

Detected VOCs which did not exceed their GWCLs in 2020 include acetone, acrylonitrile, cis-1,2-dichloroethene (cis-1,2-DCE), dichlorodifluoromethane (CFC 12), and styrene. Several VOCs with frequent historic detections (1,1-dichloroethane, chloroethane, carbon disulfide, and toluene) were not detected in 2021. All detections are summarized below and in Table 2:

- **Acetone** was detected at MW-1S and MW-2S in 2021 Q2 and at all wells in 2021 Q4. Acetone does not have a GWCL and has occasionally been detected at landfill wells, but has not previously been detected at all wells in the same quarter. It is also a common laboratory contaminant (EPA, 2014), and therefore it is possible that the sporadic detections could be associated with laboratory error.
- **Acrylonitrile** was detected at MW-1S and MW-5S in 2021 Q2 at concentrations below the GWCL 0.07 ug/L. Both wells had observed concentrations of 0.061 ug/L. Acrylonitrile has somewhat frequently been detected at MW-5S (its last detection in 2020 Q2) and occasionally at MW-1S (its last detection was 2015 Q1) (Figure 2).
- **Cis-1,2-DCE** was detected at MW-2D during 2021 Q3 and Q4, and had an annual concentration range from non-detect (less than 0.2 ug/L) to 0.26 ug/L. This range is significantly below the GWCL (70 ug/L). The historical range for cis-1,2-DCE at MW-2D is less than 0.20 to 1 ug/L.
- **Dichlorodifluoromethane** (CFC 12) was detected at MW-5S in 2021 Q4 at a concentration of 0.25 ug/L. It has no GWCL and not been previously detected at any landfill well.
- **Styrene** was detected at MW-3D in 2021 Q4 at a concentration of 0.21 ug/L. This is well below its GWCL (100 ug/L), and previously styrene has only been detected at low concentrations at MW-5S.

GROUNDWATER ELEVATIONS AND FLOW DIRECTIONS

Groundwater generally flows to the northwest in the shallow aquifer zone and roughly north in the deep aquifer zone. Figures 12 and 13 show groundwater flow directions in the deep and shallow aquifer, with the data presented from 2021 Q4.

Seasonal groundwater flow directions are generally consistent, though regions of the shallow aquifer (near MW-2S and MW-5S) have been observed dry during the third quarter of most years, and the region near MW-6S appears effectively dry (0.56 ft is the maximum amount of water observed in the well, and based on water level fluctuations it appears to be mostly stagnant endcap water). Water levels this year were observed to fluctuate between 2.45 to 4.35 ft in the deep aquifer zone and from 3.14 to greater than 5.47 ft in the shallow aquifer zone, as shown in Table 3. The larger relative range for annual water level fluctuations in the shallow aquifer is likely due to the presence of a low permeability unit (the semi-confining layer) underlying the shallow aquifer at MW-2S/D, MW-5S/D, MW-6S/D, and MW-8D. Recharging groundwater from precipitation to the shallow aquifer would be impeded from entering the deep aquifer by the confining layer, thereby causing the difference in seasonal head differentials. Additionally, MW-2S is located next to an infiltration basin where runoff from the landfill cap is diverted, likely causing higher local water levels during the winter months.

Horizontal gradients in the shallow and deep aquifer were found to be consistent throughout the year, ranging from 0.026 to over 0.033 in the shallow aquifer zone and 0.028 to 0.029 in the deep aquifer zone. Using horizontal hydraulic conductivities calculated by PGG (2017) of 37 ft/day and 11 ft/day for the shallow and deep aquifer zones, gradients of 0.030 and 0.028 (average shallow and deep gradients respectively), and an effective porosity of 0.25, groundwater velocities are calculated to be 4.4 ft/day for the shallow aquifer zone and 1.2 ft/day for the deep aquifer zone.

METHANE MONITORING RESULTS

Table 4 shows all landfill gas concentrations observed in 2021. Methane exceeded its lower explosive limit (LEL) of 5% at landfill gas vents V-1, V-3, and V-4 and at no landfill gas wells. Historically methane exceedances have been observed at landfill gas well M-5; however, because observations at nearby gas wells outside the landfill (M-6, M-7, M-8, and M-9) have never exceeded the LEL, the migration of methane west of the landfill appears limited.

The onsite landfill gas vents are completed beneath the landfill cap and are not adjacent to the landfill boundary. Elevated methane concentrations at V-1, V-3, and V-4 are consistent with microbial action and degradation beneath the landfill cap.

ANNUAL STATISTICAL ANALYSES

Two types of statistical tests were performed on groundwater data to assess impacts from the Carnation Landfill. Hypothesis tests were performed to generally compare downgradient concentrations to GWCLs or upgradient concentrations. These tests were performed on all well-constituent pairs which have historically had GWCL exceedances.

Trend tests were performed on all current well-constituent pairs (with the exception of infrequently detected VOCs[1]) and used to evaluate whether groundwater contaminant concentrations are increasing. A statistical summary of trend-test constituents is presented in Table 5.

Hypothesis Tests

Hypothesis tests were performed on well-constituent pairs with prior GWCL exceedances. Sample results from the eight most recent sampling events were used to evaluate if their central population values are in exceedance. For this discussion, "central population value" refers to either the average, geometric mean, or median concentration of a well-constituent population, and is dependent on the population distribution (average is used for normal populations, geometric mean is for lognormal populations, and median is for nonparametric populations). Two different types of hypothesis tests were applied- confidence intervals (CIs) were used to compare data sets to their GWCLs, and prediction limits (PLs) were used in cases where background concentrations exceeded GWCLs (based on recommendations from the EPA Unified Guidance for RCRA facilities (EPA, 2009)).

The last eight analyses for each well-constituent pair were first tested for normality and lognormality using the Shapiro Wilk test. Depending on normality results, well-constituent pairs had CIs constructed around their central population value using normal, lognormal, or non-parametric approaches. For most parameters, 95 percent lower confidence intervals were calculated as recommended in the EPA Unified Guidance (EPA, 2009). For pH, 95 percent upper CIs were calculated as all pH "exceedances" at the landfill have occurred when pH is less than its lower GWCL (all other landfill parameters have exceedances when a concentration is greater than a GWCL, and therefore lower CIs are applied). CIs were constructed using the eight most recent samples, with non-detect samples assumed to have concentrations equal to half their reporting limit. Sample populations were not tested for outliers, and therefore outliers were included in the sample populations. Following construction of the one-sided CIs, the lower confidence limits (or upper confidence limit for pH) were compared to GWCLs to assess if the central population value significantly exceeds the GWCL. Calculated lower confidence limits (LCLs) and upper confidence limits (UCLs) are presented in Table 6, with 17 out of 31 well-constituent pairs having a central population value exceeding a GWCL or PL with 95 percent confidence.

Dissolved arsenic exceeded its GWCL of 0.05 ug/L at background wells MW-1S and MW-1D, and therefore PLs were used to evaluate if significant concentration differences exist between downgradient and upgradient wells (as recommended in the Unified Guidance (EPA, 2009)). A non-parametric PL was calculated based on concentrations from the previous five sampling events at background wells MW-1S and MW-1D (for a combined total of 10 background samples). From this dataset, a maximum dissolved arsenic

[1] VOCs detected less than 25 percent of the time or in less than three consecutive sampling events were not statistically analyzed.

concentration of 0.8 ug/L was set as the upper PL[2]. Downgradient wells with arsenic exceedances were then compared to the PL. Most wells had normal or lognormal arsenic concentration distributions, and thus one-sided lower confidence limits were calculated and compared to the upper PL at 95 percent confidence. MW-5S and MW-7D were non-parametrically distributed, and therefore their three most recent sample concentrations were reviewed; if the median value exceeded the PL, then the PL was exceeded at 95 percent significance using a non-parametric PL for a future median of order three test (EPA, 2009). Non-detects were assumed to have concentrations equal to half their reporting limit. A comparison between the future medians of order three, LCLs, and PLs are presented in Table 6, and the LCLs at wells MW-2D, MW-3S, and MW-6D exceed the arsenic PL with 95 percent confidence.

Trend Tests

No pre-landfill background groundwater chemistry data exist for the Carnation Landfill, and thus intrawell tests cannot be performed to evaluate concentration trends. Mann-Kendall trend tests were performed instead to assess if statistically significant temporal trends are present within recent intrawell data (from 2018 Q4 through 2021 Q4). Mann-Kendall trend test results which had 95 percent or greater significance are listed in Table 7. Positive S values (the Mann-Kendall statistic) indicate a trend is increasing, while negative S values indicate a decreasing trend.

The p-values were then corrected for the number of comparisons because the probability of identifying at least one significant result due to chance increases as more hypotheses are tested. If one statistical test is performed at a 95 percent confidence level, there is a 5 percent chance of an exceedance by random variation alone. If more tests are performed, in this case 187, the chance is much greater.

The Bonferroni correction was used to reduce the chances of obtaining false-positive results (type I errors) when multiple pair-wise tests are performed on a single set of data. To perform a Bonferroni correction, the p-values were multiplied by the number of comparisons being made. The statistical power of the study is then calculated using the Bonferroni p-value, and a trend is considered statistically significant when the Bonferroni p-value is less than 0.05.

Using standard p-values, a statistically significant increasing trend was noted for one well-constituent pairs, whereas five statistically decreasing trends were noted. For the 40 well-constituent pairs that have historically exceeded GWCLs, no increasing trends were detected and one decreasing trend was detected (dissolved manganese at MW-2D). However, when Bonferroni adjusted p-values are applied, the null hypothesis was not rejected for any well-constituent pair.

[2] Historical arsenic prediction limits (calculated since 2011) have ranged from 0.7 to 0.8 ug/L, which suggests that background arsenic concentrations are stable and not trending.

LIMITATIONS

This work was performed, our findings obtained, and this document prepared, using generally accepted hydrogeologic practices used at this time and in this vicinity, for exclusive application to the Carnation Landfill, and for the exclusive use of City of Carnation, Department of Ecology, and the King County Public Health Department. This is in lieu of other warranties, express or implied.

Please feel free to contact us if you have any further questions or comments.

Sincerely,
Pacific Groundwater Group

Stephen Swope Principal Hydrogeologist	Glenn Mutti-Driscoll Hydrogeologist

Attachments:

Table 1	Constituents Detected Above GWCLs During 2021, Carnation Landfill
Table 2	VOCs Detected in 2021, Carnation Landfill
Table 3	Quarterly Groundwater Elevations and Hydrogeologic Parameters from 2021, Carnation Landfill
Table 4	Landfill Gas Concentrations in 2021, Carnation Landfill
Table 5	Statistical Summary of Parameters Sampled and VOCs Detected in Groundwater, Carnation Landfill
Table 6	95% Confidence Intervals and Prediction Limits, Carnation Landfill 2021
Table 7	Mann-Kendall Trend Test Results 2018 Q4 through 2021 Q4, Carnation Landfill
Figure 1	Time Series Plot of Commonly Detected Volatile Organic Compounds with Concentrations Below GWCLs

Lab Report and Field Data Sheet Attachments:

REFERENCES

Environmental Protection Agency, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance. EPA530-R-09-007. Office of Resource Conservation and Recovery Program Implementation and Information Division.

Environmental Protection Agency, 2014. National Functional Guidelines for Superfund Organic Methods Data Review. EPA540-R-014-002. Office of Superfund Remediation and Technology Innovation.

PGG, 2019. Groundwater and Landfill Gas Monitoring Plan Carnation Landfill. Pacific Groundwater Group, Seattle, WA.

PGG, 2017. Final Remedial Investigation Report Carnation Landfill. Pacific Groundwater Group, Seattle, WA. September 14, 2017.

2021 Carnation Annual Report.docx

Table 1. Constituents Detected Above GWCLs During 2021, Carnation Landfill

			Exceedance Concentration			
Constituent	**Well**	**GWCL**	**2021 Q1**	**2021 Q2**	**2021 Q3**	**2021 Q4**
Arsenic, Dissolved; ug/L						
	MW-1D	0.05		0.724		0.651
	MW-1S			0.228		0.249
	MW-2D		8.98	8.46	12.5	11.8
	MW-2S			0.304		2.71
	MW-3D			0.458		0.464
	MW-3S			11		5.19
	MW-5S			0.436		0.49
	MW-5D			6.1		0.823
	MW-6D			1.38		1.33
	MW-8D			0.936		0.805
Iron, Dissolved; ug/L						
	MW-2D	300	1930	2030D	2400	2120
	MW-2S			965D		2420
	MW-3S			2130D		1160
	MW-6D			526D		602
Manganese, Dissolved; ug/L						
	MW-2D	50	2160	2310D	2190	1970
	MW-2S					153
	MW-3S			2760D		1620
	MW-5S			2030D		294
	MW-6D			71.9D		76
pH, Field; standard units						
	MW-1S	6.5-8.5		6.43		6.41
	MW-2D		6.23	6.22	6.4	6.19
	MW-2S			5.76		5.74
	MW-3S					6.05
	MW-5S			6.48		6.26
	MW-7D			6.11		5.82
	MW-8D					6.43
Vinyl Chloride SIM; ug/L						
	MW-2D	0.02				0.027J
	MW-5S					0.036J

J - estimated value; H - holding time exceeded; D - sample diluted in lab

Table 2. Volatile Organic Compounds Detected In 2021 (ug/L), Carnation Landfill

Constituent/Well		GWCL	2021 Q1	2021 Q2	2021 Q3	2021 Q4
Acetone						
	MW-1D					10.1
	MW-1S			5.34J		10.7
	MW-2D					12.5
	MW-2S			5.83J		6.74
	MW-3D					8.7
	MW-3S					12.2
	MW-5D					7.22
	MW-5S					7.75
	MW-6D					8.63
	MW-7D					7.06
	MW-8D					8.67
Acrylonitrile SIM						
	MW-1S	0.07		0.061		
	MW-5S			0.061		
cis-1,2-Dichloroethene						
	MW-2D	70			0.23	0.26
Dichlorodifluoromethane (CFC 12)						
	MW-5S					0.25
Styrene						
	MW-3D	100				0.21
Vinyl Chloride SIM						
	MW-2D	0.02				0.027J
	MW-5S					0.036J

J - estimated value
Q - Initial or continuing calibration standard not met

Table 3. Quarterly Groundwater Elevations and Hydrogeologic Parameters from 2021, Carnation Landfill

	Groundwater Elevation (ft)				Annual Change in Water Table Elevation (ft)	Hydraulic Conductivity (ft/day)*
	2021 Q1	**2021 Q2**	**2021 Q3**	**2021 Q4**		
MW-1D	111.17	109.81	108.71	109.35	2.46	0.6
MW-1S	111.76	109.85	108.41	109.39	3.35	2.4
MW-2D	88.58	87.06	85.80	87.18	2.78	13
MW-2S	95.90	92.88	< 90.43	95.09	> 5.47	24
MW-3D	108.13	106.86	105.68	106.28	2.45	1.6
MW-3S	108.49	106.88	105.35	105.57	3.14	864
MW-5D	88.91	87.14	86.11	87.47	2.80	979
MW-5S	105.56	103.67	< 101.52	105.39	> 4.04	NT
MW-6D	92.03	90.80	89.33	90.50	2.70	2.3
MW-6S	98.63	98.60	98.60	< 98.05	> 0.58	NT
MW-7D	92.99	90.67	88.64	90.09	4.35	NT
MW-8D	88.56	87.09	85.81	87.21	2.75	NT
Shallow Aquifer Geometic Mean						37
Deep Aquifer Geometric Mean						11

*Hydraulic conductivity values from PGG (2017). NT indicates not tested. The deep aquifer geometric mean includes hy
conductivity data from MW-4D (90 ft/day), a well which has been decommissioned.

	2021 Q1	2021 Q2	2021 Q3	2021 Q4	Average
Shallow Aquifer Zone Gradient	0.029	0.031	0.033	0.026	0.030
Deep Aquifer Zone Gradient	0.028	0.028	0.029	0.028	0.028

Horizontal aquifer gradients are calculated perpendicular to head contours at MW-1S and MW-2S (for the shallow aquife
MW-1D and MW-8D (for the deep aquifer).

Table 4. Landfill Gas Concentrations in 2021, Carnation Landfill

Event	Sample Date	Location ID	CH_4 ~ (% vol)	CO_2 (% vol)	O_2 (% vol)	Barometric Pressure (mb)*	24-hr Barometric Trend (mb)*
2021 Q1	3/26/2021	M-1	0	4	16.6	1008.8	12.2
2021 Q1	3/26/2021	M-2	0	4.8	17.2	1008.8	12.2
2021 Q1	3/26/2021	M-3	0	4.5	15.5	1008.8	12.2
2021 Q1	3/26/2021	M-4	0	4.6	10.2	1008.8	12.2
2021 Q1	3/26/2021	M-5	4.2	6.8	3.6	1008.8	12.2
2021 Q1	3/26/2021	M-6	0	4.1	14.6	1008.8	12.2
2021 Q1	3/26/2021	M-7	0	2.7	18.3	1008.8	12.2
2021 Q1	3/26/2021	M-8	0	4.1	16.8	1008.8	12.2
2021 Q1	3/26/2021	M-9	0	10.2	8.6	1008.8	12.2
2021 Q1	3/26/2021	V-1	0	0	21.4	1008.8	11.9
2021 Q1	3/26/2021	V-2	0	0.1	21.2	1008.8	11.9
2021 Q1	3/26/2021	V-3	0	0.1	21.3	1008.8	11.9
2021 Q1	3/26/2021	V-4	0	0.1	21.3	1008.8	11.9
2021 Q2	6/30/2021	M-1	0J	4	16.6	997.0	4.4
2021 Q2	6/30/2021	M-2	0J	4.2	17.5	997.0	4.4
2021 Q2	6/30/2021	M-5	0J	4.4	16.8	997.0	4.4
2021 Q2	6/30/2021	M-6	0J	3	16.7	997.0	4.4
2021 Q2	6/30/2021	M-7	0J	1.8	19.7	997.0	4.4
2021 Q2	6/30/2021	M-8	0	5.4	15.5	997.0	4.4
2021 Q2	6/30/2021	M-9	0	9.1	11.1	997.0	4.4
2021 Q2	6/30/2021	V-1	0.7J	5.7	12	997.0	4.7
2021 Q2	6/30/2021	V-2	0J	0.1	21.3	997.0	4.7
2021 Q2	6/30/2021	V-3	0J	0	21.7	997.0	4.7
2021 Q2	6/30/2021	V-4	0J	0	21.5	997.0	4.7
2021 Q3	9/21/2021	M-1	0J	17.1	17.3	1006.4	-6.6
2021 Q3	9/21/2021	M-2	0J	2.6	18.7	1006.4	-6.6
2021 Q3	9/21/2021	M-3	0J	2.5	19.3	1006.4	-6.6
2021 Q3	9/21/2021	M-4	0J	6.3	14.1	1006.4	-6.6
2021 Q3	9/21/2021	M-5	0	3.2	17	1006.4	-6.6
2021 Q3	9/21/2021	M-6	0J	3.2	14.6	1006.4	-6.6
2021 Q3	9/21/2021	M-7	0J	1.5	19.2	1006.4	-6.6
2021 Q3	9/21/2021	M-8	0J	4.2	16.6	1006.4	-6.6
2021 Q3	9/21/2021	M-9	0J	8.6	12.2	1006.4	-6.6
2021 Q3	9/21/2021	V-1	**11.5**	18.2	0	1006.4	-6.6
2021 Q3	9/21/2021	V-2	0J	0	20.9	1006.4	-6.6
2021 Q3	9/21/2021	V-3	**8.7**	18.6	0	1006.4	-6.6
2021 Q3	9/21/2021	V-4	**10.3J**	19.3	0	1006.4	-6.6
2021 Q4	12/13/2021	M-1	0J	3.6	17.1	1001.7	-3.0
2021 Q4	12/13/2021	M-2	0	5.4	16.5	1001.7	-3.0
2021 Q4	12/13/2021	M-3	0J	4.9	14.8	1001.7	-3.0
2021 Q4	12/13/2021	M-4	0J	3.7	16	1001.7	-3.0
2021 Q4	12/13/2021	M-5	2.7J	6.3	0.5	1001.7	-3.0
2021 Q4	12/13/2021	M-6	0	4.3	12	1001.7	-3.0
2021 Q4	12/13/2021	M-7	0	2.4	18	1001.7	-3.0
2021 Q4	12/13/2021	M-8	0	4.2	16.1	1001.7	-3.0
2021 Q4	12/13/2021	M-9	0	8.3	11.1	1001.7	-3.0
2021 Q4	12/13/2021	V-1	0J	0	21.9	1001.7	-3.0
2021 Q4	12/13/2021	V-2	0J	0	21.9	1001.7	-3.0
2021 Q4	12/13/2021	V-3	**9.3J**	7.2	12.8	1001.7	-3.0
2021 Q4	12/13/2021	V-4	0.8J	1.1	20.4	1001.7	-3.0

~ Bold values are used if methane concentrations exceed the Lower Explosive Limit (LEL) of 5 percent.

*Barometric pressure data are from Seatac airport and are collected hourly. Pressures presented in the table correspond to the pressure measurement closest to sampling time. Barometric trend values are negative when it has declined over the previous 24 hours.

J: all methane concentrations are considered estimates from 2020 Q3 since readings from the landfill gas meter consistently measured 0.1% CH4 when purging atmospheric air. 0.1% was subtracted from all measured methane concentrations.

Table 5. Statistical Summary of Parameters Sampled and VOCs Detected in Groundwater, Carnation Landfill

Station	Minimum[1]	Maximum	Count	Median	25th Percentile	75th Percentile
Acrylonitrile, ug/L						
MW-1D	0.025	0.025	16	0.025	0.025	0.025
MW-1S	0.025	0.074	15	0.025	0.025	0.043
MW-2D	0.025	0.025	31	0.025	0.025	0.025
MW-2S	0.025	0.025	13	0.025	0.025	0.025
MW-3D	0.025	0.025	16	0.025	0.025	0.025
MW-3S	0.025	0.025	16	0.025	0.025	0.025
MW-5D	0.025	0.025	16	0.025	0.025	0.025
MW-5S	0.025	0.27	20	0.025	0.025	0.066
MW-6D	0.025	0.117	16	0.025	0.025	0.031
MW-7D	0.025	0.056	19	0.025	0.025	0.025
MW-8D	0.025	0.066	17	0.025	0.025	0.025
Arsenic, Dissolved, ug/L						
MW-1D	0.5	0.8	35	0.657	0.6	0.7
MW-1S	0.2	0.313	34	0.3	0.212	0.3
MW-2D	5.47	16.5	58	10.15	7.9325	12
MW-2S	0.1	3.74	25	0.1	0.1	0.691
MW-3D	0.4	0.644	35	0.5	0.47	0.5
MW-3S	0.4	18.2	35	3.9	2.45	6.63
MW-5D	0.4	0.6	35	0.436	0.4	0.5
MW-5S	0.1	6.1	38	0.1	0.1	0.175
MW-6D	1.1	1.8	35	1.3	1.22	1.4
MW-7D	0.1	0.3	19	0.1	0.1	0.150
MW-8D	0.3	0.936	18	0.4445	0.4	0.802
Iron, Dissolved, ug/L						
MW-1D	25	340	35	25	25	25
MW-1S	25	125	34	25	25	25
MW-2D	840	3550	58	1635	1390	2027.5
MW-2S	25	6880	25	25	25	907
MW-3D	25	200	35	25	25	25
MW-3S	25	2570	35	370	170	726.5
MW-5D	25	190	35	25	25	25
MW-5S	10	125	38	25	25	25
MW-6D	310	620	35	545	500	579.5
MW-7D	25	125	19	25	25	37.5
MW-8D	25	125	18	25	25	61.4

Table 5. Statistical Summary, Continued

Station	Minimum[1]	Maximum	Count	Median	25th Percentile	75th Percentile
Manganese, Dissolved, ug/L						
MW-1D	0.5	10	35	1	0.5	2.0
MW-1S	0.5	10	34	0.5	0.5	1
MW-2D	1720	5560	58	2690	2432.5	3372.5
MW-2S	0.5	192	25	6	1	53
MW-3D	0.5	10	35	0.5	0.5	0.5
MW-3S	222	4330	35	1650	1395	1975
MW-5D	0.5	22	35	0.5	0.5	1
MW-5S	0.5	2030	38	2	0.5	5.0
MW-6D	60	96	35	74	68.2	76
MW-7D	0.5	115	19	5.1	2.6	12.0
MW-8D	0.5	143	18	10.05	4.7	39.3
Nitrate, mg/L as N						
MW-1D	0.36	1.33	35	0.486	0.452	0.510
MW-1S	0.553	2.58	34	1.54	1.0425	1.94
MW-2D	0.005	0.659	35	0.191	0.129	0.299
MW-2S	0.01	1.54	25	0.073	0.021	0.499
MW-3D	0.428	0.905	35	0.599	0.521	0.814
MW-3S	0.005	1.52	35	0.029	0.010	0.141
MW-5D	0.246	0.554	35	0.384	0.329	0.484
MW-5S	0.144	5.72	26	2.4	1.68	3.12
MW-6D	0.005	0.012	35	0.005	0.005	0.01
MW-7D	0.151	3.24	15	1.15	0.359	1.25
MW-8D	0.669	1.33	12	0.856	0.770	1.004
pH, standard units						
MW-1D	6.19	7.33	35	6.90	6.78	6.99
MW-1S	5.18	6.65	35	6.41	6.34	6.46
MW-2D	5.59	7.03	57	6.30	6.21	6.40
MW-2S	5.13	6.51	24	5.76	5.65	5.90
MW-3D	5.98	7.50	35	7.08	6.96	7.18
MW-3S	5.27	6.93	35	6.38	6.22	6.62
MW-5D	6.10	7.34	34	6.91	6.63	7.00
MW-5S	5.50	7.15	42	6.37	6.20	6.53
MW-6D	6.45	7.86	34	7.47	7.21	7.54
MW-7D	5.82	7.68	20	6.11	6.01	6.19
MW-8D	6.43	7.07	18	6.63	6.56	6.71

Table 5. Statistical Summary, Continued

Station	Minimum[1]	Maximum	Count	Median	25th Percentile	75th Percentile
Specific Conductance, umhos/cm						
MW-1D	106.4	183	35	134	125.4	149.1
MW-1S	171	293	35	230	203.0	258.5
MW-2D	165.4	402	57	292	269.0	318.0
MW-2S	33	174.5	24	74.6	54.8	97.9
MW-3D	17.77	170.6	35	137	126.0	154.9
MW-3S	99	306.8	35	162	146.5	178.8
MW-5D	106	187.4	34	141	130.6	158.8
MW-5S	265	517	42	367.5	327.3	398.2
MW-6D	112	183.7	34	148.5	138.3	168.0
MW-7D	92.4	159.6	19	125.3	106.6	134.5
MW-8D	164.2	216.7	18	192	181.5	200.0
Sulfate, mg/L						
MW-1D	4.3	10.3	35	5.21	4.88	5.79
MW-1S	3.79	15.5	34	5.025	4.65	5.49
MW-2D	3.2	19.6	35	5.7	4.65	7.75
MW-2S	1	3.9	25	2.1	1.00	2.90
MW-3D	4.3	10	35	5.4	4.90	5.85
MW-3S	2.6	8.5	35	3.4	2.94	3.86
MW-5D	5.2	10.5	35	6.9	6.30	7.55
MW-5S	4.01	14.9	26	7.87	6.43	8.92
MW-6D	8	13.2	35	10.2	9.48	10.7
MW-7D	3.6	6.6	15	5.46	5.05	5.83
MW-8D	7.76	11.2	12	9.965	8.09	10.4
Temperature, Degrees Celcius						
MW-1D	8.8	13.8	35	10.8	9.8	11.6
MW-1S	11.1	13.9	35	12.2	11.7	12.7
MW-2D	9.61	14.4	57	11.6	11.3	12.0
MW-2S	7.8	15.5	24	9.85	9.2	11.1
MW-3D	8.9	15.7	35	10.6	10.0	11.4
MW-3S	8.38	15.4	35	10.3	10.0	10.6
MW-5D	9.9	13.3	34	11.8	11.4	12.4
MW-5S	10.3	16.65	42	12	11.3	12.6
MW-6D	9.9	14.2	34	12	11.4	12.5
MW-7D	9.91	12.8	19	12.1	11.6	12.4
MW-8D	9.99	13.3	18	12.05	11.5	12.3

Table 5. Statistical Summary, Continued

Station	Minimum[1]	Maximum	Count	Median	25th Percentile	75th Percentile
Vinyl Chloride, ug/L						
MW-1D	0.005	0.01	35	0.01	0.005	0.01
MW-1S	0.005	0.01	34	0.01	0.005	0.01
MW-2D	0.005	0.44	58	0.0655	0.0325	0.1375
MW-2S	0.005	0.01	25	0.01	0.005	0.01
MW-3D	0.005	0.01	35	0.01	0.005	0.01
MW-3S	0.005	0.01	35	0.01	0.005	0.01
MW-5D	0.005	0.01	35	0.01	0.005	0.01
MW-5S	0.005	0.037	42	0.01	0.005	0.01
MW-6D	0.005	0.01	35	0.01	0.005	0.01
MW-7D	0.005	0.076	19	0.005	0.005	0.005
MW-8D	0.005	0.01	17	0.005	0.005	0.005
Volatile Organic Compounds[2], ug/L						
MW-2D Vinyl Chloride	0.005	0.44	58	0.0655	0.0325	0.1375
MW-2D 1,1-DCA	0.1	1.1	58	0.1	0.1	0.3
MW-2D Chloroethane	0.1	3	58	0.4	0.1	0.8875
MW-2D Cis-1,2-DCE	0.1	1	58	0.385	0.22	0.5
MW-6D Toluene	0.1	0.6	37	0.1	0.1	0.1
MW-5S Vinyl Chloride	0.005	0.037	42	0.01	0.005	0.01
MW-5S Styrene	0.1	5.4	43	0.1	0.1	0.1
MW-6D Carbon Disulfide	0.1	0.9	35	0.1	0.1	0.1
MW-1S Acrylonitrile	0.025	0.074	15	0.025	0.025	0.043
MW-5S Acrylonitrile	0.025	0.27	20	0.025	0.025	0.066
MW-6D Acrylonitrile	0.025	0.117	16	0.025	0.025	0.031
MW-8D Acrylonitrile	0.025	0.066	17	0.025	0.025	0.025

1 Non-detect parameters are listed and statistically compiled using a concentration equal to half their reporting limit.

2 Tabulated VOC data include only constituent-well pairs with three or more consecutive detections, or constituent-well pairs with a 25 percent or greater historical detection rate.

Table 6. 95% Confidence Intervals and Prediction Limits, Carnation Landfill 2021

Constituent	GWCL	PL	Well	LCL 95	UCL 95	Future Median of Order 3	Analytical method
Acrylonitrile SIM, ug/L	0.07		MW-5S	**0.079**			Non-Parametric
Vinyl Chloride SIM, ug/L	0.02		MW-2D	**0.050**			Non-Parametric
Vinyl Chloride SIM, ug/L	0.02		MW-5S	0.018			Non-Parametric
Iron, Dissolved, ug/L	300		MW-1D	125			Non-Parametric
Iron, Dissolved, ug/L	300		MW-2D	**2072**			Ln-Normal
Iron, Dissolved, ug/L	300		MW-2S	**777**			Ln-Normal
Iron, Dissolved, ug/L	300		MW-3S	**1161**			Normal
Iron, Dissolved, ug/L	300		MW-6D	**554**			Normal
Manganese, Dissolved, ug/L	50		MW-2D	**2065**			Normal
Manganese, Dissolved, ug/L	50		MW-2S	50			Normal
Manganese, Dissolved, ug/L	50		MW-3S	**1543**			Normal
Manganese, Dissolved, ug/L	50		MW-6D	**70**			Normal
pH, Field, std. units	6.5		MW-1S		**6.47**		Normal
pH, Field, std. units	6.5		MW-2D		**6.30**		Normal
pH, Field, std. units	6.5		MW-2S		**6.01**		Normal
pH, Field, std. units	6.5		MW-3D		6.71		Non-Parametric
pH, Field, std. units	6.5		MW-3S		6.54		Normal
pH, Field, std. units	6.5		MW-5D		**6.45**		Non-Parametric
pH, Field, std. units	6.5		MW-5S		6.65		Ln-Normal
pH, Field, std. units	6.5		MW-6D		6.57		Non-Parametric
pH, Field, std. units	6.5		MW-7D		**6.01**		Non-Parametric
pH, Field, std. units	6.5		MW-8D		6.62		Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-2D	**10.2**			Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-2S	0.6			Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-3D	0.5			Ln-Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-3S	**5.8**			Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-5D	0.4			Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-5S			**0.8**	Prediction Limit
Arsenic, Dissolved, ug/L	0.05	0.8	MW-6D	**1.4**			Normal
Arsenic, Dissolved, ug/L	0.05	0.8	MW-7D			0.1	Prediction Limit
Arsenic, Dissolved, ug/L	0.05	0.8	MW-8D	0.7			Normal

Bold *values indicate that the 95% one-sided confidence interval of the mean/geomean/median exceeds the GWCL, or that the prediction limit for the future median is exceeded.*

**Confidence intervals and prediction limits were calculated for well and constituent pairs which have had a GWCL exceedance in the 8 most recent sampling events, with the statistical method determined based on normality tests. Arsenic, which exceeds its GWCL at background wells MW-1D and MW-1S, was analyzed using nonparametric prediction limits to compare background concentrations to downgradient concentrations.*

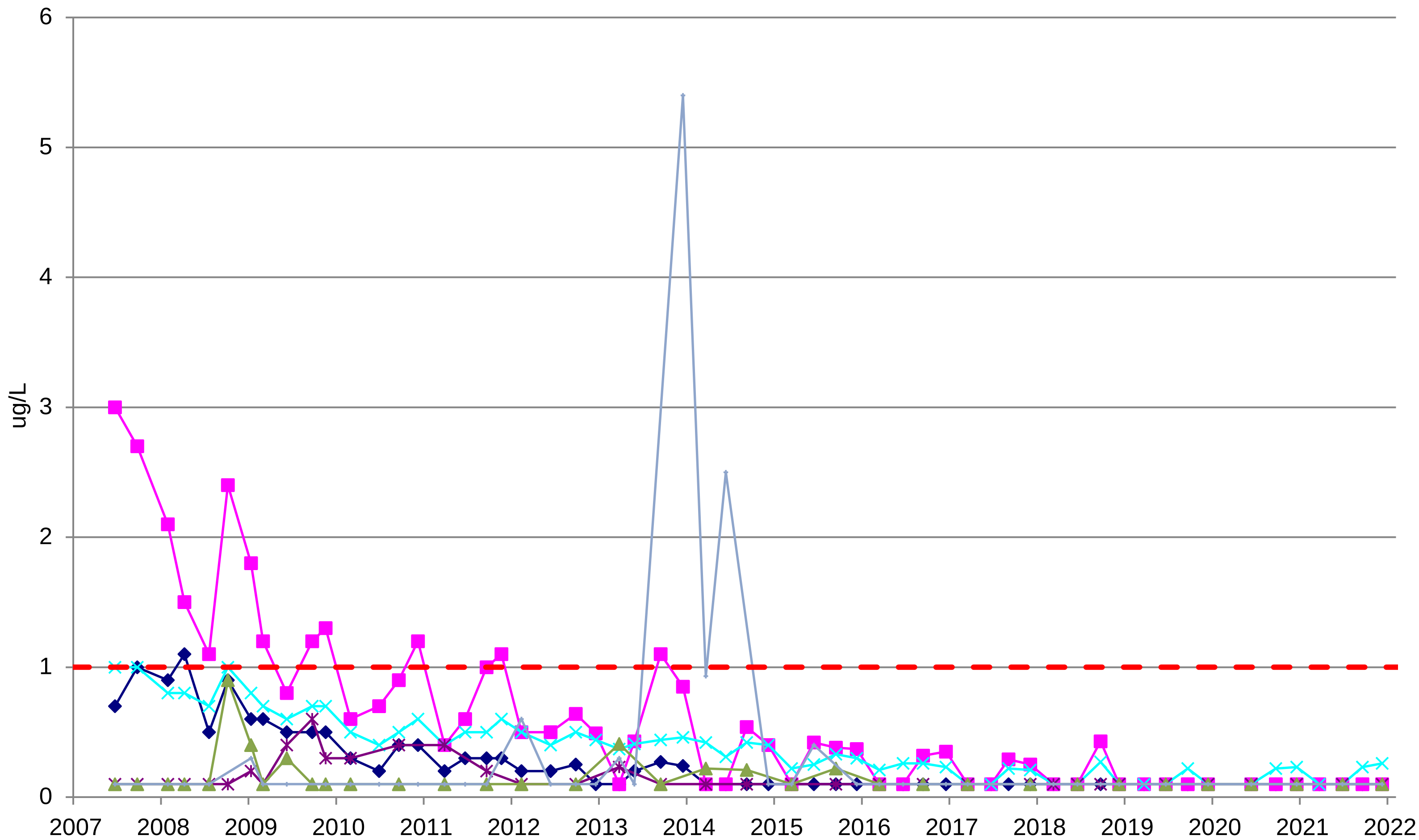
PgG

Table 7. Mann-Kendall Trend Test Results 2018 Q4 through 2021 Q4, Carnation Landfill

Constituent	Well	n	S	p	Bonferonni p value
Arsenic, Dissolved	MW-1S	6	-11	0.028	1.00
Arsenic, Dissolved	MW-3D	7	-13	0.035	1.00
Manganese, Dissolved	MW-2D	12	-34	0.010	1.00
Manganese, Dissolved	MW-7D	7	-15	0.015	1.00
Manganese, Dissolved	MW-8D	7	-14	0.025	1.00
Nitrate as N	MW-3D	7	19	0.001	0.19

Negative S values indicate a statistically significant decreasing trend is occurring with a significance equal to (1 - p), while a positive S value indicates there is a statistically significant increasing trend. Results are considered significant if (1 - p) is greater than or equal to 0.95.

The Bonferonni method corrects p-values for type I errors (false positives) by multiplying calculated p-values by the number of constituent-pair tests performed. Bonferonni adjusted p-values are statistically significant if (1 - p) is greater than or equal to 0.95, and are ***bolded*** *in this table.*

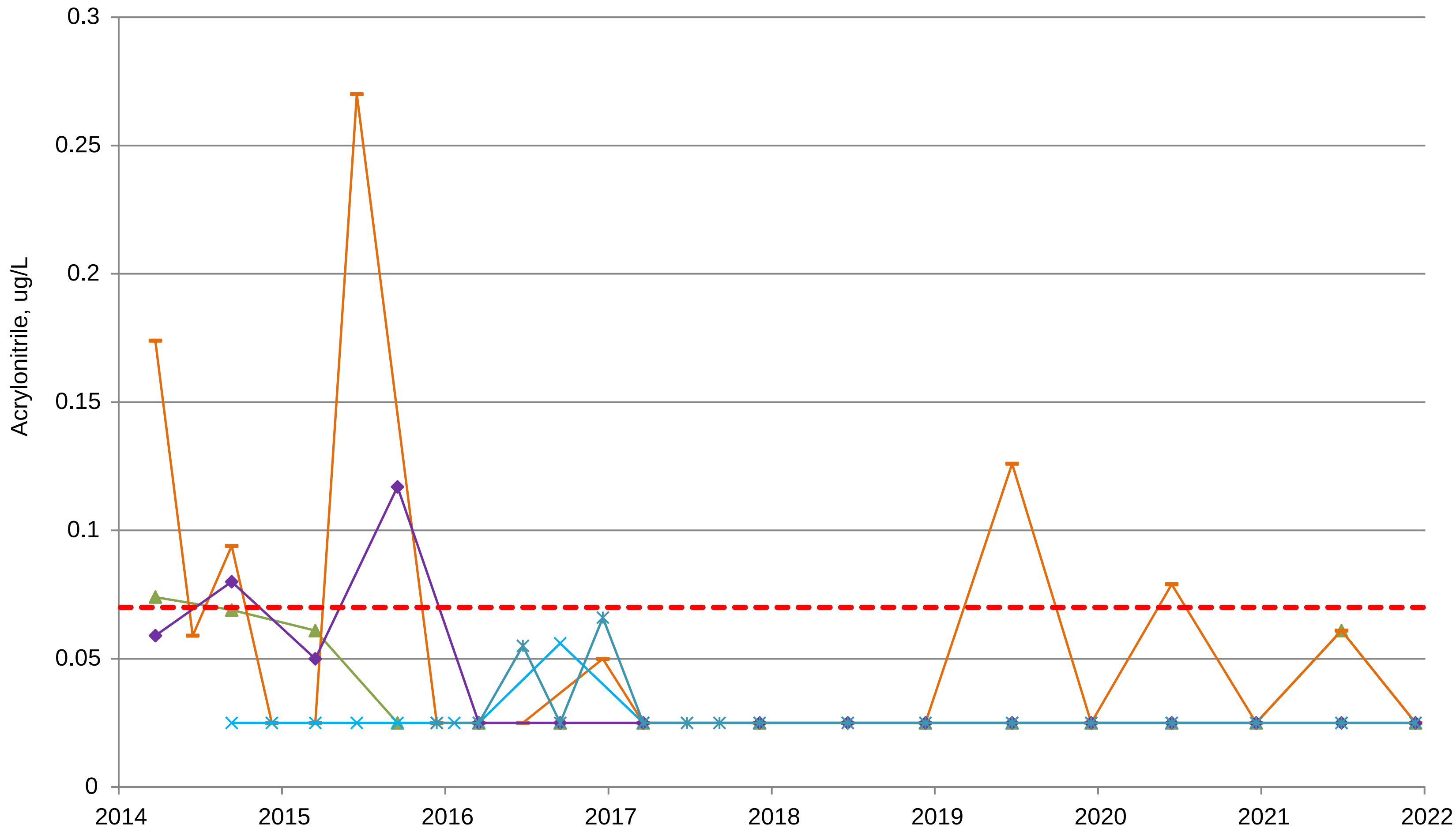


MW-2D 1,1-DCA
MW-2D Chloroethane
MW-2D Cis-1,2-DCE
MW-6D Toluene
MW-6D Carbon Disulfide
MW-5S Styrene
1,1-DCA GWCL

Notes:
-Plotted data include only constituent-well pairs with three or more consecutive detections, or constituent-well pairs with a 25 percent or greater historical detection rate.
-Non-detects are plotted at half of their reporting limit

Figure 1. Time Series Plot of Commonly Detected Volatile Organic Compounds with Concentrations Generally Below GWCLs

PGG

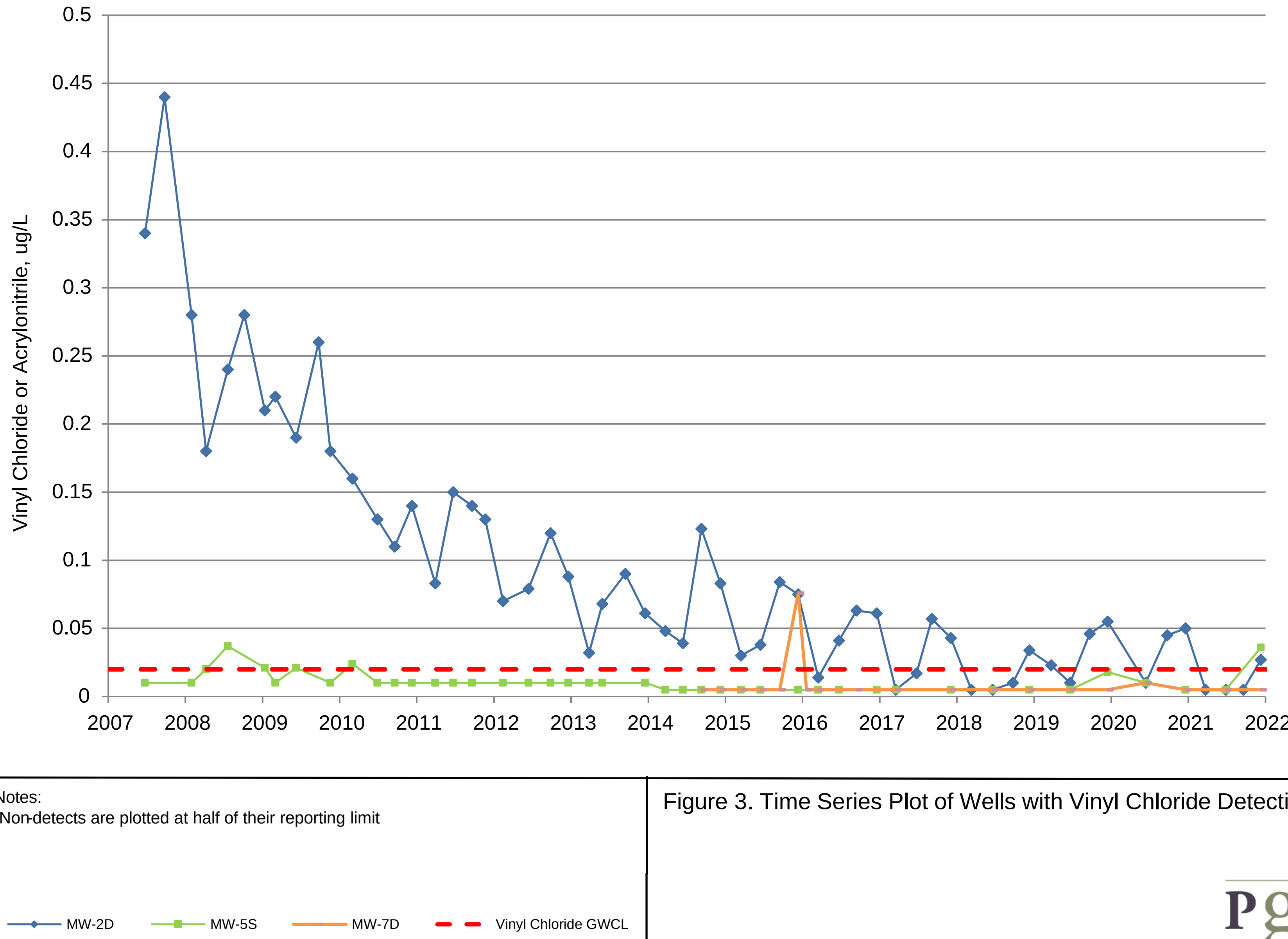


Notes:
-The reporting limit for acrylonitrile was lowered from 1 ug/L to 0.05 ug/L in 2014. Data prior to 2014 are not plotted since no detections occurred at this higher reporting limit.
-Non-detects are plotted at half of their reporting limit

MW-1S
MW-5S
MW-6D
MW-7D
MW-8D
Acrylonitrile GWCL

Figure 2. Time Series Plot of Wells with Acylonitrile Detections

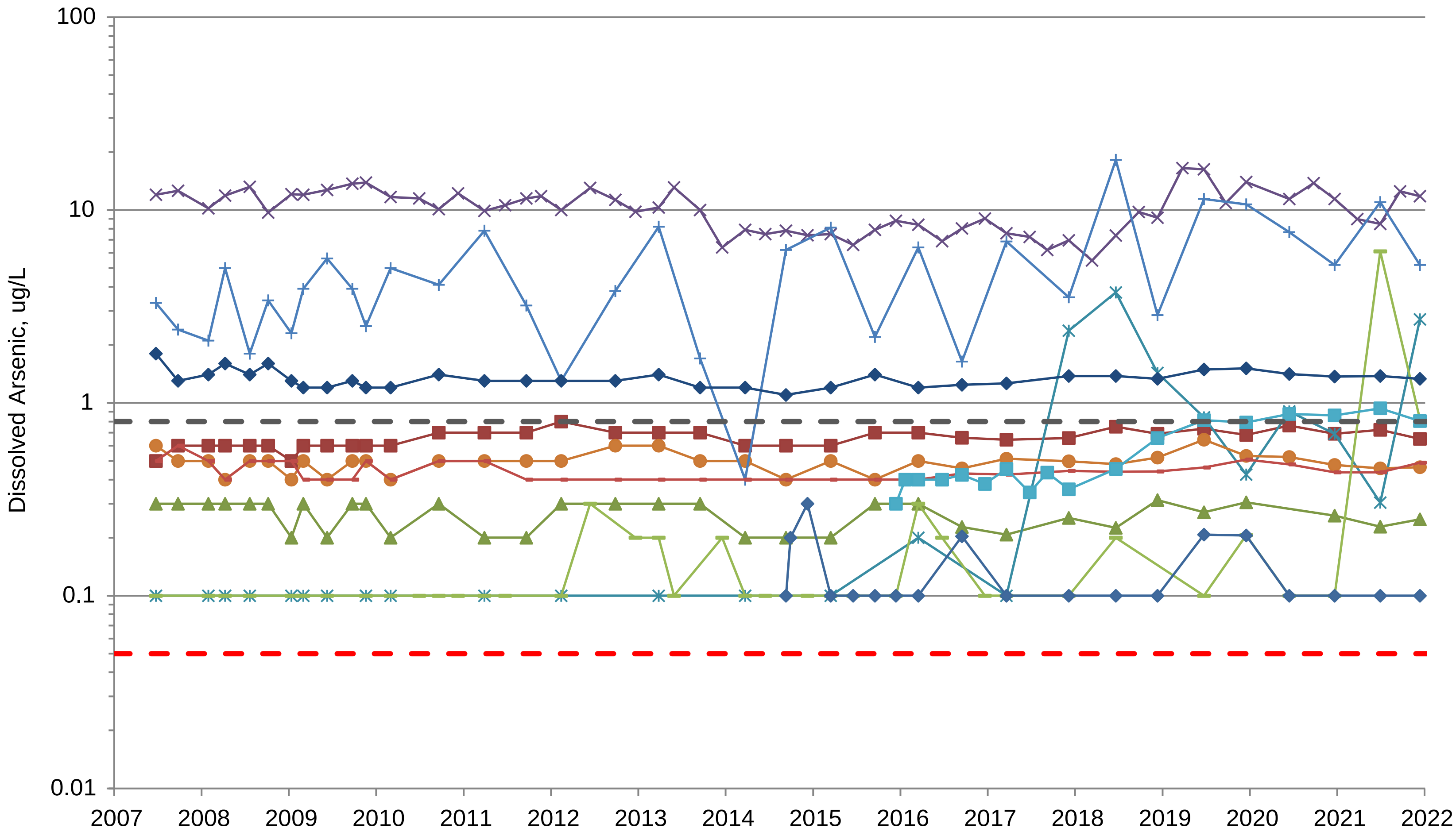
PGG



Notes:
-Non-detects are plotted at half of their reporting limit

Figure 3. Time Series Plot of Wells with Vinyl Chloride Detections

PGG

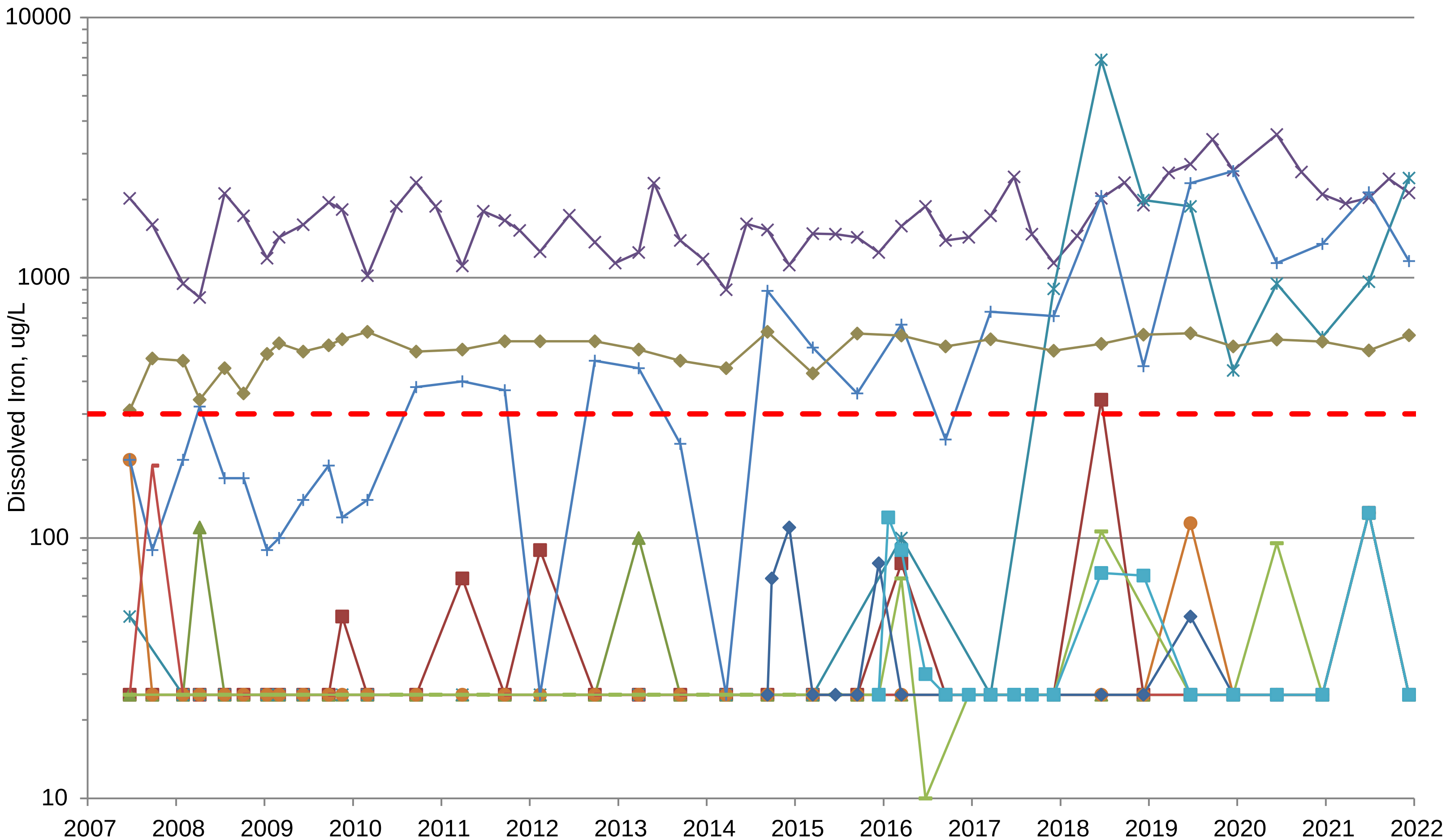


Notes:
-Non-detects are plotted at half the reporting limit

MW-1D MW-1S MW-2D MW-2S
MW-3D MW-3S MW-5D MW-5S
MW-6D MW-7D MW-8D GWCL
Prediction Limit

Figure 4. Dissolved Arsenic Concentration Time Series Plot

PGG

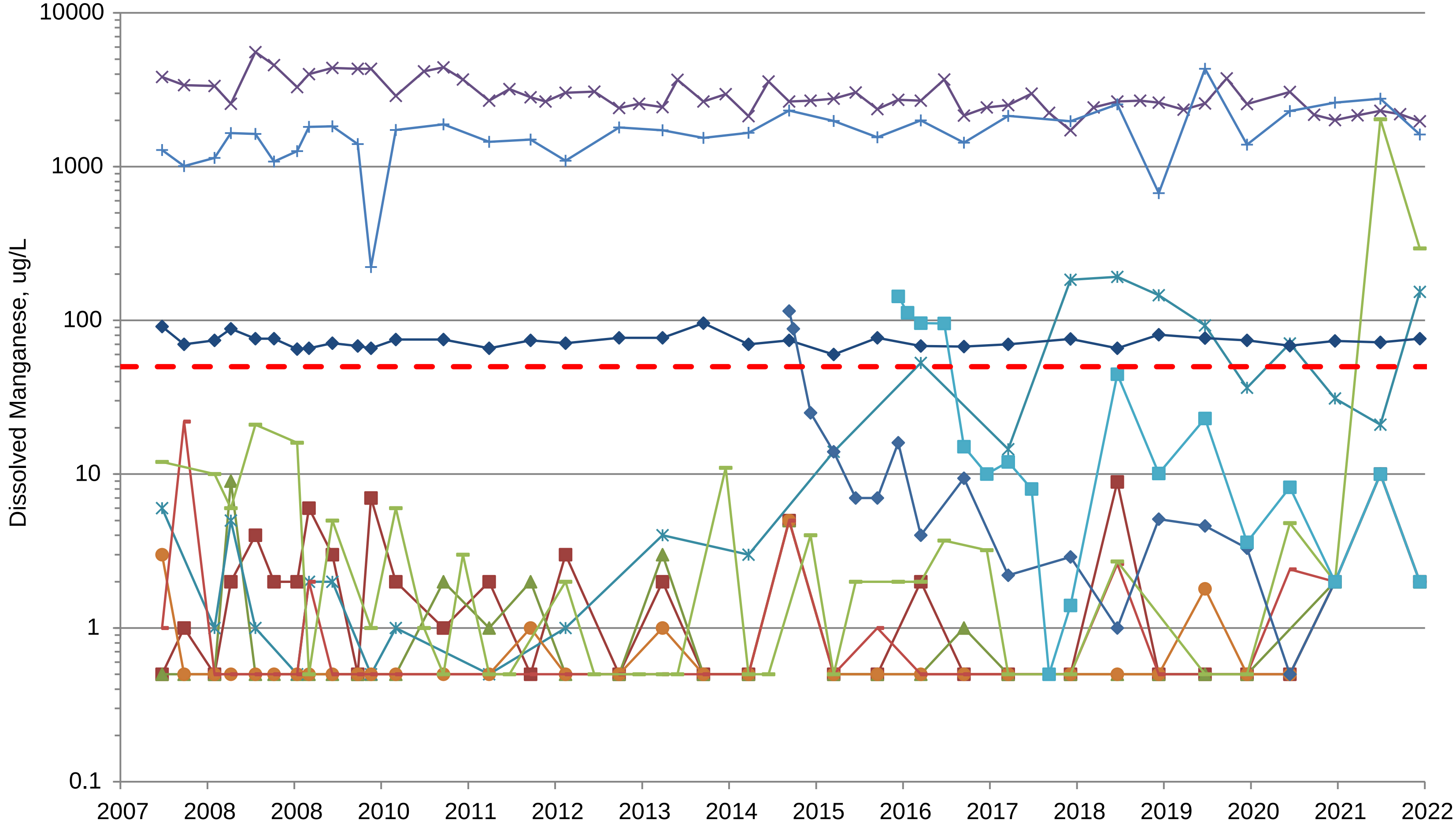


Notes:
-Non-detects are plotted at half the reporting limit

MW-1D MW-1S MW-2D MW-2S
MW-3D MW-3S MW-5D MW-5S
MW-6D MW-7D MW-8D GWCL

Figure 5. Dissolved Iron Concentration Time Series Plot

PGG



Notes:
-Non-detects are plotted at half the reporting limit

MW-1D
MW-1S
MW-2D
MW-2S
MW-3D
MW-3S
MW-5D
MW-5S
MW-6D
MW-7D
MW-8D
GWCL

Figure 6. Dissolved Manganese Concentration Time Series Plot

PGG

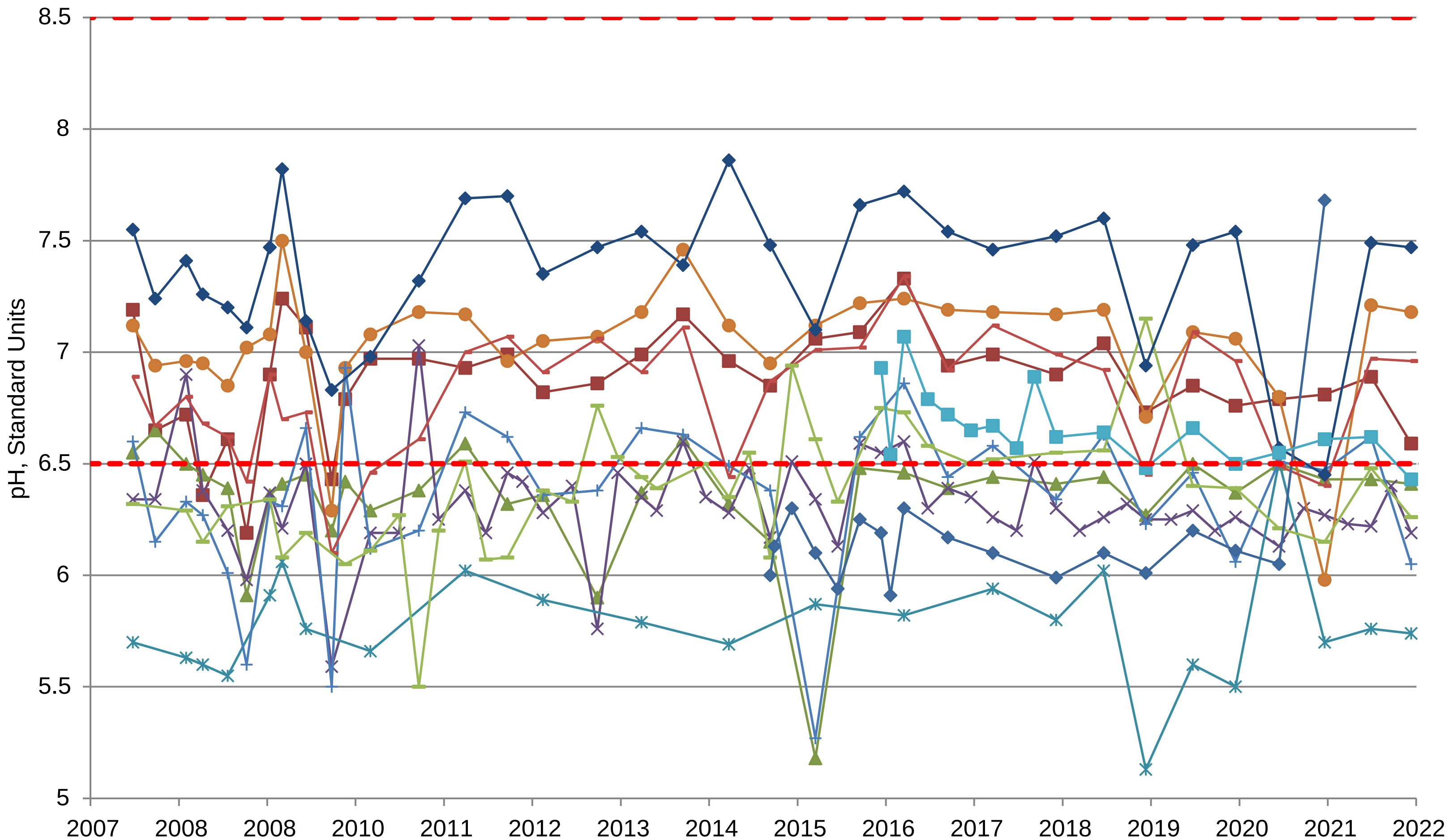
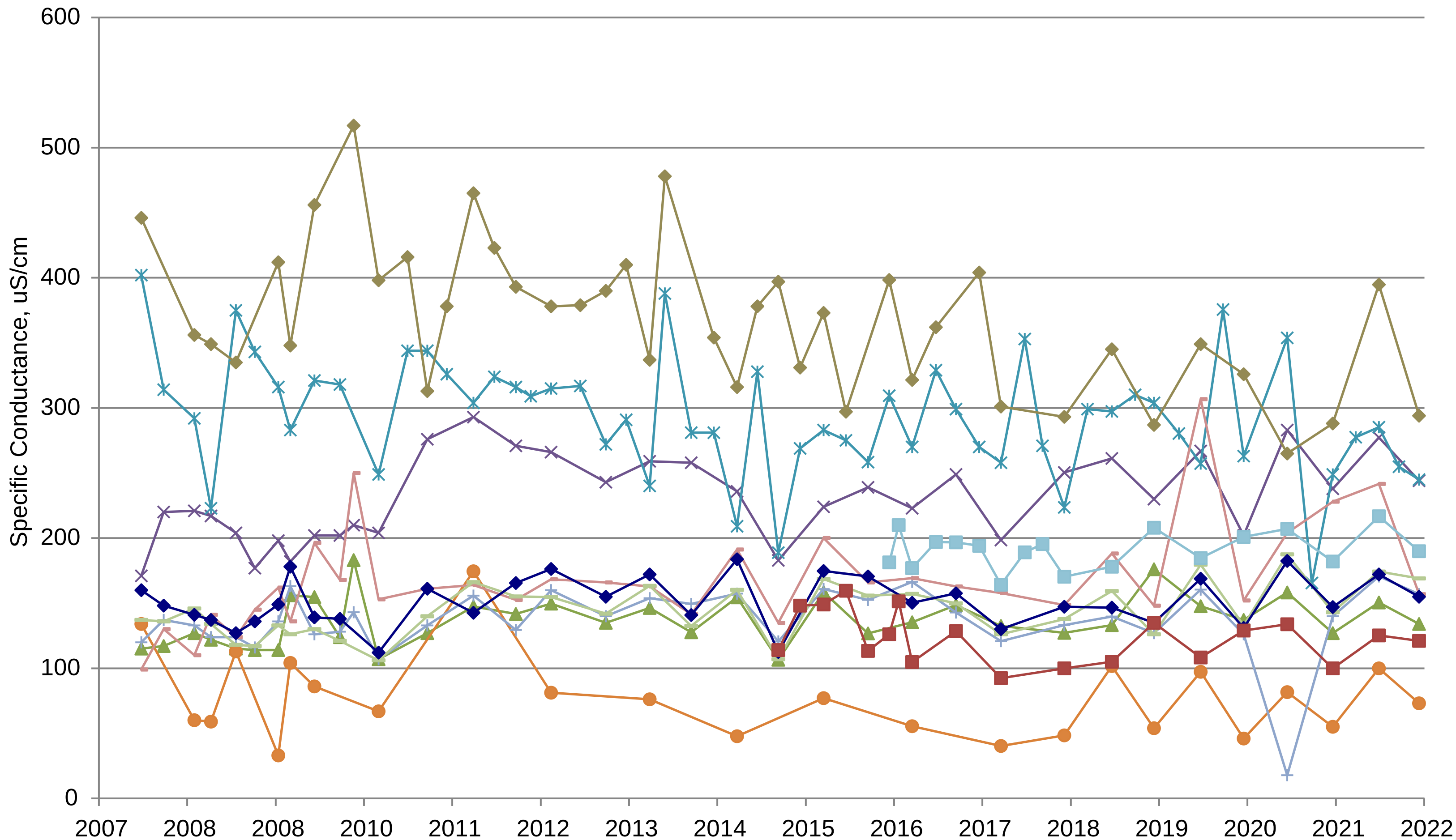


Figure 7pH Time Series Plot



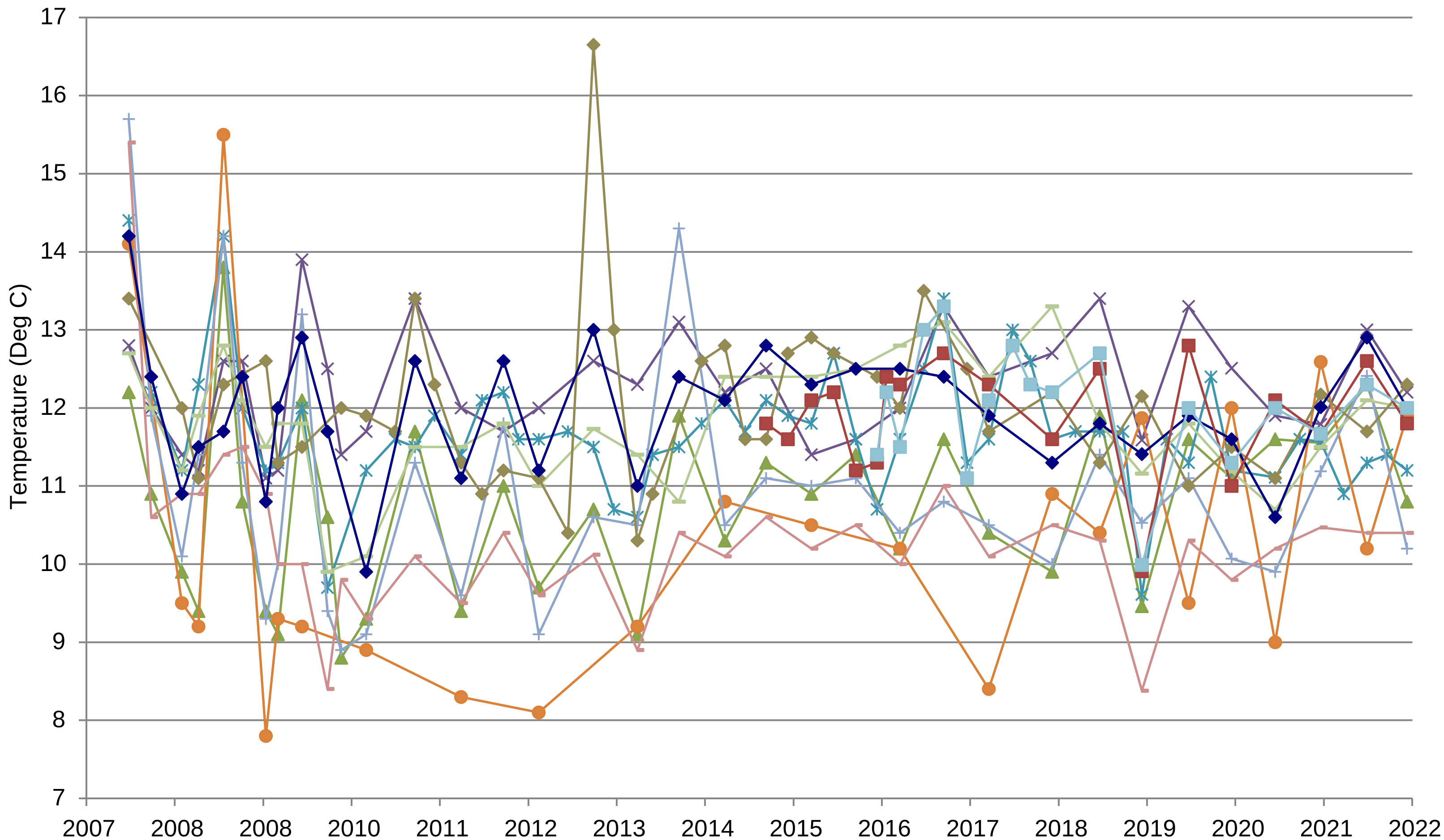
Notes:
-Specific conductance GWCL = 700 uS/cm

MW-1D MW-1S MW-2D MW-2S MW-3D MW-3S

MW-5D MW-5S MW-6D MW-7D MW-8D

Figure 8. Specific Conductance Time Series Plot

PGG

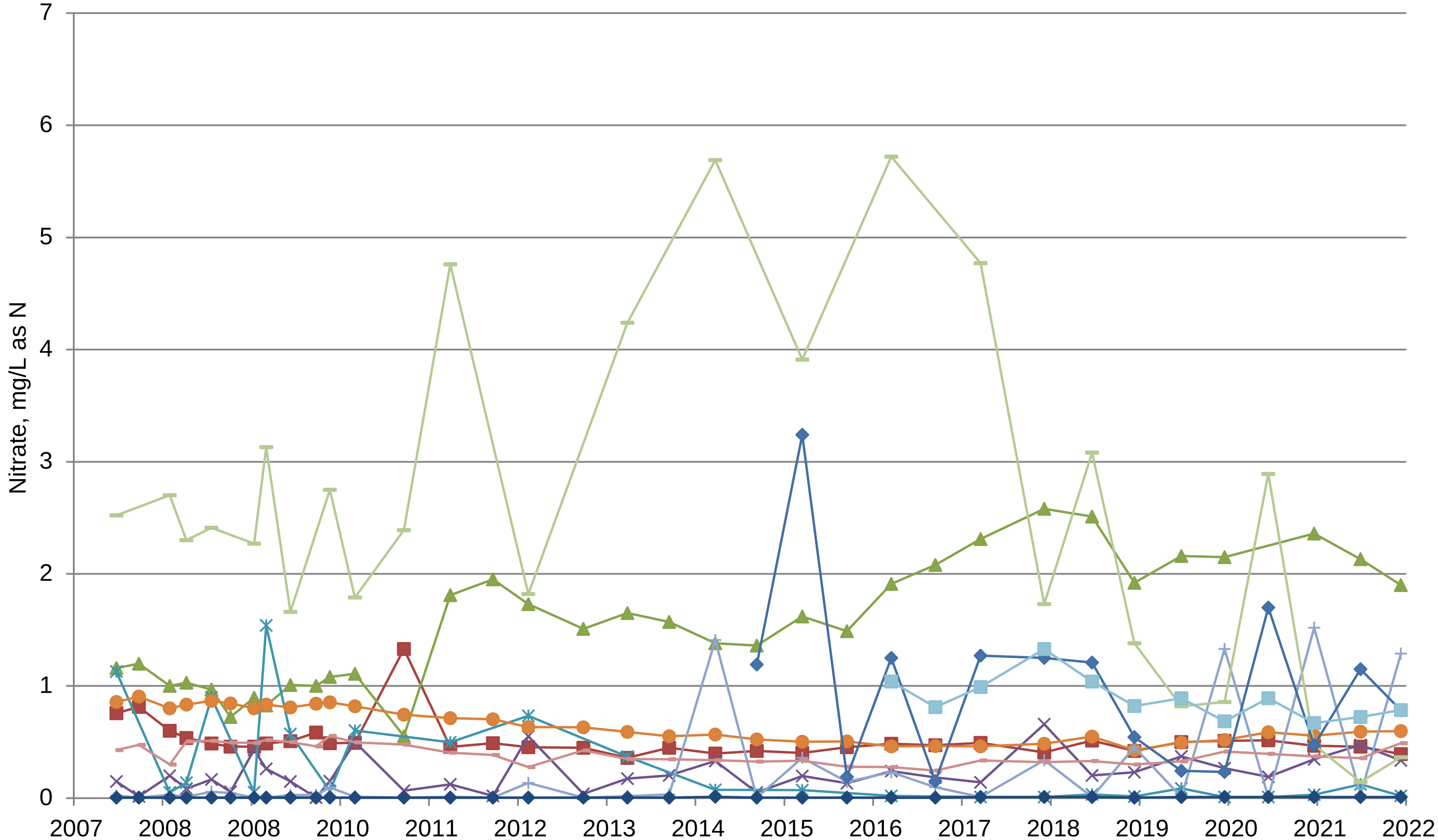


Notes:
-Temperature does not have a defined GWCL.

MW-1D MW-1S MW-2D MW-2S MW-3D MW-3S
MW-5D MW-5S MW-6D MW-7D MW-8D

Figure 9. Temperature Time Series Plot

PGG

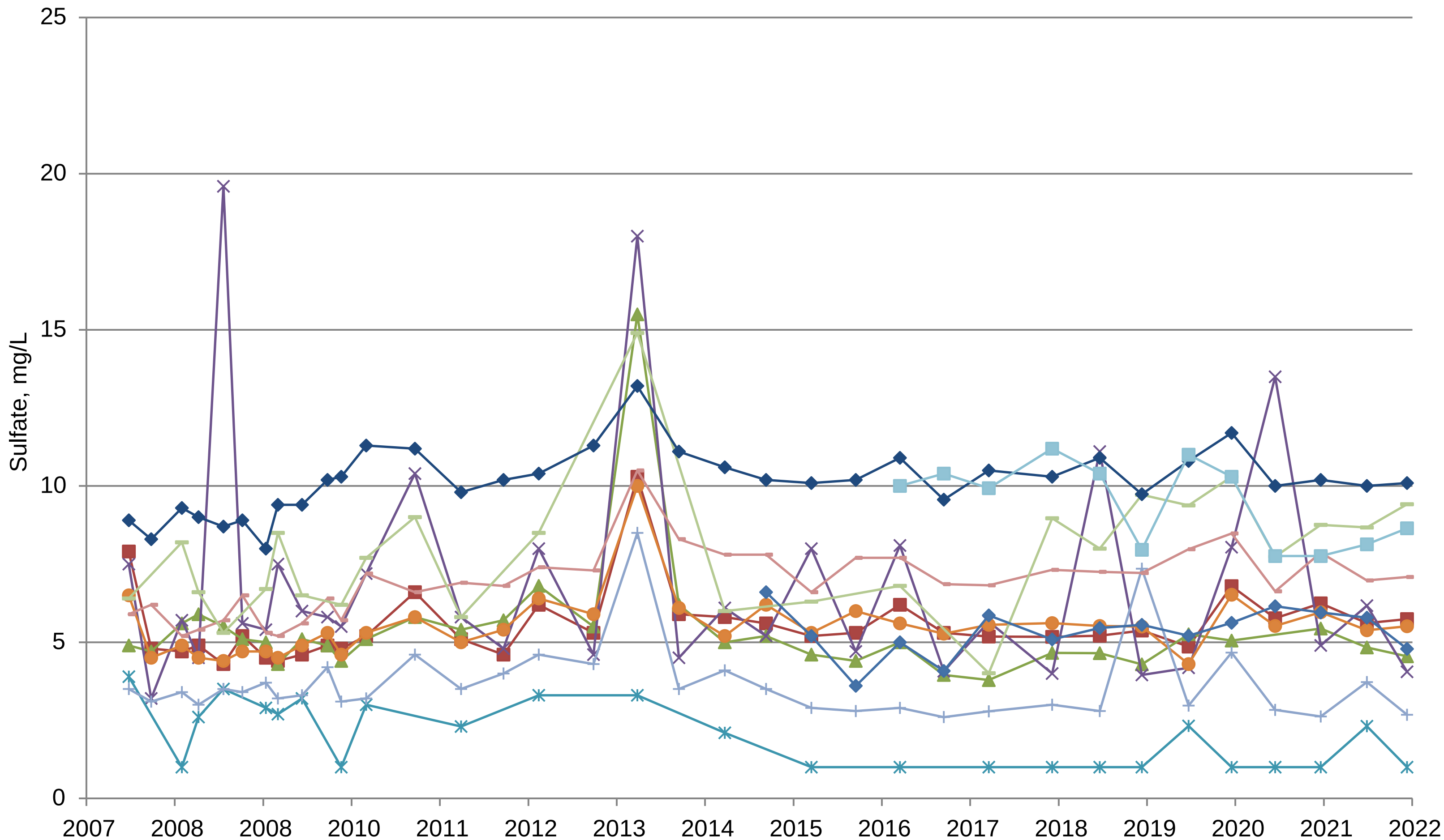


Notes:
-Nitrate GWCL = 10 mg/L as N
-Non-detects are plotted at half the reporting limit

MW-1D MW-1S MW-2D MW-2S MW-3D MW-3S
MW-5D MW-5S MW-6D MW-7D MW-8D

Figure 10. Nitrate Concentration Time Series Plot

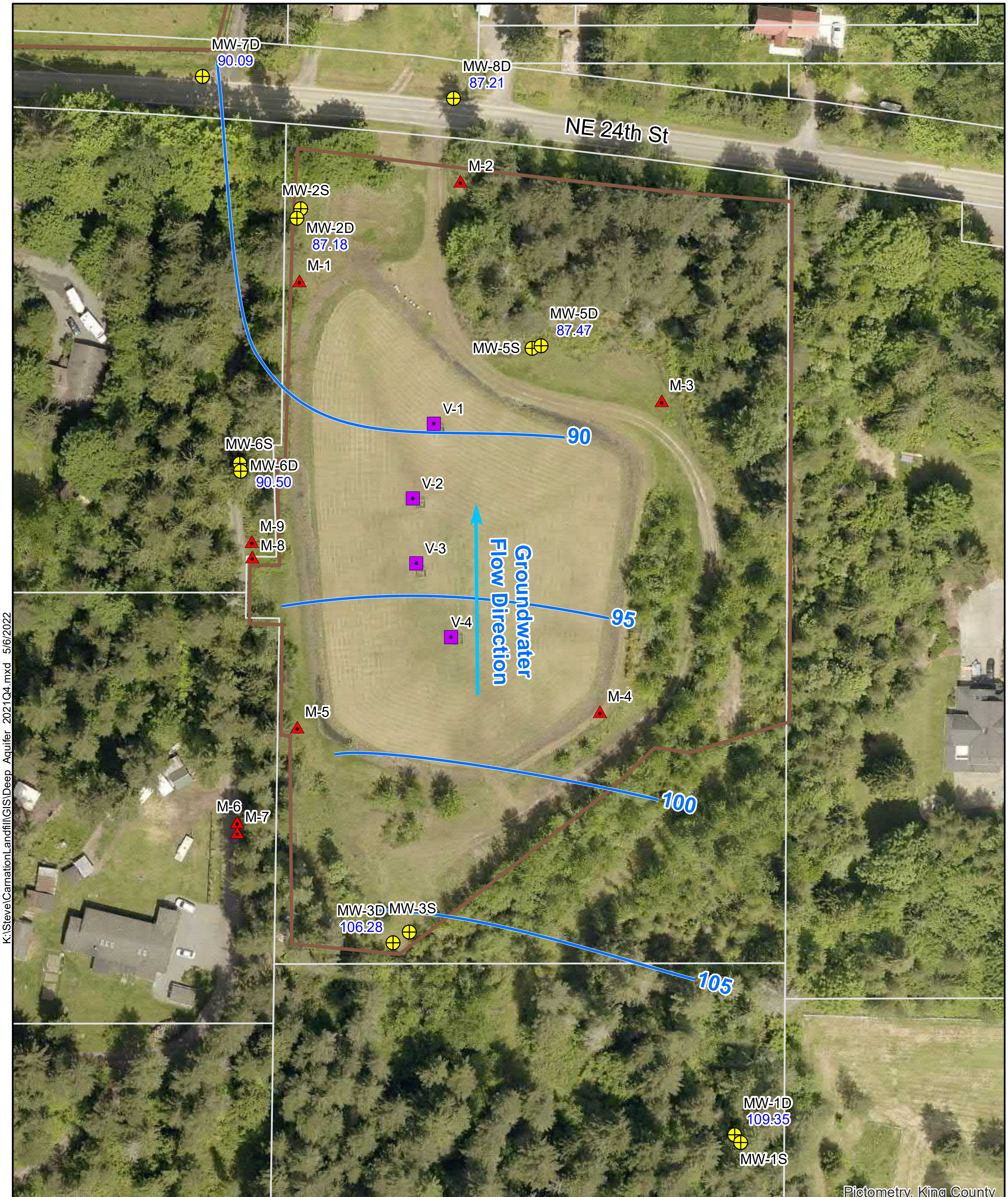
PGG



Notes:
-Sulfate GWCL = 250 mg/L
-Non-detects are plotted at half the reporting limit

Figure 11. Sulfate Concentration Time Series Plot

PgG



Monitoring Wells

Landfill Gas Monitoring Wells

Landfill Gas Vents

Groundwater Elevation Contour (Feet) in Deep Aquifer

Approximate Fence Line

Parcel Boundaries

2017 Ortho Photo from King County

0 Feet 100

N

Figure 12
Carnation Landfill
Deep Aquifer Elevations
2021Q4

Carnation Landfill
JS0903

PgG
A Mott MacDonald Company

K:\Steve\CarnationLandfill\GIS\Deep Aquifer 2021Q4.mxd 5/6/2022

K:\Steve\CarnationLandfill\GIS\Shallow Aquifer 2021Q4.mxd 5/6/2022

Monitoring Wells

Landfill Gas Monitoring Wells

Landfill Gas Vents

Groundwater Elevation Contour (Feet) in Shallow Aquifer

Approximate Fence Line

Parcel Boundaries

N

0 Feet 100

2017 Ortho Photo from King County

Figure 13
Carnation Landfill
Shallow Aquifer Elevations
2021Q4

Carnation Landfill
JS0903

PGG
A Mott MacDonald Company