LMS/MND/S13984

Sitewide Groundwater Monitoring Report Mound, Ohio, Site

Calendar Year 2015

May 2016

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Abbreviations

BVA	Buried Valley Aquifer
DCE	dichloroethene
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
MCL	maximum contaminant level
µg/L	micrograms per liter
MK	Mann-Kendall
MNA	monitored natural attenuation
nCi/L	nanocuries per liter
ODNR	Ohio Department of Natural Resources
Ohio EPA	Ohio Environmental Protection Agency
OU-1	Operable Unit 1
PCE	tetrachloroethene (perchloroethene)
RAO	remedial action objective
RIN	Report Identification Number
TCE	trichloroethene
VC	vinyl chloride
VOC	volatile organic compound
VSP	Visual Sample Plan

1.0 Introduction

1.1 Purpose

This report was prepared in support of the selected remedies for Phase I and Parcels 6, 7, and 8 of the Mound, Ohio, Site as outlined in the *Operations and Maintenance (O&M) Plan for the U.S. Department of Energy, Mound Site*, *Miamisburg, Ohio* (Sitewide Operations and Maintenance Plan) (DOE 2015). It summarizes the data collected in 2015 and documents the progress of the monitored natural attenuation (MNA) remedies for both areas of the Mound site. All sampling and data analyses were performed in accordance with the Sitewide Operations and Maintenance Plan, unless noted otherwise.

This report includes data collected during the groundwater sampling performed in 2015. Data are presented in both time-series and map-view plots. Trend analysis was performed on selected wells using the nonparametric Mann-Kendall test. This type of long-term trend analysis can be used to confirm trends in contaminant concentrations over time. The time-series plots will also be used to evaluate changes in data over time and to interpret the effectiveness of the MNA remedy.

This report also documents operational changes that occurred during the reporting period and identifies maintenance activities associated with the monitoring wells being sampled.

1.2 Project Description

The Mound site[1] is located in Miamisburg, Ohio, approximately 10 miles southwest of Dayton. In 1995, the U.S. Department of Energy (DOE) Mound Plant, named after the Miamisburg Indian Mound that is adjacent to the site, was comprised of 120 buildings on 306 acres. The Great Miami River, located west of the site, flows from northeast to southwest through Miamisburg and dominates the geography of the region surrounding the Mound site. Figure 1 shows the location of Phase I and Parcels 6, 7, and 8.

DOE remediated the Mound site to an "industrial use" standard consistent with the exposure assumptions provided in the *Mound 2000 Residual Risk Evaluation Methodology* (DOE 1997) and endorsed by the U.S. Environmental Protection Agency (EPA) and Ohio Environmental Protection Agency (Ohio EPA). The remedies for groundwater at the site combine groundwater monitoring and institutional controls in the form of deed restrictions on future land and groundwater use. These combined remedies will prevent current and future exposure of workers, the public, and the environment to contaminated groundwater from the Mound site.

[1] The Mound site has also been called the Mound Laboratory, Mound Laboratories, the Mound Plant (EPA ID OH6890008984), the USDOE Mound Plant, the Mound Facility, the USDOE Mound Facility, the Miamisburg Environmental Management Project (MEMP), and Miamisburg Closure Project (MCP). Currently, LM uses Mound, Ohio, Site as the formal name of the site.

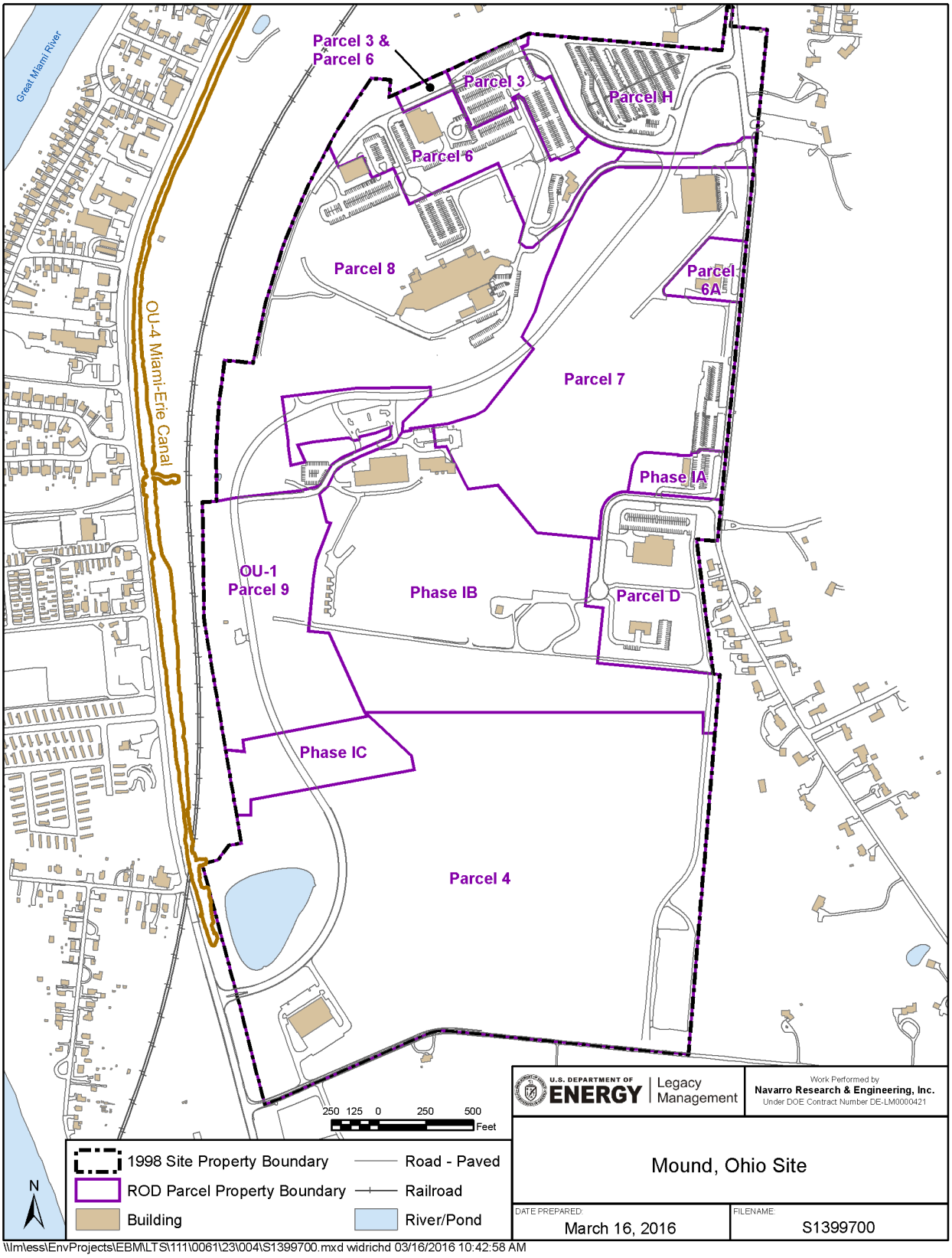

Figure 1. Mound, Ohio, Site

The long-term remedial action objective (RAO) for groundwater is to meet Safe Drinking Water Act maximum contaminant levels (MCLs) through MNA in the Phase I and Parcels 6, 7, and 8 areas. Until these goals are achieved, the near-term RAO is to prohibit the extraction and use of groundwater underlying the premises unless prior written approval is obtained from Ohio EPA and Ohio Department of Health.

1.2.1 Phase I

Phase I is an approximately 52-acre area made up of three distinct sections. It lies on the southern border of the former production area of the Mound site. This area contains monitoring wells that are screened in both the Buried Valley Aquifer (BVA) and the upgradient bedrock aquifer system. MNA is being used as the remedy for a small, discrete section of the bedrock groundwater system contaminated with trichloroethene (TCE) to ensure that concentrations of TCE within the bedrock groundwater are decreasing to levels below the Safe Drinking Water Act MCL and do not impact the downgradient BVA.

1.2.2 Parcels 6, 7, and 8

Parcels 6, 7, and 8 occupy approximately 101 acres of the northern portion of the Mound Plant site. The main production facilities were located within Parcels 6 and 8, and this area is called the Main Hill area. A tributary valley runs between these two parcels and Parcel 7; it contains a narrow tongue of glacial deposits that are in hydraulic communication with the BVA. Groundwater within the fractured bedrock beneath the Main Hill area, and in topographic highs within Parcel 7, flows along horizontal bedding planes and fractures and ultimately discharges to seeps or to the downgradient BVA.

Two monitoring wells in the BVA indicate volatile organic compound (VOC) impact, primarily TCE, that exceeds MCLs of the Safe Drinking Water Act. MNA is the remedy for the VOCs in groundwater associated with the Main Hill. Sampling is being performed to assess the contaminant concentrations and to verify that the BVA downgradient of these wells is not being affected.

Six seeps are also associated with this area and are located along the Main Hill of the plant property. Two seeps are within the plant property boundary, and the remaining four are offsite to the north. Several seeps have elevated levels of tritium and VOCs. These seeps, as well as several downgradient wells, are being monitored to verify that source removal (buildings and soil) on the Main Hill will result in decreasing concentrations over time.

1.3 Geology and Hydrology

1.3.1 Hydrogeologic Setting

The aquifer system at the Mound site consists of two distinct hydrogeologic environments: groundwater flow through the Ordovician shale and limestone bedrock beneath the hills, and groundwater flow within the unconsolidated glacial deposits and alluvium associated with the BVA in the Great Miami River valley. A thin tributary valley divides the two main portions of the Mound site and contains a narrow tongue of glacial deposits that are in hydraulic communication with the BVA. The bedrock flow system is dominated by fracture flow and is not

considered a highly productive aquifer. The BVA is dominated by porous flow, with interbedded gravel deposits providing the major pathway for water movement. The unconsolidated deposits are Quaternary-age sediments that consist of both glacial and fluvial deposits. The BVA is a highly productive aquifer capable of yielding a significant quantity of water. It is designated a sole-source aquifer. The general structure and flow characteristics for these two interconnected systems are depicted on Figure 2.

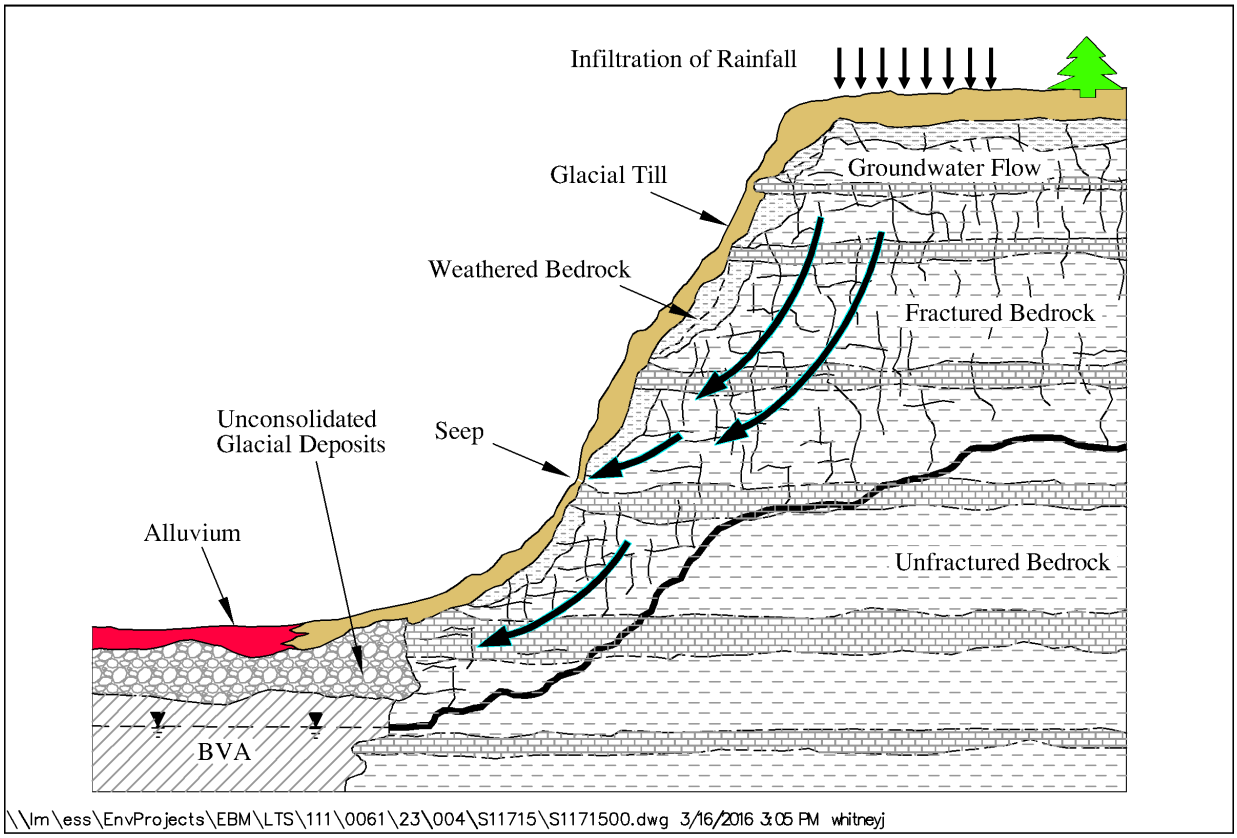

Figure 2. Generalized Cross Section Showing Flow from Bedrock to the BVA

For detailed descriptions of the geology, lithology, and groundwater flow regimes at the Mound site and specific hydrogeologic information for each area, refer to hydrogeologic investigation reports and work plans prepared for the site (DOE 1992, DOE 1994a, DOE 1994b, DOE 1995, and DOE 1999).

1.3.2 Groundwater Flow

Figure 3 is a map of the average groundwater elevations for 2015 that depicts the general groundwater flow at the Mound site. Two groundwater regimes are present at the site: groundwater in the bedrock and groundwater in the BVA. Groundwater flow in the bedrock typically mimics the topography, with groundwater discharging to the BVA or at seeps from the upper bedrock. Groundwater flow in the BVA flows south, following the downstream course of the Great Miami River.

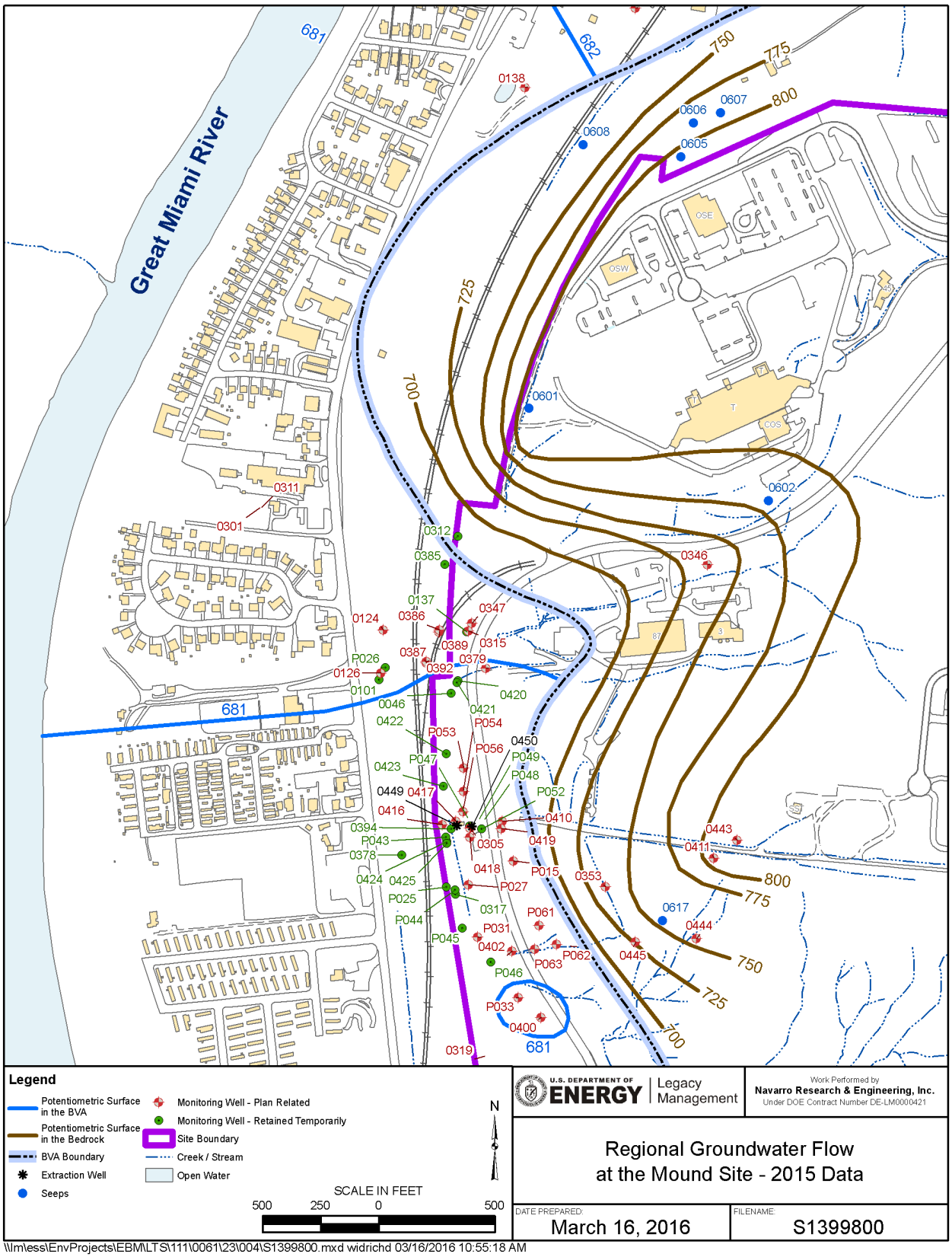

Figure 3. Regional Groundwater Flow at the Mound Site

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2.0 Monitoring Programs

2.1 Phase I

The Phase I groundwater monitoring program was established to verify that the BVA is not negatively affected by TCE-contaminated groundwater within the bedrock aquifer system. Groundwater in Phase I is monitored for TCE and its degradation products to verify that concentrations of TCE are decreasing by natural attenuation. The objective of this monitoring is to protect the BVA by verifying that the concentration of TCE near well 0411, well 0443, and seep 0617 is decreasing and to confirm that TCE is not adversely affecting the BVA. This program may be decreased or terminated when TCE concentrations in well 0411, well 0443, and seep 0617 meet conditions outlined in the Sitewide Operations and Maintenance Plan, such as reaching the MCL for four consecutive sampling events.

2.1.1 Monitored Natural Attenuation of TCE

Under the Phase I MNA monitoring program, samples are collected semiannually from selected wells and a seep (Figure 4) and analyzed as outlined in Table 1. Sampling was performed in the first and third quarters of 2015.

Table 1. Remedy (MNA) Monitoring for Phase I

Monitoring Location	Area	Parameters
Well 0411	Well 0411 area	TCE Dichloroethene Vinyl chloride
Well 0443		
Well 0353	Downgradient bedrock monitoring	
Well 0444		
Well 0445		
Seep 0617		
Well 0400	Downgradient BVA monitoring	
Well 0402		
Well P033		

All locations are sampled semiannually.

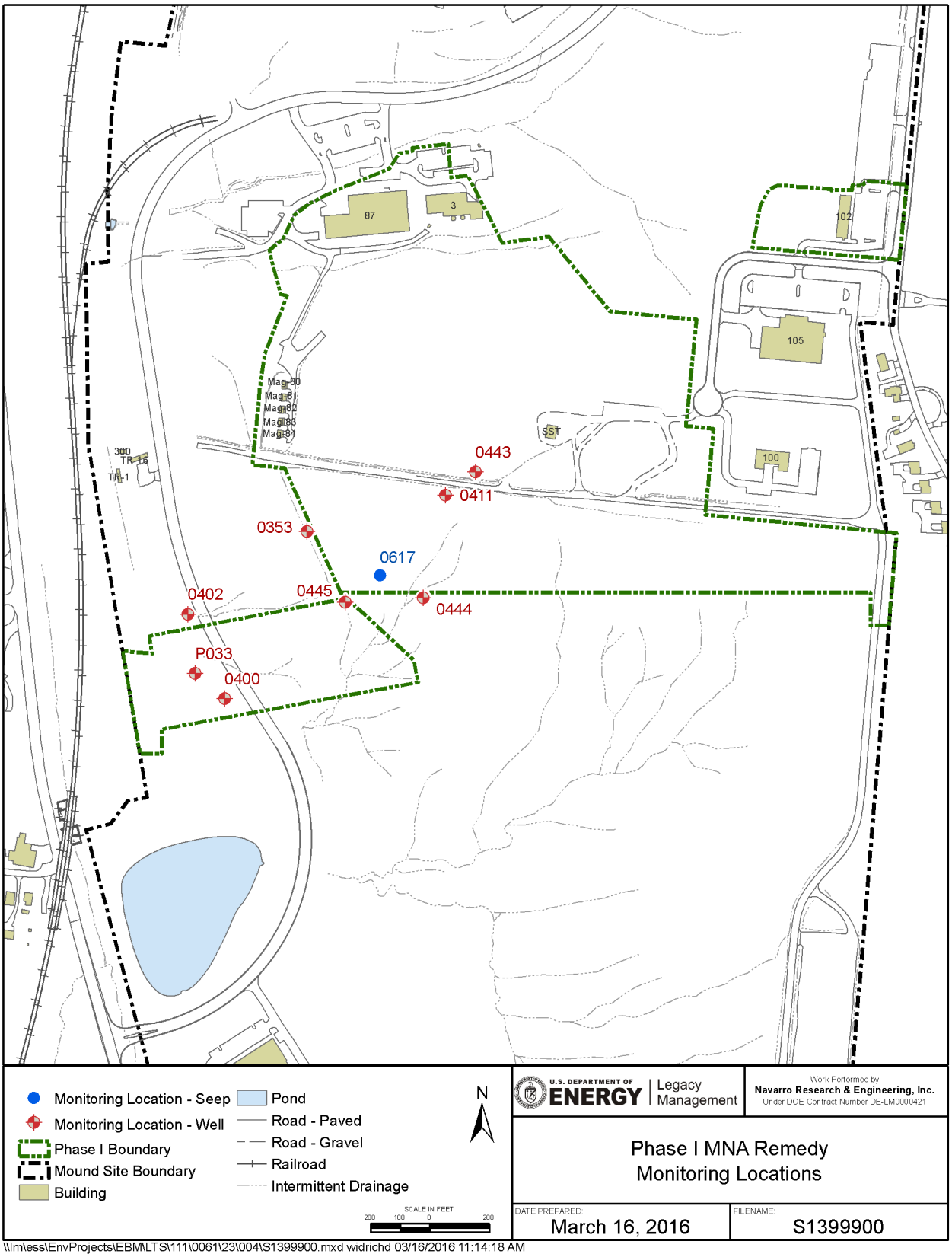

Figure 4. Phase I MNA Remedy Monitoring Locations

2.1.2 Triggers

The contaminant data are evaluated against previous data collected at each location to determine if MNA is adequately addressing groundwater impact and to monitor the geochemical conditions in the aquifer. Trigger levels and response actions have been established for each contaminant as presented in the Sitewide Operations and Maintenance Plan (DOE 2015). The triggers are summarized in Table 2.

Table 2. Trigger Levels for Phase I MNA Remedy

Location	TCE (µg/L)	DCE (µg/L)	Vinyl Chloride (µg/L)
0353	5	70	2
0400	5	70	2
0402	5	70	2
0411	30	70	2
0443	18	70	2
0444	5	70	2
0445	5	70	2
P033	5	70	2
0617 (seep)	16	70	2

DCE = dichloroethene
µg/L = micrograms per liter

EPA and Ohio EPA must be notified if trigger levels are exceeded. After notification, the Core Team (EPA, Ohio EPA, and DOE) will determine an appropriate course of action.

2.2 Parcels 6, 7, and 8

Groundwater in the Parcels 6, 7, and 8 area is monitored for TCE and its degradation products to verify that the downgradient BVA is not affected and that concentrations are decreasing. In addition, groundwater discharging from seeps is monitored for tritium and TCE and its degradation products to verify that source removal will result in decreasing concentrations over time.

The sampling program focuses on the following areas:

- **Well 0315/0347 Area:** Wells at the edge of the BVA on the southwestern corner of Parcel 8 that have elevated concentrations of VOCs. The program consists of wells that have TCE concentrations greater than the MCL and downgradient wells to the west. Wells 0315 and 0347 (source wells) and other selected downgradient BVA wells are monitored for VOCs—namely, tetrachloroethene (also known as perchloroethene or PCE), dichloroethene (DCE) isomers, TCE, and vinyl chloride (VC).
- **Main Hill Seeps:** Seeps on the northern and southern sides of the Main Hill that have elevated concentrations of VOCs and tritium. The program consists of seeps and downgradient wells to the west. Water from seeps 0601, 0602, 0605, 0606, 0607, and 0608 is collected and analyzed for VOCs and tritium. Select wells within the BVA that are downgradient of the bedrock groundwater discharge area of the Main Hill are also sampled to monitor VOCs and tritium.

2.2.1 Monitored Natural Attenuation of TCE and Tritium

Under the Parcels 6, 7, and 8 MNA monitoring program, samples are collected quarterly for VOCs and semiannually for tritium in selected wells and seeps (Figure 5). Table 3 provides a summary of the monitoring locations as specified in the Sitewide Operations and Maintenance Plan.

Table 3. Monitoring for Parcels 6, 7, and 8 Area

Monitoring Location	Area	VOC	Tritium
Well 0315	Source wells	X	
Well 0347		X	
Well 0118	Downgradient BVA monitoring	X	X
Well 0124		X	
Well 0126		X	
Well 0138		X	X
Well 0301		X	X
Well 0346		X	X
Well 0379		X	X
Well 0386		X	
Well 0387		X	
Well 0389		X	
Well 0392		X	
Seep 0601	Main Hill seeps	X	X
Seep 0602		X	X
Seep 0605		X	X
Seep 0606		X	X
Seep 0607		X	X

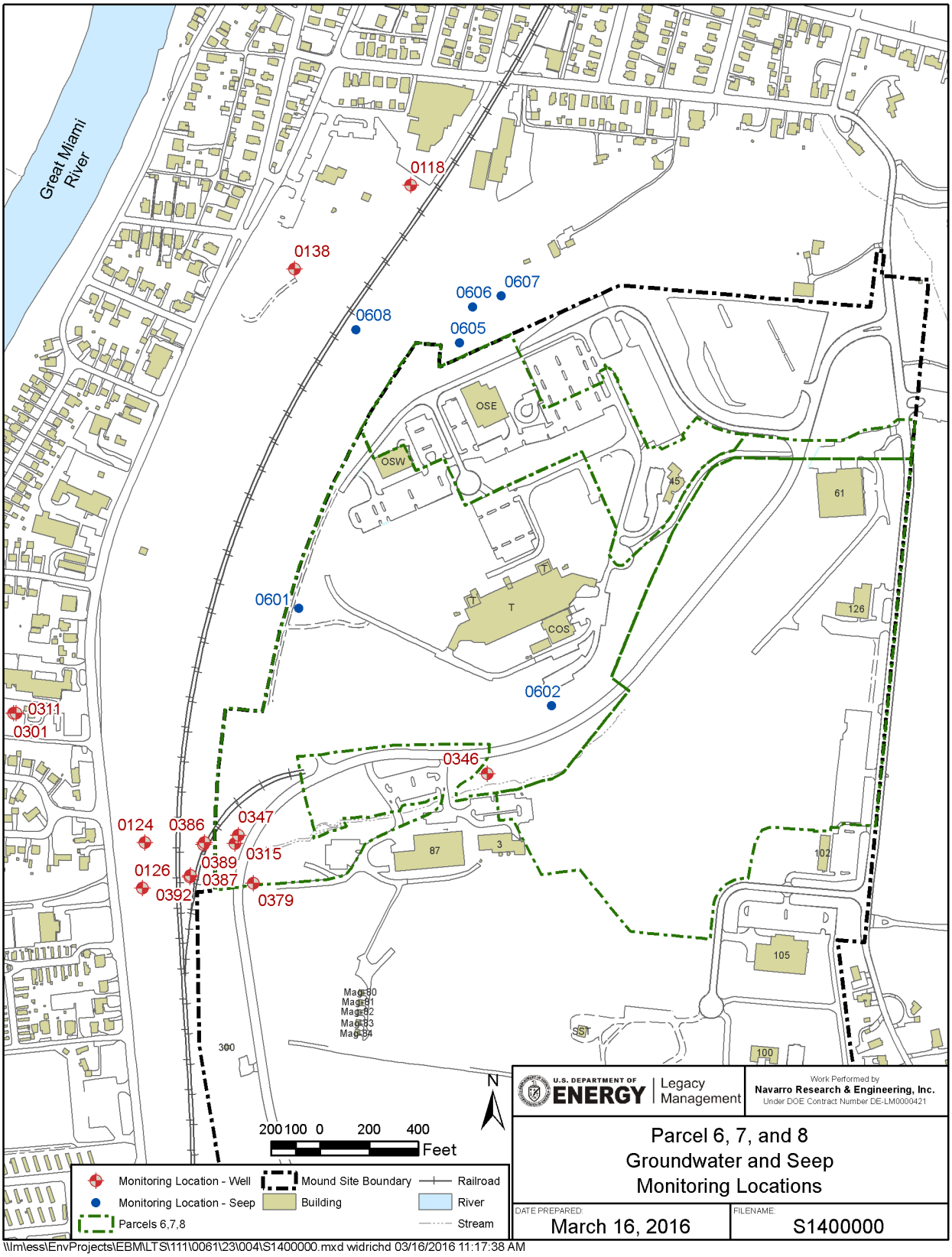

Figure 5. Parcels 6, 7, and 8 Remedy Monitoring Locations

2.2.2 Triggers

The contaminant data are evaluated against previous data collected at each location to determine if downward trends are occurring. Trigger levels and response actions have been established for each contaminant as presented in the Sitewide Operations and Maintenance Plan (DOE 2015). The triggers are summarized in Table 4.

Table 4. Trigger Levels for Parcels 6, 7, and 8 Monitoring Locations

Location	TCE (µg/L)	PCE (µg/L)	Tritium (nCi/L)
0315	30		
0347	30		
0124	5		
0126	5		
0386	5		
0387	5		
0389	5		
0392	5		
0601 (seep)		75	1,500
0605 (seep)	150		

µg/L = micrograms per liter
nCi/L = nanocuries per liter

EPA and Ohio EPA must be notified if these trigger levels are exceeded. After notification, the Core Team (EPA, Ohio EPA, and DOE) will determine an appropriate course of action.

2.3 Monitoring Network

The monitoring well and seep locations sampled under these programs were selected to provide data of sufficient quality to meet the objectives of the groundwater remedies for either Phase I or Parcels 6, 7, and 8. These wells were initially installed to support various site characterization activities and were designed and constructed to provide high-quality groundwater data. Appendix A contains construction information for each well used to support these remedies.

Wells 0301 and 0311, both located offsite, were removed from the monitoring network in 2015 due to construction activities by the City of Miamisburg. The Core Team approved these wells being removed from the program with no additional wells required as replacements. The wells were abandoned in accordance with Ohio Department of Natural Resources (ODNR) requirements (see Section 5).

Seep 0608 will no longer be sampled after 2015. This location was not identified in the record of decision as a long-term sampling location for the Parcels 6, 7, and 8 monitoring program. Data that were collected for 2015 are included in this report.

2.4 Deviations from the Sitewide Operations and Maintenance Plan

Sampling was performed as outlined in the Sitewide Operations and Maintenance Plan (DOE 2015), which compiles the sampling requirements outlined in previous plans for each area. Modifications to these monitoring programs (e.g., reduction in sampling frequency or discontinuation of monitoring locations) are also incorporated into the Sitewide Operations and Maintenance Plan.

Sampling was performed as follows:

- All required locations in Phase I were sampled in 2015.
- All required locations in Parcels 6, 7, and 8 were sampled in 2015 except seep 0602, which was dry during the third quarter.
- Site-specific sampling methods for the Mound site were followed during these sampling events. These methods were developed by the Mound Groundwater Technical Team and approved by the Mound Core Team and are integrated into the Sitewide Operations and Maintenance Plan.

2.5 Trend Analysis Methodology

The computer program Visual Sample Plan (VSP), developed by Battelle Memorial Institute, was used to perform trend analysis; the method used was the nonparametric Mann-Kendall test. The analyses indicate the potential presence of statistically significant downward or upward trends in concentrations at a given location. All locations were previously evaluated for seasonality as part of the annual review in 2014. Results indicate there are no seasonal trends in contaminant data collected from any of the monitoring locations.

The Mann-Kendall test is used for temporal trend identification because it can easily accommodate missing data and does not require the data to conform to a particular distribution (such as a normal or log-normal distribution). The nonparametric method is valid for data sets that have a high number of nondetect data points. Data reported as trace concentrations or less than the detection limit can be used by assigning them a common value that is smaller than the smallest measured value in the data set (i.e., specified detection limit). This approach is valid because only the relative magnitudes of the data points, rather than their measured values, are used in the method. A possible consequence of this approach is that the test can produce biased results if a large fraction of data within a time series is nondetect and if detection limits change between sampling events. The specified detection limit (on the date of analysis) was used in place of concentrations reported as nondetect.

The one-tailed version of the Mann-Kendall test was used to detect a trend for each data set. As part of this approach, a test statistic, Z, was calculated. A positive value of Z would indicate that the data were skewed in an upward direction, and a negative value of Z would indicate that the data were skewed in a downward direction. Data sets were initially evaluated for downward trends. Those data sets that did not indicate a downward trend were then evaluated for upward trends. Summary reports for each monitoring location are contained in Appendix B.

The alpha value (or false rejection rate) used to identify a significant trend was 0.05. The beta value (or false acceptance rate) was set at 0.10. A nonparametric estimate of the slope, which is calculated independently of the trend, was determined for each data set using the Sen's nonparametric estimate of the slope in the VSP program. In addition, a 95 percent ($1-\alpha$) two-sided confidence interval about the true slope was obtained.

3.0 Phase I MNA Remedy

3.1 Monitoring Results

Monitoring results for 2015 (Table 5) continue to show low-level detections of TCE and *cis*-1,2-DCE, a TCE degradation product, in wells 0411 and 0443 and in seep 0617. All VOC concentrations were below the applicable trigger levels (Table 2). Concentrations of TCE in wells 0411 and 0443 and seep 0617 continue to exceed the MCL of 5 micrograms per liter (µg/L). No detectable concentrations of *trans*-1,2-DCE or VC were reported at these three monitoring locations. None of the downgradient wells indicated impact attributable to VOCs originating from the Phase I area. An estimated detection of TCE was reported in BVA well 0402; however, the value was within historical ranges and is attributable to VOC impact in Operable Unit (OU)-1. No detectable concentrations of *cis*-1,2-DCE, *trans*-1,2-DCE, or VC were reported in the downgradient BVA and bedrock wells.

Table 5. Summary of VOC Monitoring Results in Phase I for 2015

Well ID	Location	Parameter	First Semiannual Event	Second Semiannual Event
Source Area Wells and Seep				
0411	0411 Area	TCE (µg/L)	**10.8**	**10.3**
		cis-1,2-DCE (µg/L)	3.3	1.7
0443	0411 Area	TCE (µg/L)	**6.0**	**5.9**
		cis-1,2-DCE (µg/L)	0.27 (J)	0.33 (J)
0617	Seep/ Bedrock	TCE (µg/L)	**8.3**	**8.0**
		cis-1,2-DCE (µg/L)	1.9	1.9
Downgradient Wells				
0353	Bedrock	TCE (µg/L)	ND (<1)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)
0444	Bedrock	TCE (µg/L)	ND (<1)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)
0445	Bedrock	TCE (µg/L)	ND (<1)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)
0400	BVA	TCE (µg/L)	ND (<1)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)
0402	BVA	TCE (µg/L)	0.43 (J)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)
P033	BVA	TCE (µg/L)	ND (<1)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)

J = estimated value less than the reporting limit
ND = not detected above reporting limit
Values in **bold** exceed the MCL of 5 µg/L for TCE

TCE concentrations in well 0411 (Figure 6) generally decreased since monitoring began in 1999. Since 2002, the concentrations of TCE in well 0411 have ranged between 9 and 15 µg/L. Concentrations of TCE in well 0443 and seep 0617 have varied since monitoring of these locations started in 2002. Concentrations of TCE in well 0443 have been consistently greater than the MCL since 2010. The time-concentration plots for well 0443 and seep 0617 indicate that concentrations vary and are less than those in well 0411.

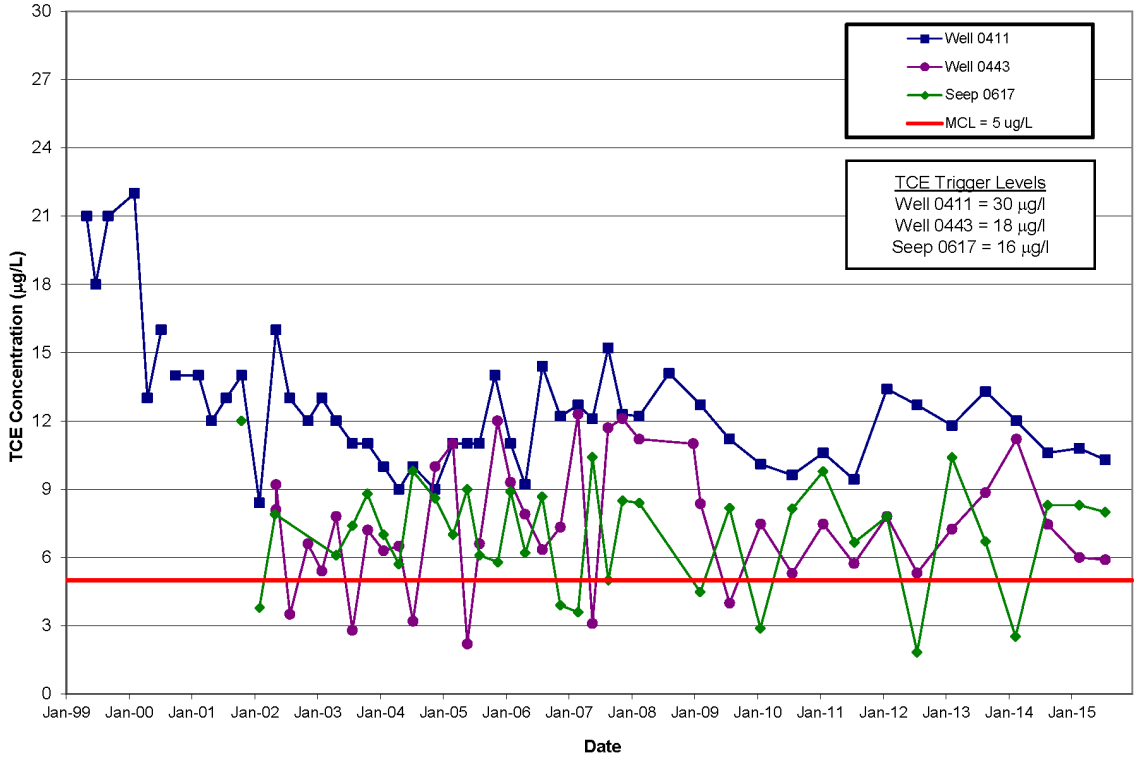

Figure 6. TCE Concentrations in Phase I—1999 Through 2015

The concentrations of *cis*-1,2-DCE in groundwater (Figure 7) have varied. Detectable concentrations have consistently been reported in well 0411 and seep 0617. Concentrations of *cis*-1,2-DCE in well 0411 have increased compared to monitoring results reported prior to 2009. Estimated detections less than 1 µg/L have been reported in well 0443 during the same period. None of the locations had concentrations of *cis*-1,2-DCE that exceeded the MCL of 70 µg/L.

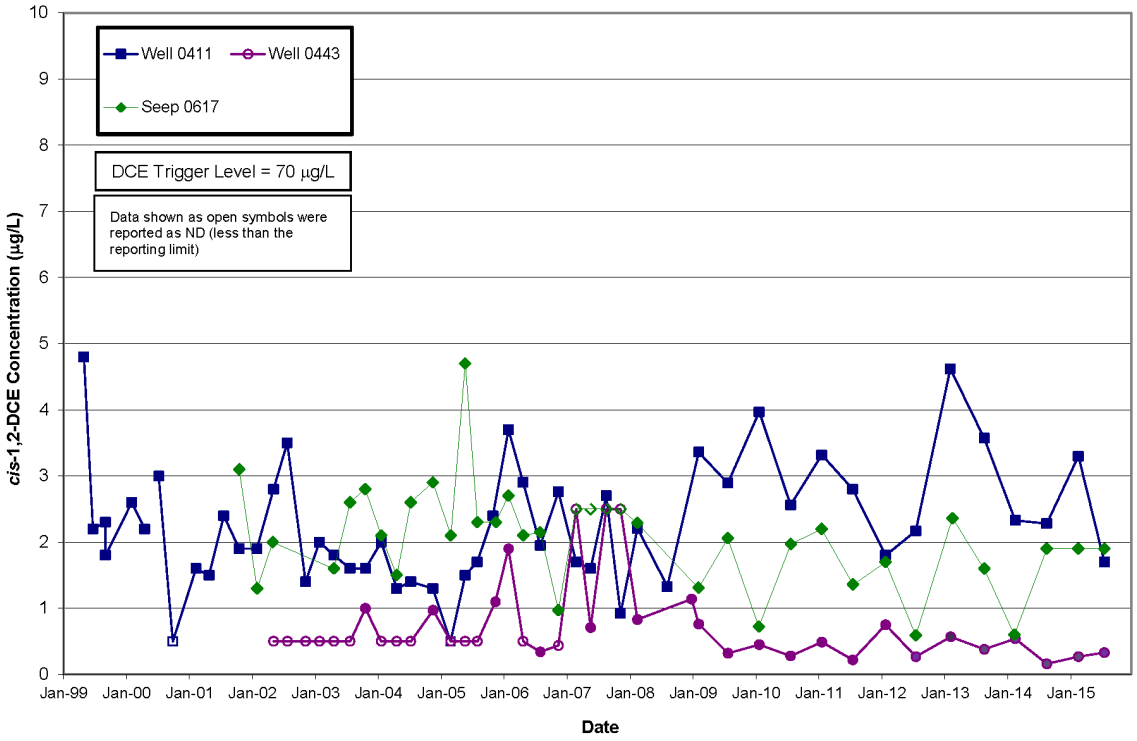

Figure 7. cis-1,2-DCE Concentrations in Phase I—1999 Through 2015

The distributions of TCE and DCE in groundwater (Figure 8) indicate that impact is localized in the bedrock groundwater near wells 0411 and 0443 and seep 0617. Wells screened in the bedrock and BVA that are downgradient of the area of VOC impact do not have detectable concentrations of TCE or DCE, with the exception of well 0402, where estimated detections have occasionally been reported. It has been determined that VOC impact in well 0402 is attributable to groundwater impact from OU-1, which is located immediately upgradient.

3.2 Trend Analysis

Trend analysis for TCE data collected since 1999 continues to indicate decreasing TCE concentrations in well 0411 and seep 0617, as indicated by negative slopes of the trend lines (Table 6). A statistical downward trend was calculated for TCE in well 0411. No statistical trend, either upward or downward, was evident in the data for TCE in well 0443 and seep 0617.

Table 6. Summary of Trend Analysis Results for TCE in Phase I for 2015

Location	Analyte	No. of Samples	Trend	Slope (µg/L/year)
0411	TCE	51	**Down**	–0.22
0443		39	None	0.10
0617		37	None	–0.06
0411	*cis*-1,2-DCE	51	**Up**	0.04
0443		39	**Down**	–0.05
0617		37	**Down**	–0.07

µg/L/year = micrograms per liter per year

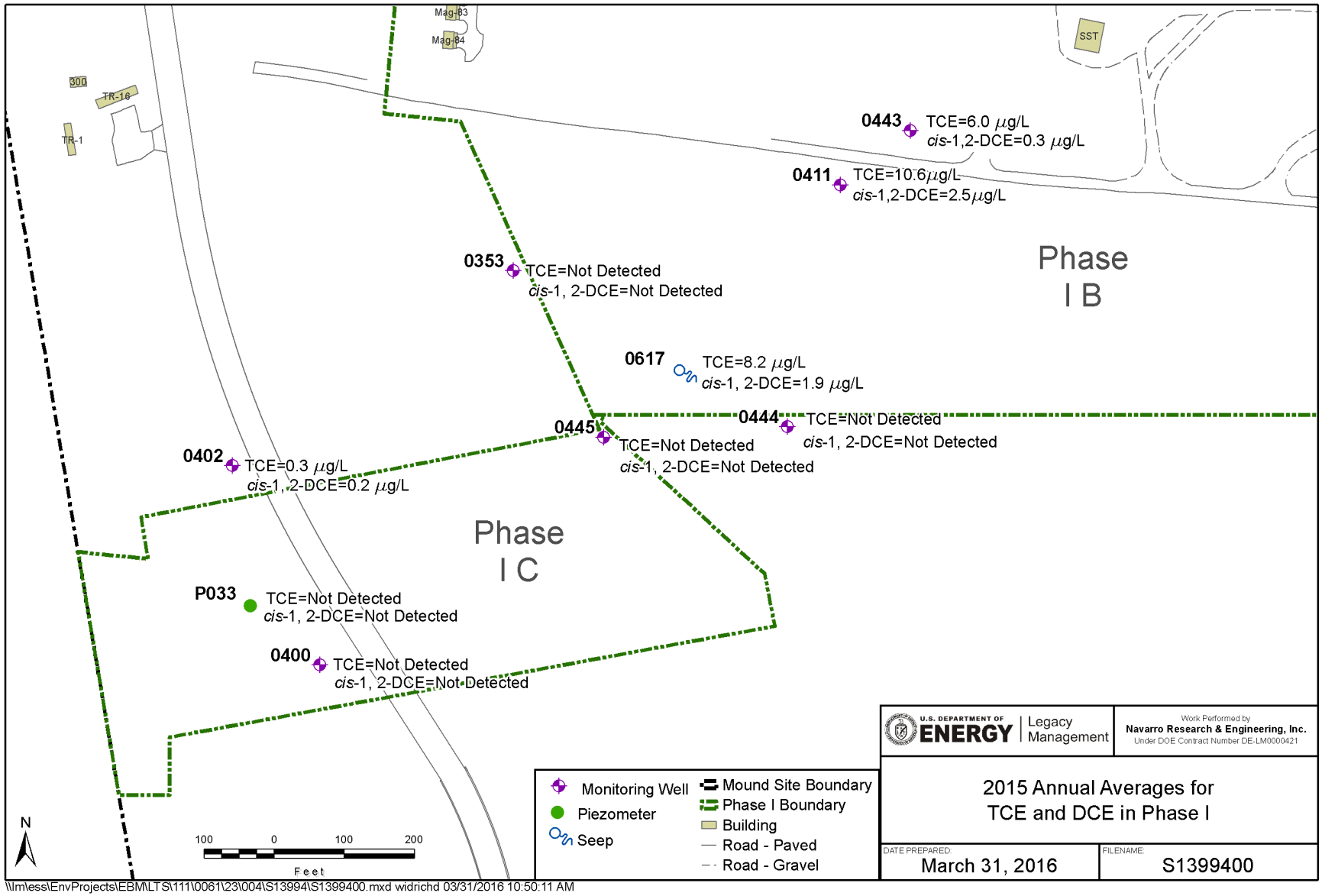

Figure 8. 2015 Annual Averages for TCE and DCE in Phase I

Decreasing *cis*-1,2-DCE concentrations, although small, are present in well 0443 and seep 0617, as indicated by negative slopes. Statistical downward trends were calculated for *cis*-1,2-DCE at both locations. A small statistical upward trend was determined for the *cis*-1,2-DCE data in well 0411.

Evaluation of the slope of the downward trend in TCE concentrations in well 0411 may indicate the time frame when concentrations may approach the MCL of 5 µg/L. The nonparametric slope calculated for the trend analysis continues to suggest that the MCL may be reached by 2034. The nonparametric analysis typically represents the decrease of contaminant concentrations in groundwater over time and provides good estimates of cleanup time frames.

3.3 Groundwater Elevations

A map of the average groundwater elevations measured in the Phase I area during 2015 (Figure 9) indicates two flow regimes: bedrock and BVA. The approximate location of contact of the BVA with the bedrock is indicated on this figure. Groundwater originating from the well 0411/0443 area flows southwest within the bedrock, following the bedrock topography. This groundwater enters the BVA along this contact. Flow within the BVA is generally to the south-southeast (parallel to the bedrock contact), although the groundwater elevations measured in the three wells screened in the BVA are similar. Appendix C presents a summary of the groundwater elevations measured during 2015.

3.4 Data Evaluation

The distribution of TCE and *cis*-1,2-DCE in groundwater continues to indicate that VOC impact is localized in the bedrock groundwater near wells 0411 and 0443 and downgradient seep 0617. Concentrations at these three monitoring locations continue to exceed the MCL of 5 µg/L. Overall, TCE concentrations in well 0411, which has the highest concentrations in Phase I, have decreased since monitoring began in 1999. Low levels of *cis*-1,2-DCE continue to be present at all three locations. Trend analysis continued to indicate decreasing concentrations of TCE in well 0411 and seep 0617 and a statistical downward trend in TCE concentrations in well 0411. Trend analysis estimates that the MCL of 5 µg/L for TCE in well 0411 may be reached by 2034. No statistical trends in the TCE were present in the data from well 0443 and seep 0617. Downward trends were calculated for *cis*-1,2-DCE in well 0443 and seep 0617 and an upward trend was calculated in well 0411. Increases in *cis*-1,2-DCE are expected as TCE degrades. Data continued to show that the downgradient BVA is not affected by localized TCE impact in the bedrock groundwater.

3.5 Recommendations

No changes to the Phase I MNA monitoring program are warranted based on data collected in 2015. On the basis of no upward trends in TCE concentrations and the concentrations being considerably less than the trigger levels, monitoring frequency is recommended to remain semiannual for 2016. Sampling will continue during the first and third quarters of the year in an effort to bracket possible seasonal variations.

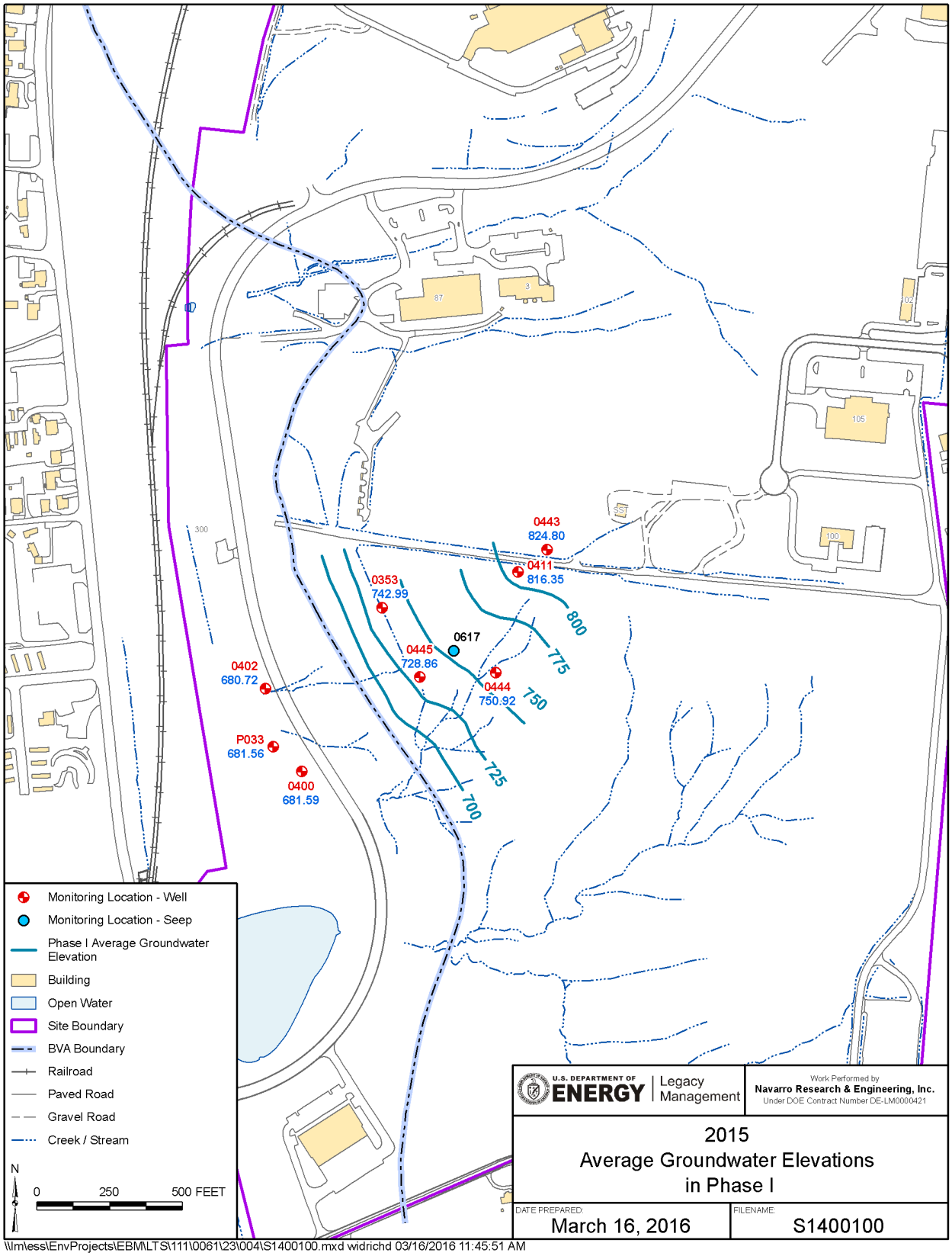

Figure 9. 2015 Average Groundwater Elevations in Phase I

4.0 Parcels 6, 7, and 8 MNA Remedy

4.1 Monitoring Results—VOCs

4.1.1 Seeps

Concentrations of TCE in all Main Hill seeps continued to exceed the MCL in 2015 (Table 7). However, no locations had concentrations that exceeded the trigger level of 150 µg/L (established for seep 0605). The highest concentrations of TCE continued to be measured in seep 0602, which is onsite. This seep was dry during the third quarter and could not be sampled. PCE concentrations continued to exceed the MCL of 5 µg/L in seep 0601; however, PCE concentrations at this location did not exceed the trigger level of 75 µg/L. Estimated detections of PCE were reported in seeps 0605 and 0607. *cis*-1,2-DCE was reported in seeps 0602 and 0605; seep 0602 had the highest concentrations. Estimated detections of *cis*-1,2-DCE (less than 1 µg/L) were reported in seeps 0601, 0606, and 0607. Estimated detections of *trans*-1,2-DCE (less than 1 µg/L) were reported in seep 0602 and 0605. No VC was detected in the seeps.

Table 7. Summary of VOC Results in the Main Hill Seeps for 2015

Location	Area	VOC Concentrations				
		VOC	Q1	Q2	Q3	Q4
Seeps						
0601	Onsite	PCE (µg/L)	**14.9**	**12.8**	**12.2**	1.3
		TCE (µg/L)	**6.7**	**4.0**	**6.9**	1.0
		cis-1,2-DCE (µg/L)	0.57 (J)	0.73 (J)	0.62 (J)	ND (<1)
		trans-1,2-DCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0602	Onsite	PCE (µg/L)	ND (<1)	ND (<1)	Dry	ND (<1)
		TCE (µg/L)	**19.0**	**21.4**		14.7
		cis-1,2-DCE (µg/L)	9.9	7.5		4.6
		trans-1,2-DCE (µg/L)	0.67 (J)	0.45 (J)		ND (<1)
0605	Offsite	PCE (µg/L)	0.23 (J)	0.26 (J)	0.28 (J)	ND (<1)
		TCE (µg/L)	**13.0**	**10.9**	**12.3**	**7.2**
		cis-1,2-DCE (µg/L)	3.6	1.9	1.1	2.2
		trans-1,2-DCE (µg/L)	0.22 (J)	ND (<1)	0.24 (J)	ND (<1)
0606	Offsite	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	1.0	0.61 (J)	**7.0**	4.1
		cis-1,2-DCE (µg/L)	0.18 (J)	0.16 (J)	0.70 (J)	0.50 (J)
		trans-1,2-DCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0607	Offsite	PCE (µg/L)	ND (<1)	0.20 (J)	0.18 (J)	ND (<1)
		TCE (µg/L)	4.9	4.4	**6.7**	3.2
		cis-1,2-DCE (µg/L)	0.91 (J)	0.52 (J)	0.90 (J)	0.28 (J)
		trans-1,2-DCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0608	Offsite	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	1.4	1.4	ND (<1)	ND (<1)
		cis-1,2-DCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		trans-1,2-DCE (µg/L)	ND (< 1)	ND (< 1)	ND (<1)	ND (<1)

ND = Not detected
J = Estimated value that is less than the reporting limit
Q = Quarter

PCE trigger level at 0601 = 75 µg/L
TCE trigger level at the seeps = 150 µg/L
Values in **bold** exceed the MCL

A graph of TCE concentrations measured in the seeps since the remediation of contaminated buildings and soil on the Main Hill (completed in mid-2006) (Figure 10) shows that the highest concentrations of TCE were measured in seeps 0602 and 0605. Concentrations of TCE have varied significantly in seep 0602, ranging from 15 µg/L to 139 µg/L. Concentrations of TCE in seep 0605 are relatively stable and the remainder of the seeps follow a similar fluctuation. TCE concentrations in seep 0605 have been consistently less than 20 µg/L and the concentrations in the remainder of the seeps have been less than 10 µg/L.

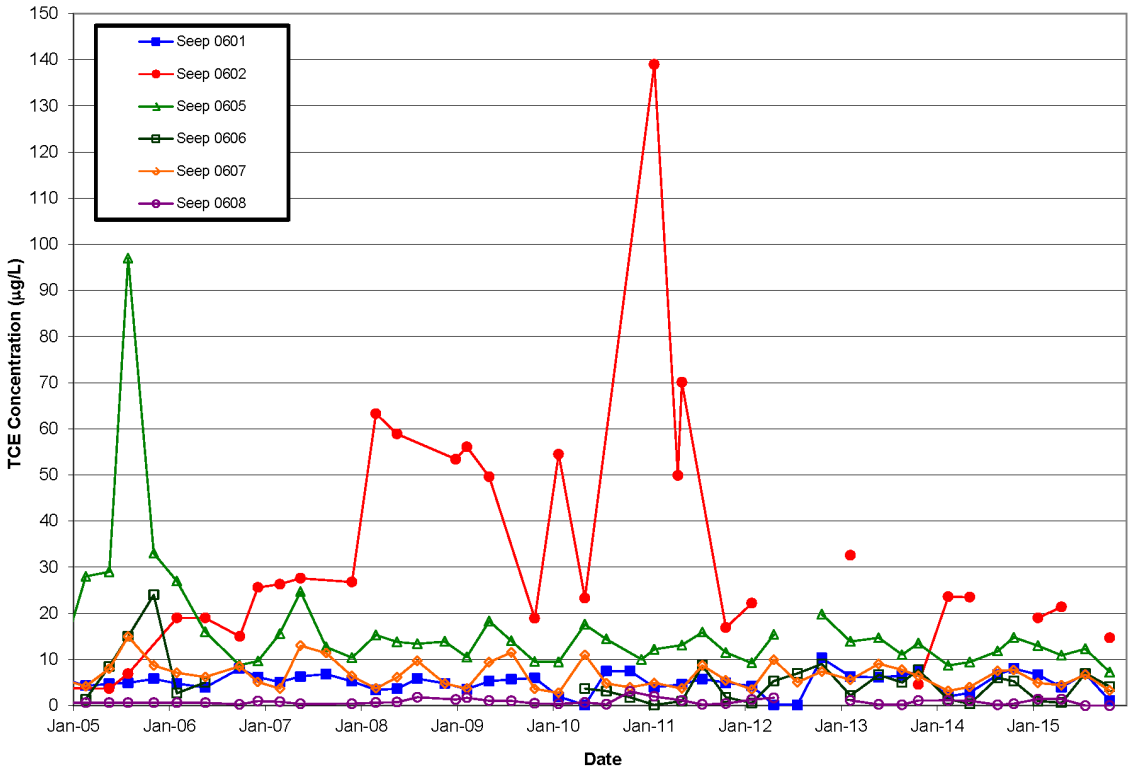

Figure 10. TCE Concentrations in Parcels 6, 7, and 8 Main Hill Seeps

Seep 0601 is the only location where detectable concentrations of PCE were reported. PCE concentrations in this seep (Figure 11) have decreased since remediation on the Main Hill. Estimated detections of PCE (less than 1 µg/L) were reported in seeps 0605 and 0607.

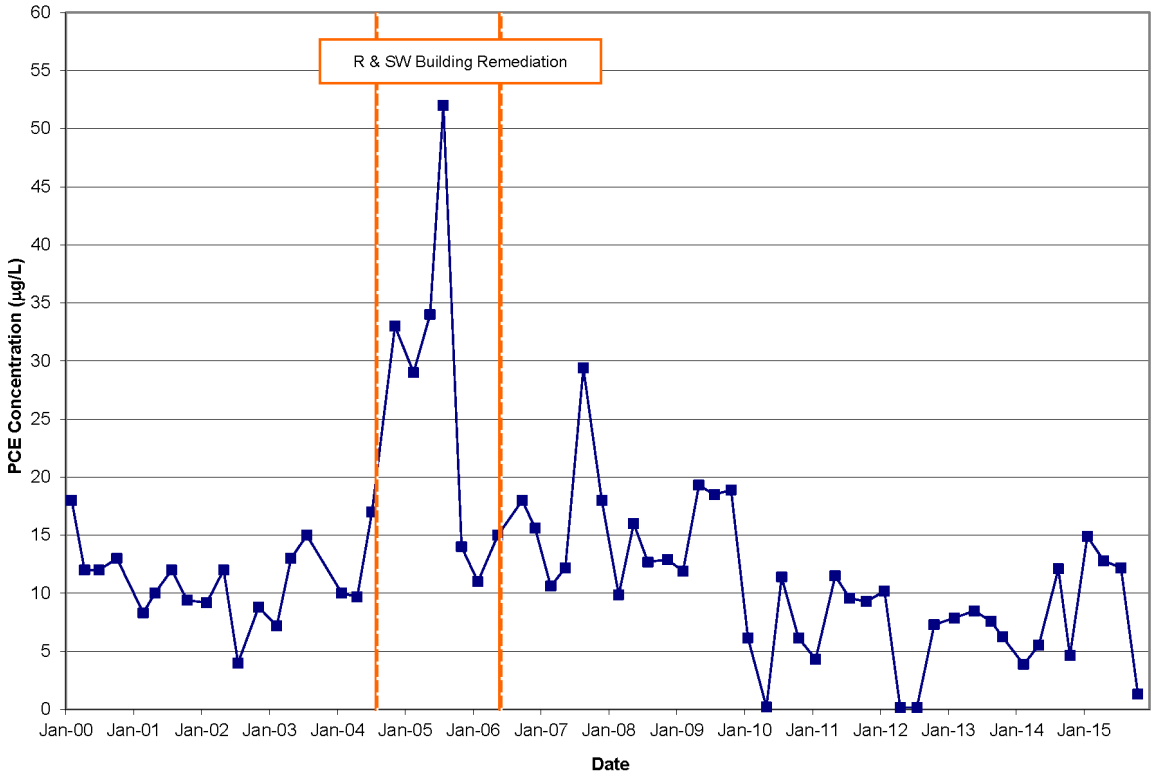

Figure 11. PCE Concentrations in Parcels 6, 7, and 8 Seep 0601

4.1.2 Groundwater

Monitoring results for 2015 (Table 8) continue to show TCE in wells 0315, 0347, 0379, and 0386; the highest concentrations are detected in wells 0315 and 0347 (source area wells), where concentrations also exceed the MCL. The concentrations of TCE reported in wells 0315 and 0347 were less than the trigger level of 30 µg/L established for these source area wells. Well 0386 is located downgradient of wells 0315 and 0347 just outside the Mound site boundary. Well 0379 is located onsite within the tributary valley, where wells 0315 and 0347 are also located. Estimated detections of TCE were reported in well 0389. No detectable concentrations of TCE were measured in the other wells. All TCE concentrations were below applicable trigger levels.

Estimated detections of PCE less than 1 µg/L were reported in wells 0126, 0379, 0386, 0387, 0389, and 0392. All of these wells are located where the tributary valley enters into the BVA. No trigger levels for PCE have been set for these locations. No detectable concentrations of *cis*-1,2-DCE, *trans*-1,2-DCE, or VC were reported in any of the wells monitored as part of this program.

Table 8. Summary of VOC Results in Parcels 6, 7, and 8 Groundwater for 2015

Location	Area	VOC Concentrations				
		VOC	Q1	Q2	Q3	Q4
Onsite Wells						
0315	Source Area	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	**9.6**	**6.1**	**6.4**	**8.2**
0347	Source Area	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	**25.4**	**24.5**	**17.6**	**19.6**
0346	Onsite	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0379	Onsite	PCE (µg/L)	0.32 (J)	0.34 (J)	0.25 (J)	0.35 (J)
		TCE (µg/L)	1.7	1.5	1.3	1.8
Downgradient Wells—Near						
0386	BVA	PCE (µg/L)	ND (<1)	0.16 (J)	ND (<1)	0.17 (J)
		TCE (µg/L)	2.4	2.1	1.9	2.1
0387	BVA	PCE (µg/L)	0.24 (J)	0.22 (J)	0.30 (J)	0.26 (J)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0389	BVA	PCE (µg/L)	ND (<1)	ND (<1)	0.16	0.20 (J)
		TCE (µg/L)	0.23 (J)	0.16 (J)	0.18 (J)	0.29 (J)
0392	BVA	PCE (µg/L)	0.29 (J)	0.29 (J)	0.27 (J)	0.25 (J)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
Downgradient Wells—Far						
0118	BVA	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0124	BVA	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0126	BVA	PCE (µg/L)	1.0	0.88 (J)	0.90 (J)	0.88 (J)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
0138	BVA	PCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)
		TCE (µg/L)	ND (<1)	ND (<1)	ND (<1)	ND (<1)

J = Estimated value that is less than the reporting limit
ND = Not detected
Q = Quarter
TCE trigger level for 0315 and 0347 = 30 µg/L
TCE trigger level for other wells = 5 µg/L
Values in **bold** exceed the MCL

A graph of TCE concentrations measured in select wells shows that concentrations in wells 0315 and 0347 have consistently been greater than the MCL of 5 µg/L (Figure 12). The concentrations of TCE in the downgradient wells have been less than the MCL since 2000.

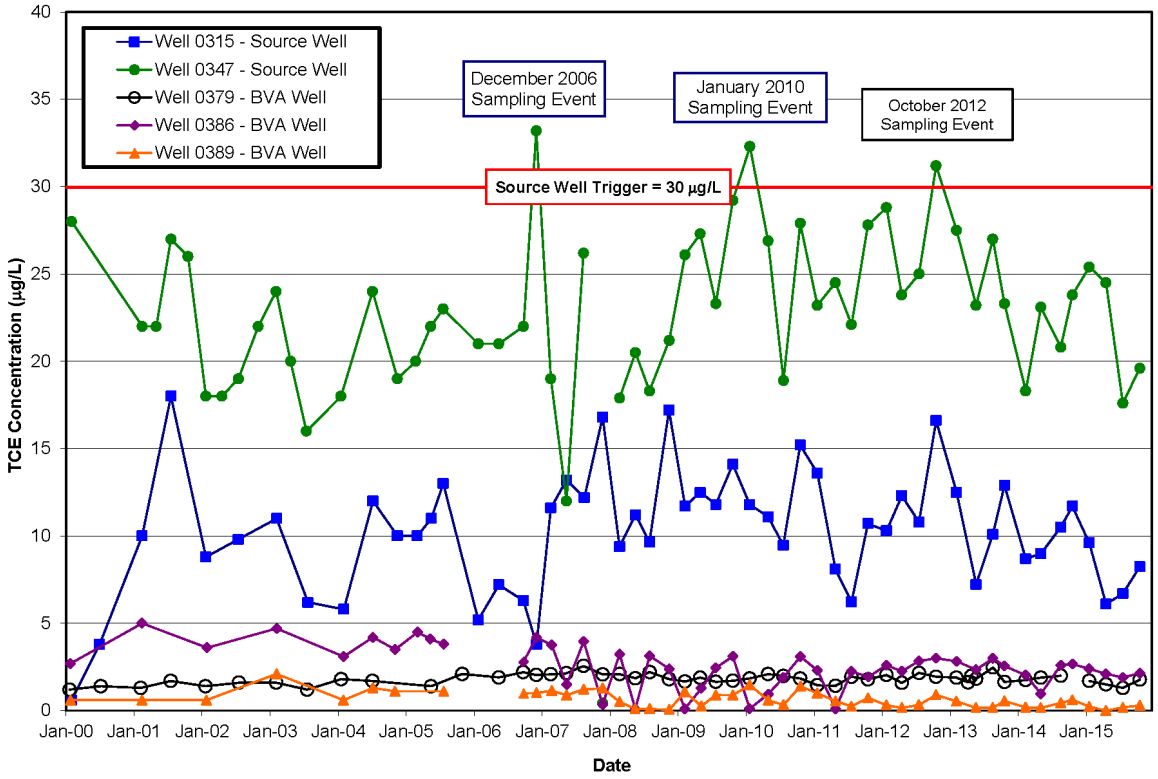

Figure 12. TCE Concentrations in Parcels 6, 7, and 8 Groundwater

4.1.3 Distribution of TCE

The distribution of TCE in groundwater (Figure 13) in the Main Hill area indicates that the highest area of impact is associated with the seeps, particularly seep 0602. The greatest groundwater impact is still associated with wells 0315 and 0347. The BVA wells immediately downgradient of this area have TCE concentrations below the MCL. Figure 13 depicts the 2015 annual averages of TCE in the monitoring network.

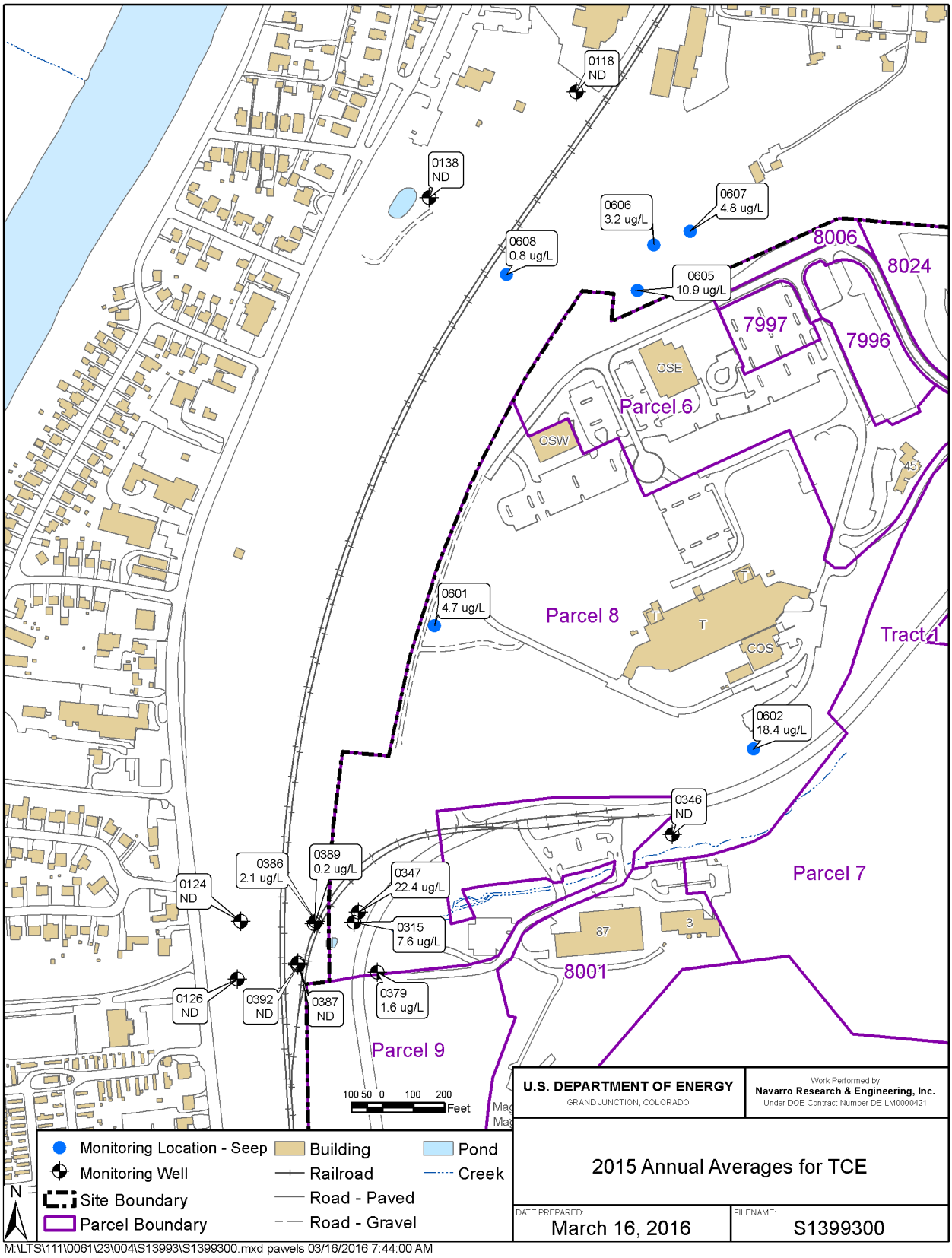

Figure 13. 2015 Annual Averages for TCE in Parcels 6, 7, and 8 Seeps and Groundwater

4.2 Monitoring Results—Tritium

Tritium levels in the Main Hill seeps continued to be elevated in 2015 and were higher than those in the downgradient groundwater wells (Table 9). The highest tritium activity was observed in seep 0601, which is located onsite. Seep 0601 is the only location that exceeded the MCL of 20 nanocuries per liter (nCi/L) during 2015. None of the seeps had tritium levels that exceeded the trigger level of 1,500 nCi/L.

Elevated tritium continued to be measured in well 0347. The remaining wells had tritium levels less than 1.1 nCi/L, which is similar to background (0.77 nCi/L [DOE 1996]). None of the groundwater wells had tritium levels that exceeded the MCL of 20 nCi/L.

Table 9. Summary of Tritium Results in the Main Hill Area for 2015

Location	Tritium Activity (nCi/L)	
	S1	S2
Seeps		
0601	**22.3**	**29.0**
0602	7.3	Dry
0605	7.9	8.3
0606	2.5	5.6
0607	2.8	3.9
0608	5.8	6.2
Downgradient Wells		
0118	ND (<0.36)	ND (<0.32)
0138	0.43	1.1
0346	ND (<0.37)	0.74
0347	2.8	1.7
0379	1.0	0.95

J = Estimated value that is less than the reporting limit
ND = Not detected
S = Semiannual
Tritium trigger level at the seeps = 1,500 nCi/L
Values in **bold** exceed the MCL of 20 nCi/L

Tritium levels in the seeps were highest during remediation activities on the Main Hill (2004−2006). Tritium data collected after building demolition and soil removal indicate decreasing levels in all of the seeps (Figure 14). The decrease in tritium levels in post-remediation data continues to support that the majority of the source was removed from the Main Hill area and that, with continued flushing, levels should continue to decline. Starting in 2009, the tritium levels in all of the seeps except seep 0601 were less than the MCL of 20 nCi/L. Changes in tritium levels in seep 0601 indicate a seasonal effect, as levels are typically higher in late summer to early fall.

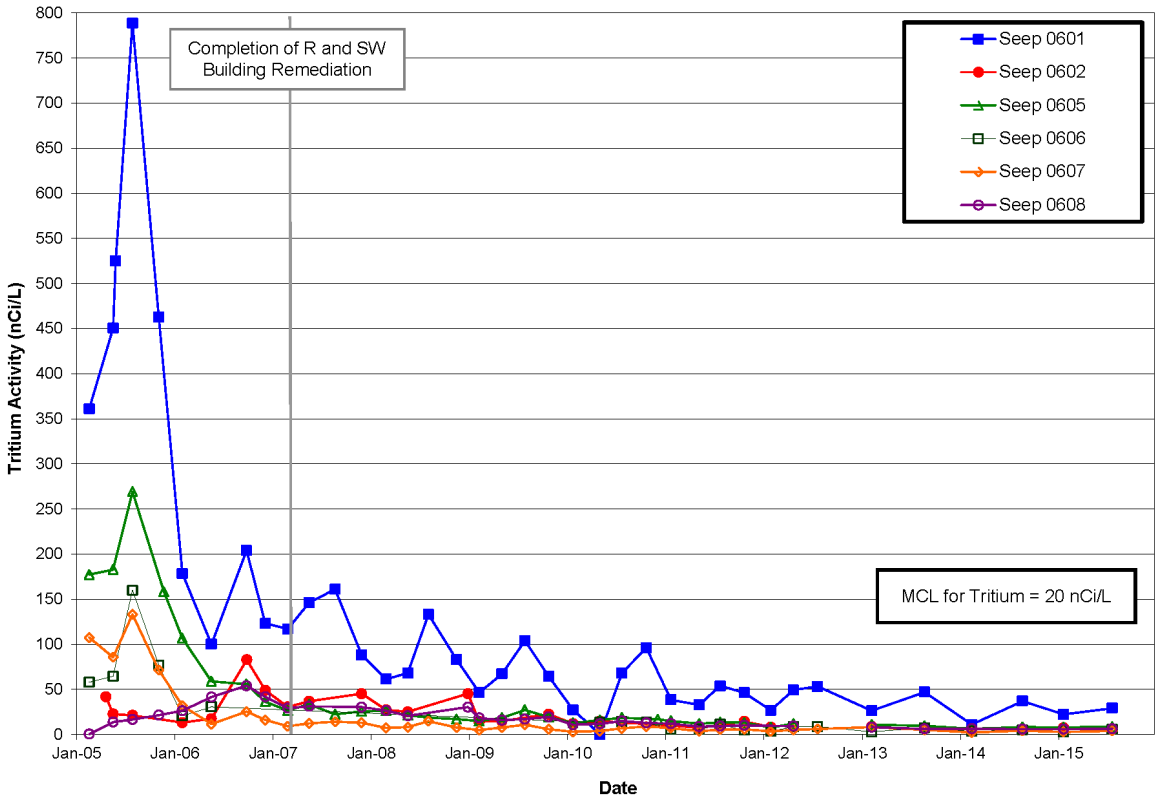

Figure 14. Tritium Activity in Parcels 6, 7, and 8 Main Hill Seeps

Comparisons of tritium levels in the seeps with those measured in downgradient monitoring wells indicate that the seeps responded more quickly than the wells because they are direct discharge points for groundwater originating beneath the Main Hill. A graph of tritium levels in downgradient wells (Figure 15) illustrates that groundwater impact in the wells lagged behind impact expressed in the seeps. Groundwater impact increased near the end of remediation activities on the Main Hill, and impact in the seeps occurred as remediation activities were being performed and began to decrease as activities were completed. The tritium levels in the wells responded quickly to remediation activities. Well 0347 has the highest levels of tritium. Tritium levels in wells 0138, 0346, and 0379 have leveled off and are similar to background.

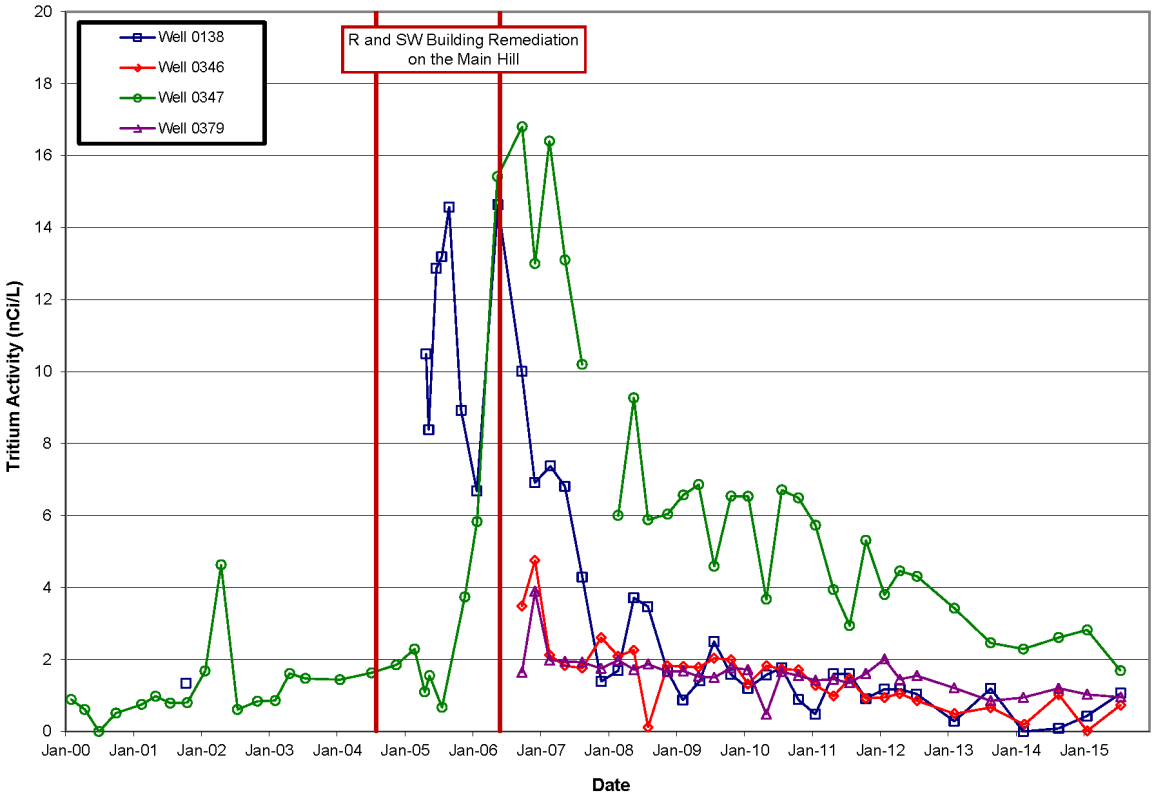

Figure 15. Tritium Activity in Parcels 6, 7, and 8 Wells 0138, 0346, 0347, and 0379

The distribution of tritium in groundwater (Figure 16) in the Main Hill area indicates that the greatest impact is still associated with the seeps, particularly seep 0601. Downgradient well 0347 also had elevated levels of tritium. Figure 16 depicts the 2015 annual averages of tritium in the monitoring network.

4.3 Trend Analysis

Trend analysis was performed on VOCs and tritium data using the nonparametric Mann-Kendall test. Trend analysis is reported for data collected since 2005. This period was selected to represent data collected since the completion of remediation activities on the Main Hill.

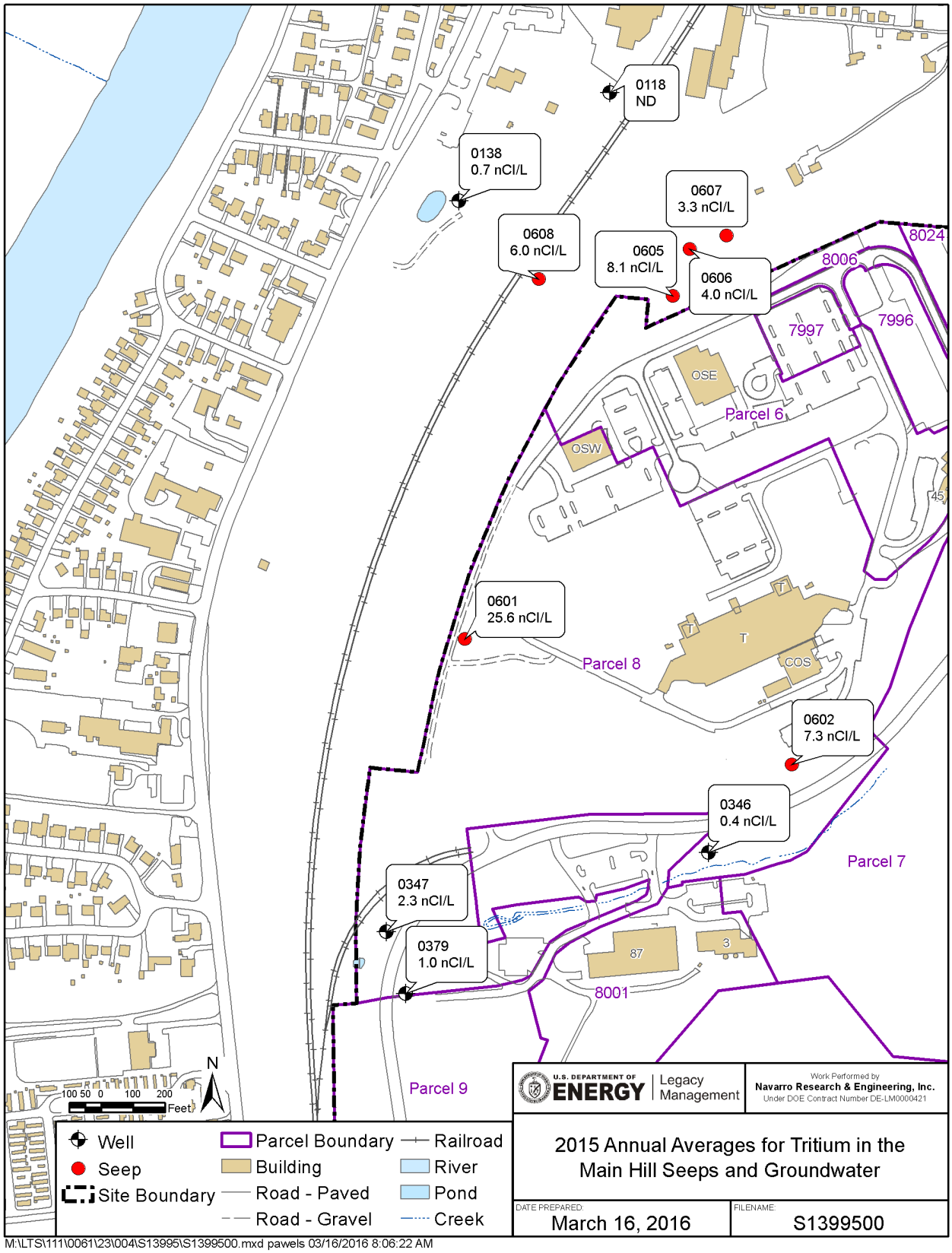

Figure 16. 2015 Annual Averages for Tritium in Parcels 6, 7, and 8 Seeps and Groundwater

4.3.1 VOCs

Trend analysis for TCE data collected since 2005 indicates increasing TCE concentrations in seep 0602 and well 0347, as indicated by positive slopes (Table 10). Although the slope is positive for seep 0601, the slope value is near zero and indicates a small increase. TCE concentrations are decreasing in the remainder of the seeps and wells, as indicated by negative slopes. Statistical downward trends were calculated for seep 0605 and wells 0386 and 0389. Trend analysis was not performed on data from the remainder of the wells because results consistently showed nondetects or sporadic estimated detections.

Table 10. Summary of Trend Analysis Results for VOCs in Parcels 6, 7, and 8 (2005–2015)

Location	Number of Samples	Trend	Slope (µg/L/year)
TCE			
0601	44	None	0.06
0602	29	None	0.20
0605	44	**Down**	–0.64
0606	29	None	–0.20
0607	44	None	–0.20
0608	41	None	–0.03
0315	43	None	–0.14
0347	43	None	0.24
0386	41	**Down**	–0.11
0389	39	**Down**	–0.09
PCE			
0601	45	**Down**	–1.2
***cis*-1,2-DCE**			
0602	29	None	–0.44
0605	44	**Down**	–1.4

µg/L/year = micrograms per liter per year

Concentrations of PCE in seep 0601 are decreasing, as implied by a negative slope (Table 10), and a statistical downward trend was indicated in the data from this seep. Data from seeps 0602 and 0605 were evaluated for trends in *cis*-1,2-DCE concentrations (Table 10). Concentrations of *cis*-1,2-DCE are decreasing in both seeps and a statistical downward trend was calculated for seep 0605.

4.3.2 Tritium

Trend analysis for tritium data collected since 2005 indicates decreasing tritium levels in all of the seeps and the four wells with detectable tritium levels, as implied by negative slopes. Statistical downward trends in tritium were calculated in all of the seeps and wells (Table 11).

Table 11. Summary of Trend Analysis Results for Tritium in the Main Hill Seeps and Downgradient Wells (2005−2015)

Location	Number of Samples	Trend	Slope (nCi/L/year)
0601	38	**Down**	–20.1
0602	25	**Down**	–3.1
0605	37	**Down**	–4.1
0606	22	**Down**	–3.2
0607	37	**Down**	–1.8
0608	35	**Down**	–2.4
0138	39	**Down**	–1.0
0346	41	**Down**	–0.38
0347	38	**Down**	–0.29
0379	36	**Down**	–0.08

nCi/L/year = nanocuries per liter per year

4.4 Groundwater Elevations

A map of the average groundwater elevations measured in the Parcels 6, 7, and 8 area during 2015 (Figure 17) indicates two flow regimes: bedrock and BVA. The approximate location of contact of the BVA with the bedrock is indicated on this figure. Groundwater originating from the well 0411/0443 area flows southwest within the bedrock, following the bedrock topography. This groundwater enters the BVA along this contact. Flow within the BVA is parallel to the bedrock contact. Flow near wells 0315/0347 is generally to the south-southeast. Appendix C presents a summary of the groundwater elevations measured during 2015.

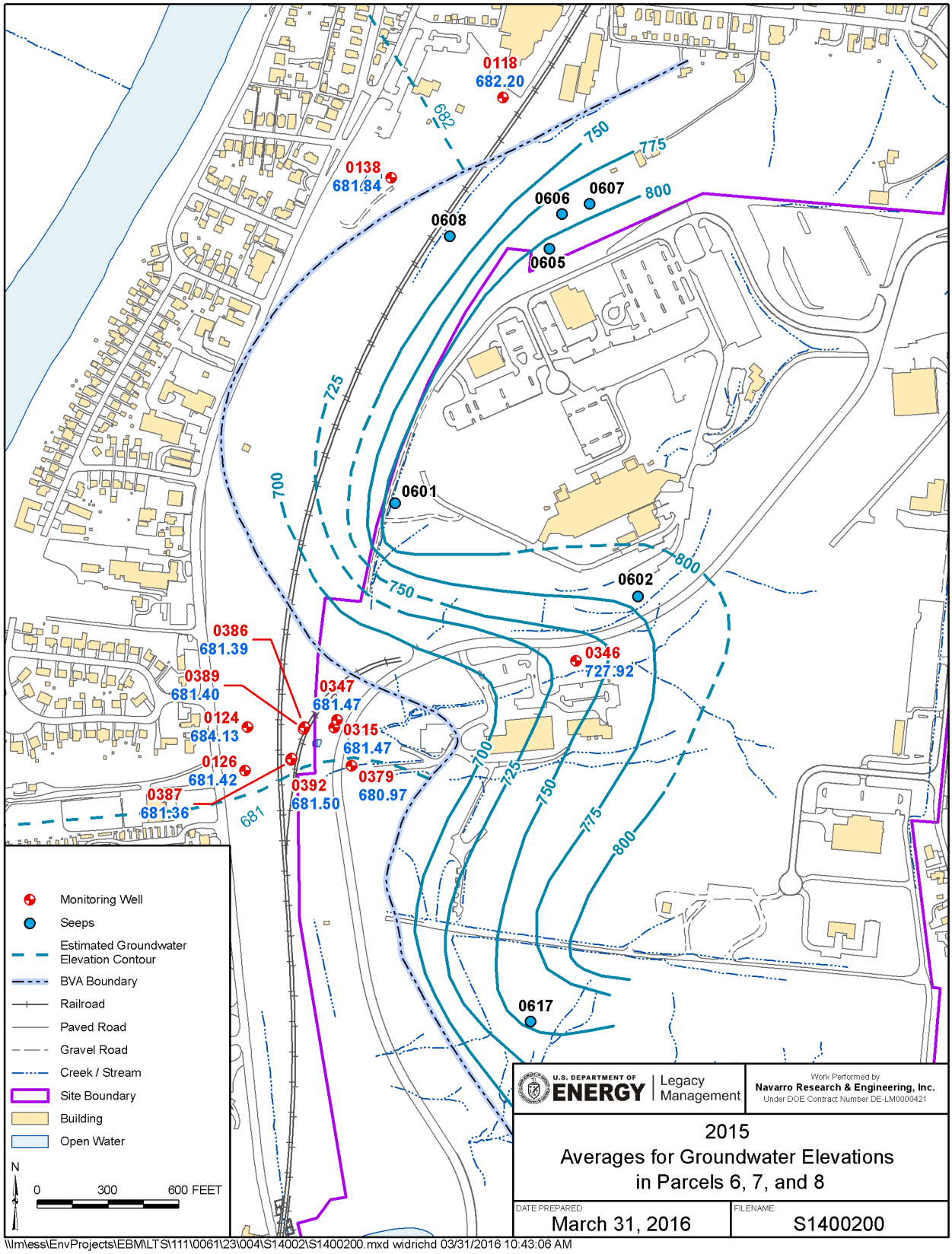

Figure 17. 2015 Averages for Groundwater Elevations in Parcels 6, 7, and 8

4.5 Data Evaluation

4.5.1 VOCs

Concentrations of TCE in the Main Hill seeps continued to exceed the MCL in 2015. The highest concentrations were measured in seep 0602 and wells 0315 and 0347. None of these values exceeded trigger levels. Detectable concentrations of *cis*-1,2-DCE were reported in seeps 0602, 0605, 0606, and 0607, with the highest concentrations reported for seep 0602. Estimated detections of *trans*-1,2-DCE, another breakdown product, were reported in seeps 0602 and 0605. No DCE or VC was detected in the downgradient wells.

Data collected over the past several years indicates variable concentrations of VOCs, primarily TCE, in the groundwater in Parcels 6, 7, and 8 as exhibited from the data from seep 0602 (Figure 10) and wells 0315 and 0347 (Figure 12). Increases in VOCs were first observed in seep 0602 starting in 2008. Increases in VOC concentrations in the wells were observed later. An investigation for the cause(s) for the increases was initiated in 2011 (DOE 2014). The most probable cause for the changes and overall increases may be surface water infiltration that resulted in flushing residual VOCs from the vadose zone. Site improvement by others started not long after remediation activities were completed on the Main Hill and continued for several years. Several observances of surface water entering the subsurface were noted in the field. In late 2009 it was determined that grading had exposed two manholes over a large tritium capture pit, which extended into the bedrock. Another instance was surface water entering the subsurface along the foundation of the east head house of T building. It is possible that surface water has found other access points into the subsurface via abandoned utility lines or other access ports that have been exposed by construction activities.

Seep 0602 and the downgradient wells 0315 and 0347 are located in the tributary valley. As discussed in Section 1.3, the tributary valley is a narrow tongue of glacial deposits connected to the BVA that overlies the fractured bedrock at the site. Water infiltrating on the Main Hill moves through the fractured bedrock and ultimately discharges into the unconsolidated materials. Figure 18 depicts the bedrock topography beneath the tributary valley. Groundwater flow within the bedrock mimics the bedrock topography. TCE-impacted groundwater originated on the Main Hill may move southward and discharge to seeps or the tributary valley. Seep 0602 is located along the northern side of the tributary valley and the wells are located along the axis of the valley. Figure 19 depicts the cross section along the transect from well pair 0315/0347 within the tributary valley to well 0126 in the BVA. Annual average TCE concentrations posted on the cross section show that the deep wells that are screened directly above the bedrock have the highest TCE concentrations. It is likely that these wells monitor the TCE-impacted groundwater discharging from the bedrock.

Analysis of TCE data collected since 2005 indicated increasing TCE concentrations in seep 0602 and well 0347 (positive slopes – Table 10). The increases at these two locations do not constitute a statistical upward trend in the data. The concentrations at these two locations are higher than those generally measured prior to soil remediation on the Main Hill. Concentrations observed since the 2008 through 2011 timeframe in seep 0602 are declining as well as the concentration measured in the wells during the 2009 through 2012 timeframe. No exceedences of the trigger level for TCE in the source wells have occurred since 2012.

Data analysis indicated decreasing TCE concentrations in seeps 0605, 0606, 0607, and 0608 and wells 0315, 0386, and 0389. Statistical downward trends in TCE concentrations were calculated for seep 0605 and wells 0386 and 0389. A statistical downward trend in PCE concentrations was calculated for data from seep 0601. Concentrations of *cis*-1,2-DCE are decreasing in seeps 0602 and 0605. A statistical downward trend was calculated for seep 0605.

4.5.2 Tritium

Tritium levels in the Main Hill seeps continued to be higher than those in the downgradient groundwater wells. The highest tritium activity was observed in seep 0601, which is onsite; this is the only location that exceeded the MCL of 20 nCi/L. No locations had tritium levels that exceeded the trigger level of 1,500 nCi/L. Detectable levels of tritium were measured in four wells (0138, 0346, 0347, and 0379) downgradient of the seeps; however, most of the levels were similar to background. The highest tritium levels in groundwater are in well 0347. None of the groundwater wells had tritium levels that exceeded the MCL of 20 nCi/L.

Trend analysis of tritium data collected since 2005 indicated decreasing levels in all of the seeps and in four downgradient wells. Statistical downward trends were calculated for all of the seeps and wells. The downward trends determined from post-remediation data continue to support the interpretation that the majority of the source was removed from the Main Hill area during remediation and that flushing should continue to lower the levels. Also, tritium concentrations will likely decrease more rapidly than those of the VOCs because tritium does not attenuate through degradation or sorption in the natural environment; therefore, it moves more quickly in the groundwater system.

4.6 Recommendations

The evaluation of the 2015 data does not indicate that the VOC monitoring program should be changed. TCE concentrations greater than the MCL have continued to be measured in several seeps and in downgradient monitoring wells. The concentrations of VOCs continue to be variable at a few locations and increasing VOCs are also observed. Quarterly sampling will continue at the seep and monitoring well locations in 2016 as it appears that the system has not yet stabilized since completion of soil remediation on the Main Hill and surface water infiltration may be continuing that results in flushing of VOCs from the vadose zone.

No changes to the tritium monitoring program are warranted at this time; semiannual sampling for tritium will continue in 2016. Samples continue to be collected during the first and third quarters of the year to capture seasonal variation in the tritium levels.

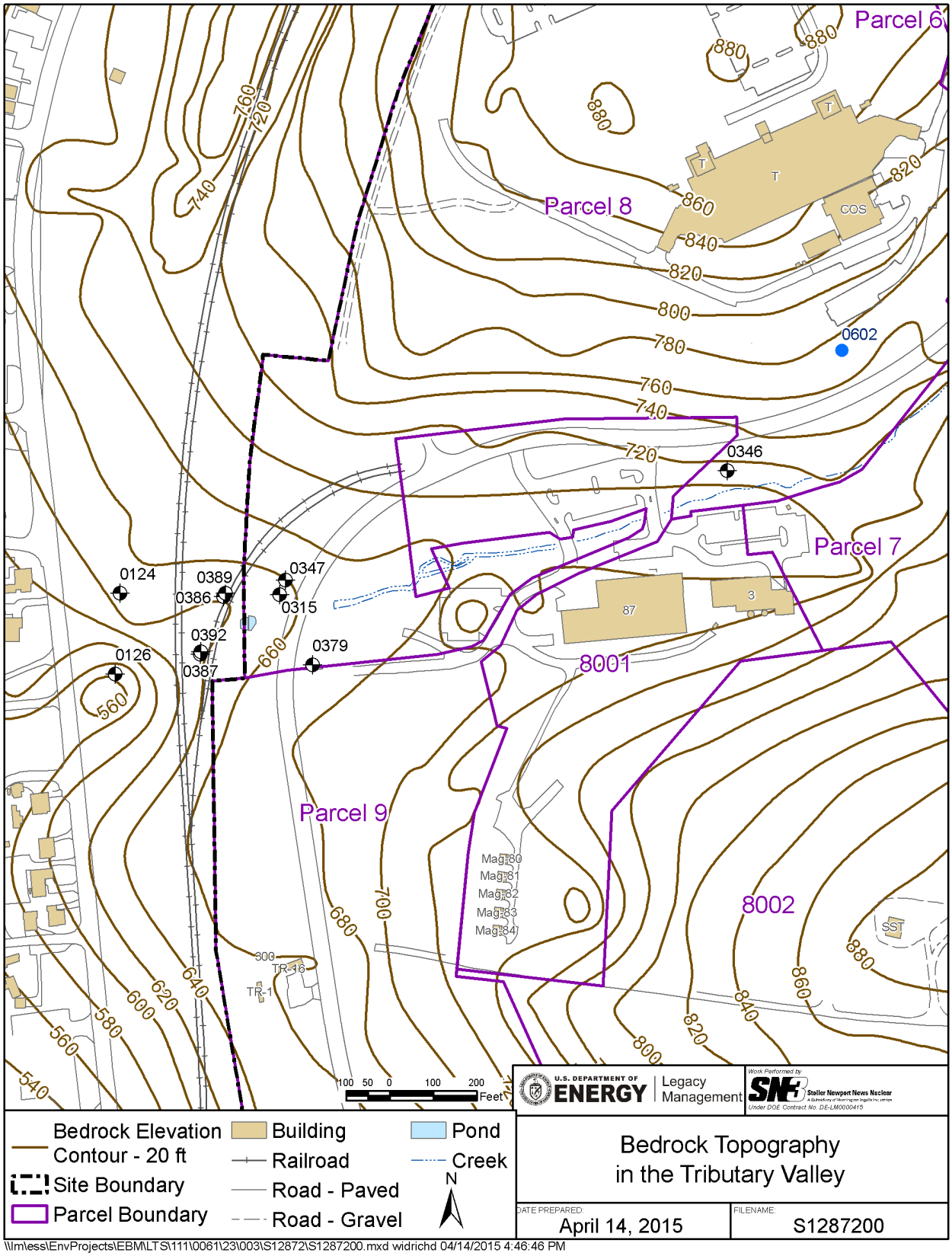

Figure 18. Bedrock Topography in the Tributary Valley

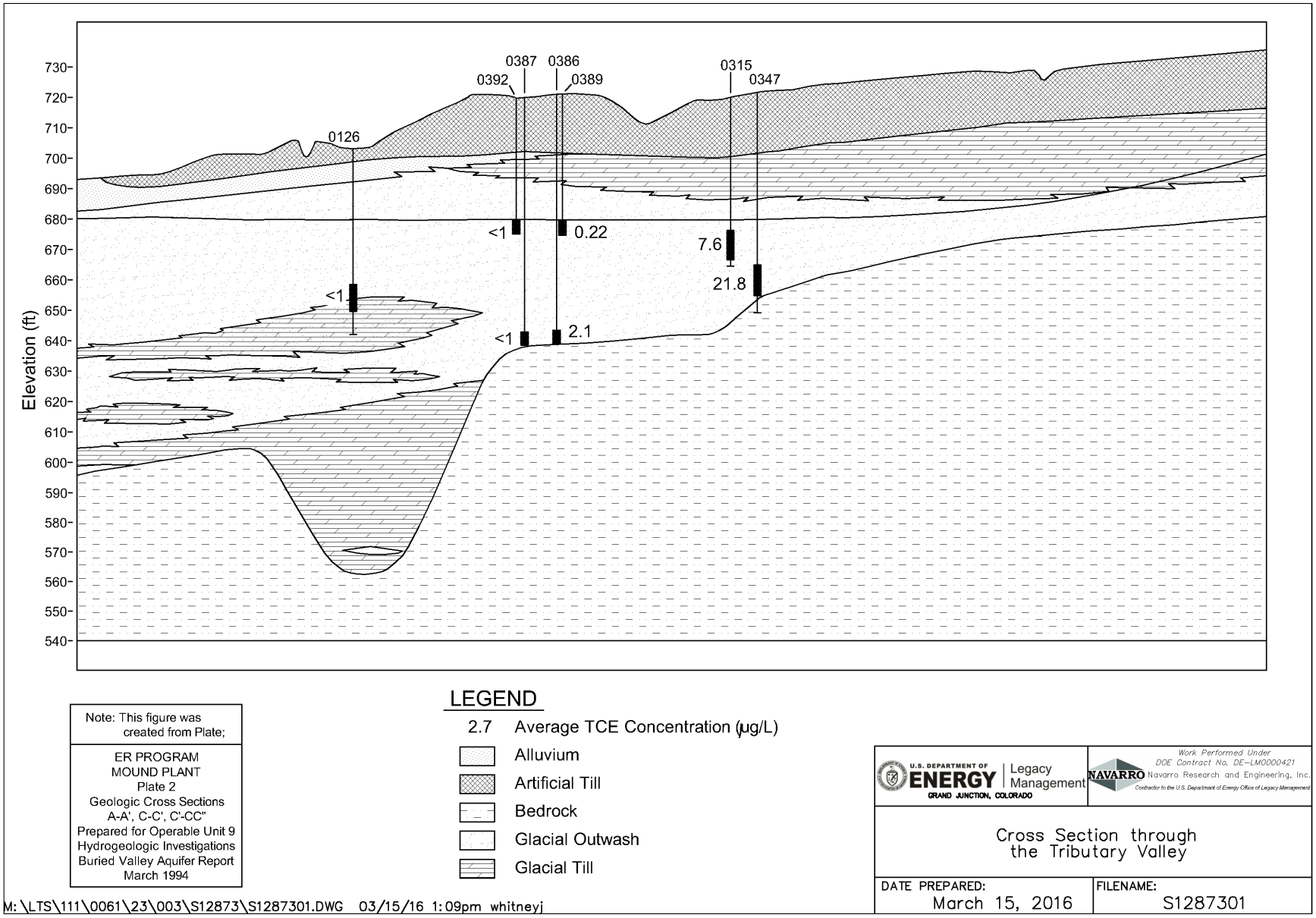

Figure 19. Cross Section Through the Tributary Valley

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5.0 Inspection of the Monitoring System

A routine maintenance program has been established for the long-term groundwater monitoring locations at the Mound site. This program includes periodic inspections that focus on the integrity of each well and the condition of the protective casing and surface pad, the surrounding area, and the route of access. These inspections are usually performed during each sampling event.

Overall, the wells were in good condition and some routine repainting and vegetation removal were performed during 2015. Construction activities near well 0138, which is located in the City Park, resulted in the need for riser pipe to be added to the top of the well on two occasions. When construction activities are completed a protective casing and well pad will be installed and the top of the well casing resurveyed.

Well 0138 – A pond near well 0138 is being backfilled by the City. As additional soil was added to the pond and the surrounding area, 5 ft sections of well casing were added on two occasions.

Well 0301, 0311, 0333, and 0334 were abandoned during 2015. Wells 0333 and 0334 had been removed from the Parcels 6, 7, and 8 monitoring program previously and wells 0301 and 0311 were removed in early 2015. Well sealing reports, which were filed with ODNR, are presented in Appendix D.

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6.0 Data Validation

All data collected was validated in accordance with procedures specified in the Sitewide Operations and Maintenance Plan (DOE 2015). This procedure also fulfills the requirements of applicable procedures in the *Mound Methods Compendium* (MD 80045). Data validation was documented in reports prepared for each data package. All 2015 data, including data validation qualifiers, are summarized in Appendix E.

Laboratory performance is assessed by a review and evaluation of the following quality indicators:

- Sample shipping and receiving practices
- Chain of custody
- Laboratory blanks
- Preparation blanks
- Laboratory replicates
- Serial dilutions
- Detection limits
- Peak integrations
- Matrix spikes and matrix spike duplicates
- Holding times
- Instrument calibrations
- Interference check samples
- Radiochemical uncertainty
- Laboratory control samples
- Sample dilutions
- Surrogate recoveries
- Confirmation analyses
- Electronic data

A total of six Report Identification Numbers (RINs) were established for the 2015 environmental sampling efforts at the Mound site. An RIN is a set of samples that are relinquished to the laboratory using a Chain of Custody form. Data Assessment Reports are prepared for each RIN and are presented in Appendix F.

The laboratory prepares an analytical package for each RIN that includes a summary of results, a complete set of supporting analytical data for every analysis reported, and an electronic data deliverable that is used to upload analytical data into databases for validation and qualification prior to the release of the data. Every RIN received from the laboratory is thoroughly reviewed and evaluated before the data package is finalized and released to the public. Table 12 lists the RINs associated with this report.

Table 12. RINs for Calendar Year 2015 Sampling

RIN	Area	Sampling Date(s)
15016744	Phase I	January 26–29, 2015
15016745	Parcels 6, 7, and 8	January 27–29, 2015
15046952	Parcels 6, 7, and 8	April 27–29, 2015
15077233	Parcels 6, 7, and 8	July 27–29, 2015
15077239	Phase I	July 29, 2015
15107445	Parcels 6, 7, and 8	October 26–28, 2015

The Data Assessment Reports also summarize and assess the sampling quality control for each sampling event. The following items are included:

- Sampling protocol
- Trip blanks
- Outliers
- Equipment blanks
- Field duplicates

7.0 References

DOE (U.S. Department of Energy), 1992. *Remedial Investigation/Feasibility Study, Operable Unit 9, Site-Wide Work Plan*, Final.

DOE (U.S. Department of Energy), 1994a. *Operable Unit 9 Hydrogeologic Investigation: Bedrock Report*, Technical Memorandum.

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DOE (U.S. Department of Energy), 1997. *Mound 2000 Residual Risk Evaluation Methodology*, *Mound Plant*, Final, Revision 0.

DOE (U.S. Department of Energy), 1999. *Work Plan for Environmental Restoration at the Mound Plant, The Mound 2000 Approach*.

DOE (U.S. Department of Energy), 2015. *Operations and Maintenance (O&M) Plan for the U.S. Department of Energy*, *Miamisburg, Ohio, Site (Mound Site)*, January.

Mound Methods Compendium, Issue 2, MD-80045, prepared by BWXT of Ohio Inc.

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Appendix A

Well Construction Summary

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Location ID	Program	Northing	Easting	Ground Elevation	TOC Elevation	Well Depth	Top of Screen Elevation	Bottom of Screen Elevation	Screen Length	Well Material	Screened Formation
0118	Parcels 6, 7, & 8	600464.95	1464737.80	705.36	704.86	40.1	674.73	664.73	10	4-inch SS	BVA
0124	Parcels 6, 7, & 8	597789.14	1463654.10	704.18	705.12	55.9	659.18	649.18	10	4-inch SS	BVA
0126	Parcels 6, 7, & 8	597603.58	1463643.30	704.61	705.54	54.8	660.78	650.78	10	4-inch SS	BVA
0138	Parcels 6, 7, & 8	600124.02	1464263.30	698.59	697.76	40.2	667.59	657.59	10	4-inch SS	BVA
0301	Parcels 6, 7, & 8	598315.05	1463120.40	693.10	692.46	84.9	617.60	607.60	10	4-inch SS	BVA
0311	Parcels 6, 7, & 8	598316.27	1463129.30	693.58	692.91	29.8	672.38	663.08	9.3	4-inch SS	BVA
0315	Phase I	597786.28	1464020.40	722.57	723.99	54.8	679.17	669.17	10	4-inch SS	BVA
0346	Parcels 6, 7, & 8	598070.11	1465048.90	743.50	742.97	45.5	702.50	697.50	5	4-inch SS	BVA
0347	Parcels 6, 7, & 8	597819.31	1464034.10	723.76	725.20	68.4	666.76	656.76	10	4-inch SS	BVA
0353	Phase I	596686.11	1464609.40	744.04	745.33	19.3	731.04	726.04	5	4-inch SS	Bedrock
0379	Parcels 6, 7, & 8	597624.41	1464095.90	715.24	716.11	40.9	685.24	675.24	10	4-inch SS	BVA
0386	Parcels 6, 7, & 8	597789.23	1463896.00	725.16	724.79	86.6	648.16	638.16	10	4-inch SS	BVA
0387	Parcels 6, 7, & 8	597654.63	1463839.50	721.26	720.89	81.6	644.26	639.26	5	4-inch SS	BVA
0389	Parcels 6, 7, & 8	597781.29	1463891.90	724.96	724.65	51.7	682.96	672.96	10	4-inch SS	BVA
0392	Parcels 6, 7, & 8	597648.77	1463838.30	721.18	720.84	44.7	681.18	676.18	5	4-inch SS	BVA
0400	Phase I	596122.80	1464333.10	703.22	705.11	34.4	680.72	670.72	10	2-inch SS	BVA
0402	Phase I	596407.78	1464208.00	702.48	704.02	32.3	681.74	671.74	10	2-inch SS	BVA
0411	Phase I	596808.81	1465077.10	834.83	836.57	39.7	806.89	796.89	10	2-inch SS	Bedrock
0443	Phase I	596886.22	1465177.11	856.89	858.78	39.6	829.20	819.20	10	2-inch PVC	Bedrock
0444	Phase I	596463.35	1465001.58	770.71	773.00	32.8	750.20	740.20	10	2-inch PVC	Bedrock
0445	Phase I	596448.12	1464738.54	741.29	743.43	42.5	710.93	700.93	10	2-inch PVC	Bedrock
P033	Phase I	596208.15	1464233.80	706.03	705.83	24.8	686.03	681.03	5	2-inch PVC	BVA
0601	Parcels 6, 7, & 8	598743.22	1464280.80	817.52						Seep	Bedrock
0602	Parcels 6, 7, & 8	598346.65	1465311.40	779.61						Seep	Bedrock
0605	Parcels 6, 7, & 8	599824.63	1464935.40	817.70						Seep	Bedrock
0606	Parcels 6, 7, & 8	699971.45	1464989.00	789.23						Seep	Bedrock
0607	Parcels 6, 7, & 8	600015.30	1465105.70	797.00						Seep	Bedrock
0608	Parcels 6, 7, & 8	599877.40	1464513.60	726.09						Seep	Bedrock
0617	Phase I	596539.80	1464855.80	766.07						Seep	Bedrock

TOC = top of casing
SS = stainless steel

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Appendix B

Mann-Kendall Trending Summaries

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	An upward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of 1 per year within tolerable error limits [a]	54

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 3rd option (an upward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \geq Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): an upward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	54

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1,2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0411. The following table lists the data points that were used in the analysis.

0411							
Time	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**
4/29/1999	4.8		7/25/2003	1.6		2/19/2008	2.21
6/21/1999	2.2		10/22/2003	1.6		8/11/2008	1.33
9/2/1999	1.8		1/22/2004	2		2/10/2009	3.36
9/2/1999	2.3		4/21/2004	1.3		7/29/2009	2.89
2/1/2000	2.6		7/12/2004	1.4		1/27/2010	3.97
4/17/2000	2.2		11/17/2004	1.3		7/29/2010	2.56
7/7/2000	3		2/28/2005	1		1/26/2011	3.32
9/27/2000	1		5/24/2005	1.5		7/25/2011	2.8
2/9/2001	1.6		8/2/2005	1.7		1/30/2012	1.81
4/26/2001	1.5		11/1/2005	2.4		7/26/2012	2.17
7/20/2001	2.4		1/31/2006	3.7		2/14/2013	4.71
10/18/2001	1.9		4/26/2006	2.9		8/28/2013	3.57
1/29/2002	1.9		8/4/2006	1.95		2/24/2014	2.33
5/6/2002	2.8		11/17/2006	2.76		8/26/2014	2.28
7/24/2002	3.5		2/28/2007	1.7		1/27/2015	3.34
11/8/2002	1.4		5/23/2007	1.56		7/29/2015	1.69
1/28/2003	2		8/22/2007	2.73			
4/22/2003	1.8		11/13/2007	2.74			

SUMMARY STATISTICS for cis-1,2-Dichloroethene								
n				52				
Min				1				
Max				4.8				
Range				3.8				
Mean				2.3246				
Median				2.2				
Variance				0.77018				
StdDev				0.8776				
Std Error				0.1217				
Skewness				0.90871				
Interquartile Range				1.1775				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1	1.195	1.351	1.623	2.2	2.8	3.549	4.229	4.8

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

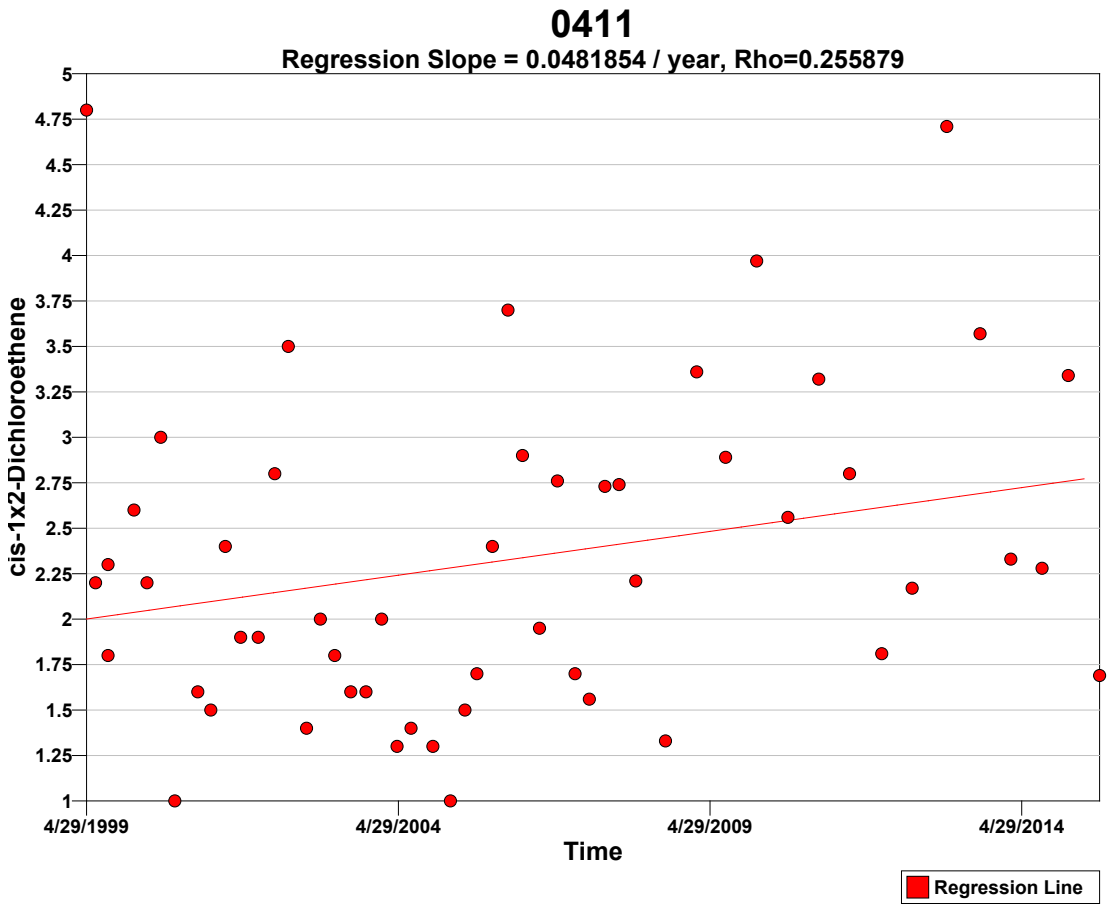
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

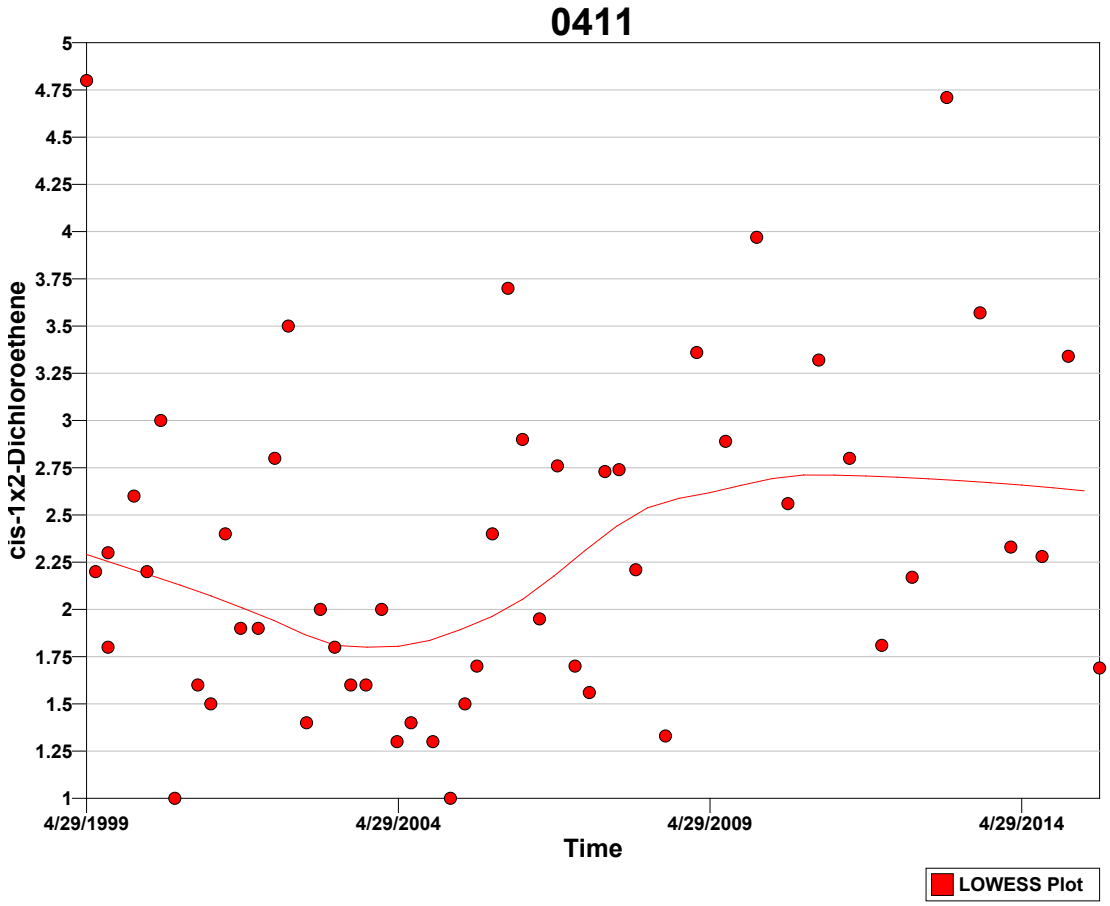
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Lilliefors test was determined most appropriate for this VSP application because the size of the data set (n=52) is greater than 50.

Normal Distribution Test for cis-1,2-Dichloroethene	
Lilliefors Test Statistic	0.10581
Lilliefors 5% Critical Value	0.12287

The calculated test statistic exceeds the 5% Lilliefors critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	208	
MK Test Statistic	Z_{MK}	1.6342	
Alpha	α	0.05	
Critical Value	$Z_{1-\alpha}$	1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	An upward monotonic trend exists	Reject
Conclude with 95% confidence that an upward monotonic trend does not exist.			

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0411. The following table lists the data points that were used in the analysis.

0411							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
4/29/1999	21		7/25/2003	11		2/19/2008	12.2
6/21/1999	18		10/22/2003	11		8/11/2008	14.1
9/2/1999	21		1/22/2004	10		2/10/2009	12.7
9/2/1999	21		4/21/2004	9		7/29/2009	11.2
2/1/2000	22		7/12/2004	10		1/27/2010	10.1
4/17/2000	13		11/17/2004	9		7/29/2010	9.62
7/7/2000	16		2/28/2005	11		1/26/2011	10.6
9/27/2000	14		5/24/2005	11		7/25/2011	9.42
2/9/2001	14		8/2/2005	11		1/30/2012	13.4
4/26/2001	12		11/1/2005	14		7/26/2012	12.7
7/20/2001	13		1/31/2006	11		2/14/2013	12.5
10/18/2001	14		4/26/2006	9.2		8/28/2013	13.3
1/29/2002	8.4		8/4/2006	14.4		2/24/2014	12
5/6/2002	16		11/17/2006	12.2		8/26/2014	10.6
7/24/2002	13		2/28/2007	12.7		1/27/2015	10.8
11/8/2002	12		5/23/2007	12.1		7/29/2015	10.3
1/28/2003	13		8/22/2007	15.2			
4/22/2003	12		11/13/2007	12.3			

SUMMARY STATISTICS for Trichloroethene								
n				52				
Min				8.4				
Max				22				
Range				13.6				
Mean				12.789				
Median				12.2				
Variance				9.8469				
StdDev				3.138				
Std Error				0.43516				
Skewness				1.4649				
Interquartile Range				3.15				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
8.4	9	9.48	10.85	12.2	14	17.4	21	22

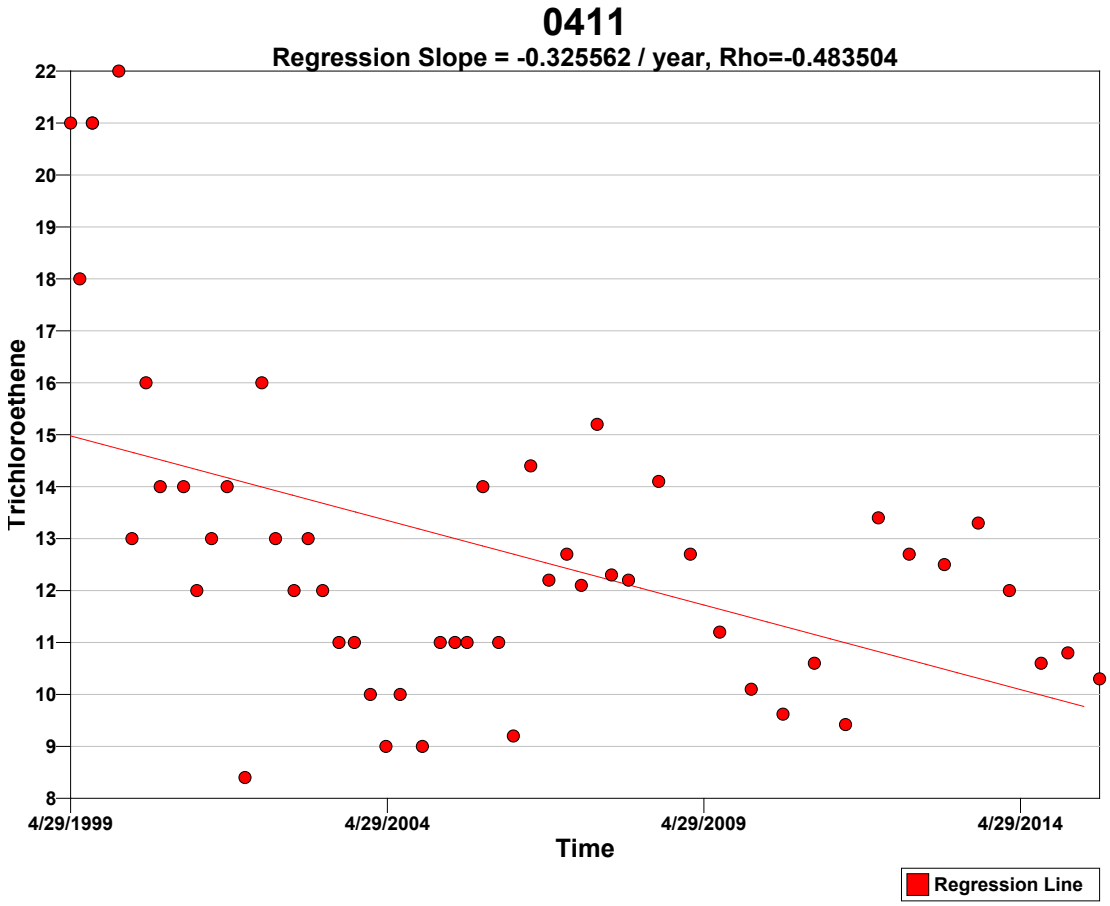
Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0411
Regression Slope = -0.325562 / year, Rho=-0.483504
Trichloroethene
22
21
20
19
18
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16
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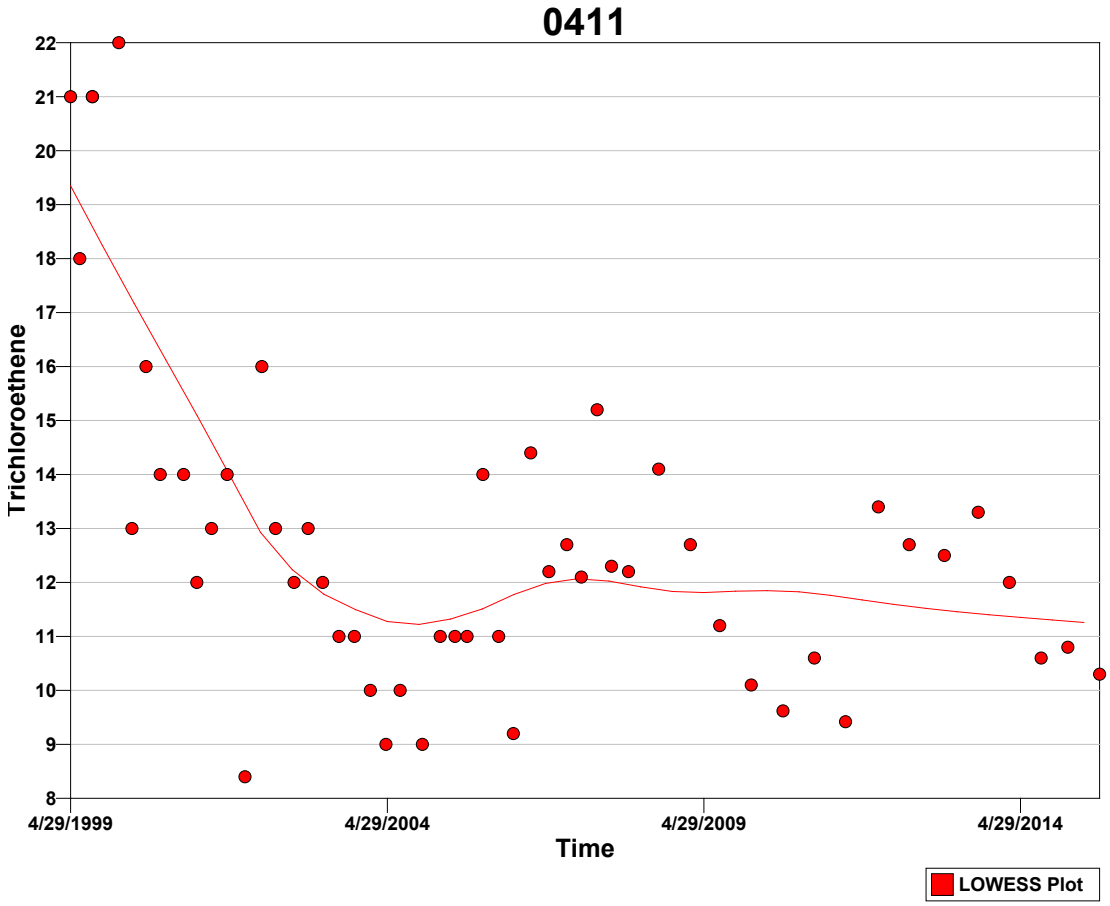
14
13
12
11
10
9
8
4/29/1999
4/29/2004
4/29/2009
4/29/2014
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Lilliefors test was determined most appropriate for this VSP application because the size of the data set (n=52) is greater than 50.

Normal Distribution Test for Trichloroethene	
Lilliefors Test Statistic	0.16553
Lilliefors 5% Critical Value	0.12287

The calculated test statistic exceeds the 5% Lilliefors critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-402	
MK Test Statistic	Z_{MK}	-3.17091	
Alpha	α	0.05	
Critical Value	$Z_{1-\alpha}$	1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	An upward monotonic trend exists	Reject
Conclude with 95% confidence that an upward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0608. The following table lists the data points that were used in the analysis.

0608							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
2/17/2005	1.2		12/29/2008	1.26		4/25/2012	1.68
5/17/2005	1.2		2/9/2009	1.7		2/11/2013	1.13
7/28/2005	1.2		5/5/2009	1.07		5/30/2013	0.24
11/3/2005	1.2		7/29/2009	1.01		8/27/2013	0.16
1/30/2006	1.2		10/26/2009	0.476		10/28/2013	1.09
5/19/2006	1.2		1/25/2010	0.378		2/19/2014	1.13
9/26/2006	0.26		5/5/2010	0.68		5/12/2014	1.03
12/5/2006	0.971		7/26/2010	0.28		8/26/2014	0.16
2/27/2007	0.837		10/25/2010	3.07		10/27/2014	0.39
5/17/2007	0.386		1/25/2011	1.98		1/29/2015	1.45
11/29/2007	0.392		5/10/2011	1.12		4/27/2015	1.42
2/28/2008	0.64		7/27/2011	0.23		7/29/2015	0.16
5/19/2008	0.729		10/25/2011	0.42		10/28/2015	0.16
8/4/2008	1.82		1/31/2012	1.34			

SUMMARY STATISTICS for Trichloroethene								
n				41				
Min				0.16				
Max				3.07				
Range				2.91				
Mean				0.93778				
Median				1.03				
Variance				0.3771				
StdDev				0.61409				
Std Error				0.095904				
Skewness				0.98866				
Interquartile Range				0.812				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.16	0.16	0.174	0.388	1.03	1.2	1.696	1.964	3.07

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

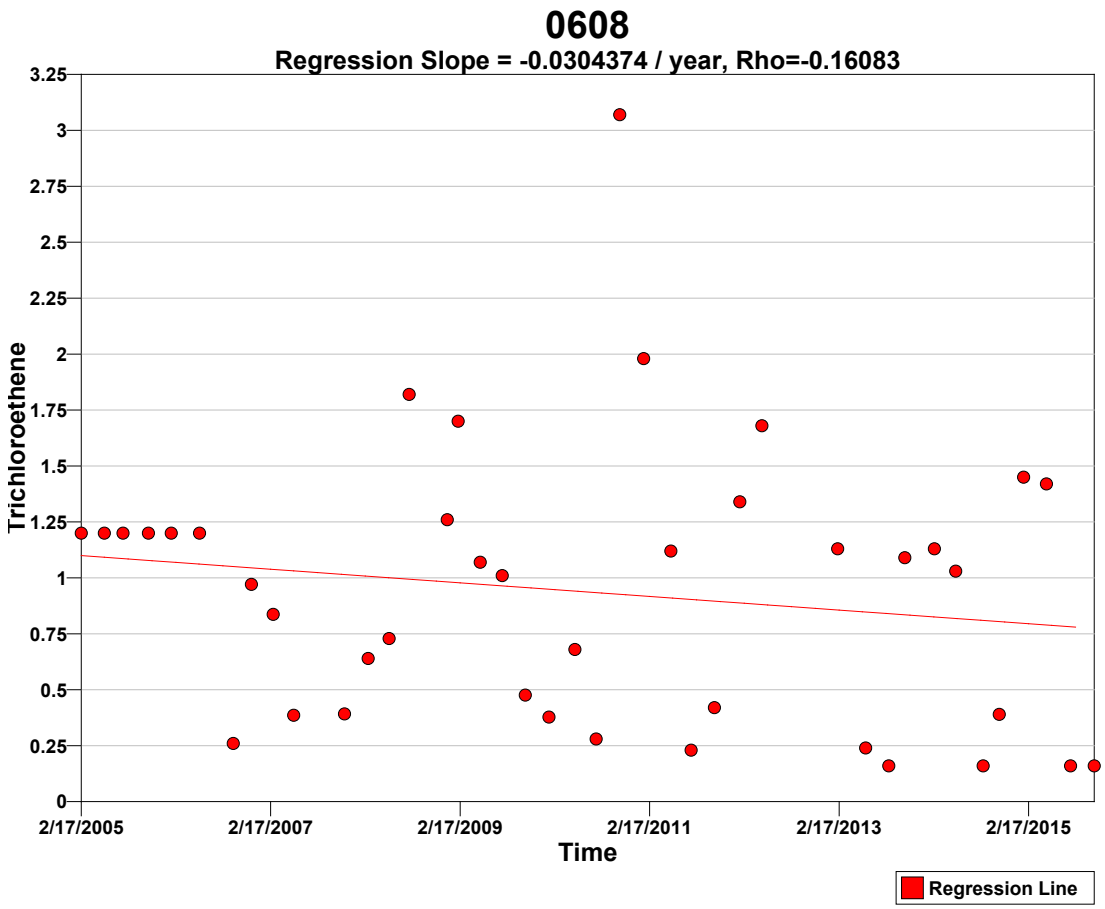
SUSPECTED OUTLIERS	
Date/Time	**Value**
10/25/2010	3.07

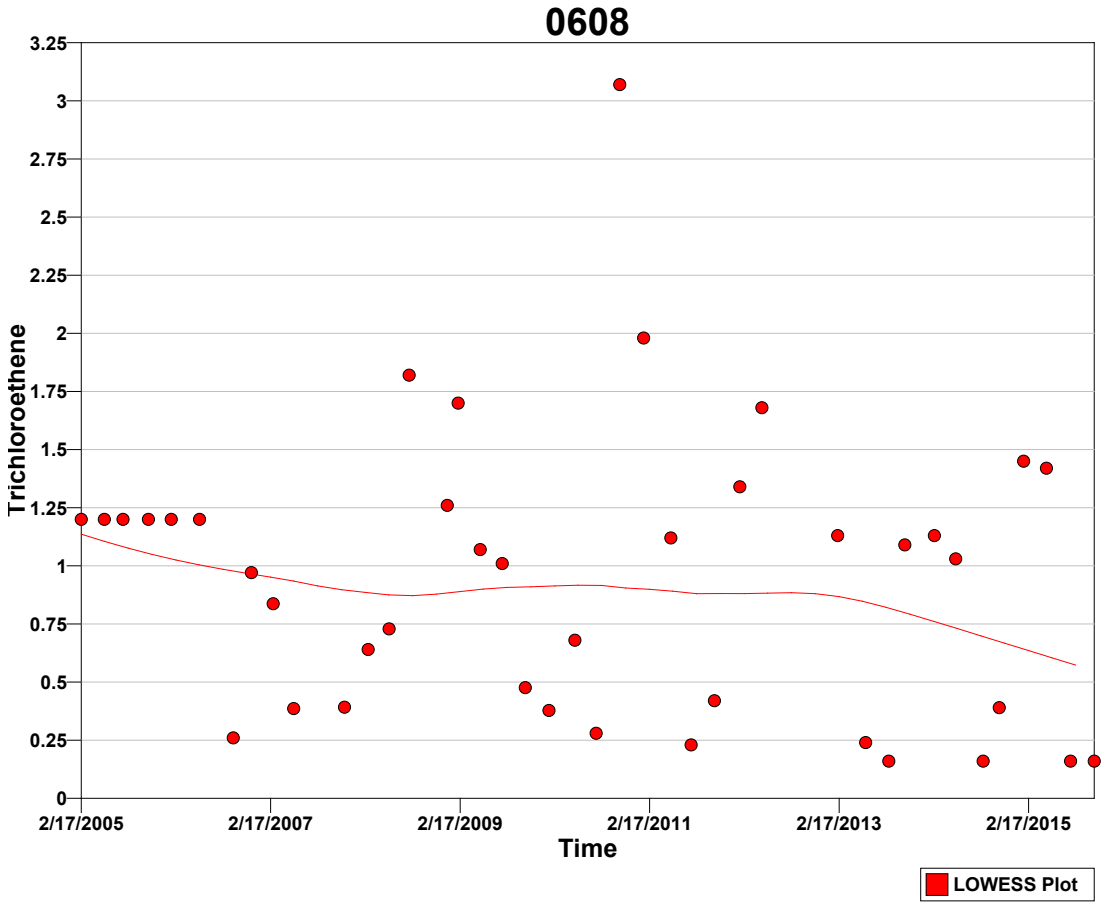
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=41) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.90777
Shapiro-Wilk 5% Critical Value	0.941

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-142	
MK Test Statistic	Z_{MK}	-1.58751	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

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Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0607. The following table lists the data points that were used in the analysis.

0607							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
2/17/2005	4.2		11/17/2008	4.77		7/24/2012	5.05
5/17/2005	8		2/9/2009	3.67		10/25/2012	7.45
7/28/2005	15		5/5/2009	9.43		2/11/2013	5.61
11/3/2005	8.7		7/29/2009	11.5		5/30/2013	9.04
1/30/2006	7.1		10/26/2009	3.63		8/27/2013	7.75
5/18/2006	6.2		1/25/2010	2.74		10/28/2013	6.41
9/26/2006	8.5		5/5/2010	11		2/19/2014	3.18
12/5/2006	5.12		7/26/2010	4.79		5/12/2014	4.05
2/27/2007	3.67		10/25/2010	3.98		8/26/2014	7.53
5/17/2007	13		1/25/2011	4.9		10/27/2014	7.74
8/22/2007	11.4		5/10/2011	3.7		1/29/2015	4.86
11/29/2007	6.38		7/27/2011	8.72		4/27/2015	4.38
2/28/2008	3.75		10/25/2011	5.51		7/29/2015	6.67
5/19/2008	6.11		1/31/2012	3.46		10/28/2015	3.25
8/4/2008	9.69		4/25/2012	9.95			

SUMMARY STATISTICS for Trichloroethene								
n				44				
Min				2.74				
Max				15				
Range				12.26				
Mean				6.6259				
Median				6.155				
Variance				8.5027				
StdDev				2.9159				
Std Error				0.4396				
Skewness				0.88042				
Interquartile Range				4.5625				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
2.74	3.198	3.545	4.088	6.155	8.65	11.2	12.63	15

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

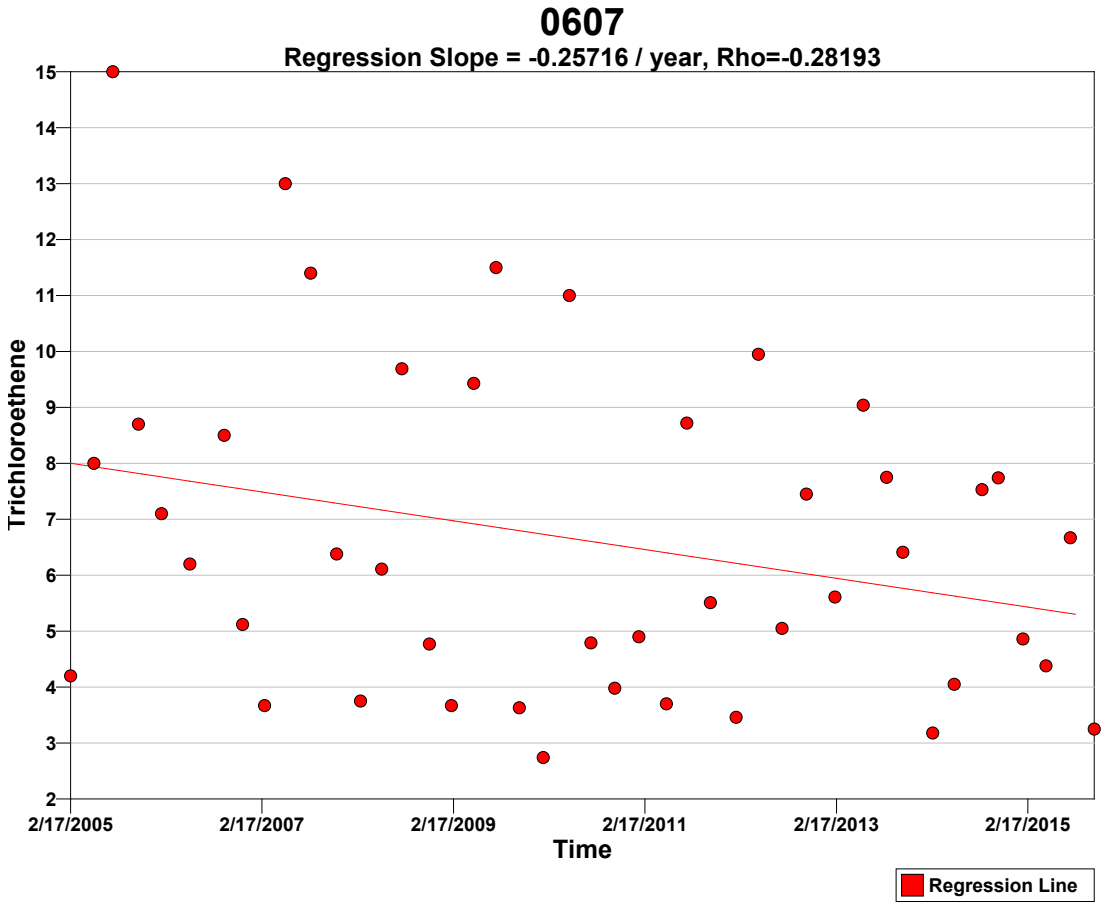
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

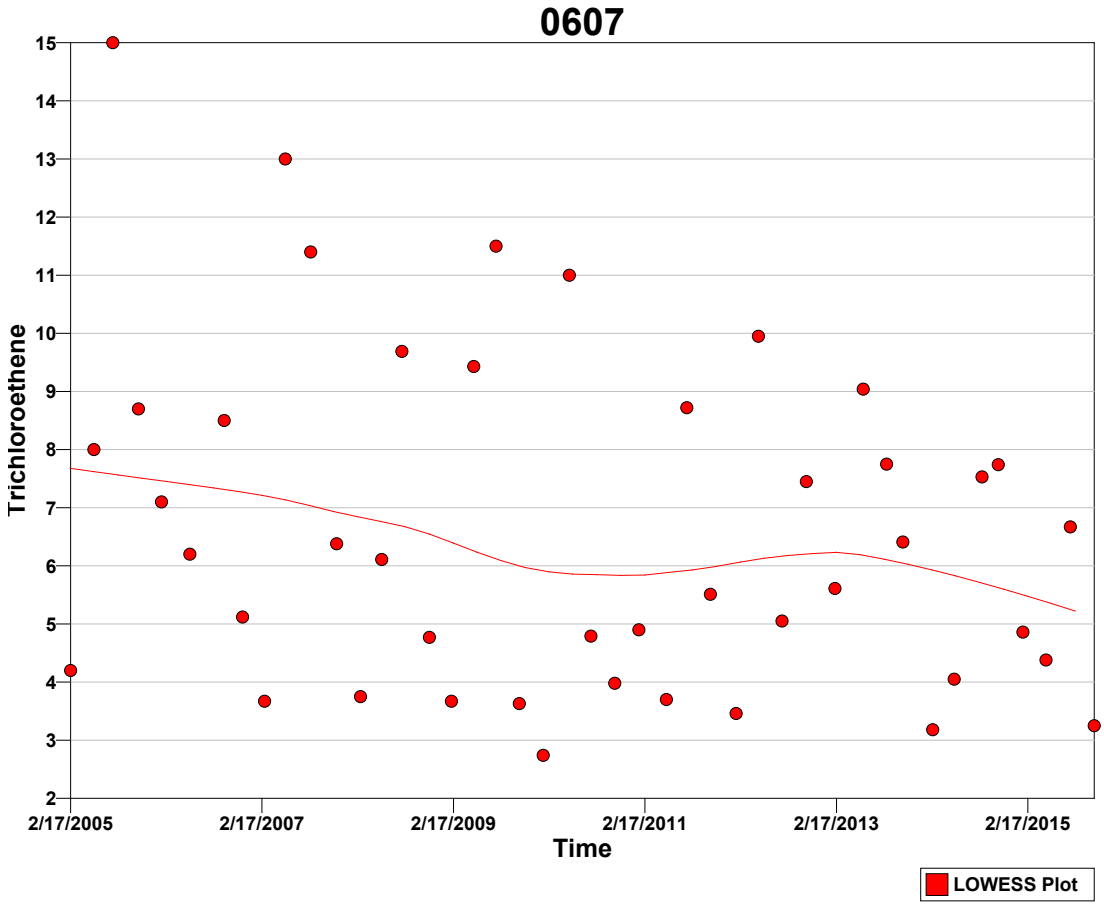
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the

value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=44) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.92231
Shapiro-Wilk 5% Critical Value	0.944

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-149	
MK Test Statistic	Z_{MK}	-1.49699	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0607. The following table lists the data points that were used in the analysis.

0607							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/17/2005	107450		5/19/2008	8060		7/27/2011	5370
5/17/2005	85560		8/4/2008	14700		10/25/2011	5690
7/28/2005	133130		11/17/2008	7680		1/31/2012	3430
11/3/2005	71410		2/9/2009	4760		4/25/2012	5170
1/30/2006	31830		5/5/2009	7660		7/24/2012	6120
5/18/2006	11430		7/29/2009	10700		2/11/2013	4510
9/26/2006	25300		10/26/2009	5750		8/27/2013	5100
12/5/2006	16000		1/25/2010	2910		2/19/2014	2170
2/27/2007	9030		5/5/2010	3880		8/26/2014	4160
5/17/2007	12200		7/26/2010	6630		1/29/2015	2760
8/22/2007	14100		10/25/2010	8840		7/29/2015	3900
11/29/2007	12900		1/25/2011	7040			
2/28/2008	7190		5/10/2011	3710			

SUMMARY STATISTICS for Tritium								
n	37							
Min	2170							
Max	133130							
Range	1.3096e+005							
Mean	18331							
Median	7190							
Variance	9.1528e+008							
StdDev	30254							
Std Error	4973.7							
Skewness	2.7799							
Interquartile Range	8865							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
2170	2701	3326	4635	7190	1.35e+004	7.424e+004	1.1e+005	1.331e+005

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
2/17/2005	107450
7/28/2005	133130
1/30/2006	31830
5/18/2006	11430
9/26/2006	25300
12/5/2006	16000
2/27/2007	9030
5/17/2007	12200

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme

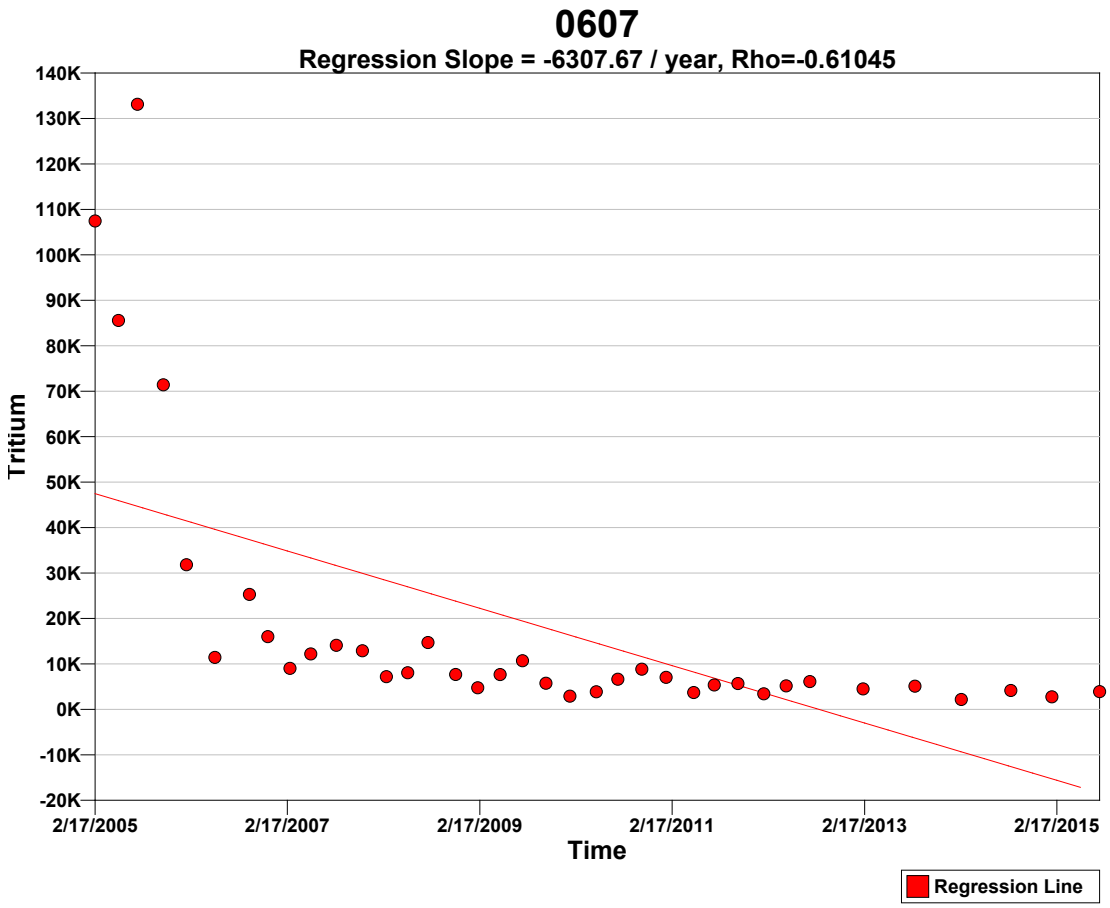
cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

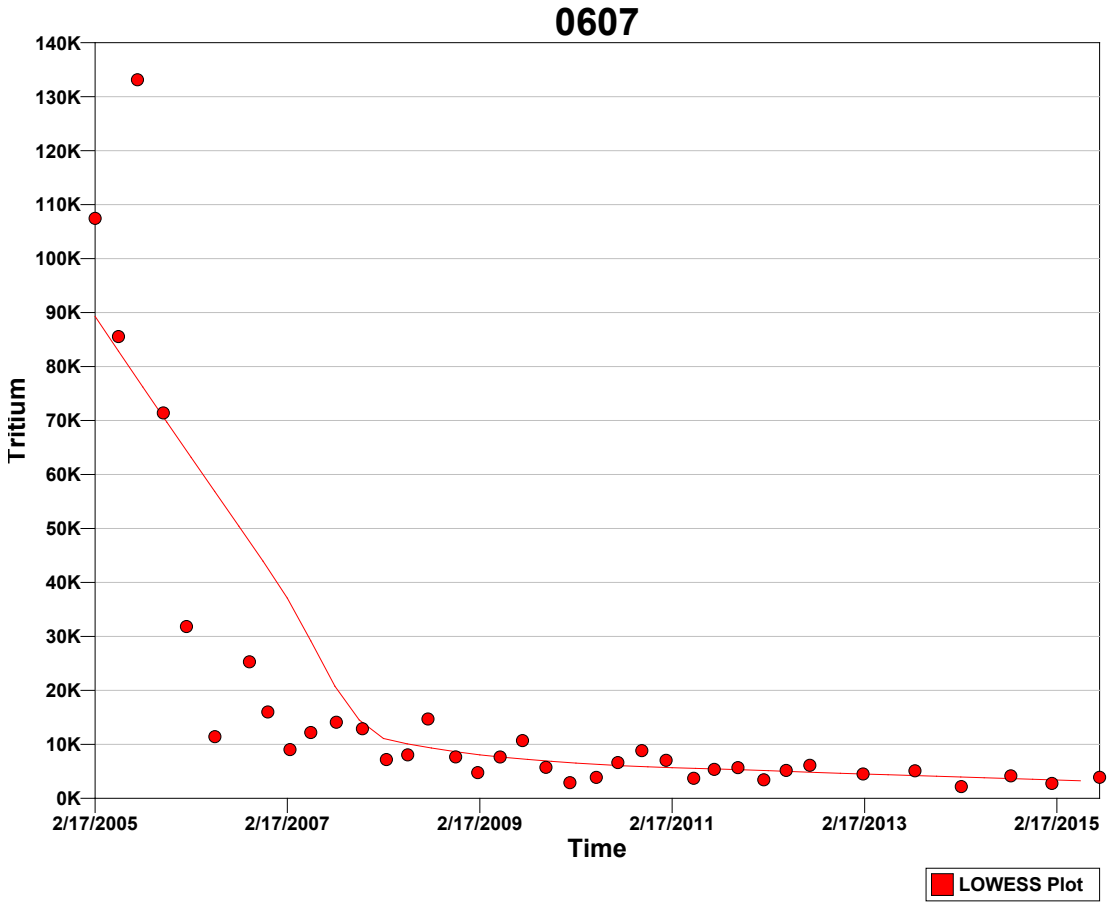
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=37) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.53267
Shapiro-Wilk 5% Critical Value	0.936

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-474	
MK Test Statistic	Z_{MK}	-6.18631	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0606. The following table lists the data points that were used in the analysis.

0606							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
2/17/2005	1.4		5/10/2011	0.95		10/28/2013	7.72
5/17/2005	8.5		7/27/2011	8.72		2/19/2014	1.39
7/28/2005	15		10/25/2011	1.8		5/12/2014	0.36
11/3/2005	24		1/31/2012	0.56		8/26/2014	6.06
1/30/2006	2.7		4/25/2012	5.34		10/27/2014	5.29
5/18/2006	5		7/24/2012	6.98		1/29/2015	1
5/5/2010	3.69		10/25/2012	9.01		4/27/2015	0.61
7/26/2010	3.16		2/11/2013	2.19		7/29/2015	6.99
10/25/2010	1.78		5/30/2013	6.66		10/28/2015	4.08
1/25/2011	0.15		8/27/2013	5			

SUMMARY STATISTICS for Trichloroethene								
n				29				
Min				0.15				
Max				24				
Range				23.85				
Mean				5.0376				
Median				4.08				
Variance				25.166				
StdDev				5.0166				
Std Error				0.93156				
Skewness				2.2059				
Interquartile Range				5.59				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.15	0.255	0.56	1.395	4.08	6.985	9.01	19.5	24

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
11/3/2005	24

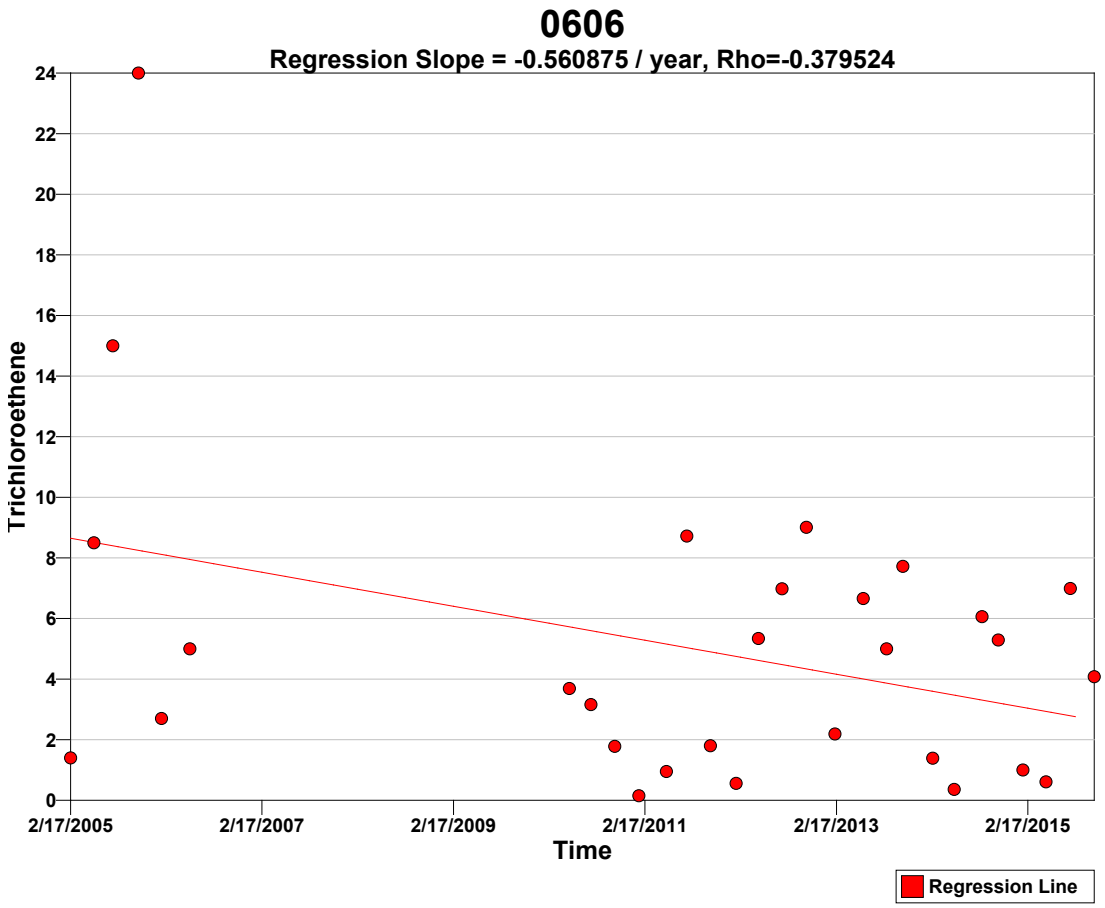
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

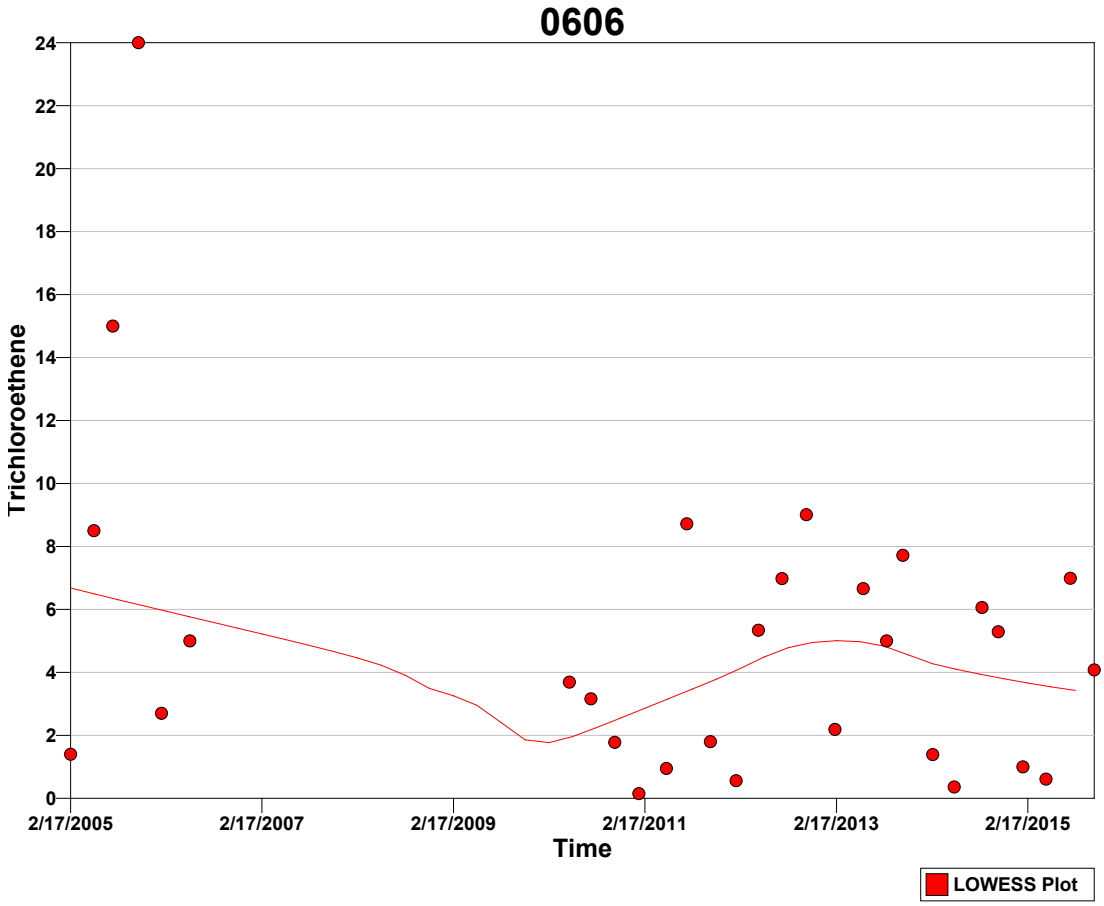
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the

linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=29) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.79192
Shapiro-Wilk 5% Critical Value	0.926

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-41	
MK Test Statistic	Z_{MK}	-0.750455	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0606. The following table lists the data points that were used in the analysis.

0606							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/17/2005	57800		10/25/2010	13200		2/11/2013	3020
5/17/2005	64460		1/25/2011	5900		8/27/2013	7370
7/28/2005	159930		5/10/2011	5760		2/19/2014	3290
11/3/2005	76640		7/27/2011	11100		8/26/2014	5020
1/30/2006	20590		10/25/2011	4930		1/29/2015	2480
5/18/2006	30620		1/31/2012	3640		7/29/2015	5580
5/5/2010	13200		4/25/2012	8440			
7/26/2010	14600		7/24/2012	8860			

SUMMARY STATISTICS for Tritium								
n				22				
Min				2480				
Max				159930				
Range				1.5745e+005				
Mean				23929				
Median				8650				
Variance				1.3709e+009				
StdDev				37026				
Std Error				7893.9				
Skewness				2.7686				
Interquartile Range				18100				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
2480	2561	3101	4998	8650	2.31e+004	7.299e+004	1.474e+005	1.599e+005

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
2/17/2005	57800
7/28/2005	159930
1/30/2006	20590
5/18/2006	30620

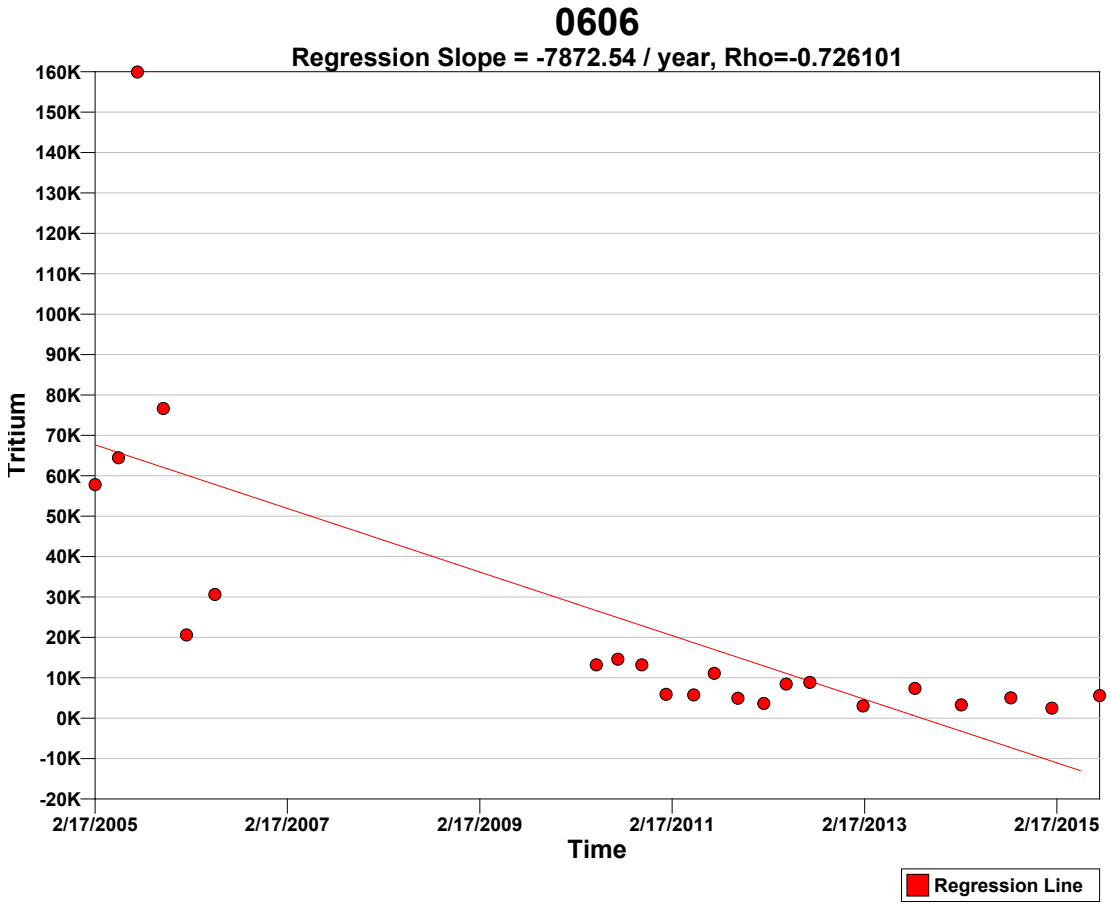
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

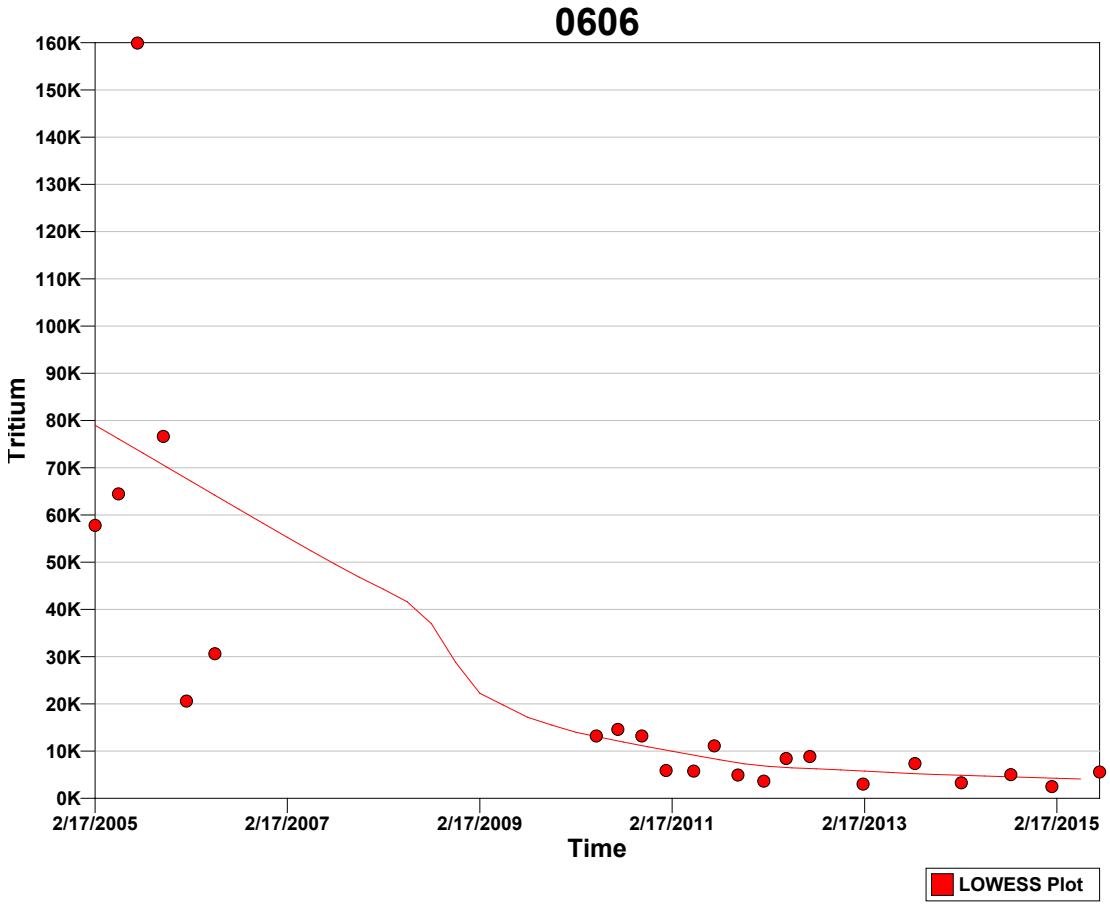
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the

value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=22) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.60372
Shapiro-Wilk 5% Critical Value	0.911

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-162	
MK Test Statistic	Z_{MK}	-4.54167	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0602. The following table lists the data points that were used in the analysis.

0602							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
5/17/2005	3.7		5/19/2008	58.9		10/25/2011	16.9
7/28/2005	6.9		12/29/2008	53.4		1/31/2012	22.2
1/30/2006	19		2/9/2009	56.1		2/11/2013	32.6
5/18/2006	19		5/5/2009	49.6		10/28/2013	4.58
9/27/2006	15		10/26/2009	18.9		2/19/2014	23.6
12/5/2006	25.6		1/25/2010	54.5		5/12/2014	23.5
2/27/2007	26.3		5/5/2010	23.3		1/29/2015	19
5/17/2007	27.6		1/25/2011	139		4/27/2015	21.4
11/29/2007	26.8		4/25/2011	49.9		10/28/2015	14.7
2/28/2008	63.3		5/10/2011	70.1			

SUMMARY STATISTICS for Trichloroethene								
n				29				
Min				3.7				
Max				139				
Range				135.3				
Mean				33.979				
Median				23.6				
Variance				746.08				
StdDev				27.315				
Std Error				5.0722				
Skewness				2.1957				
Interquartile Range				32.7				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
3.7	4.14	6.9	18.95	23.6	51.65	63.3	104.6	139

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
2/28/2008	63.3
10/26/2009	18.9
5/5/2010	23.3
1/25/2011	139
5/10/2011	70.1
10/25/2011	16.9

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

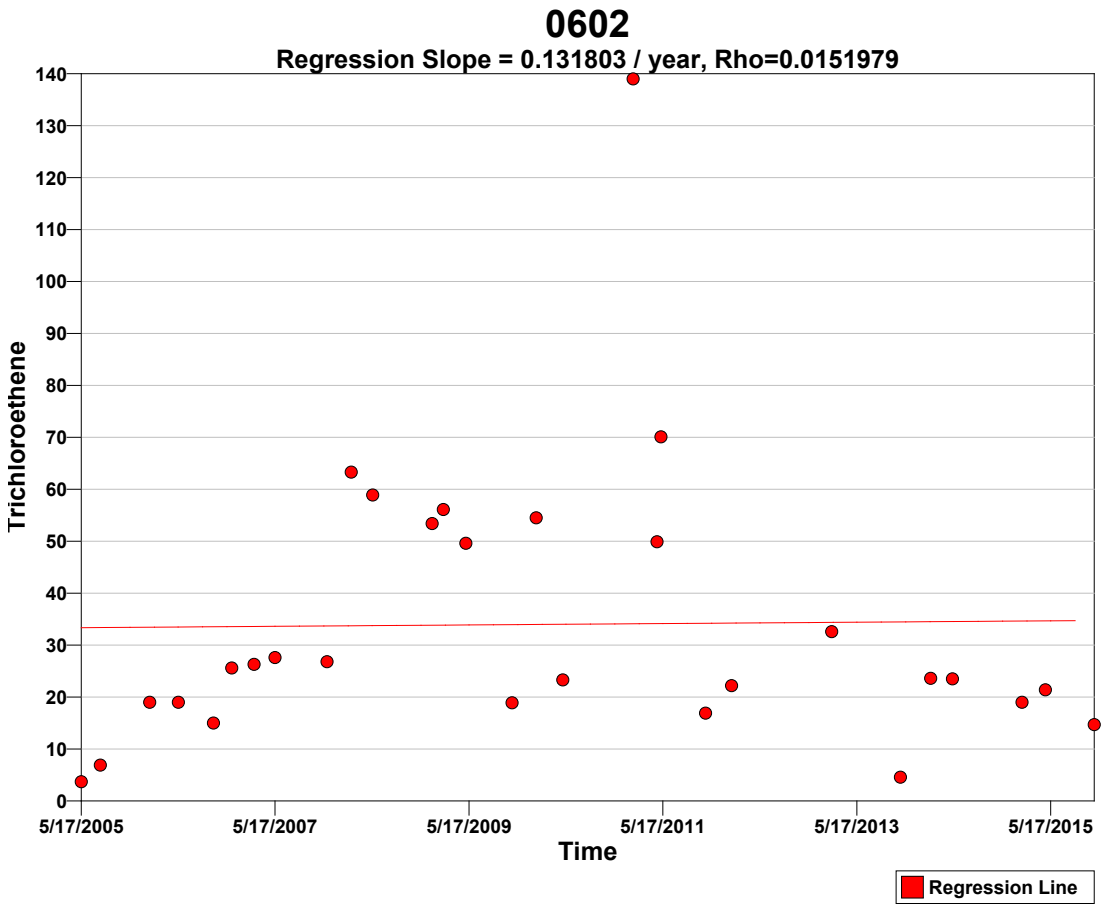
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

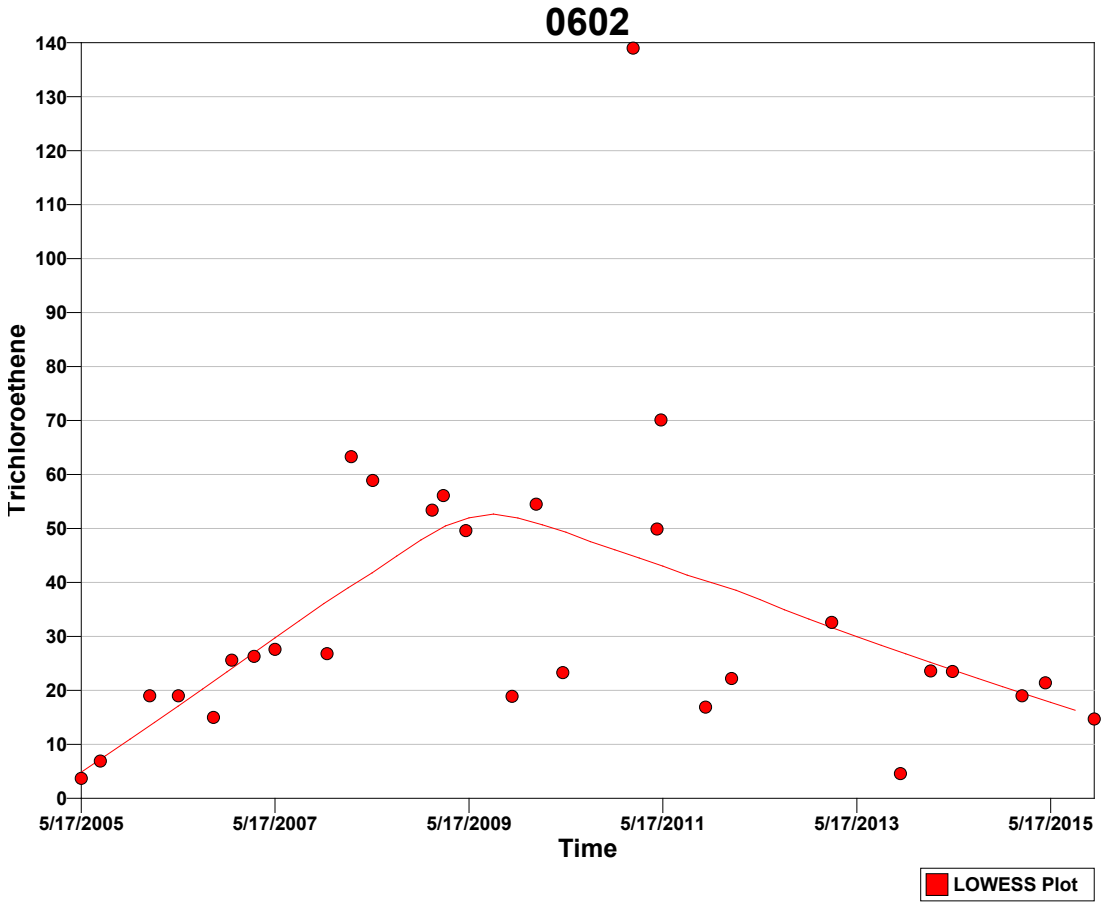
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=29) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.78763
Shapiro-Wilk 5% Critical Value	0.926

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	13	
MK Test Statistic	Z_{MK}	0.225242	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0605. The following table lists the data points that were used in the analysis.

0605							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/17/2005	177210		2/28/2008	26100		5/10/2011	11900
5/17/2005	182750		5/19/2008	21300		7/27/2011	13200
7/28/2005	269300		8/4/2008	18600		10/25/2011	13100
11/3/2005	9390		11/17/2008	16900		1/31/2012	7820
11/22/2005	158300		2/9/2009	14800		4/25/2012	12000
1/30/2006	106520		5/5/2009	18400		2/11/2013	10700
5/18/2006	58880		7/29/2009	27100		8/27/2013	9610
9/26/2006	55800		10/26/2009	19300		2/19/2014	6300
12/5/2006	36200		1/25/2010	12500		8/26/2014	8060
2/27/2007	26500		5/5/2010	16000		1/29/2015	7910
5/17/2007	33400		7/26/2010	18500		7/29/2015	8340
8/22/2007	22200		12/7/2010	16700			
11/29/2007	25600		1/25/2011	14900			

SUMMARY STATISTICS for Tritium								
n				37				
Min				6300				
Max				269300				
Range				2.63e+005				
Mean				40867				
Median				18400				
Variance				3.575e+009				
StdDev				59792				
Std Error				9829.7				
Skewness				2.5672				
Interquartile Range				18300				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
6300	7668	8030	1.195e+004	1.84e+004	3.025e+004	1.621e+005	1.914e+005	2.693e+005

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
5/17/2005	182750
7/28/2005	269300
11/3/2005	9390
11/22/2005	158300
5/18/2006	58880
9/26/2006	55800
12/5/2006	36200
2/27/2007	26500

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme

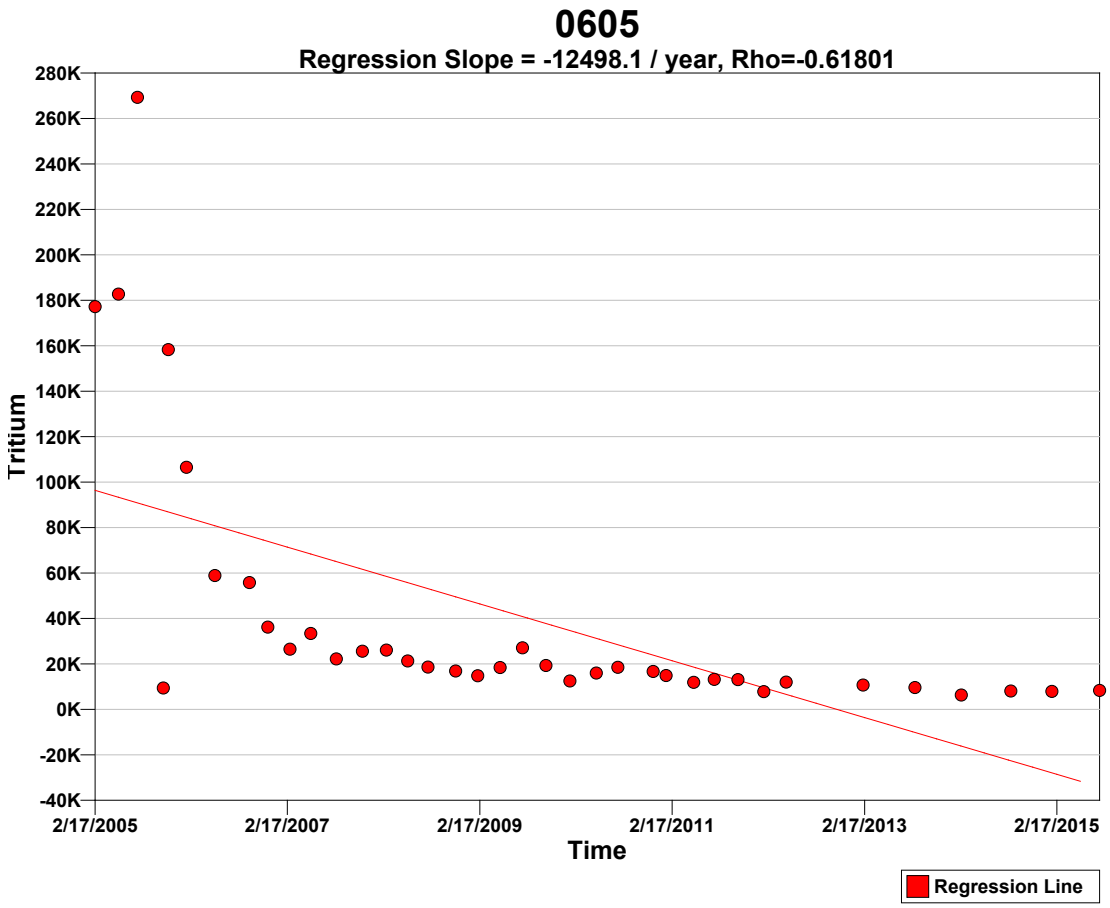
cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

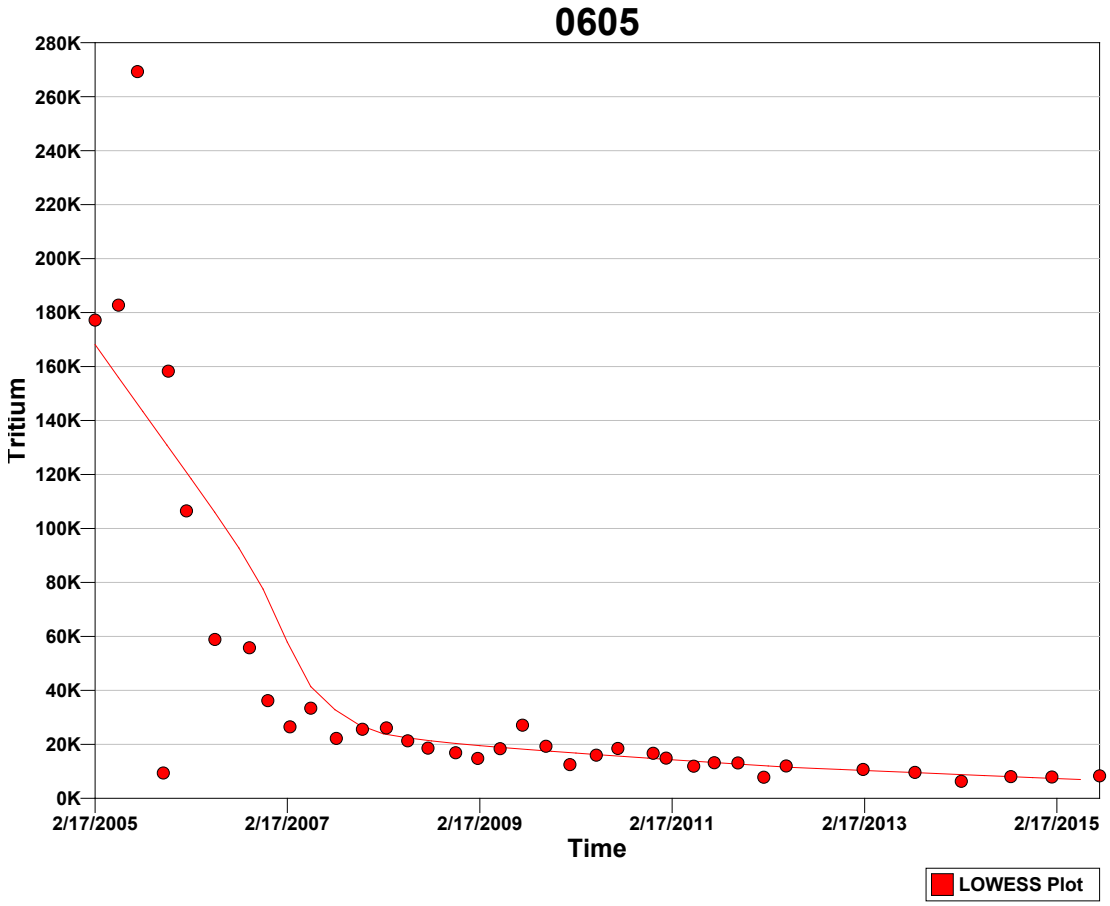
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=37) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.57908
Shapiro-Wilk 5% Critical Value	0.936

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-510	
MK Test Statistic	Z_{MK}	-6.65715	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

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Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

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Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

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The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

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VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
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3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0605. The following table lists the data points that were used in the analysis.

0605							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
2/17/2005	28		8/4/2008	13.4		4/25/2012	15.4
5/17/2005	29		11/17/2008	13.9		10/25/2012	19.8
7/28/2005	97		2/9/2009	10.5		2/11/2013	13.9
7/28/2005	1		5/5/2009	18.3		5/30/2013	14.7
11/3/2005	33		7/29/2009	14		8/27/2013	11
1/30/2006	27		10/26/2009	9.54		10/28/2013	13.5
5/18/2006	16		1/25/2010	9.47		2/19/2014	8.69
9/26/2006	8.8		5/5/2010	17.6		5/12/2014	9.43
12/5/2006	9.61		7/26/2010	14.4		8/26/2014	11.8
2/27/2007	15.6		12/7/2010	10		10/27/2014	14.8
5/17/2007	24.7		1/25/2011	12.2		1/29/2015	13
8/22/2007	12.7		5/10/2011	13.1		4/27/2015	10.9
11/29/2007	10.4		7/27/2011	15.9		7/29/2015	12.3
2/28/2008	15.3		10/25/2011	11.5		10/28/2015	7.23
5/19/2008	13.8		1/31/2012	9.16			

SUMMARY STATISTICS for Trichloroethene								
n				44				
Min				1				
Max				97				
Range				96				
Mean				16.167				
Median				13.45				
Variance				192.64				
StdDev				13.879				
Std Error				2.0924				
Skewness				4.836				
Interquartile Range				5.4				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1	7.595	8.98	10.43	13.45	15.82	27.5	32	97

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
7/28/2005	97
7/28/2005	1

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

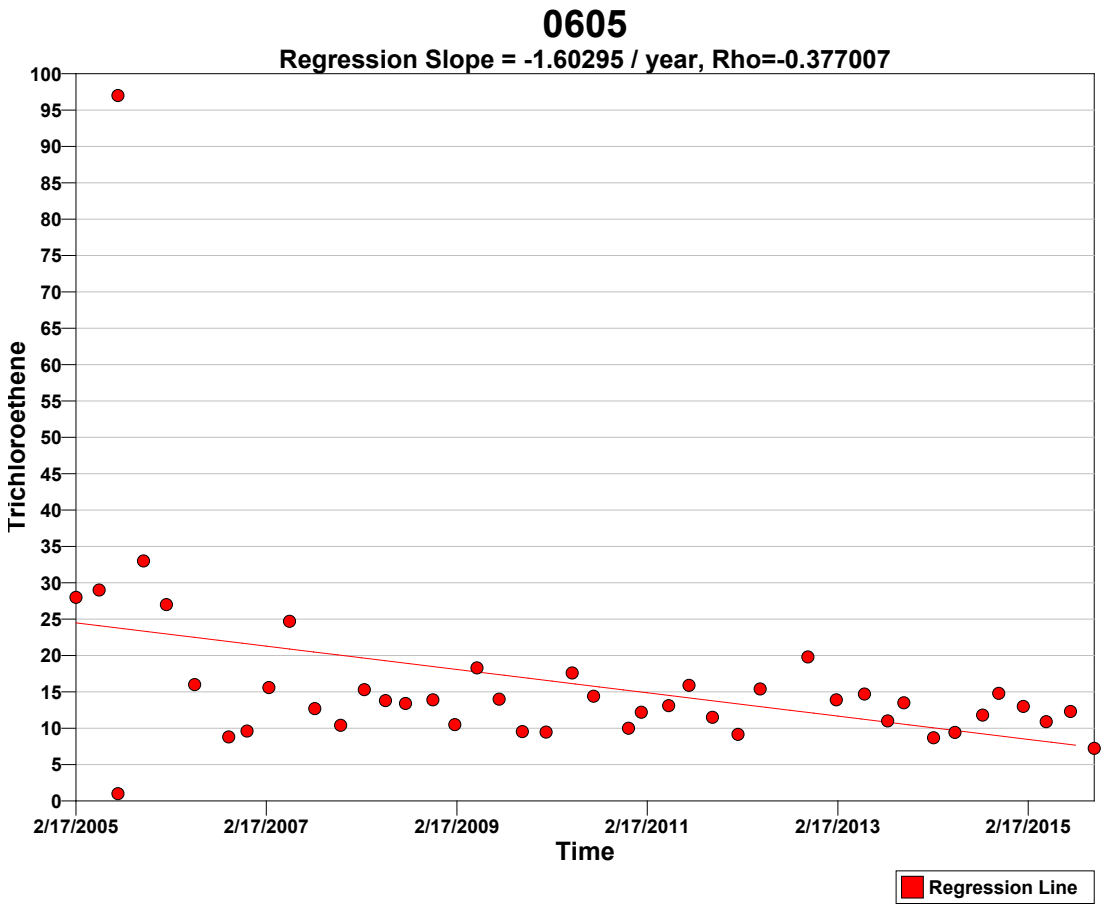
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

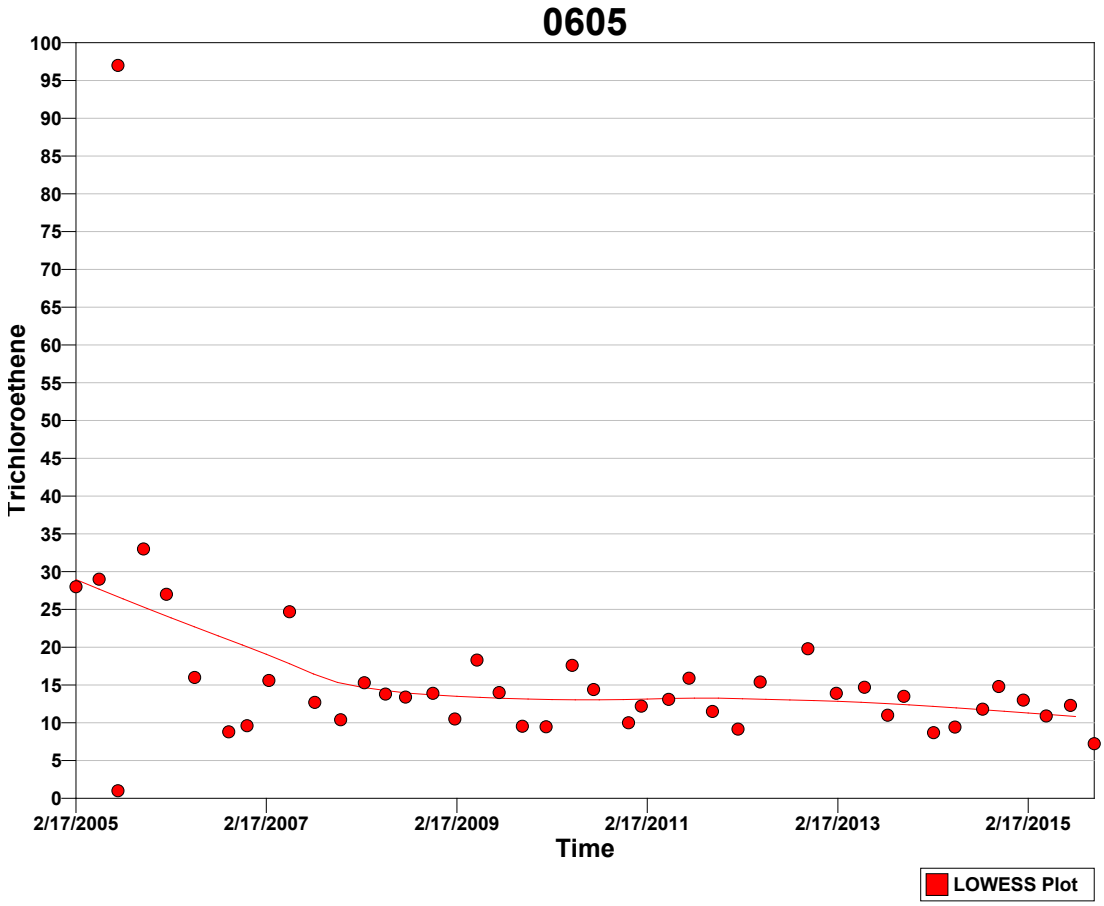
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=44) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.51902
Shapiro-Wilk 5% Critical Value	0.944

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-259	
MK Test Statistic	Z_{MK}	-2.60961	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

Data Analysis for cis-1x2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0605. The following table lists the data points that were used in the analysis.

0605							
Time	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**
2/17/2005	26		8/4/2008	2.53		4/25/2012	1.41
5/17/2005	30		11/17/2008	12.4		10/25/2012	2.47
7/28/2005	50		2/9/2009	7.92		2/11/2013	3.02
7/28/2005	1		5/5/2009	8.8		5/30/2013	1.98
11/3/2005	17		7/29/2009	6.83		8/27/2013	1.49
1/30/2006	21		10/26/2009	4.35		10/28/2013	1.34
5/18/2006	16		1/25/2010	4.52		2/19/2014	2.9
9/26/2006	1.9		5/5/2010	4.49		5/12/2014	3.1
12/5/2006	9.91		7/26/2010	1.91		8/26/2014	9.93
2/27/2007	20.4		12/7/2010	6.25		10/27/2014	1.56
5/17/2007	32.2		1/25/2011	4.48		1/29/2015	3.56
8/22/2007	31.7		5/10/2011	1.62		4/27/2015	1.86
11/29/2007	9.54		7/27/2011	7.08		7/29/2015	1.09
2/28/2008	7.58		10/25/2011	3.22		10/28/2015	2.19
5/19/2008	5.15		1/31/2012	2.39			

SUMMARY STATISTICS for cis-1x2-Dichloroethene								
n				44				
Min				1				
Max				50				
Range				49				
Mean				9.0016				
Median				4.485				
Variance				114.81				
StdDev				10.715				
Std Error				1.6153				
Skewness				2.0632				
Interquartile Range				7.8925				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1	1.153	1.45	2.032	4.485	9.925	28	32.08	50

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

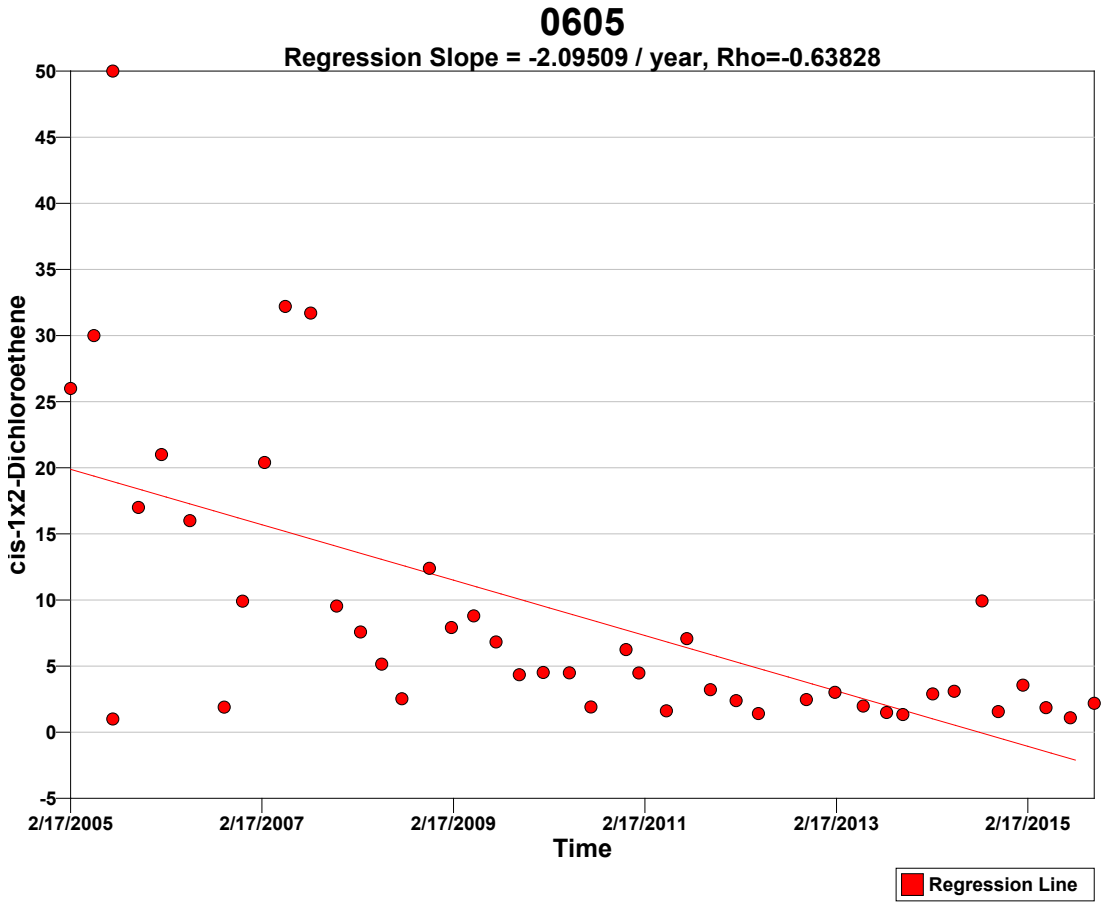
SUSPECTED OUTLIERS	
Date/Time	**Value**
7/28/2005	50
7/28/2005	1
9/26/2006	1.9
5/17/2007	32.2
8/22/2007	31.7

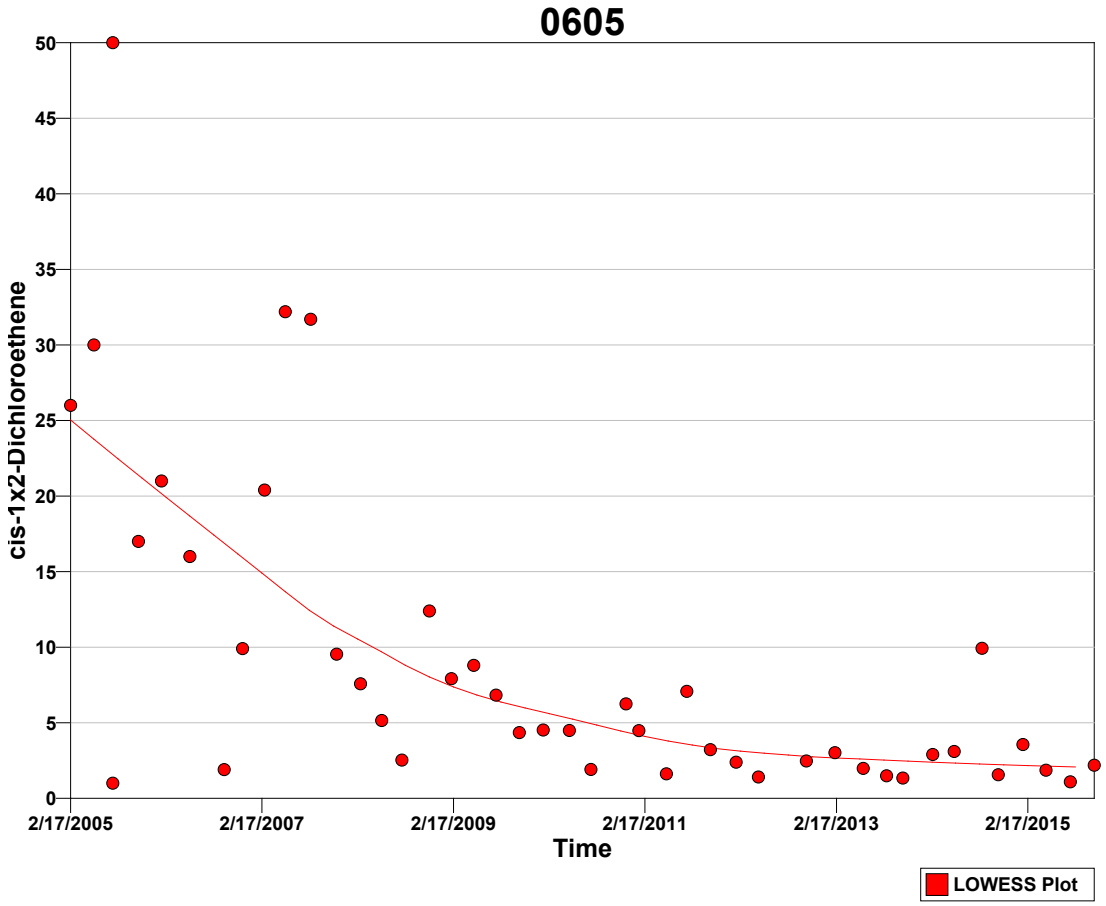
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0605
Regression Slope = -2.09509 / year, Rho=-0.63828
cis-1x2-Dichloroethene
50
45
40
35
30
25
20
15
10
5
0
-5
2/17/2005
2/17/2007
2/17/2009
2/17/2011
2/17/2013
2/17/2015
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=44) is less than 50.

Normal Distribution Test for cis-1x2-Dichloroethene	
Shapiro-Wilk Test Statistic	0.72605
Shapiro-Wilk 5% Critical Value	0.944

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-498	
MK Test Statistic	Z_{MK}	-5.02679	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0605. The following table lists the data points that were used in the analysis.

0605							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/17/2005	177210		2/28/2008	26100		5/10/2011	11900
5/17/2005	182750		5/19/2008	21300		7/27/2011	13200
7/28/2005	269300		8/4/2008	18600		10/25/2011	13100
11/3/2005	9390		11/17/2008	16900		1/31/2012	7820
11/22/2005	158300		2/9/2009	14800		4/25/2012	12000
1/30/2006	106520		5/5/2009	18400		2/11/2013	10700
5/18/2006	58880		7/29/2009	27100		8/27/2013	9610
9/26/2006	55800		10/26/2009	19300		2/19/2014	6300
12/5/2006	36200		1/25/2010	12500		8/26/2014	8060
2/27/2007	26500		5/5/2010	16000		1/29/2015	7910
5/17/2007	33400		7/26/2010	18500		7/29/2015	8340
8/22/2007	22200		12/7/2010	16700			
11/29/2007	25600		1/25/2011	14900			

SUMMARY STATISTICS for Tritium								
n				37				
Min				6300				
Max				269300				
Range				2.63e+005				
Mean				40867				
Median				18400				
Variance				3.575e+009				
StdDev				59792				
Std Error				9829.7				
Skewness				2.5672				
Interquartile Range				18300				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
6300	7668	8030	1.195e+004	1.84e+004	3.025e+004	1.621e+005	1.914e+005	2.693e+005

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
5/17/2005	182750
7/28/2005	269300
11/3/2005	9390
11/22/2005	158300
5/18/2006	58880
9/26/2006	55800
12/5/2006	36200
2/27/2007	26500

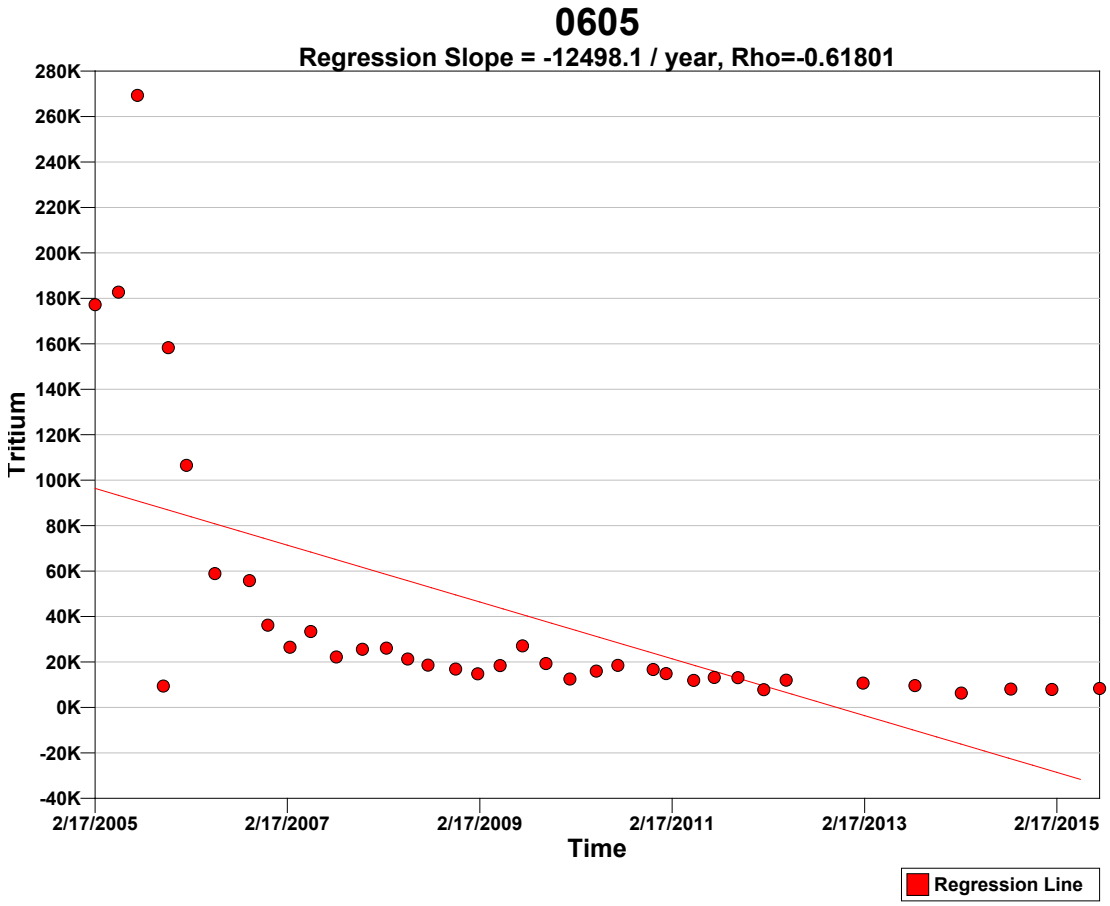
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

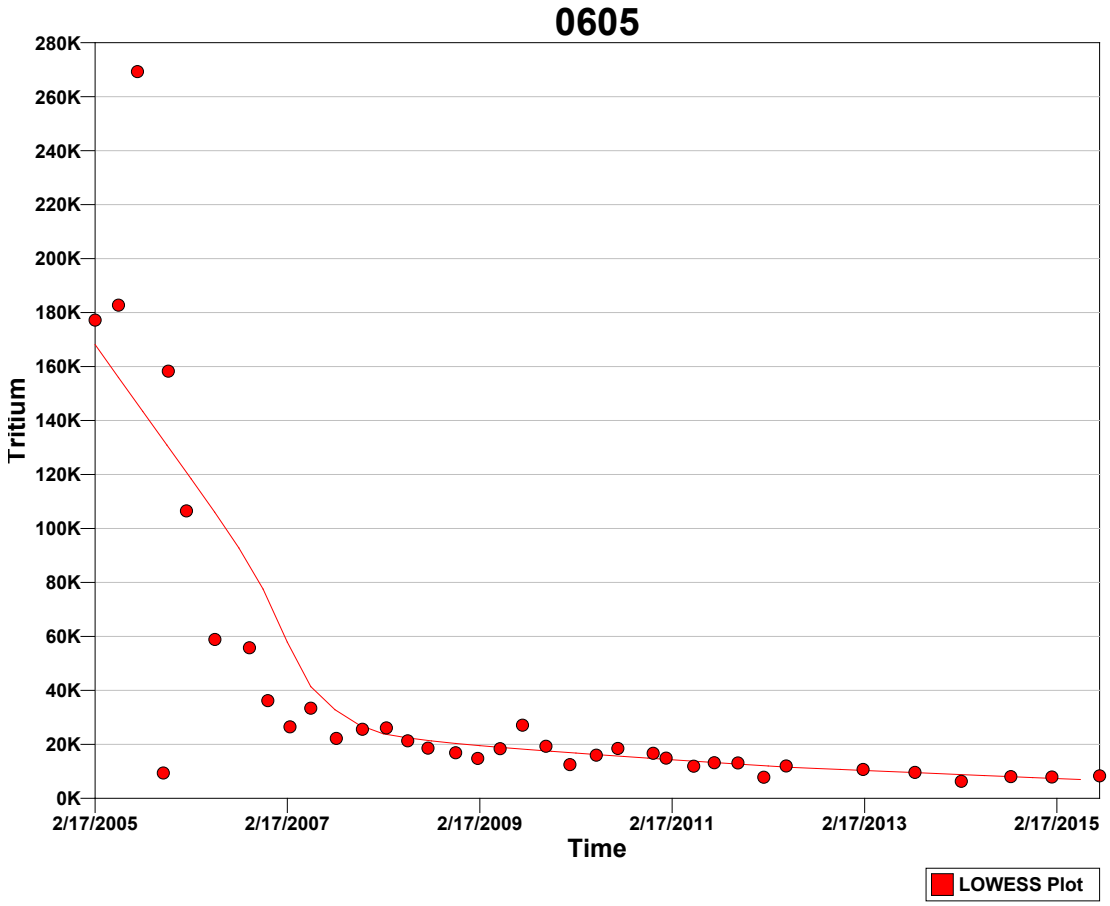
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0605
Regression Slope = -12498.1 / year, Rho=-0.61801
Tritium
280K
260K
240K
220K
200K
180K
160K
140K
120K
100K
80K
60K
40K
20K
0K
-20K
-40K
2/17/2005
2/17/2007
2/17/2009
2/17/2011
2/17/2013
2/17/2015
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=37) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.57908
Shapiro-Wilk 5% Critical Value	0.936

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-510	
MK Test Statistic	Z_{MK}	-6.65715	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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This design was last modified 2/22/2016 10:08:14 AM.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1,2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0605. The following table lists the data points that were used in the analysis.

0605							
Time	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**
2/17/2005	26		8/4/2008	2.53		4/25/2012	1.41
5/17/2005	30		11/17/2008	12.4		10/25/2012	2.47
7/28/2005	50		2/9/2009	7.92		2/11/2013	3.02
7/28/2005	1		5/5/2009	8.8		5/30/2013	1.98
11/3/2005	17		7/29/2009	6.83		8/27/2013	1.49
1/30/2006	21		10/26/2009	4.35		10/28/2013	1.34
5/18/2006	16		1/25/2010	4.52		2/19/2014	2.9
9/26/2006	1.9		5/5/2010	4.49		5/12/2014	3.1
12/5/2006	9.91		7/26/2010	1.91		8/26/2014	9.93
2/27/2007	20.4		12/7/2010	6.25		10/27/2014	1.56
5/17/2007	32.2		1/25/2011	4.48		1/29/2015	3.56
8/22/2007	31.7		5/10/2011	1.62		4/27/2015	1.86
11/29/2007	9.54		7/27/2011	7.08		7/29/2015	1.09
2/28/2008	7.58		10/25/2011	3.22		10/28/2015	2.19
5/19/2008	5.15		1/31/2012	2.39			

SUMMARY STATISTICS for cis-1,2-Dichloroethene								
n	44							
Min	1							
Max	50							
Range	49							
Mean	9.0016							
Median	4.485							
Variance	114.81							
StdDev	10.715							
Std Error	1.6153							
Skewness	2.0632							
Interquartile Range	7.8925							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1	1.153	1.45	2.032	4.485	9.925	28	32.08	50

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
7/28/2005	50
7/28/2005	1
9/26/2006	1.9
5/17/2007	32.2
8/22/2007	31.7

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme

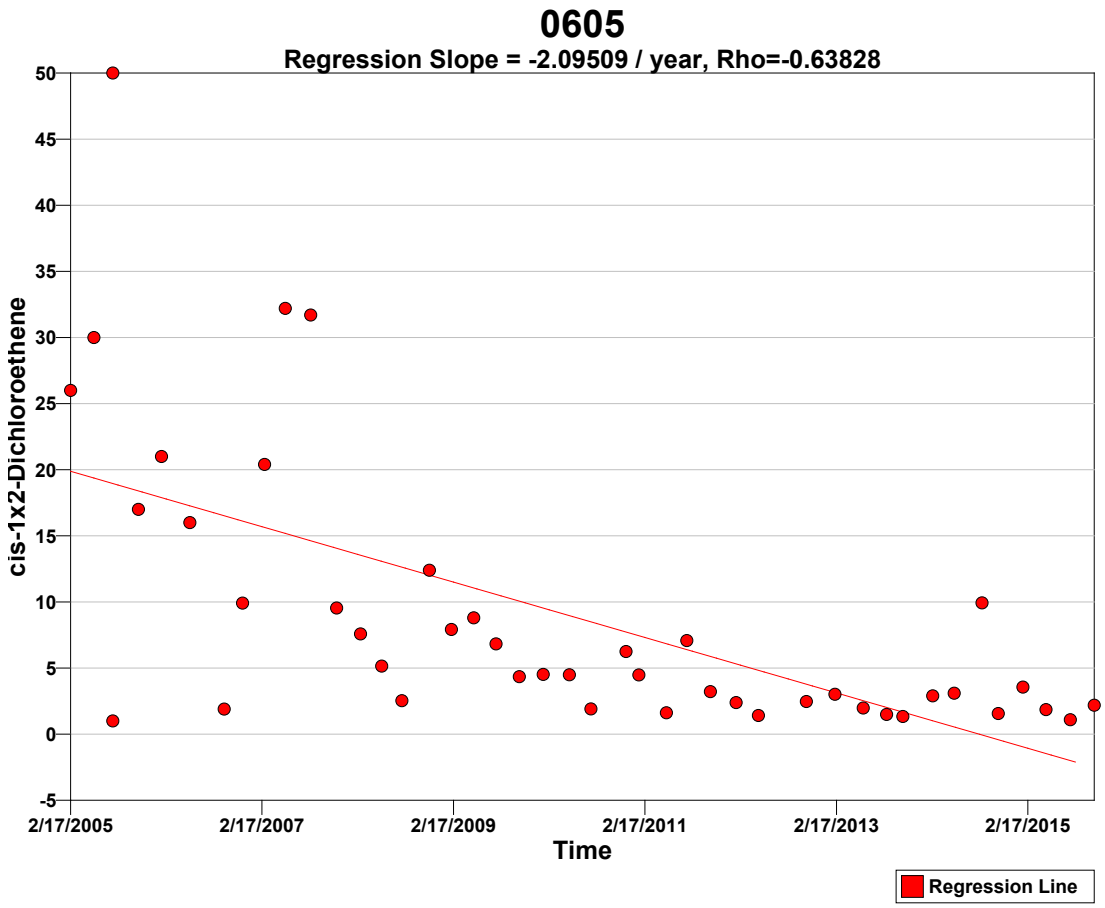
cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

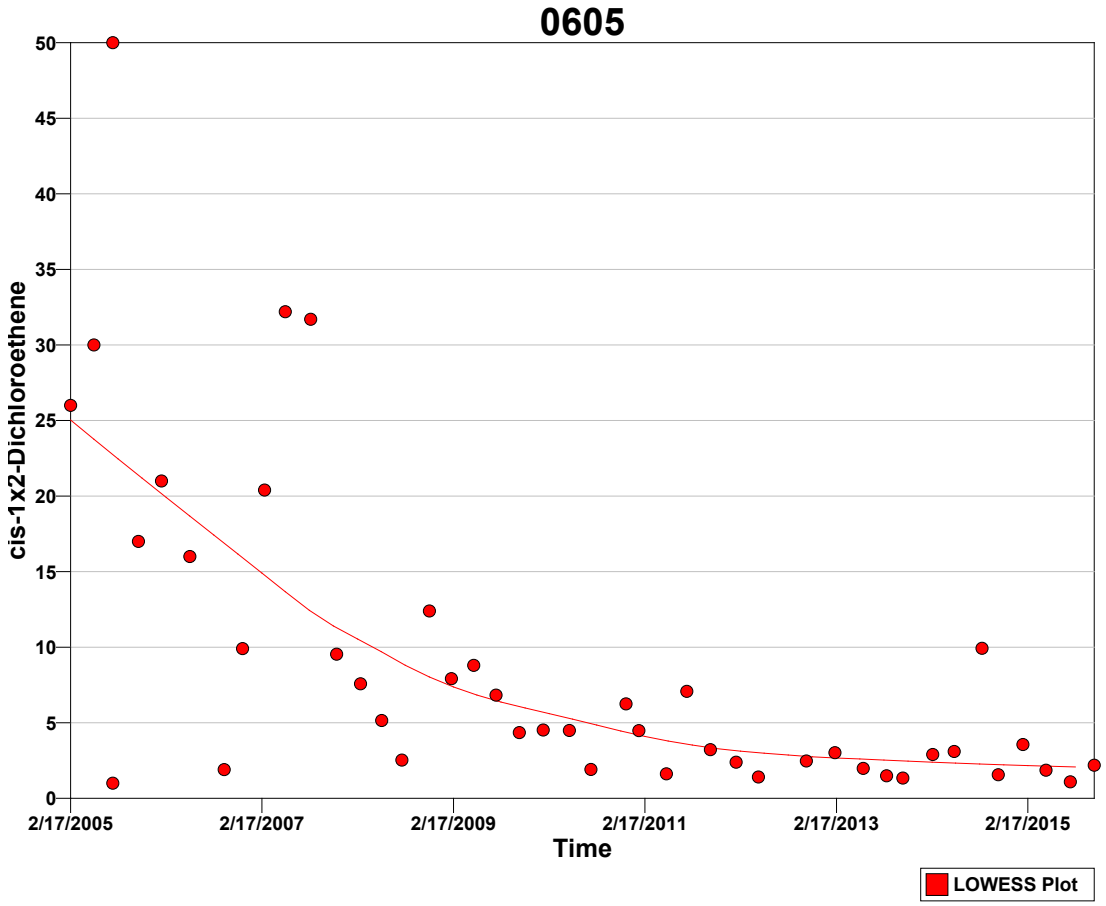
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=44) is less than 50.

Normal Distribution Test for cis-1,2-Dichloroethene	
Shapiro-Wilk Test Statistic	0.72605
Shapiro-Wilk 5% Critical Value	0.944

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-498	
MK Test Statistic	Z_{MK}	-5.02679	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0602. The following table lists the data points that were used in the analysis.

0602							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
4/20/2005	41770		11/29/2007	45100		1/25/2011	10100
5/17/2005	22740		2/28/2008	27200		5/10/2011	7240
7/28/2005	21090		5/19/2008	25100		10/25/2011	14500
1/30/2006	13160		12/29/2008	15400		1/31/2012	8120
5/18/2006	17380		2/9/2009	14200		2/11/2013	8810
9/27/2006	82700		5/5/2009	14800		2/19/2014	4570
12/5/2006	48900		10/26/2009	22500		1/29/2015	7280
2/27/2007	30500		1/25/2010	11900			
5/17/2007	36800		5/5/2010	14700			

SUMMARY STATISTICS for Tritium								
n				25				
Min				4570				
Max				82700				
Range				78130				
Mean				22662				
Median				15400				
Variance				3.0688e+008				
StdDev				17518				
Std Error				3503.6				
Skewness				1.9413				
Interquartile Range				17850				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
4570	5371	7264	1.1e+004	1.54e+004	2.885e+004	4.662e+004	7.256e+004	8.27e+004

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
9/27/2006	82700

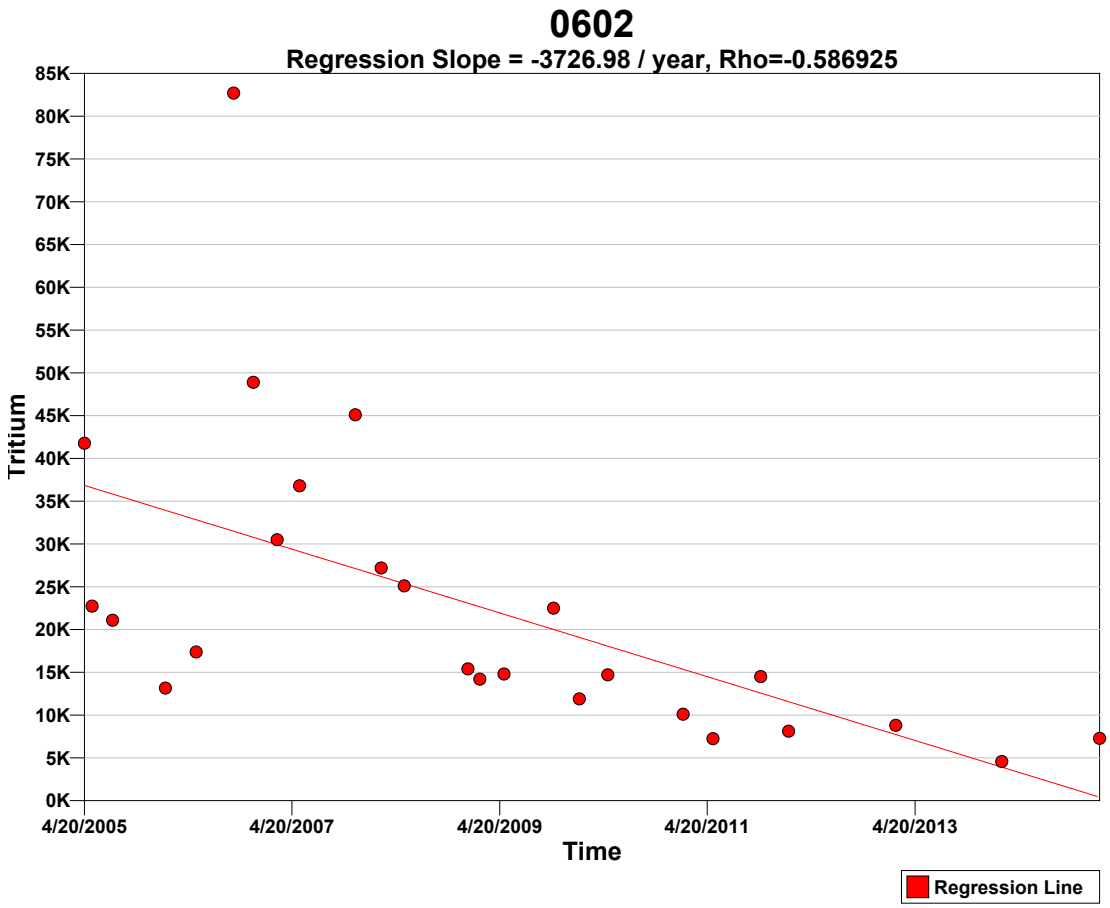
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

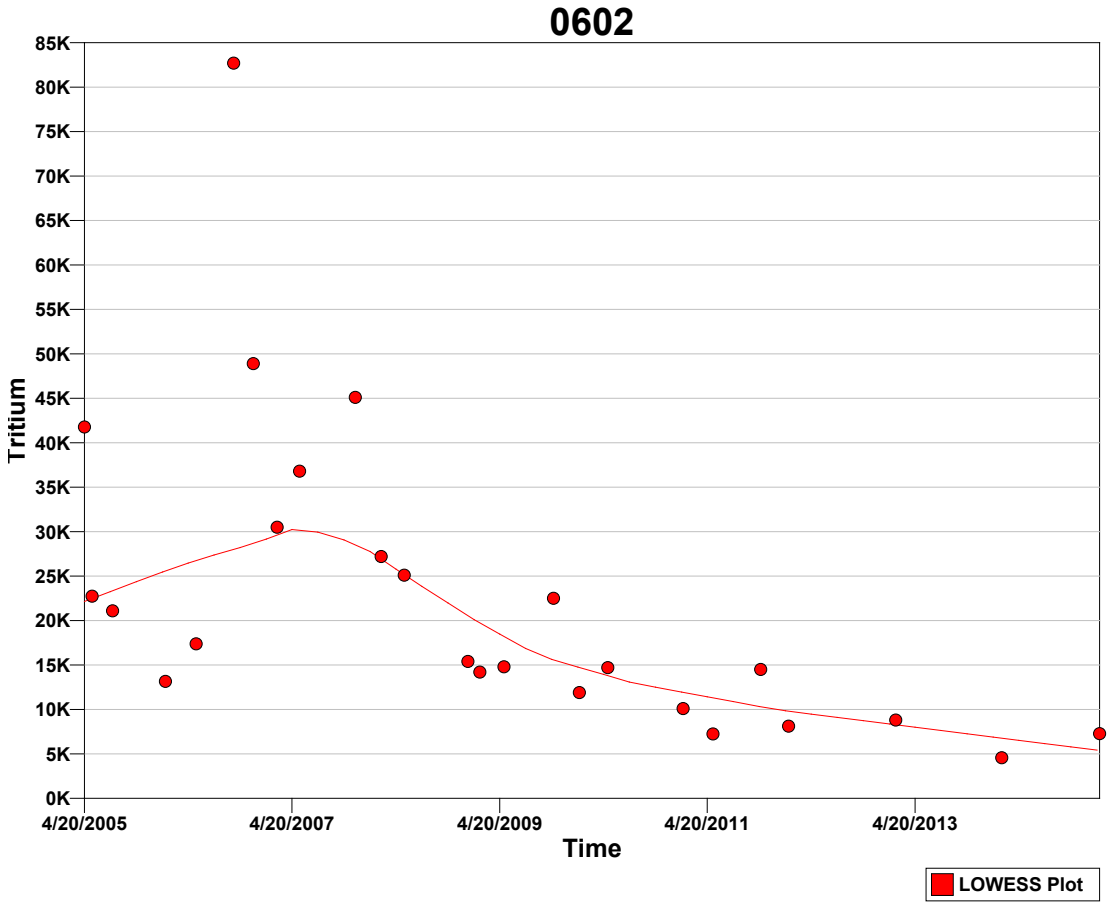
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in

the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=25) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.81236
Shapiro-Wilk 5% Critical Value	0.918

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-184	
MK Test Statistic	Z_{MK}	-4.27396	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

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Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1,2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0602. The following table lists the data points that were used in the analysis.

0602							
Time	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**
5/17/2005	2.7		5/19/2008	26.3		10/25/2011	22.6
7/28/2005	8.3		12/29/2008	17.9		1/31/2012	14.9
1/30/2006	21		2/9/2009	19.1		2/11/2013	42.3
5/18/2006	19		5/5/2009	17.8		10/28/2013	12.2
9/27/2006	16		10/26/2009	18.1		2/19/2014	19.4
12/5/2006	17.8		1/25/2010	34.7		5/12/2014	15.2
2/27/2007	23.9		5/5/2010	12.2		1/29/2015	9.89
5/17/2007	19.7		1/25/2011	38		4/27/2015	7.5
11/29/2007	18.2		4/25/2011	8.11		10/28/2015	4.56
2/28/2008	30.6		5/10/2011	30.5			

SUMMARY STATISTICS for cis-1,2-Dichloroethene								
n				29				
Min				2.7				
Max				42.3				
Range				39.6				
Mean				18.912				
Median				18.1				
Variance				91.882				
StdDev				9.5855				
Std Error				1.78				
Skewness				0.6436				
Interquartile Range				11.05				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
2.7	3.63	7.5	12.2	18.1	23.25	34.7	40.15	42.3

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
2/11/2013	42.3

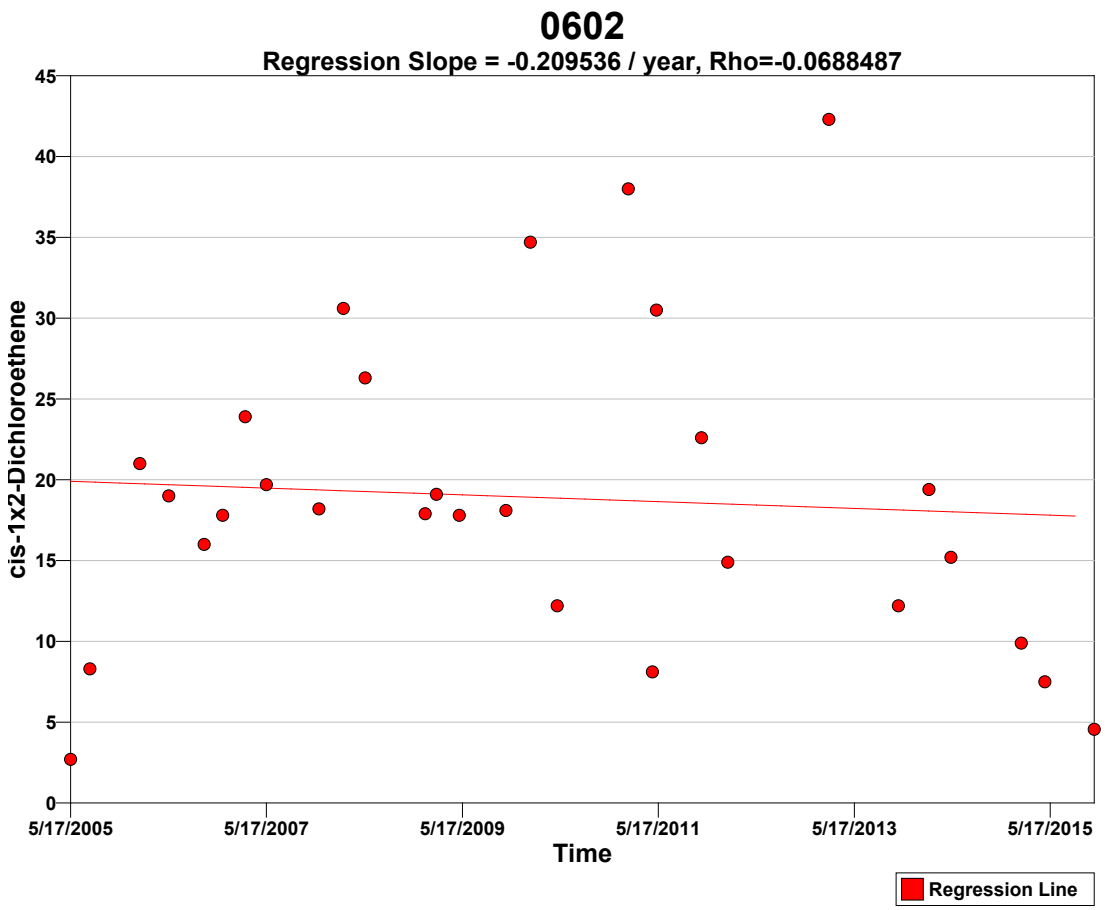
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

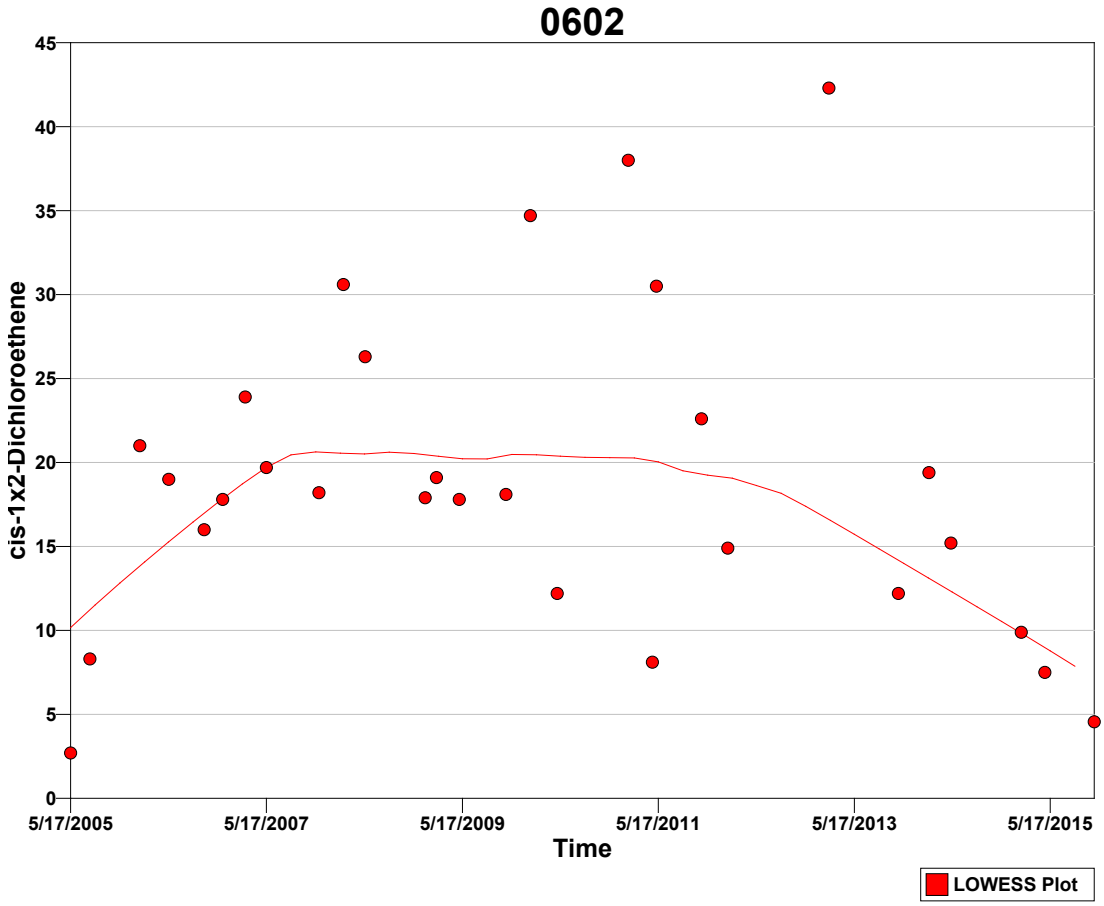
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the

value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=29) is less than 50.

Normal Distribution Test for cis-1,2-Dichloroethene	
Shapiro-Wilk Test Statistic	0.95317
Shapiro-Wilk 5% Critical Value	0.926

The calculated test statistic exceeds the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-40	
MK Test Statistic	Z_{MK}	-0.731822	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0601. The following table lists the data points that were used in the analysis.

0601							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
2/17/2005	4.3		11/17/2008	4.82		7/24/2012	0.16
5/17/2005	4.7		2/9/2009	3.55		10/25/2012	10.3
7/28/2005	4.9		5/5/2009	5.28		2/11/2013	6.3
11/3/2005	5.8		7/29/2009	5.71		5/30/2013	6.1
1/30/2006	4.8		10/26/2009	5.97		8/27/2013	6.52
5/18/2006	3.9		1/25/2010	1.95		10/28/2013	7.34
9/26/2006	8		5/5/2010	0.11		2/19/2014	1.98
12/5/2006	6.18		7/26/2010	7.46		5/12/2014	2.8
2/27/2007	5.08		10/25/2010	7.48		8/26/2014	6.73
5/17/2007	6.32		1/25/2011	3.94		10/27/2014	8.03
8/22/2007	6.84		5/10/2011	4.62		1/29/2015	6.68
11/29/2007	5.25		7/27/2011	5.78		4/27/2015	3.98
2/28/2008	3.41		10/25/2011	4.95		7/29/2015	6.94
5/19/2008	3.63		1/31/2012	4.16		10/28/2015	1.04
8/4/2008	5.83		4/25/2012	0.16			

SUMMARY STATISTICS for Trichloroethene								
n				44				
Min				0.11				
Max				10.3				
Range				10.19				
Mean				4.995				
Median				5.165				
Variance				4.8812				
StdDev				2.2093				
Std Error				0.33307				
Skewness				-0.45073				
Interquartile Range				2.56				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.11	0.16	1.495	3.91	5.165	6.47	7.47	8.022	10.3

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

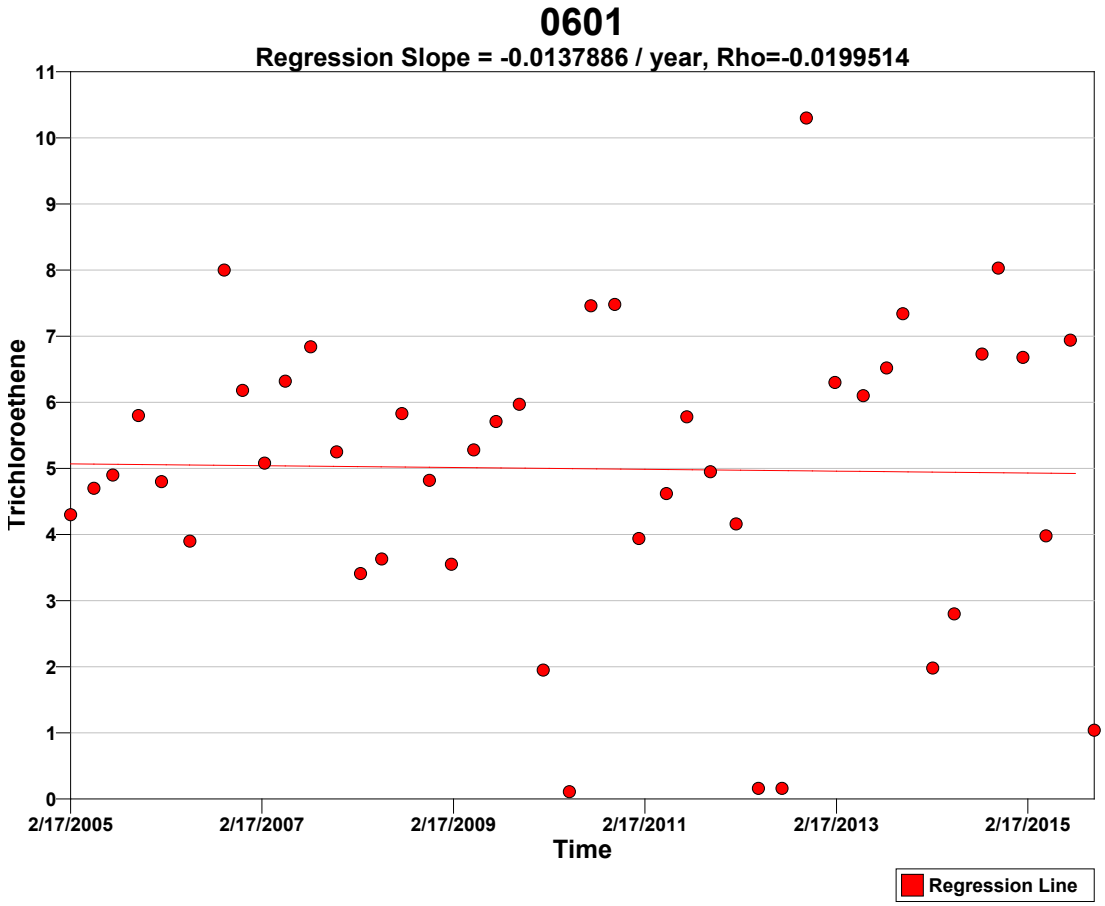
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

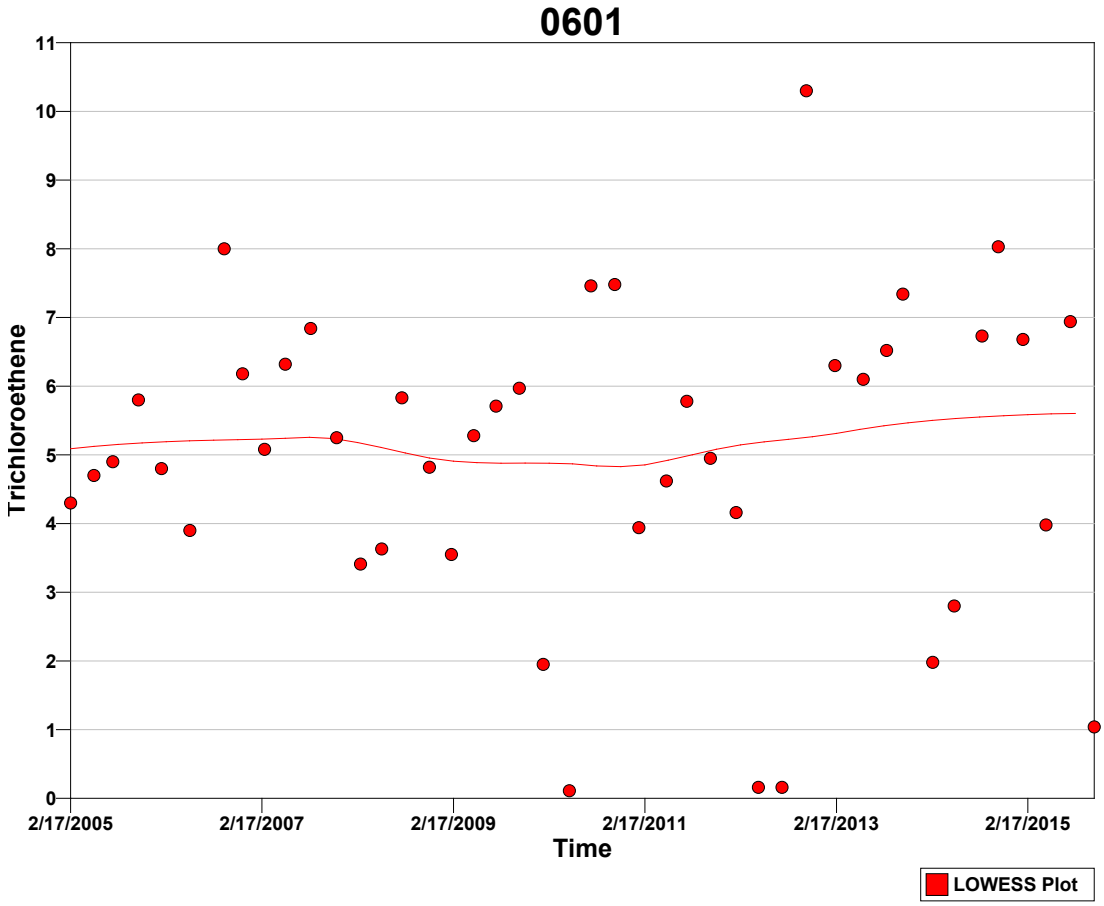
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the

value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=44) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.96044
Shapiro-Wilk 5% Critical Value	0.944

The calculated test statistic exceeds the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	61	
MK Test Statistic	Z_{MK}	0.606887	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0601. The following table lists the data points that were used in the analysis.

0601							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/17/2005	361200		2/28/2008	61200		5/10/2011	32700
5/17/2005	450460		5/19/2008	68100		7/27/2011	54000
5/26/2005	525340		8/4/2008	133000		10/25/2011	46200
7/28/2005	789040		11/17/2008	82900		1/31/2012	26800
11/3/2005	463100		2/9/2009	46300		4/25/2012	49200
1/30/2006	178480		5/5/2009	67100		7/24/2012	53200
5/18/2006	99900		7/29/2009	104000		2/11/2013	26300
9/26/2006	204000		10/26/2009	64500		8/27/2013	46900
12/5/2006	123000		1/25/2010	27400		2/19/2014	11000
2/27/2007	117000		5/5/2010	89.3		8/26/2014	36900
5/17/2007	146000		7/26/2010	68100		1/29/2015	22300
8/22/2007	161000		10/25/2010	96100		7/29/2015	29000
11/29/2007	88000		1/25/2011	38300			

SUMMARY STATISTICS for Tritium								
n				38				
Min				89.3				
Max				789040				
Range				7.8895e+005				
Mean				1.3153e+005				
Median				67600				
Variance				2.8236e+010				
StdDev				1.6803e+005				
Std Error				27259				
Skewness				2.4611				
Interquartile Range				98300				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
89.3	1.045e+004	2.59e+004	3.795e+004	6.76e+004	1.363e+005	4.517e+005	5.385e+005	7.89e+005

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
2/17/2005	361200
7/28/2005	789040
1/30/2006	178480
5/18/2006	99900

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

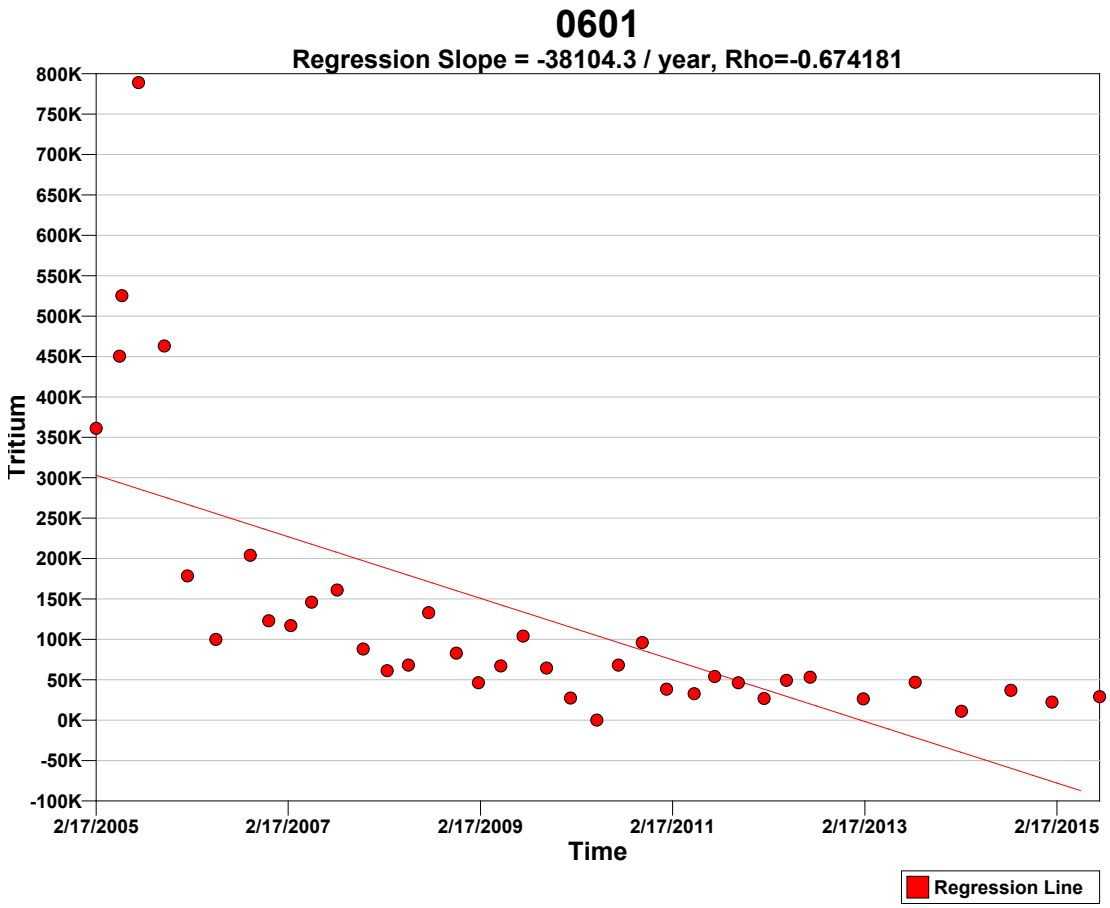
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

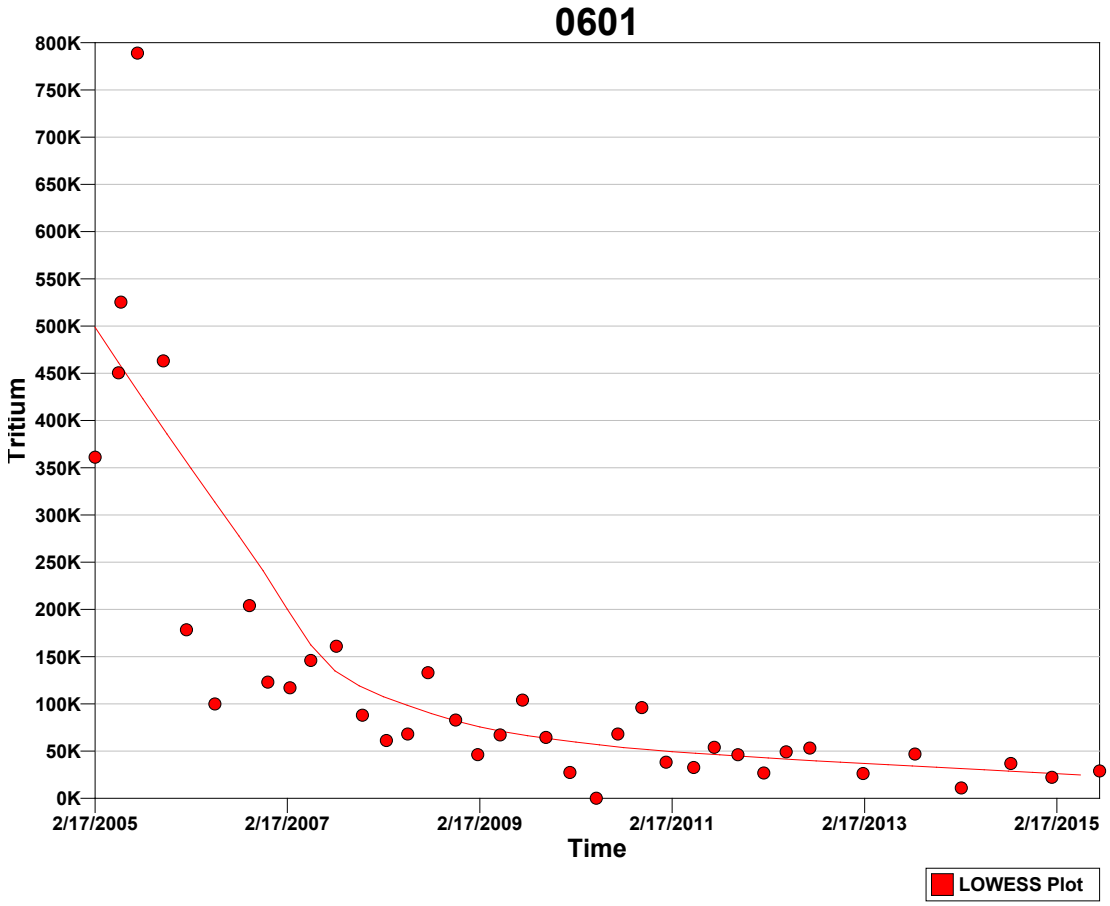
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=38) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.6666
Shapiro-Wilk 5% Critical Value	0.938

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-486	
MK Test Statistic	Z_{MK}	-6.09786	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

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Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1x2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0443. The following table lists the data points that were used in the analysis.

0443							
Time	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**
5/6/2002	1		11/16/2005	1.1		1/27/2010	0.451
7/26/2002	1		1/31/2006	1.9		7/29/2010	0.28
11/8/2002	1		4/26/2006	1		1/26/2011	0.49
1/28/2003	1		8/4/2006	0.341		7/25/2011	0.22
4/22/2003	1		11/17/2006	0.438		1/30/2012	0.75
7/25/2003	1		2/28/2007	0.919		7/26/2012	0.27
10/22/2003	1		5/23/2007	5		2/14/2013	0.57
1/22/2004	1		8/22/2007	0.708		8/28/2013	0.38
4/21/2004	1		11/13/2007	0.872		2/24/2014	0.54
7/12/2004	1		2/19/2008	0.83		8/26/2014	0.36
11/18/2004	0.97		12/30/2008	1.14		1/27/2015	0.27
3/2/2005	1		12/30/2008	1.04		7/29/2015	0.33
5/24/2005	1		2/10/2009	0.762			
8/3/2005	1		7/30/2009	0.32			

SUMMARY STATISTICS for cis-1x2-Dichloroethene								
n				40				
Min				0.22				
Max				5				
Range				4.78				
Mean				0.88127				
Median				0.9445				
Variance				0.56771				
StdDev				0.75346				
Std Error				0.11913				
Skewness				4.3503				
Interquartile Range				0.55875				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.22	0.27	0.284	0.4413	0.9445	1	1.094	1.862	5

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
1/31/2006	1.9
8/4/2006	0.341
11/17/2006	0.438
5/23/2007	5
8/22/2007	0.708
12/30/2008	1.14
12/30/2008	1.04
7/30/2009	0.32
7/29/2010	0.28
7/25/2011	0.22
1/30/2012	0.75

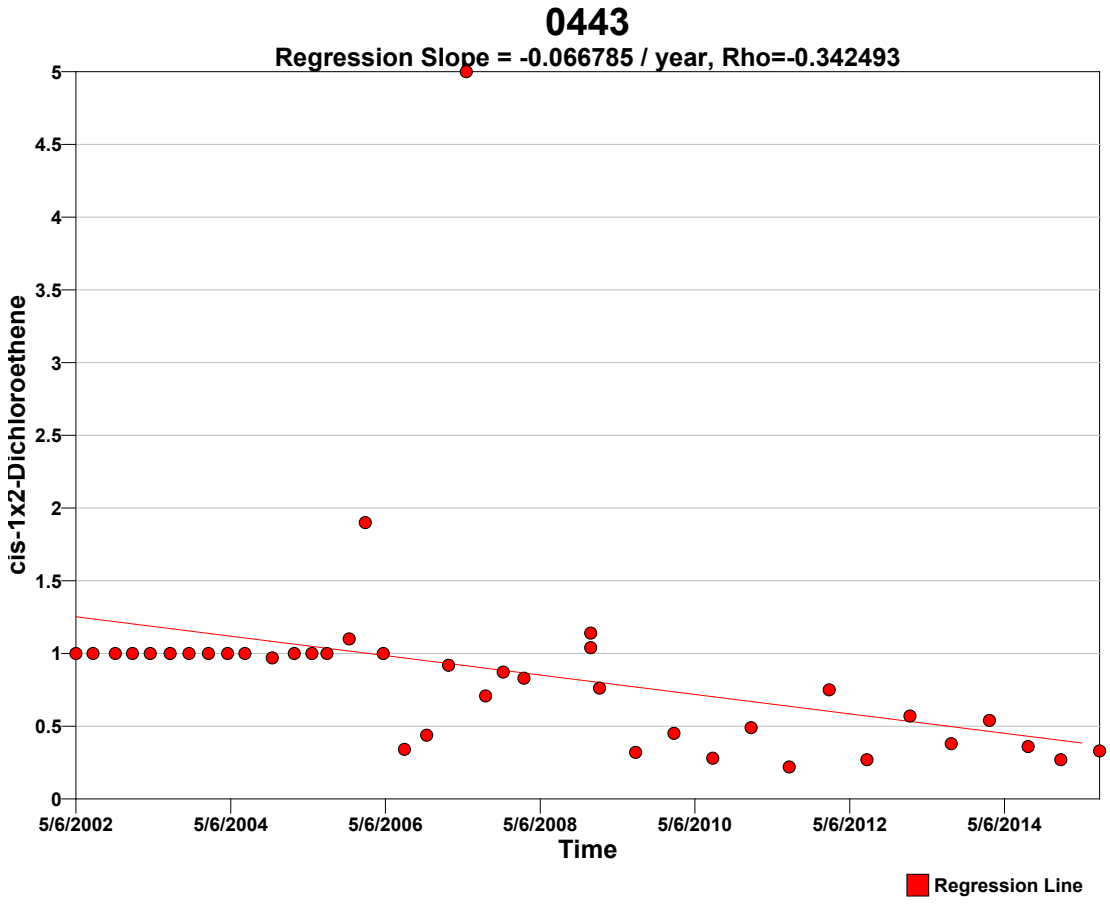
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

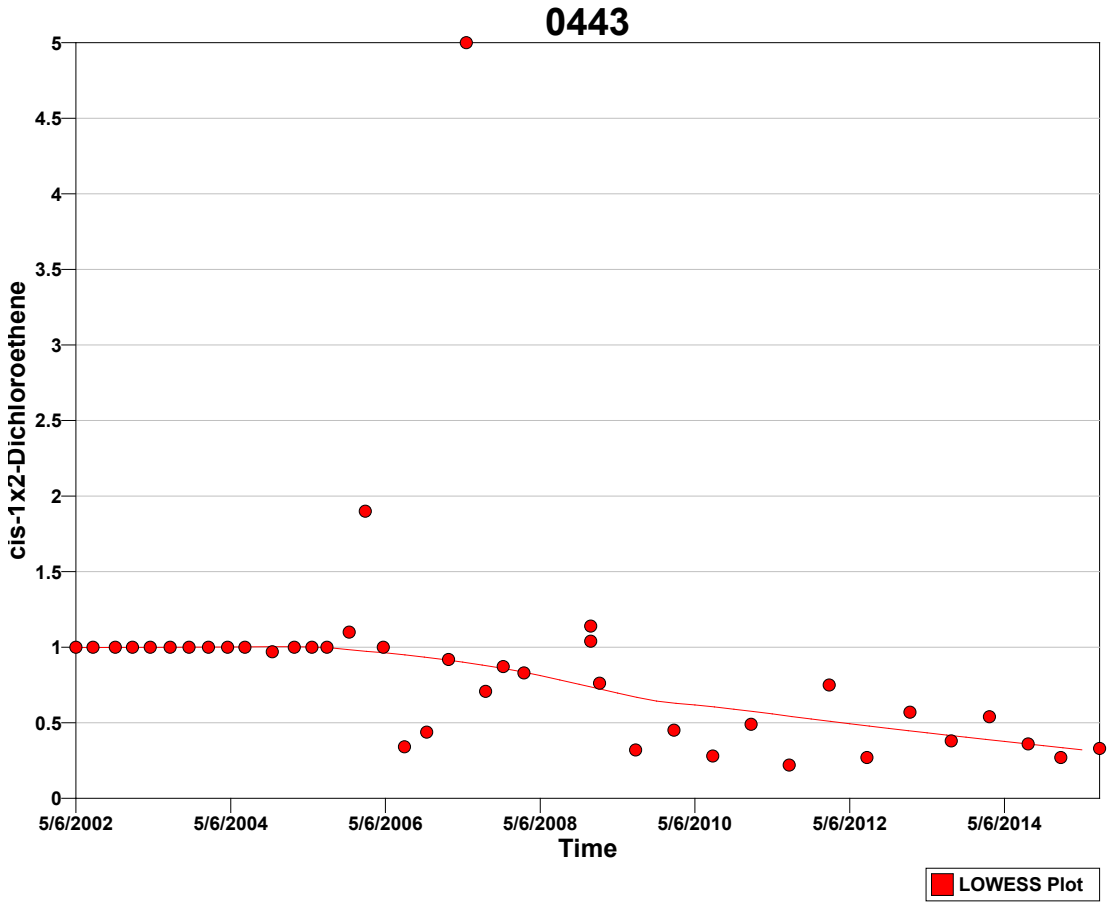
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=40) is less than 50.

Normal Distribution Test for cis-1x2-Dichloroethene	
Shapiro-Wilk Test Statistic	0.55264
Shapiro-Wilk 5% Critical Value	0.94

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test
The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-368	
MK Test Statistic	Z_{MK}	-4.3765	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

Data Analysis for Trichloroethene
Analysis was performed on the data that was entered for the location labeled "0443. The following table lists the data points that were used in the analysis.

0443							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
5/6/2002	9.2		8/3/2005	6.6		1/27/2010	7.47
5/6/2002	8.1		11/16/2005	12		7/29/2010	5.3
7/26/2002	3.5		1/31/2006	9.3		1/26/2011	7.47
11/8/2002	6.6		4/26/2006	7.9		7/25/2011	5.73
1/28/2003	5.4		8/4/2006	6.34		1/30/2012	14
4/22/2003	7.8		11/17/2006	7.33		7/26/2012	5.32
7/25/2003	2.8		2/28/2007	12.3		2/14/2013	7.25
10/22/2003	7.2		5/23/2007	3.06		8/28/2013	8.85
1/22/2004	6.3		8/22/2007	11.7		2/24/2014	11.2
4/21/2004	6.5		11/13/2007	12.1		8/26/2014	7.45
7/12/2004	3.2		2/19/2008	11.2		1/27/2015	6.03
11/18/2004	10		12/30/2008	11		7/29/2015	5.87
3/2/2005	11		2/10/2009	8.36			
5/24/2005	2.2		7/30/2009	3.99			

SUMMARY STATISTICS for Trichloroethene								
n				40				
Min				2.2				
Max				14				
Range				11.8				
Mean				7.623				
Median				7.39				
Variance				8.6004				
StdDev				2.9326				
Std Error				0.46369				
Skewness				0.1762				
Interquartile Range				4.06				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
2.2	2.813	3.23	5.765	7.39	9.825	11.97	12.29	14

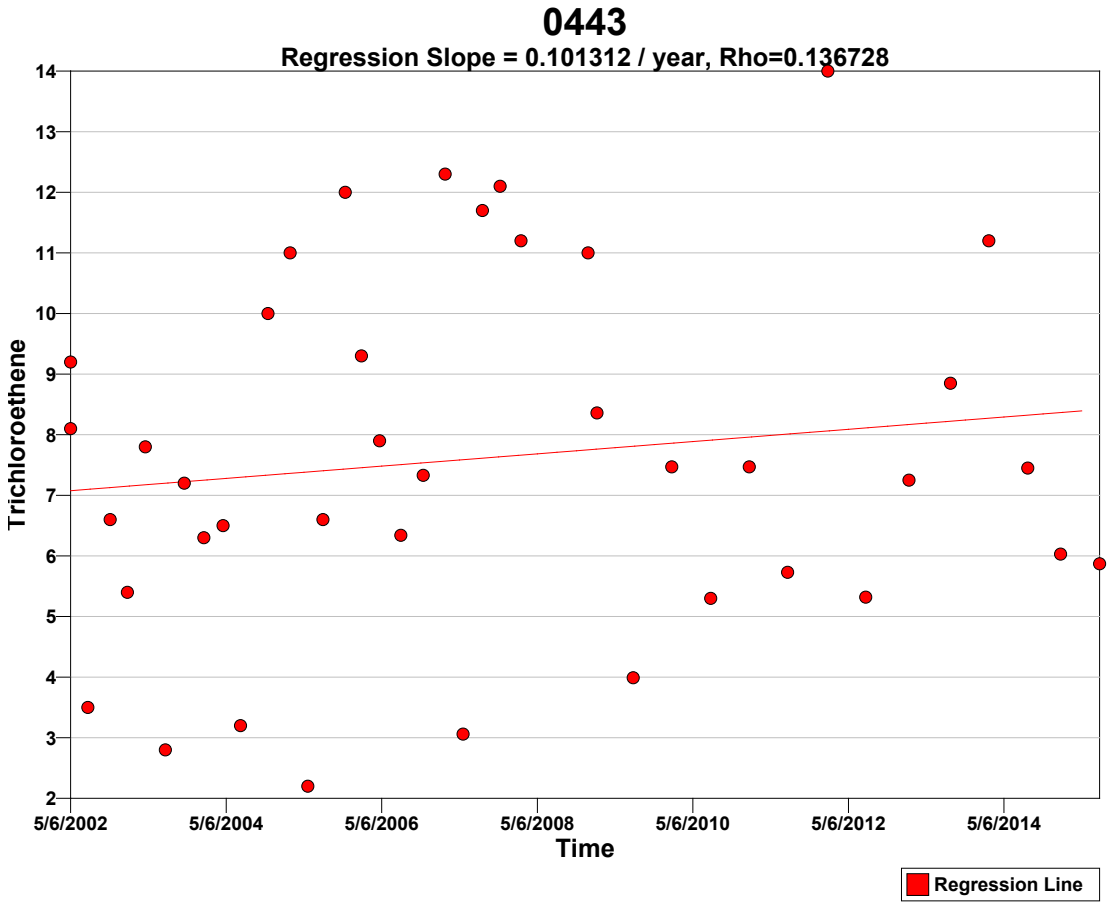
Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

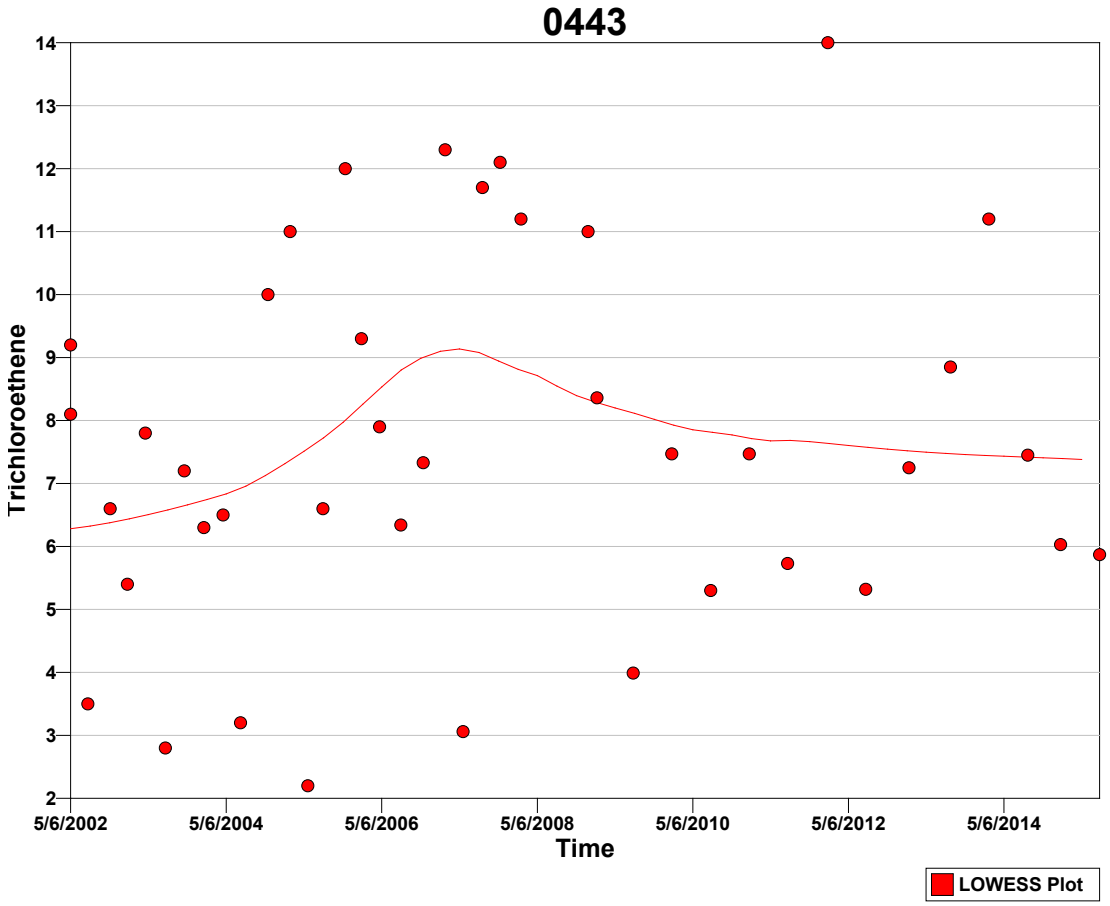
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0443
Regression Slope = 0.101312 / year, Rho=0.136728
Trichloroethene
14
13
12
11
10
9
8
7
6
5
4
3
2
5/6/2002
5/6/2004
5/6/2006
5/6/2008
5/6/2010
5/6/2012
5/6/2014
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=40) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.96674
Shapiro-Wilk 5% Critical Value	0.94

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	58	
MK Test Statistic	Z_{MK}	0.664289	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

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Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tetrachloroethene

Analysis was performed on the data that was entered for the location labeled "0601. The following table lists the data points that were used in the analysis.

0601							
Time	**Tetrachloroethene**		**Time**	**Tetrachloroethene**		**Time**	**Tetrachloroethene**
2/17/2005	29		8/4/2008	12.7		4/25/2012	0.16
5/17/2005	34		11/17/2008	12.9		7/24/2012	0.16
7/28/2005	52		2/9/2009	11.9		10/25/2012	7.29
7/28/2005	0.1		5/5/2009	19.3		2/11/2013	7.88
11/3/2005	14		7/29/2009	18.5		5/30/2013	8.49
1/30/2006	11		10/26/2009	18.9		8/27/2013	7.59
5/18/2006	15		1/25/2010	6.15		10/28/2013	6.26
9/26/2006	18		5/5/2010	0.2		2/19/2014	3.86
12/5/2006	15.6		7/26/2010	11.4		5/12/2014	5.53
2/27/2007	10.6		10/25/2010	6.13		8/26/2014	12.1
5/17/2007	12.2		1/25/2011	4.33		10/27/2014	4.64
8/22/2007	29.4		5/10/2011	11.5		1/29/2015	14.9
11/29/2007	18		7/27/2011	9.59		4/27/2015	12.8
2/28/2008	9.86		10/25/2011	9.29		7/29/2015	12.2
5/19/2008	16		1/31/2012	10.2		10/28/2015	1.31

SUMMARY STATISTICS for Tetrachloroethene								
n				45				
Min				0.1				
Max				52				
Range				51.9				
Mean				12.287				
Median				11.4				
Variance				91.666				
StdDev				9.5743				
Std Error				1.4272				
Skewness				1.964				
Interquartile Range				9.095				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.1	0.16	0.866	6.205	11.4	15.3	23.18	32.62	52

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
7/28/2005	52
7/28/2005	0.1

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

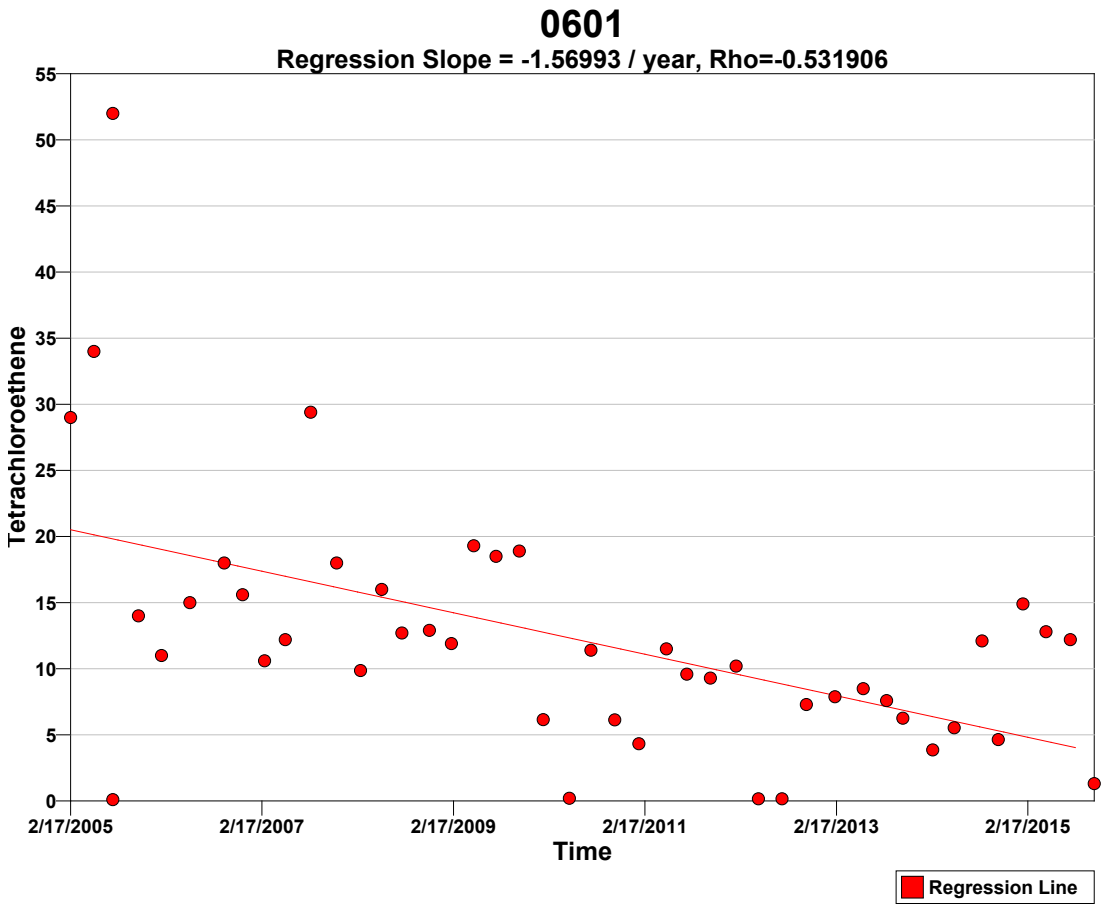
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

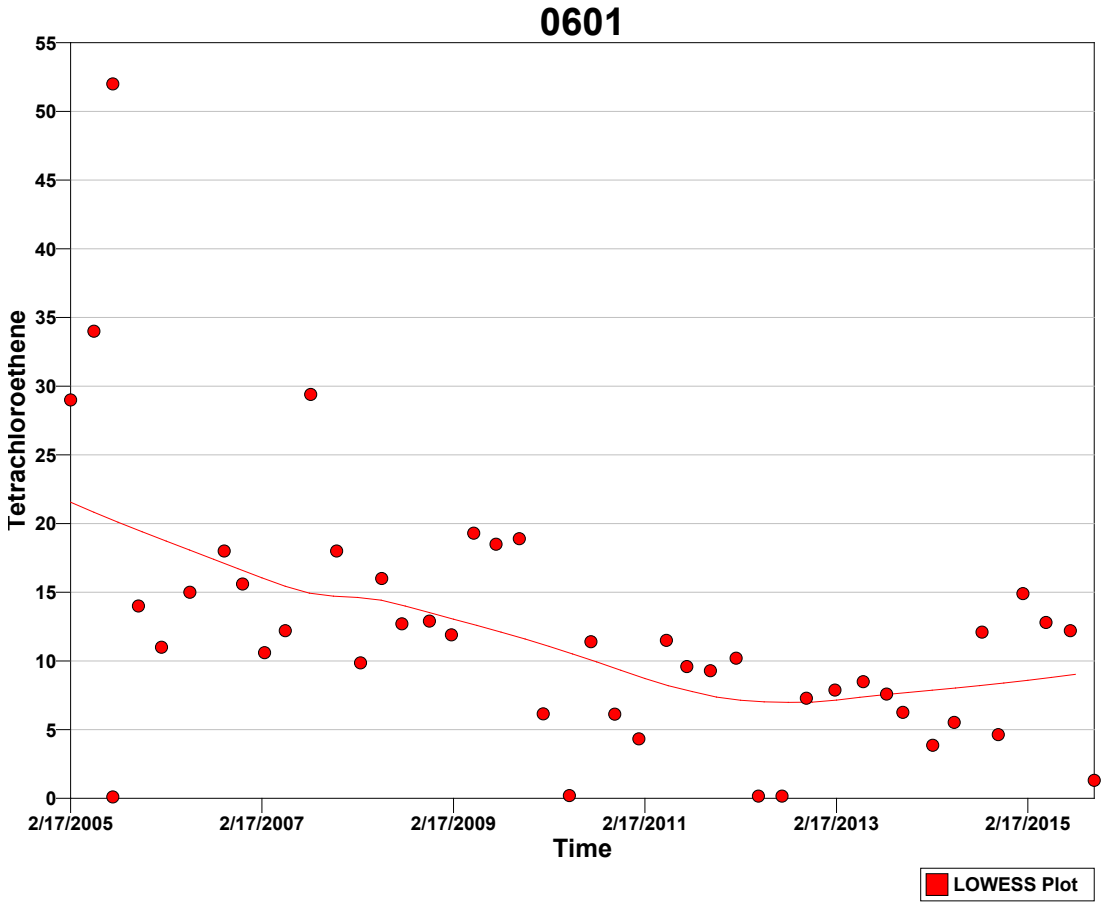
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=45) is less than 50.

Normal Distribution Test for Tetrachloroethene	
Shapiro-Wilk Test Statistic	0.84561
Shapiro-Wilk 5% Critical Value	0.945

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-373	
MK Test Statistic	Z_{MK}	-3.63955	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1,2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0443. The following table lists the data points that were used in the analysis.

0443							
Time	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**		**Time**	**cis-1,2-Dichloroethene**
5/6/2002	1		11/16/2005	1.1		1/27/2010	0.451
7/26/2002	1		1/31/2006	1.9		7/29/2010	0.28
11/8/2002	1		4/26/2006	1		1/26/2011	0.49
1/28/2003	1		8/4/2006	0.341		7/25/2011	0.22
4/22/2003	1		11/17/2006	0.438		1/30/2012	0.75
7/25/2003	1		2/28/2007	0.919		7/26/2012	0.27
10/22/2003	1		5/23/2007	5		2/14/2013	0.57
1/22/2004	1		8/22/2007	0.708		8/28/2013	0.38
4/21/2004	1		11/13/2007	0.872		2/24/2014	0.54
7/12/2004	1		2/19/2008	0.83		8/26/2014	0.36
11/18/2004	0.97		12/30/2008	1.14		1/27/2015	0.27
3/2/2005	1		12/30/2008	1.04		7/29/2015	0.33
5/24/2005	1		2/10/2009	0.762			
8/3/2005	1		7/30/2009	0.32			

SUMMARY STATISTICS for cis-1,2-Dichloroethene								
n				40				
Min				0.22				
Max				5				
Range				4.78				
Mean				0.88127				
Median				0.9445				
Variance				0.56771				
StdDev				0.75346				
Std Error				0.11913				
Skewness				4.3503				
Interquartile Range				0.55875				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.22	0.27	0.284	0.4413	0.9445	1	1.094	1.862	5

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
1/31/2006	1.9
8/4/2006	0.341
11/17/2006	0.438
5/23/2007	5
8/22/2007	0.708
12/30/2008	1.14
12/30/2008	1.04
7/30/2009	0.32
7/29/2010	0.28
7/25/2011	0.22
1/30/2012	0.75

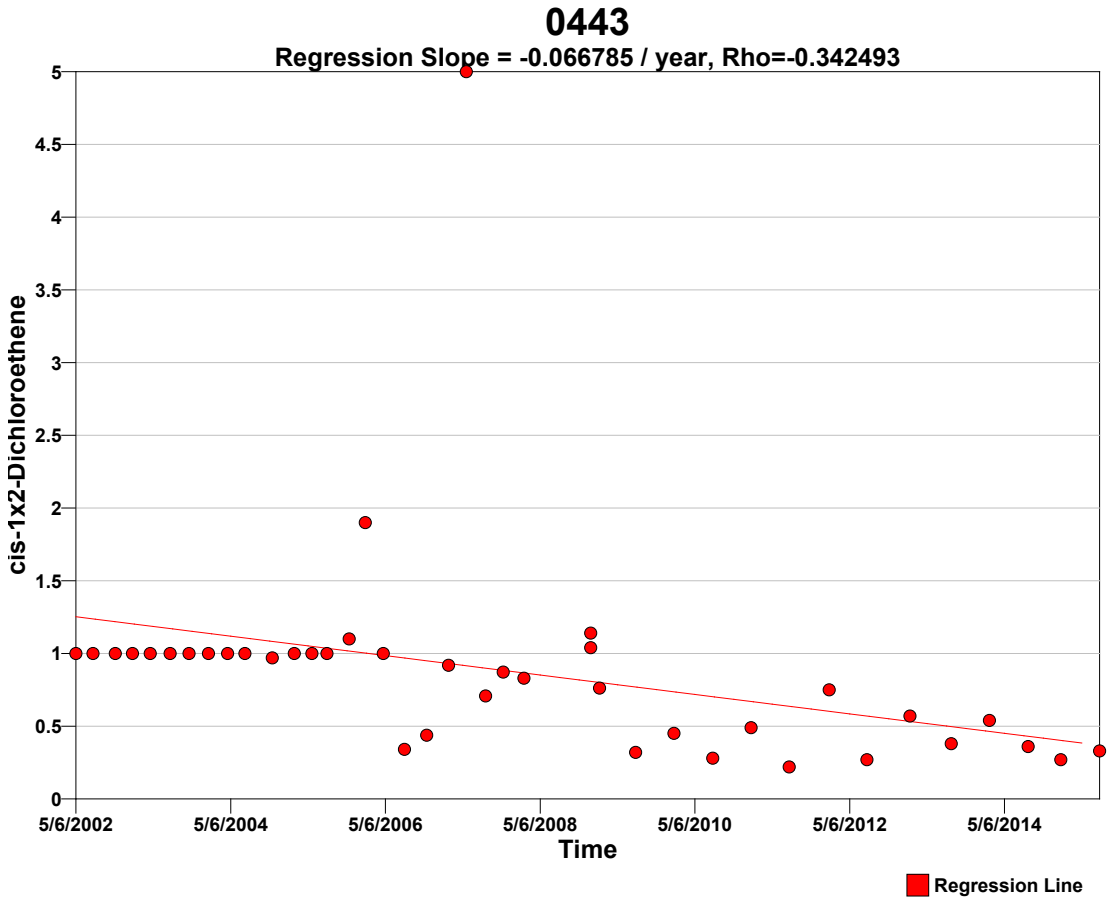
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

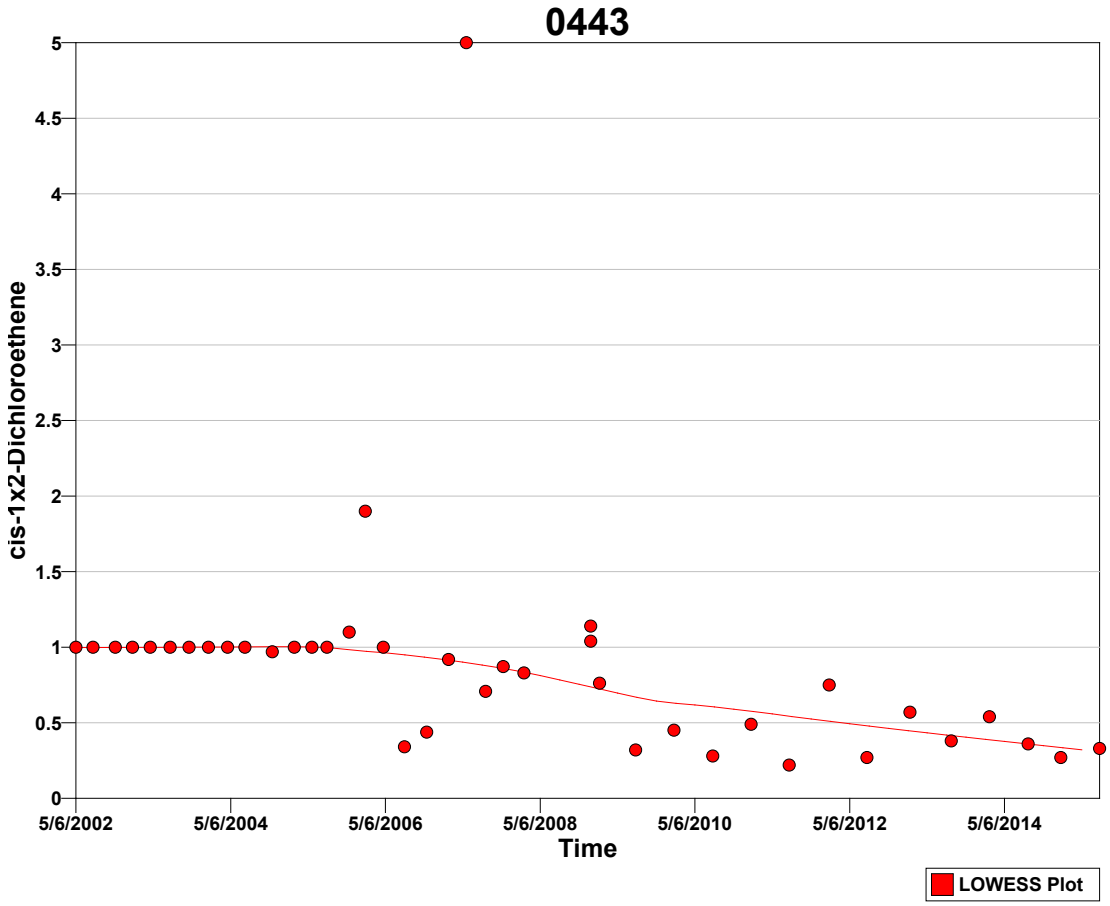
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=40) is less than 50.

Normal Distribution Test for cis-1,2-Dichloroethene	
Shapiro-Wilk Test Statistic	0.55264
Shapiro-Wilk 5% Critical Value	0.94

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test
The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-368	
MK Test Statistic	Z_{MK}	-4.3765	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

Data Analysis for Trichloroethene
Analysis was performed on the data that was entered for the location labeled "0443. The following table lists the data points that were used in the analysis.

0443							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
5/6/2002	9.2		8/3/2005	6.6		1/27/2010	7.47
5/6/2002	8.1		11/16/2005	12		7/29/2010	5.3
7/26/2002	3.5		1/31/2006	9.3		1/26/2011	7.47
11/8/2002	6.6		4/26/2006	7.9		7/25/2011	5.73
1/28/2003	5.4		8/4/2006	6.34		1/30/2012	14
4/22/2003	7.8		11/17/2006	7.33		7/26/2012	5.32
7/25/2003	2.8		2/28/2007	12.3		2/14/2013	7.25
10/22/2003	7.2		5/23/2007	3.06		8/28/2013	8.85
1/22/2004	6.3		8/22/2007	11.7		2/24/2014	11.2
4/21/2004	6.5		11/13/2007	12.1		8/26/2014	7.45
7/12/2004	3.2		2/19/2008	11.2		1/27/2015	6.03
11/18/2004	10		12/30/2008	11		7/29/2015	5.87
3/2/2005	11		2/10/2009	8.36			
5/24/2005	2.2		7/30/2009	3.99			

SUMMARY STATISTICS for Trichloroethene								
n				40				
Min				2.2				
Max				14				
Range				11.8				
Mean				7.623				
Median				7.39				
Variance				8.6004				
StdDev				2.9326				
Std Error				0.46369				
Skewness				0.1762				
Interquartile Range				4.06				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
2.2	2.813	3.23	5.765	7.39	9.825	11.97	12.29	14

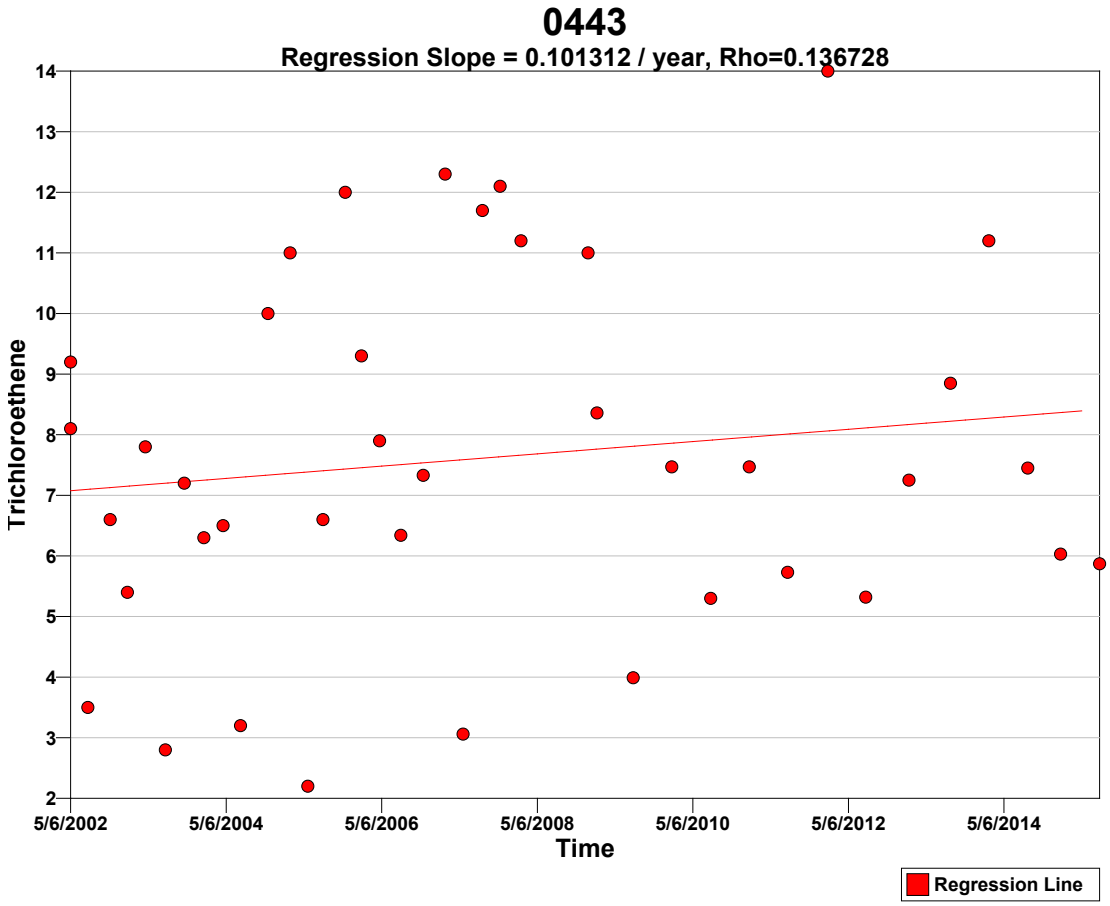
Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

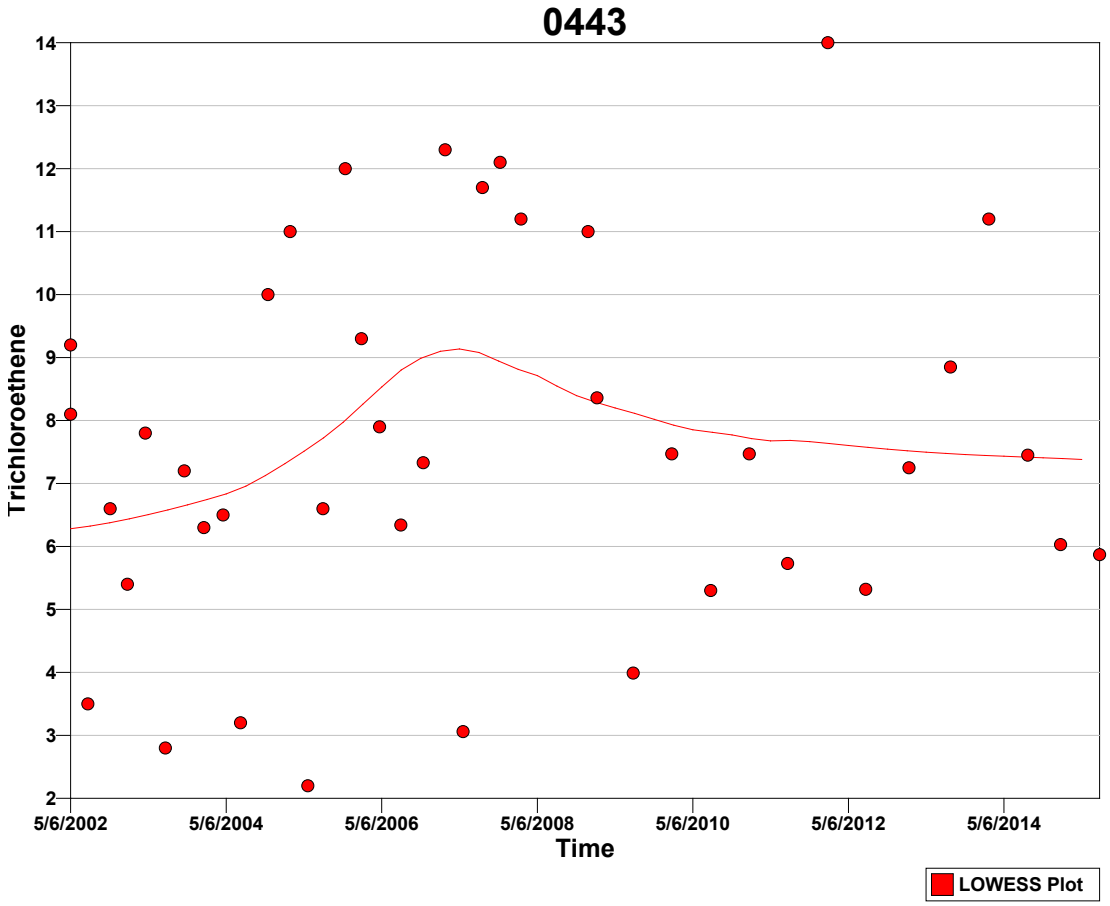
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0443
Regression Slope = 0.101312 / year, Rho=0.136728
Trichloroethene
14
13
12
11
10
9
8
7
6
5
4
3
2
5/6/2002
5/6/2004
5/6/2006
5/6/2008
5/6/2010
5/6/2012
5/6/2014
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=40) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.96674
Shapiro-Wilk 5% Critical Value	0.94

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	58	
MK Test Statistic	Z_{MK}	0.664289	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0347. The following table lists the data points that were used in the analysis.

0347							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
2/24/2005	20		2/12/2009	26.1		10/24/2012	31.2
5/16/2005	22		5/5/2009	27.3		2/12/2013	27.5
7/22/2005	23		7/28/2009	23.3		5/28/2013	23.2
1/27/2006	21		10/27/2009	29.2		8/26/2013	27
5/17/2006	21		1/27/2010	32.3		10/28/2013	23.3
9/27/2006	22		5/5/2010	26.9		2/19/2014	18.3
12/5/2006	33.2		7/27/2010	18.9		5/12/2014	23.1
2/21/2007	19		10/25/2010	27.9		8/28/2014	20.8
5/16/2007	12		1/25/2011	23.2		10/27/2014	23.8
8/16/2007	26.2		5/2/2011	24.5		1/28/2015	25.4
11/27/2007	0.431		7/28/2011	22.1		4/27/2015	24.5
2/26/2008	17.9		10/24/2011	27.8		7/27/2015	17.6
5/21/2008	20.5		2/1/2012	28.8		10/28/2015	19.6
8/5/2008	18.3		4/23/2012	23.8			
11/19/2008	21.2		7/25/2012	25			

SUMMARY STATISTICS for Trichloroethene								
n				43				
Min				0.431				
Max				33.2				
Range				32.769				
Mean				23.026				
Median				23.2				
Variance				30.731				
StdDev				5.5436				
Std Error				0.84538				
Skewness				-1.4968				
Interquartile Range				6.4				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.431	13.12	18.06	20.5	23.2	26.9	29.04	32.08	33.2

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
11/27/2007	0.431

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

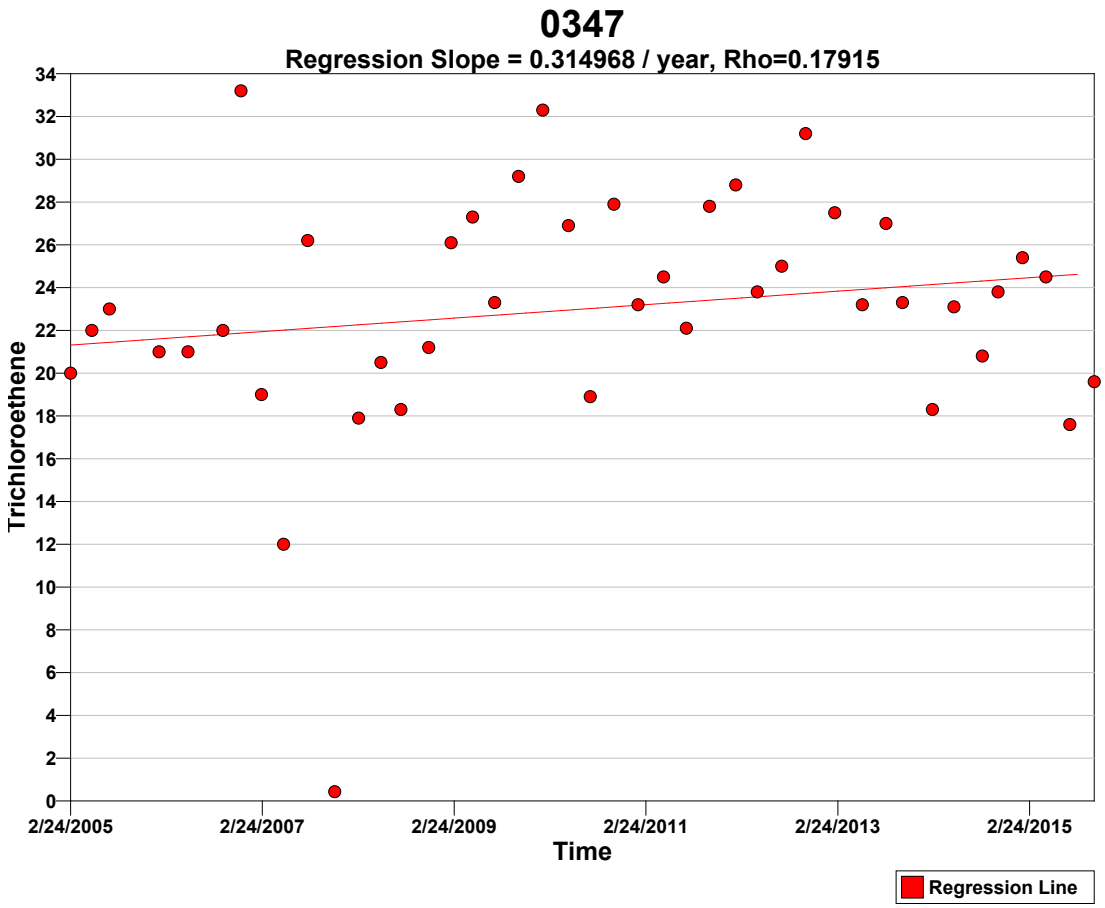
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

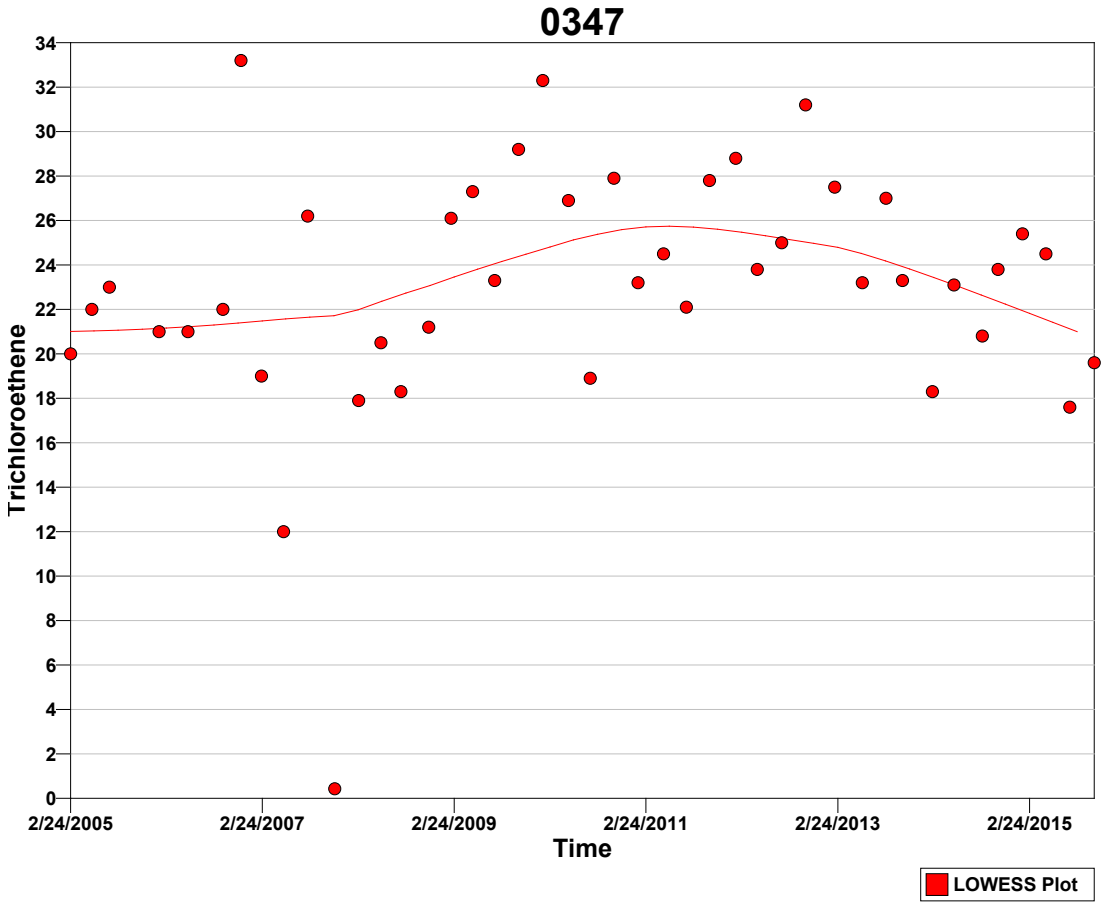
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=43) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.90389
Shapiro-Wilk 5% Critical Value	0.943

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	102	
MK Test Statistic	Z_{MK}	1.05741	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

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Mann-Kendall Test for Monotonic Trend

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The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

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The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1x2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0411. The following table lists the data points that were used in the analysis.

0411							
Time	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**
4/29/1999	4.8		7/25/2003	1.6		2/19/2008	2.21
6/21/1999	2.2		10/22/2003	1.6		8/11/2008	1.33
9/2/1999	1.8		1/22/2004	2		2/10/2009	3.36
9/2/1999	2.3		4/21/2004	1.3		7/29/2009	2.89
2/1/2000	2.6		7/12/2004	1.4		1/27/2010	3.97
4/17/2000	2.2		11/17/2004	1.3		7/29/2010	2.56
7/7/2000	3		2/28/2005	1		1/26/2011	3.32
9/27/2000	1		5/24/2005	1.5		7/25/2011	2.8
2/9/2001	1.6		8/2/2005	1.7		1/30/2012	1.81
4/26/2001	1.5		11/1/2005	2.4		7/26/2012	2.17
7/20/2001	2.4		1/31/2006	3.7		2/14/2013	4.71
10/18/2001	1.9		4/26/2006	2.9		8/28/2013	3.57
1/29/2002	1.9		8/4/2006	1.95		2/24/2014	2.33
5/6/2002	2.8		11/17/2006	2.76		8/26/2014	2.28
7/24/2002	3.5		2/28/2007	1.7		1/27/2015	3.34
11/8/2002	1.4		5/23/2007	1.56		7/29/2015	1.69
1/28/2003	2		8/22/2007	2.73			
4/22/2003	1.8		11/13/2007	2.74			

SUMMARY STATISTICS for cis-1x2-Dichloroethene								
n				52				
Min				1				
Max				4.8				
Range				3.8				
Mean				2.3246				
Median				2.2				
Variance				0.77018				
StdDev				0.8776				
Std Error				0.1217				
Skewness				0.90871				
Interquartile Range				1.1775				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1	1.195	1.351	1.623	2.2	2.8	3.549	4.229	4.8

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

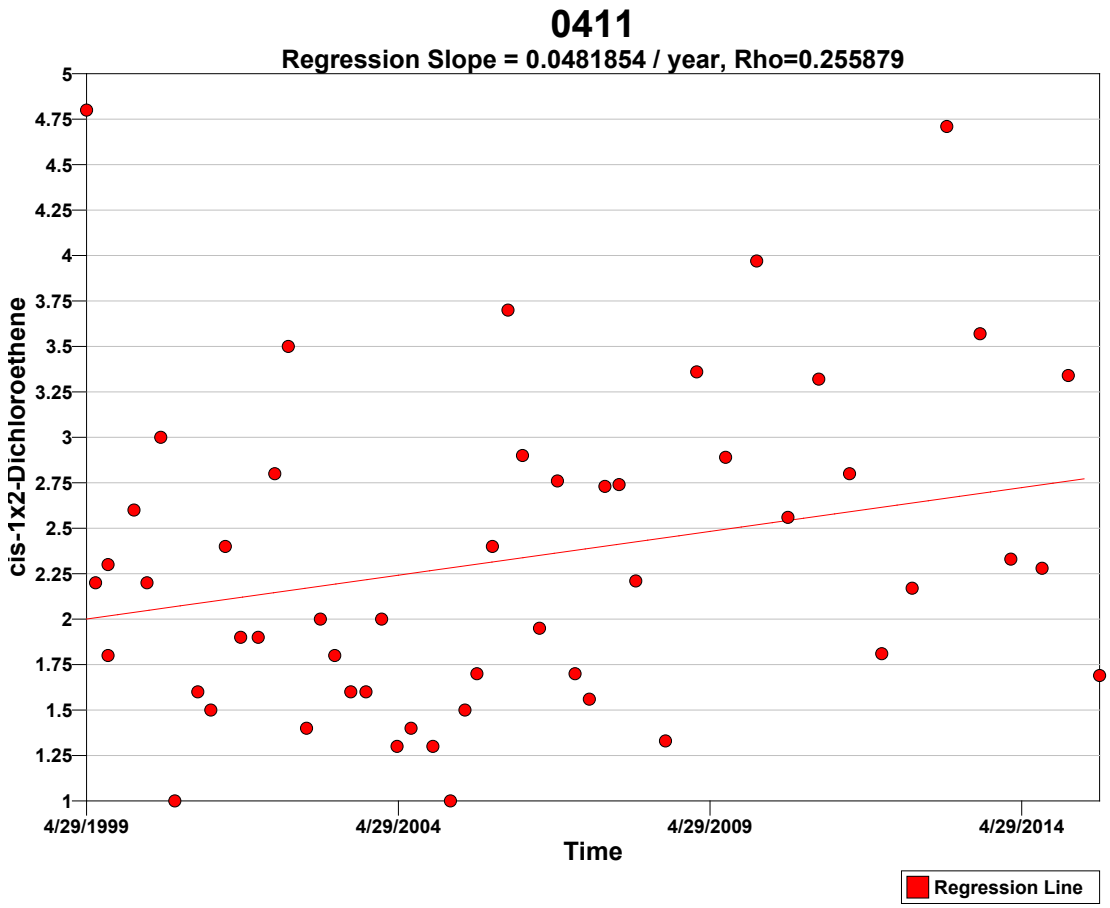
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

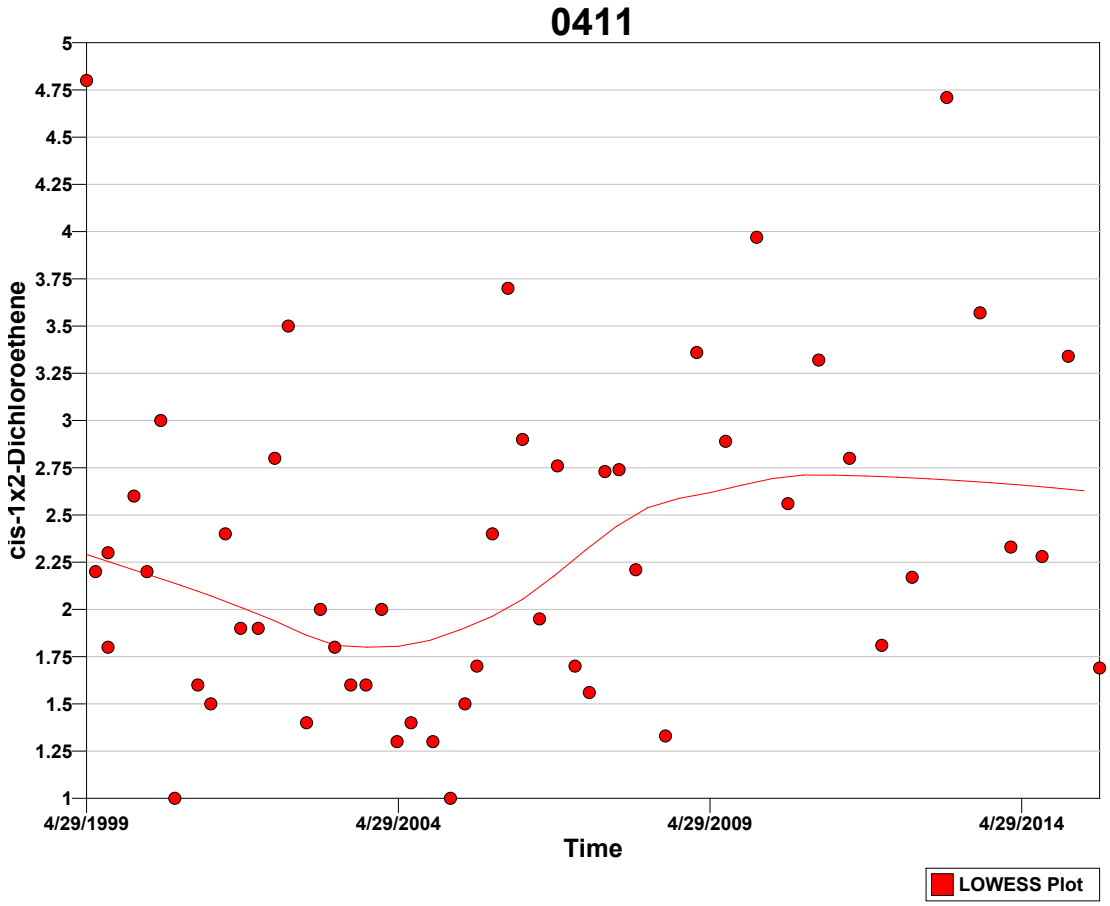
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Lilliefors test was determined most appropriate for this VSP application because the size of the data set (n=52) is greater than 50.

Normal Distribution Test for cis-1x2-Dichloroethene	
Lilliefors Test Statistic	0.10581
Lilliefors 5% Critical Value	0.12287

The calculated test statistic exceeds the 5% Lilliefors critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	208	
MK Test Statistic	Z_{MK}	1.6342	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0411. The following table lists the data points that were used in the analysis.

0411							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
4/29/1999	21		7/25/2003	11		2/19/2008	12.2
6/21/1999	18		10/22/2003	11		8/11/2008	14.1
9/2/1999	21		1/22/2004	10		2/10/2009	12.7
9/2/1999	21		4/21/2004	9		7/29/2009	11.2
2/1/2000	22		7/12/2004	10		1/27/2010	10.1
4/17/2000	13		11/17/2004	9		7/29/2010	9.62
7/7/2000	16		2/28/2005	11		1/26/2011	10.6
9/27/2000	14		5/24/2005	11		7/25/2011	9.42
2/9/2001	14		8/2/2005	11		1/30/2012	13.4
4/26/2001	12		11/1/2005	14		7/26/2012	12.7
7/20/2001	13		1/31/2006	11		2/14/2013	12.5
10/18/2001	14		4/26/2006	9.2		8/28/2013	13.3
1/29/2002	8.4		8/4/2006	14.4		2/24/2014	12
5/6/2002	16		11/17/2006	12.2		8/26/2014	10.6
7/24/2002	13		2/28/2007	12.7		1/27/2015	10.8
11/8/2002	12		5/23/2007	12.1		7/29/2015	10.3
1/28/2003	13		8/22/2007	15.2			
4/22/2003	12		11/13/2007	12.3			

SUMMARY STATISTICS for Trichloroethene								
n				52				
Min				8.4				
Max				22				
Range				13.6				
Mean				12.789				
Median				12.2				
Variance				9.8469				
StdDev				3.138				
Std Error				0.43516				
Skewness				1.4649				
Interquartile Range				3.15				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
8.4	9	9.48	10.85	12.2	14	17.4	21	22

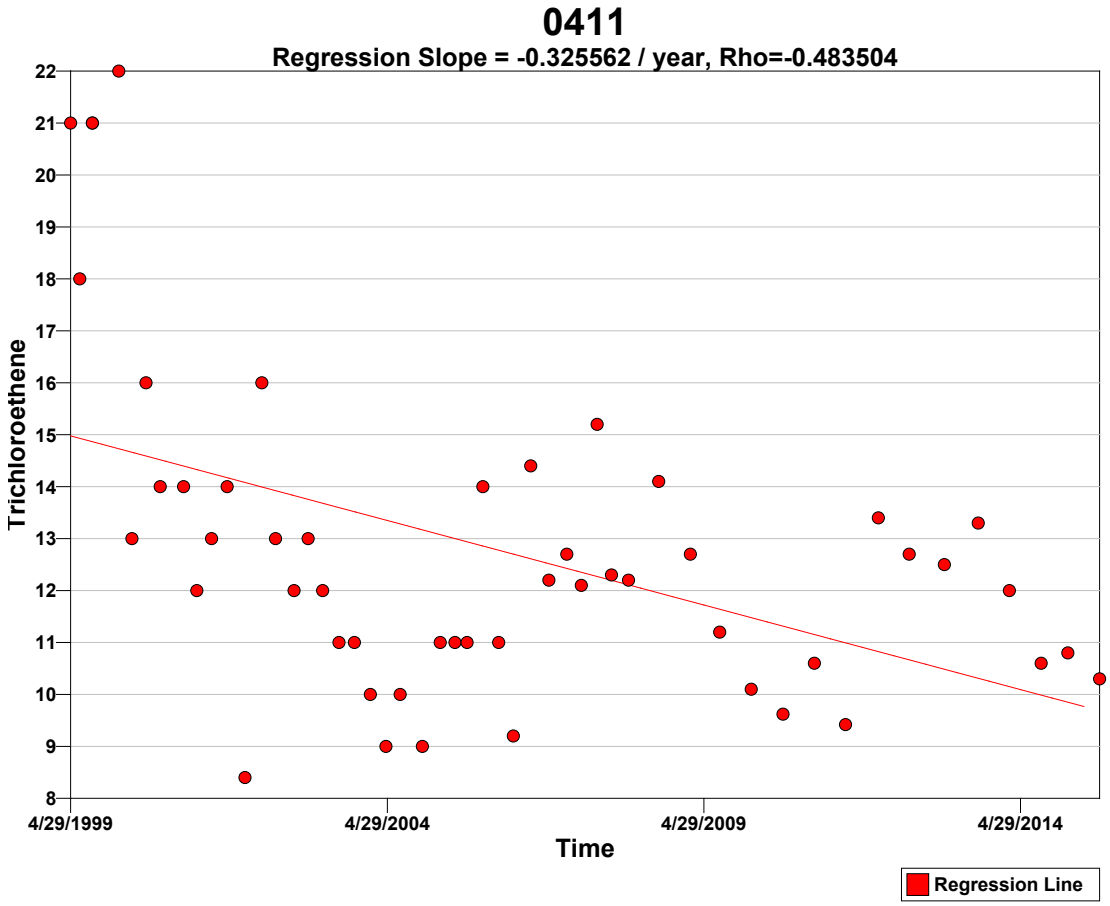
Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

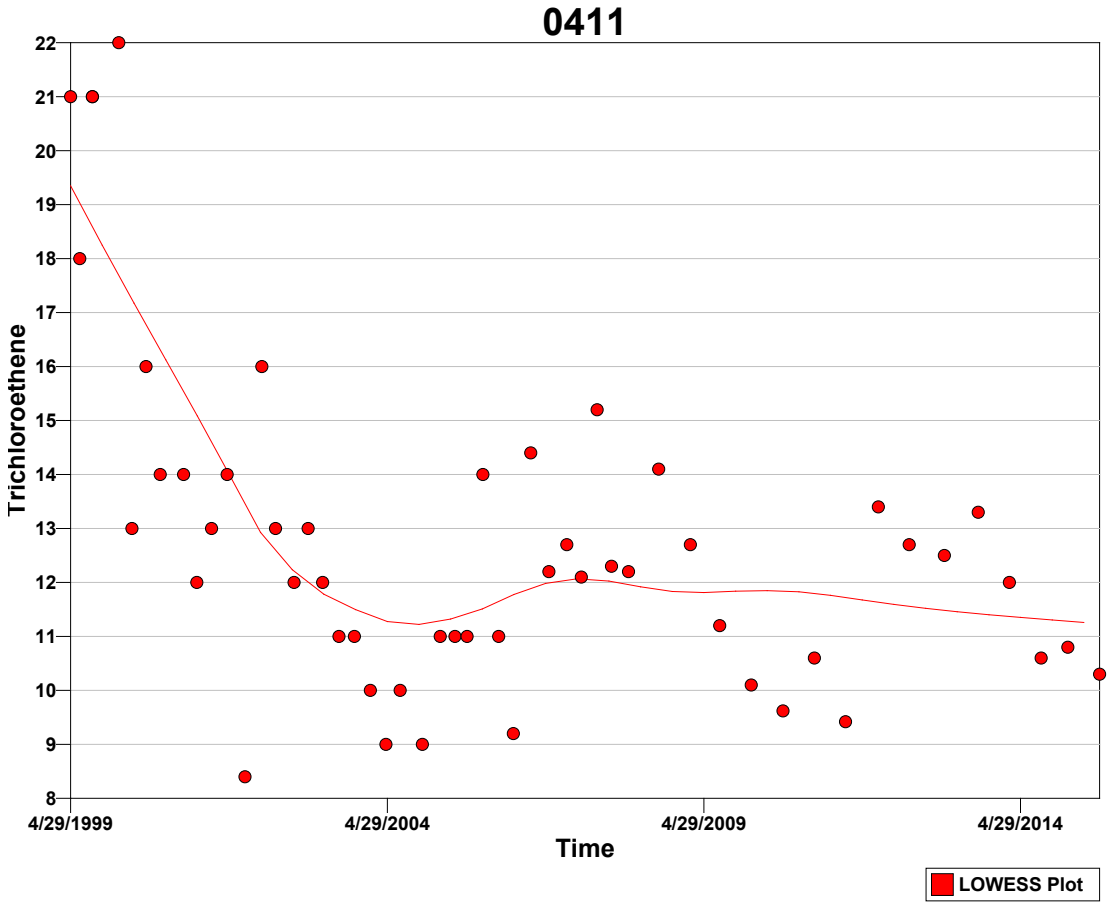
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0411
Regression Slope = -0.325562 / year, Rho=-0.483504
Trichloroethene
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
4/29/1999
4/29/2004
4/29/2009
4/29/2014
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Lilliefors test was determined most appropriate for this VSP application because the size of the data set (n=52) is greater than 50.

Normal Distribution Test for Trichloroethene	
Lilliefors Test Statistic	0.16553
Lilliefors 5% Critical Value	0.12287

The calculated test statistic exceeds the 5% Lilliefors critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-402	
MK Test Statistic	Z_{MK}	-3.17091	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

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Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	54

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	54

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for cis-1x2-Dichloroethene

Analysis was performed on the data that was entered for the location labeled "0617. The following table lists the data points that were used in the analysis.

0617							
Time	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**		**Time**	**cis-1x2-Dichloroethene**
10/18/2001	3.1		11/18/2005	2.3		7/30/2010	1.97
1/30/2002	1.3		1/31/2006	2.7		1/25/2011	2.2
5/1/2002	2		4/27/2006	2.1		7/27/2011	1.36
4/22/2003	1.6		8/3/2006	2.15		1/31/2012	1.71
7/25/2003	2.6		11/17/2006	0.969		7/26/2012	0.59
10/21/2003	2.8		2/28/2007	1.1		2/11/2013	2.36
1/22/2004	2.1		5/23/2007	2.82		8/27/2013	1.59
4/21/2004	1.5		8/24/2007	1.72		2/19/2014	0.6
7/12/2004	2.6		11/14/2007	2.57		12/8/2014	1.88
11/17/2004	2.9		2/19/2008	2.29		1/29/2015	1.94
3/2/2005	2.1		2/9/2009	1.31		7/29/2015	1.86
5/24/2005	4.7		7/29/2009	2.06			
8/3/2005	2.3		1/25/2010	0.724			

SUMMARY STATISTICS for cis-1x2-Dichloroethene								
n				37				
Min				0.59				
Max				4.7				
Range				4.11				
Mean				2.0128				
Median				2.06				
Variance				0.61792				
StdDev				0.78608				
Std Error				0.12923				
Skewness				0.74727				
Interquartile Range				0.92				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.59	0.599	0.92	1.545	2.06	2.465	2.836	3.26	4.7

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
5/24/2005	4.7

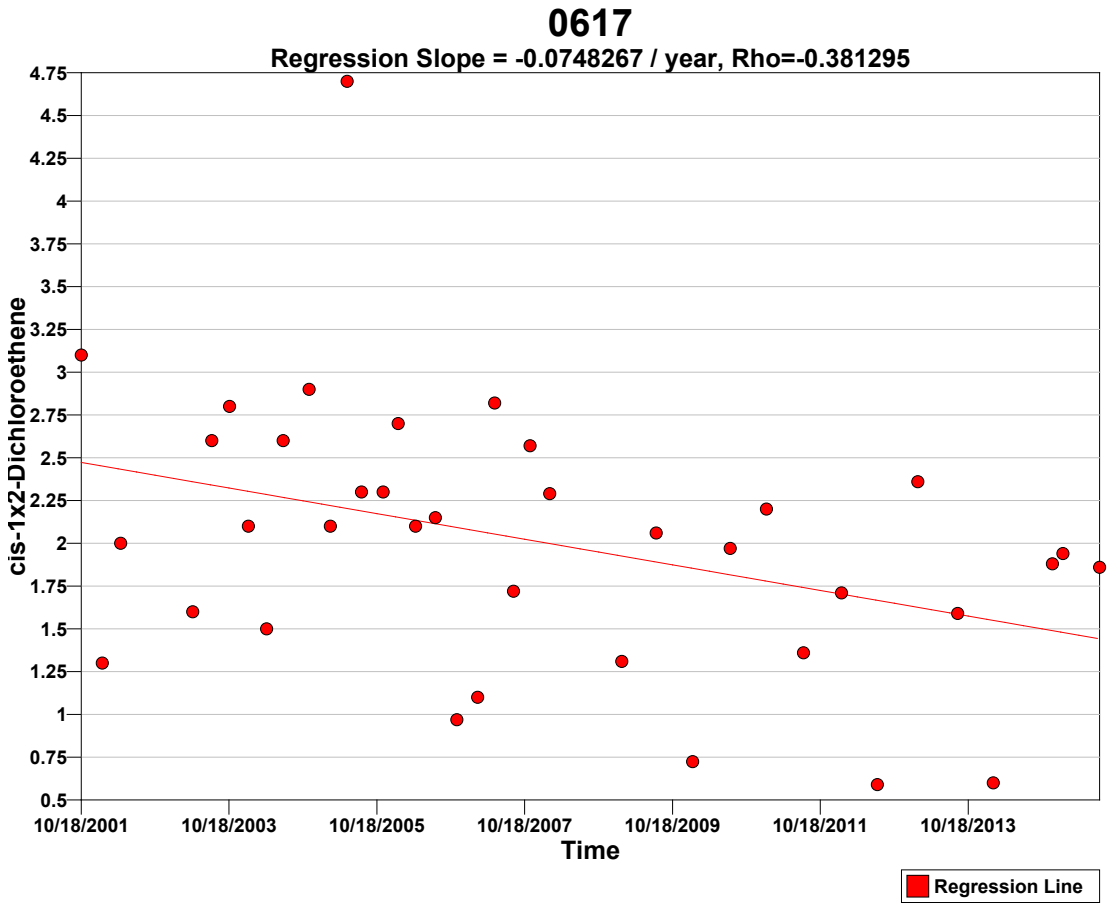
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

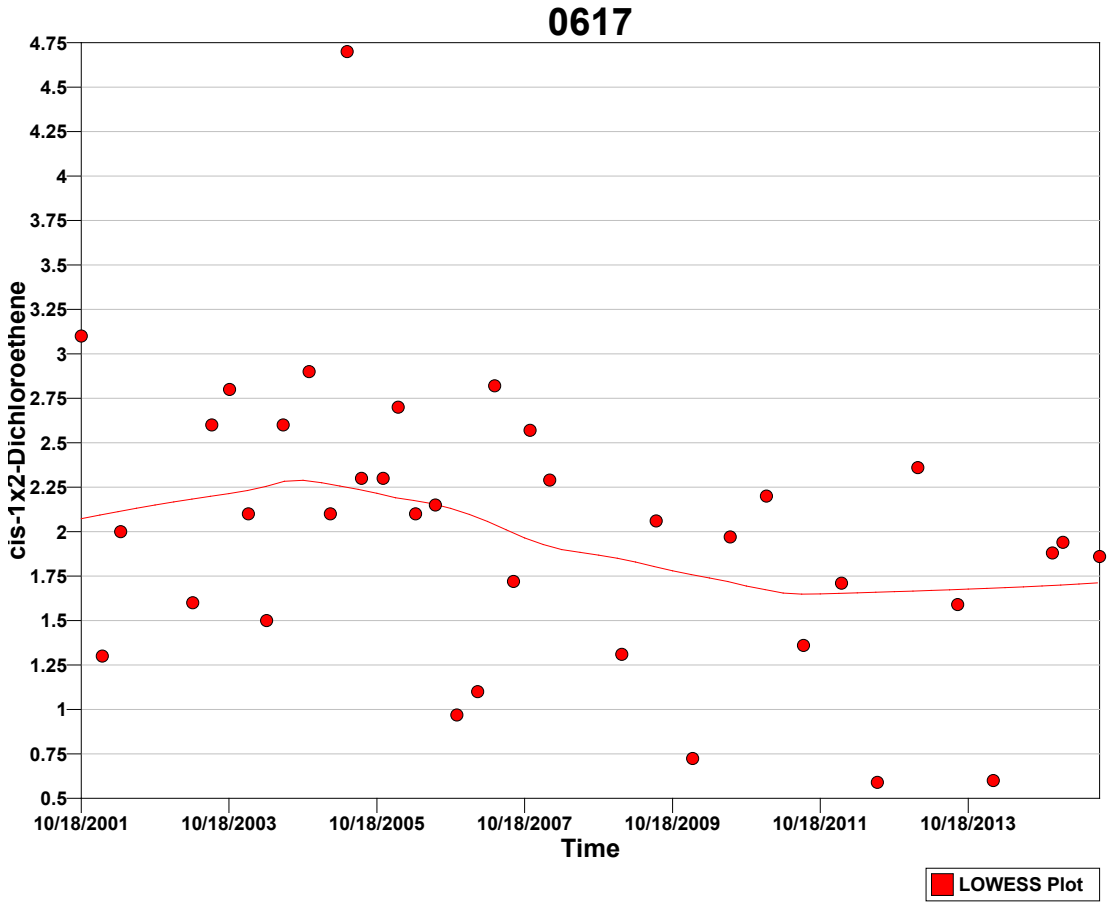
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=37) is less than 50.

Normal Distribution Test for cis-1x2-Dichloroethene	
Shapiro-Wilk Test Statistic	0.94706
Shapiro-Wilk 5% Critical Value	0.936

The calculated test statistic exceeds the 5% Shapiro-Wilk critical value, so we cannot reject the hypothesis that the values are normally distributed, or in other words the values appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-185	
MK Test Statistic	Z_{MK}	-2.40768	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0617. The following table lists the data points that were used in the analysis.

0617							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
10/18/2001	12		11/18/2005	5.8		7/30/2010	8.14
1/30/2002	3.8		1/31/2006	8.9		1/25/2011	9.78
5/1/2002	7.9		4/27/2006	6.2		7/27/2011	6.66
4/22/2003	6.1		8/3/2006	8.67		1/31/2012	7.76
7/25/2003	7.4		11/17/2006	3.9		7/26/2012	1.84
10/21/2003	8.8		2/28/2007	3.57		2/11/2013	10.4
1/22/2004	7		5/23/2007	10.4		8/27/2013	6.7
4/21/2004	5.7		8/24/2007	4.95		2/19/2014	2.52
7/12/2004	9.8		11/14/2007	8.5		12/8/2014	8.31
11/17/2004	8.6		2/19/2008	8.4		1/29/2015	8.26
3/2/2005	7		2/9/2009	4.48		7/29/2015	8.05
5/24/2005	9		7/29/2009	8.17			
8/3/2005	6.1		1/25/2010	2.89			

SUMMARY STATISTICS for Trichloroethene								
n	37							
Min	1.84							
Max	12							
Range	10.16							
Mean	7.0932							
Median	7.76							
Variance	5.6597							
StdDev	2.379							
Std Error	0.39111							
Skewness	-0.4251							
Interquartile Range	2.885							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1.84	2.452	3.434	5.75	7.76	8.635	9.92	10.56	12

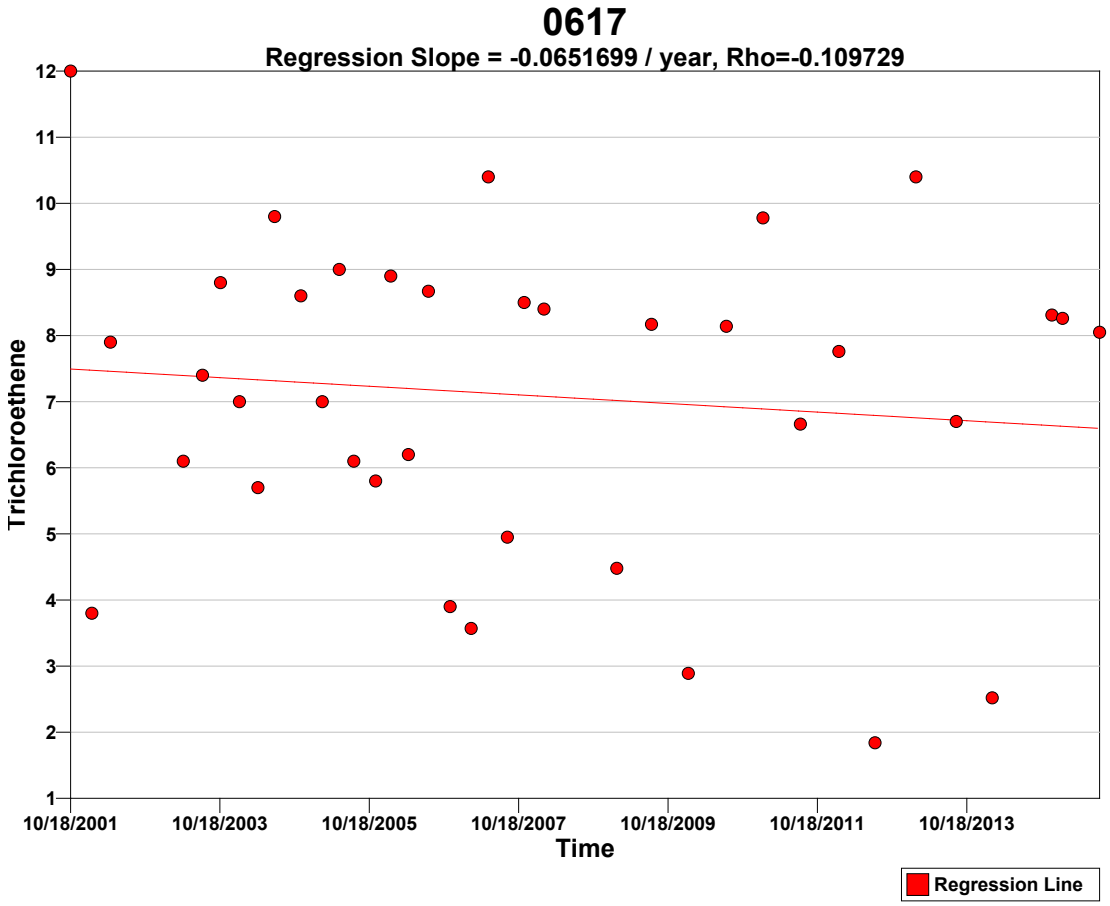
Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

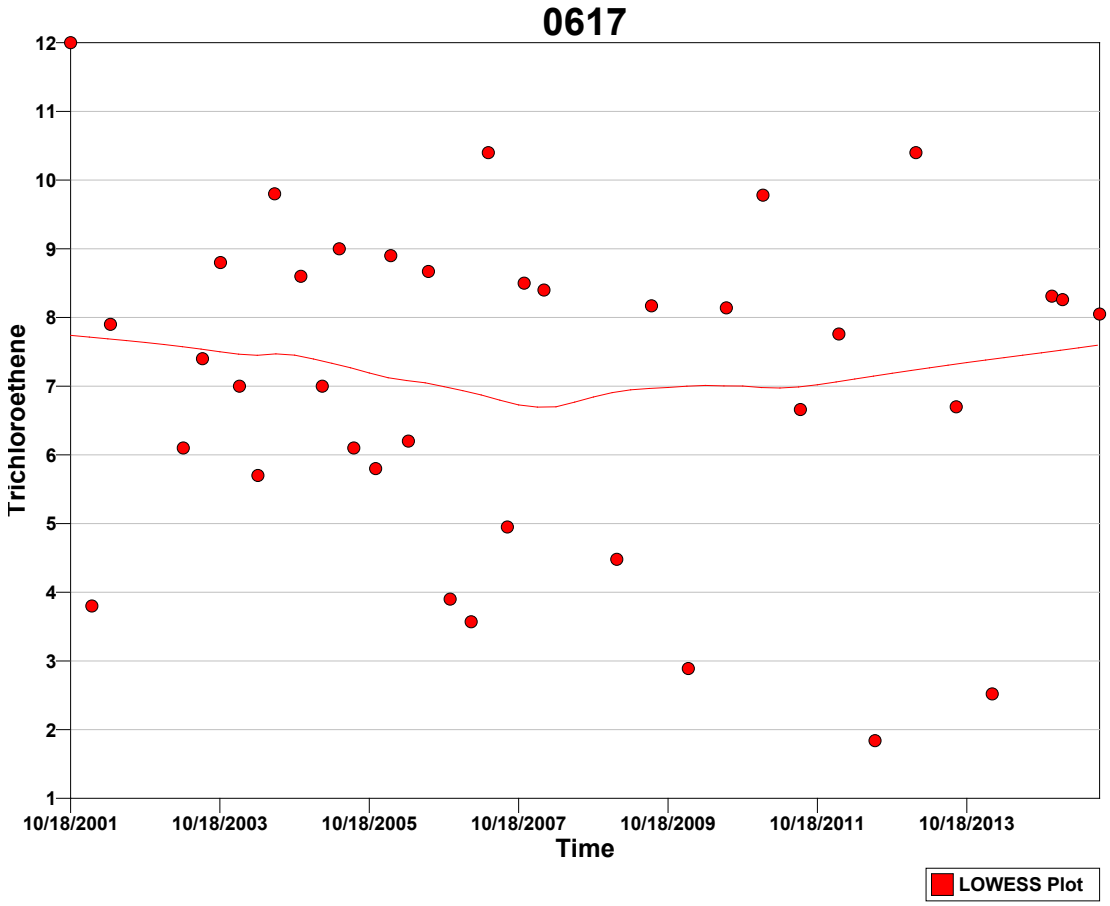
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.


0617
Regression Slope = -0.0651699 / year, Rho=-0.109729
Trichloroethene
12
11
10
9
8
7
6
5
4
3
2
1
10/18/2001
10/18/2003
10/18/2005
10/18/2007
10/18/2009
10/18/2011
10/18/2013
Time
Regression Line



Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=37) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.96421
Shapiro-Wilk 5% Critical Value	0.936

The calculated test statistic exceeds the 5% Shapiro-Wilk critical value, so we cannot reject the hypothesis that the values are normally distributed, or in other words the values appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-55	
MK Test Statistic	Z_{MK}	-0.706441	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

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Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0389. The following table lists the data points that were used in the analysis.

0389							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
7/25/2005	1.1		7/28/2009	0.894		10/24/2012	0.9
9/27/2006	0.98		10/27/2009	0.887		2/12/2013	0.53
12/6/2006	1.01		1/26/2010	1.48		5/28/2013	0.16
2/26/2007	1.14		5/6/2010	0.59		8/26/2013	0.16
5/17/2007	0.881		7/27/2010	0.33		10/28/2013	0.55
8/17/2007	1.22		10/26/2010	1.39		2/19/2014	0.19
11/27/2007	1.28		1/25/2011	0.99		5/12/2014	0.16
2/26/2008	0.398		5/3/2011	0.54		8/27/2014	0.44
5/20/2008	0.52		7/28/2011	0.24		10/27/2014	0.61
8/6/2008	0.408		10/26/2011	0.72		1/28/2015	0.23
11/19/2008	1.19		2/1/2012	0.31		4/27/2015	0.16
2/11/2009	1.07		4/24/2012	0.16		7/28/2015	0.18
5/11/2009	0.256		7/24/2012	0.32		10/27/2015	0.29

SUMMARY STATISTICS for Trichloroethene								
n				39				
Min				0.16				
Max				1.48				
Range				1.32				
Mean				0.63754				
Median				0.54				
Variance				0.16493				
StdDev				0.40612				
Std Error				0.065031				
Skewness				0.44342				
Interquartile Range				0.734				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.16	0.16	0.16	0.256	0.54	0.99	1.22	1.39	1.48

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

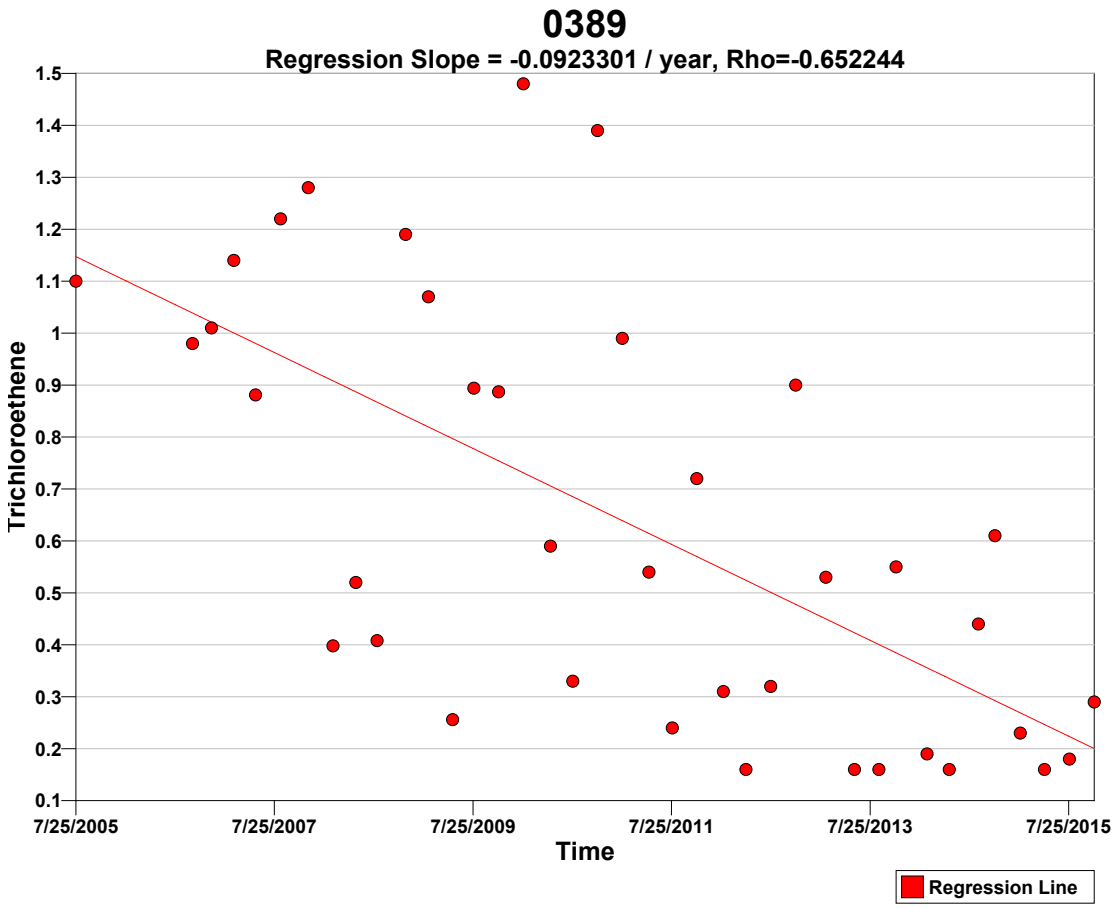
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

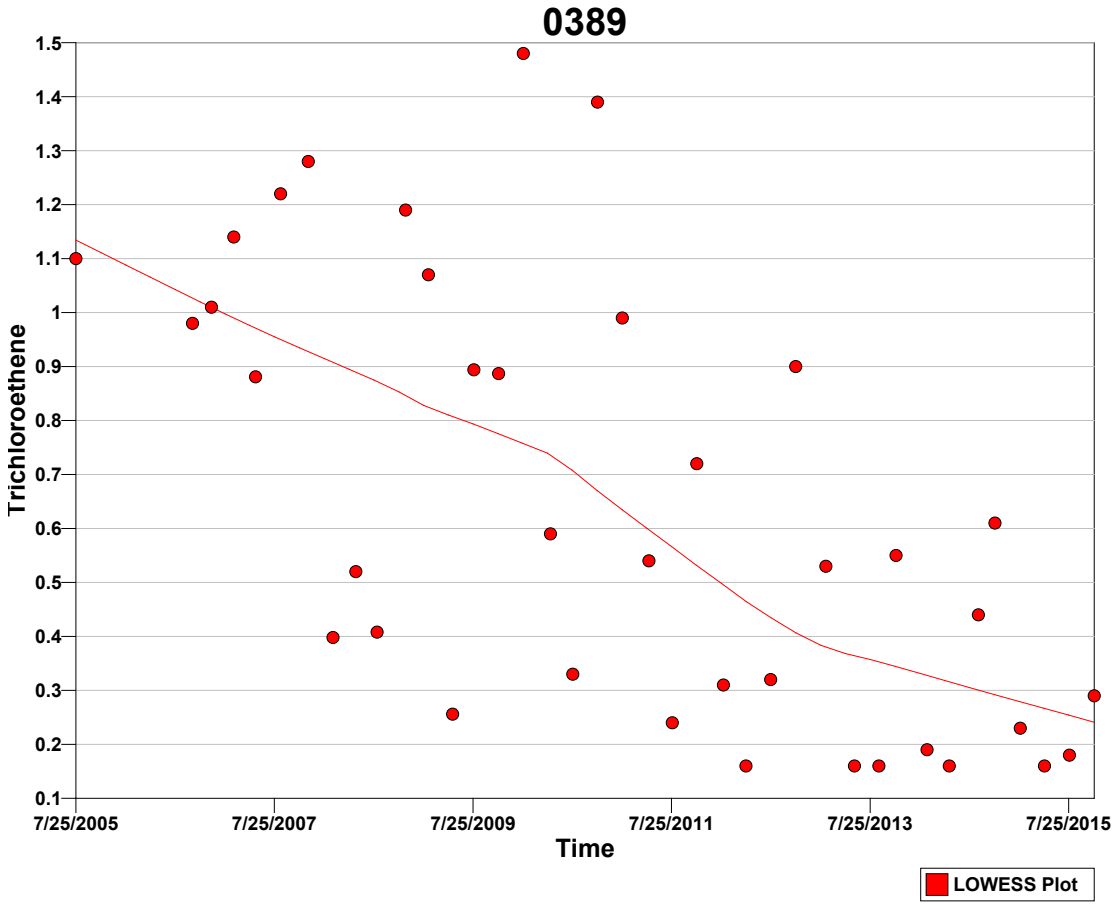
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in

the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=39) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.90093
Shapiro-Wilk 5% Critical Value	0.939

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-337	
MK Test Statistic	Z_{MK}	-4.06951	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0386. The following table lists the data points that were used in the analysis.

0386							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
3/7/2005	4.5		5/11/2009	1.28		10/24/2012	3.04
5/13/2005	4.1		7/28/2009	2.45		2/12/2013	2.82
7/25/2005	3.8		10/27/2009	3.11		5/28/2013	2.35
9/27/2006	2.8		1/26/2010	0.11		8/26/2013	2.99
12/6/2006	4.2		5/6/2010	0.94		10/28/2013	2.56
2/26/2007	3.76		7/27/2010	1.9		2/19/2014	2.03
5/17/2007	1.49		10/26/2010	3.09		5/12/2014	0.97
8/17/2007	3.96		1/25/2011	2.3		8/27/2014	2.56
11/27/2007	0.345		5/3/2011	0.11		10/27/2014	2.67
2/26/2008	3.24		7/28/2011	2.25		1/28/2015	2.35
5/20/2008	0.2		10/26/2011	1.93		4/27/2015	2.11
8/6/2008	3.13		2/1/2012	2.65		7/28/2015	1.94
11/19/2008	2.39		4/24/2012	2.25		10/27/2015	2.14
2/11/2009	0.11		7/24/2012	2.84			

SUMMARY STATISTICS for Trichloroethene								
n				41				
Min				0.11				
Max				4.5				
Range				4.39				
Mean				2.3357				
Median				2.39				
Variance				1.3099				
StdDev				1.1445				
Std Error				0.17874				
Skewness				-0.39266				
Interquartile Range				1.15				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0.11	0.11	0.229	1.915	2.39	3.065	3.928	4.19	4.5

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
11/27/2007	0.345
5/20/2008	0.2

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

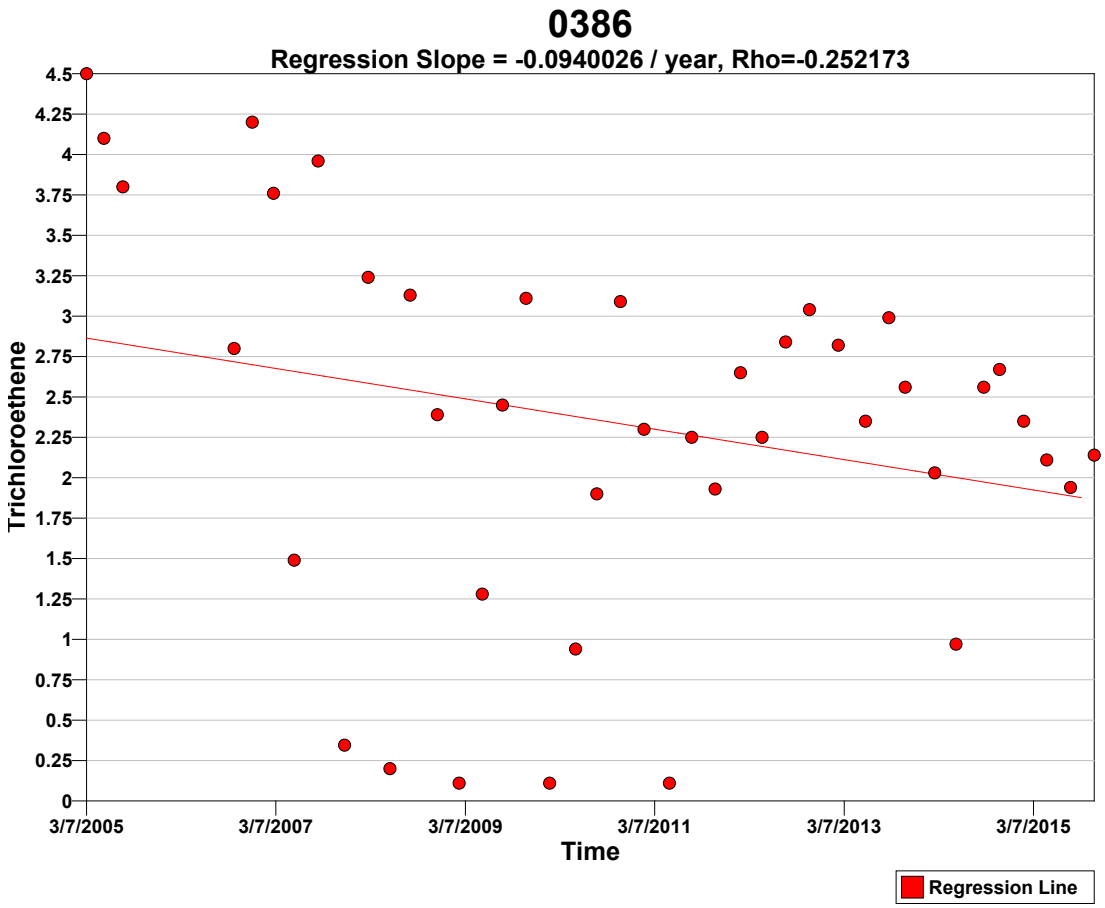
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

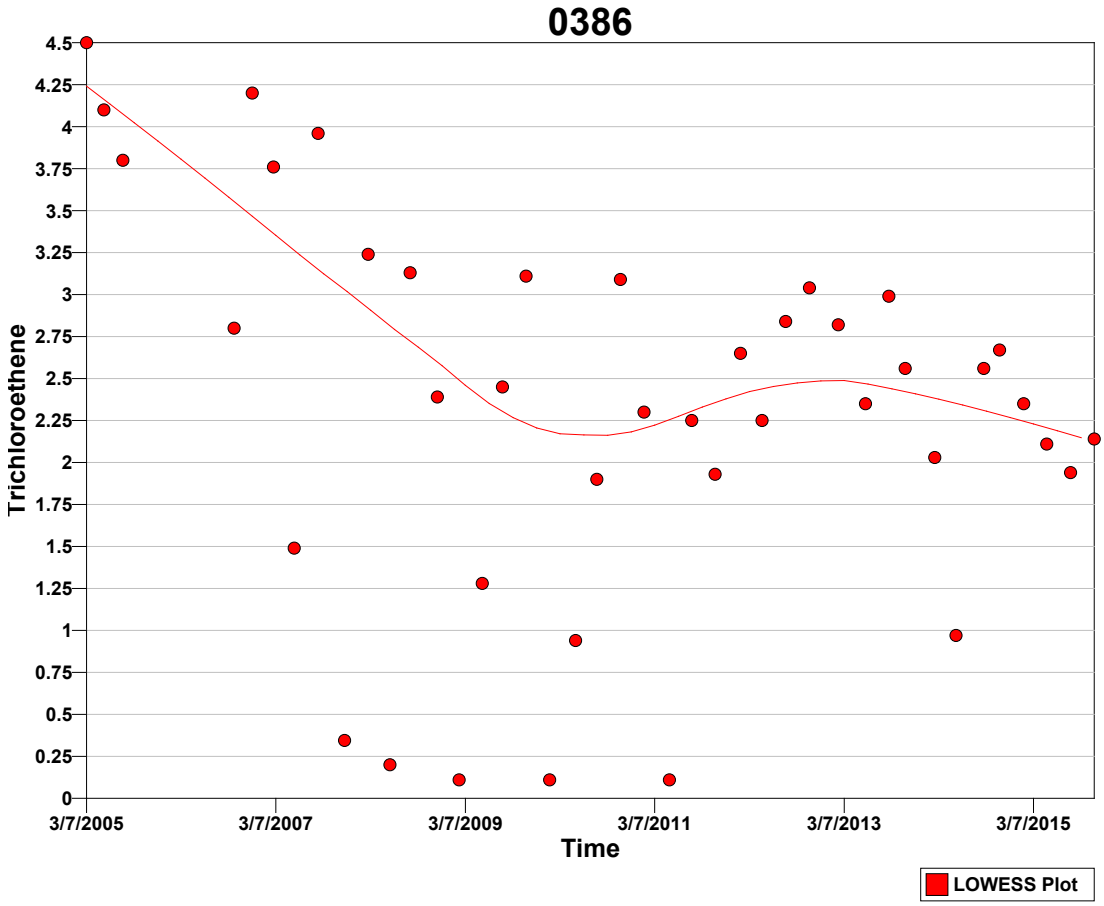
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=41) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.94466
Shapiro-Wilk 5% Critical Value	0.941

The calculated test statistic exceeds the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-184	
MK Test Statistic	Z_{MK}	-2.05631	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

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Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0379. The following table lists the data points that were used in the analysis.

0379							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
4/19/2005	1410		5/21/2008	1720		5/3/2011	1450
5/18/2005	750		8/6/2008	1870		7/27/2011	1350
11/1/2005	1730		11/18/2008	1660		10/24/2011	1610
1/24/2006	600		2/12/2009	1680		2/1/2012	2010
5/17/2006	780		5/5/2009	1530		4/24/2012	1450
9/26/2006	1640		7/28/2009	1500		7/25/2012	1550
12/5/2006	3890		10/27/2009	1770		2/11/2013	1210
2/21/2007	1980		1/26/2010	1720		8/27/2013	852
5/16/2007	1950		5/5/2010	479		2/19/2014	948
8/16/2007	1920		7/26/2010	1660		8/28/2014	1200
11/27/2007	1750		10/25/2010	1550		1/29/2015	1030
2/26/2008	1980		1/25/2011	1420		7/28/2015	954

SUMMARY STATISTICS for Tritium								
n				36				
Min				479				
Max				3890				
Range				3411				
Mean				1515.4				
Median				1550				
Variance				3.3542e+005				
StdDev				579.15				
Std Error				96.526				
Skewness				1.6221				
Interquartile Range				542.5				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
479	581.9	771	1203	1550	1745	1980	2292	3890

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
1/24/2006	600
5/17/2006	780
12/5/2006	3890
5/5/2010	479

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

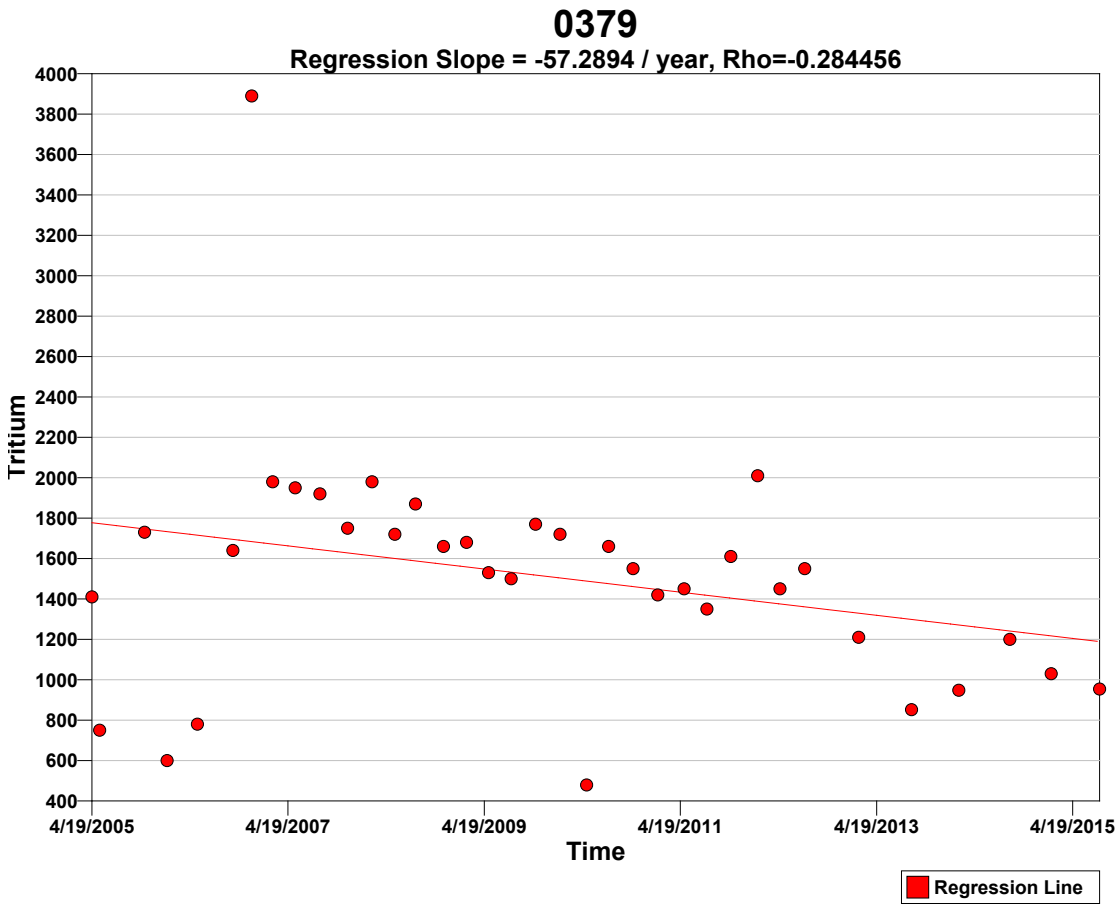
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

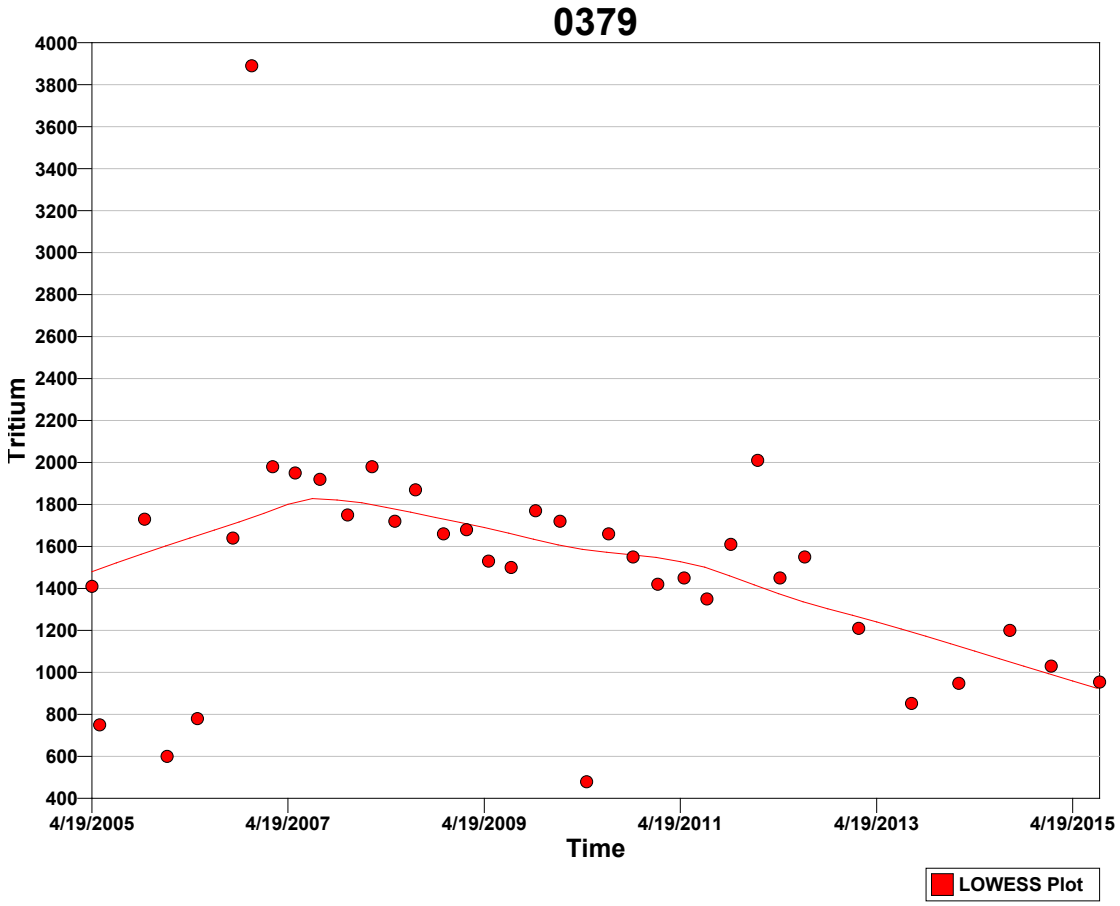
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=36) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.84988
Shapiro-Wilk 5% Critical Value	0.935

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-193	
MK Test Statistic	Z_{MK}	-2.61643	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0347. The following table lists the data points that were used in the analysis.

0347							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/24/2005	2290		2/26/2008	6000		5/2/2011	3940
4/20/2005	1100		5/21/2008	9270		7/28/2011	2940
5/16/2005	1550		8/5/2008	5880		10/24/2011	5310
7/22/2005	670		11/19/2008	6040		2/1/2012	3800
11/22/2005	3740		2/12/2009	6570		4/23/2012	4460
1/27/2006	5830		5/5/2009	6860		7/25/2012	4310
5/17/2006	15420		7/28/2009	4590		2/12/2013	3420
9/27/2006	16800		10/27/2009	6540		8/26/2013	2460
12/5/2006	13000		1/27/2010	6530		2/19/2014	2290
2/21/2007	16400		5/5/2010	3670		8/28/2014	2610
5/16/2007	13100		7/27/2010	6710		1/28/2015	2820
8/16/2007	10200		10/25/2010	6490		7/27/2015	1690
11/27/2007	157		1/25/2011	5730			

SUMMARY STATISTICS for Tritium								
n				38				
Min				157				
Max				16800				
Range				16643				
Mean				5820.7				
Median				4950				
Variance				1.8175e+007				
StdDev				4263.3				
Std Error				691.59				
Skewness				1.266				
Interquartile Range				3837.5				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
157	644.3	1505	2768	4950	6605	1.333e+004	1.642e+004	1.68e+004

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
5/17/2006	15420
9/27/2006	16800
12/5/2006	13000
2/21/2007	16400
11/27/2007	157

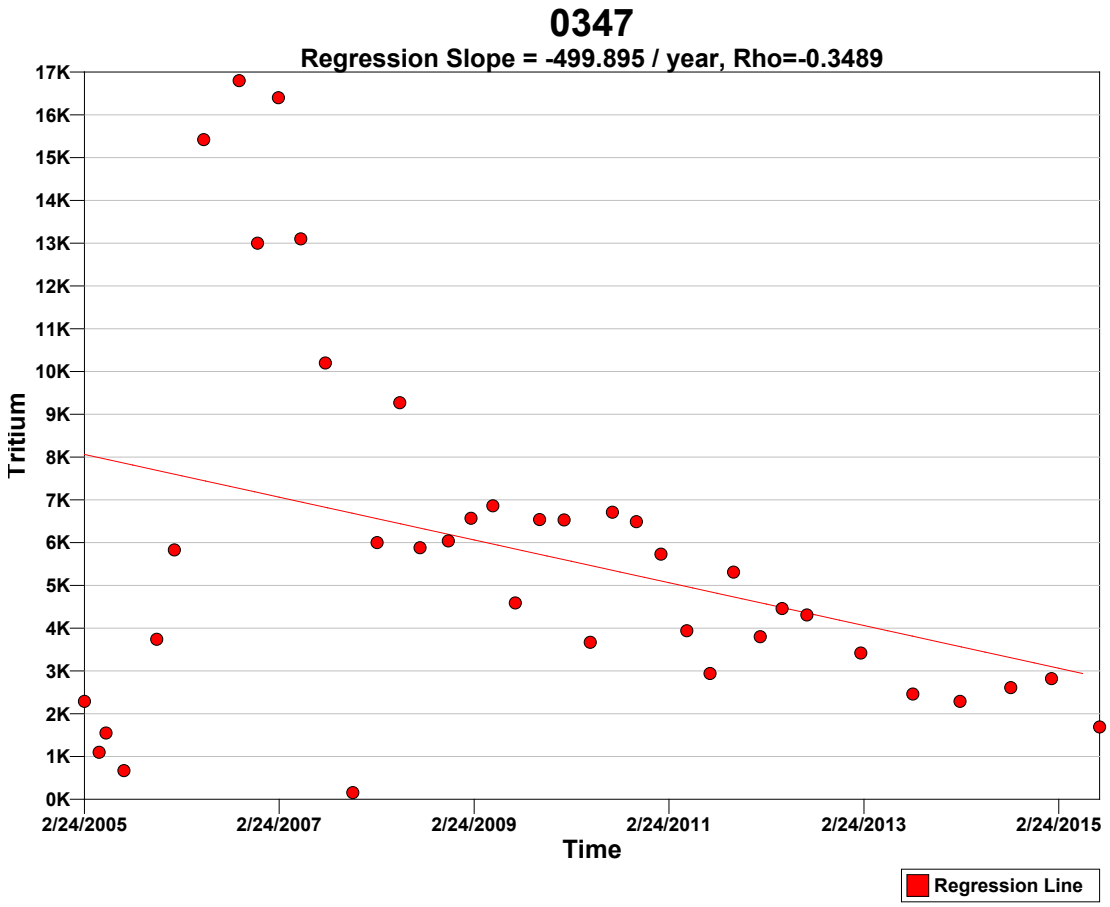
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

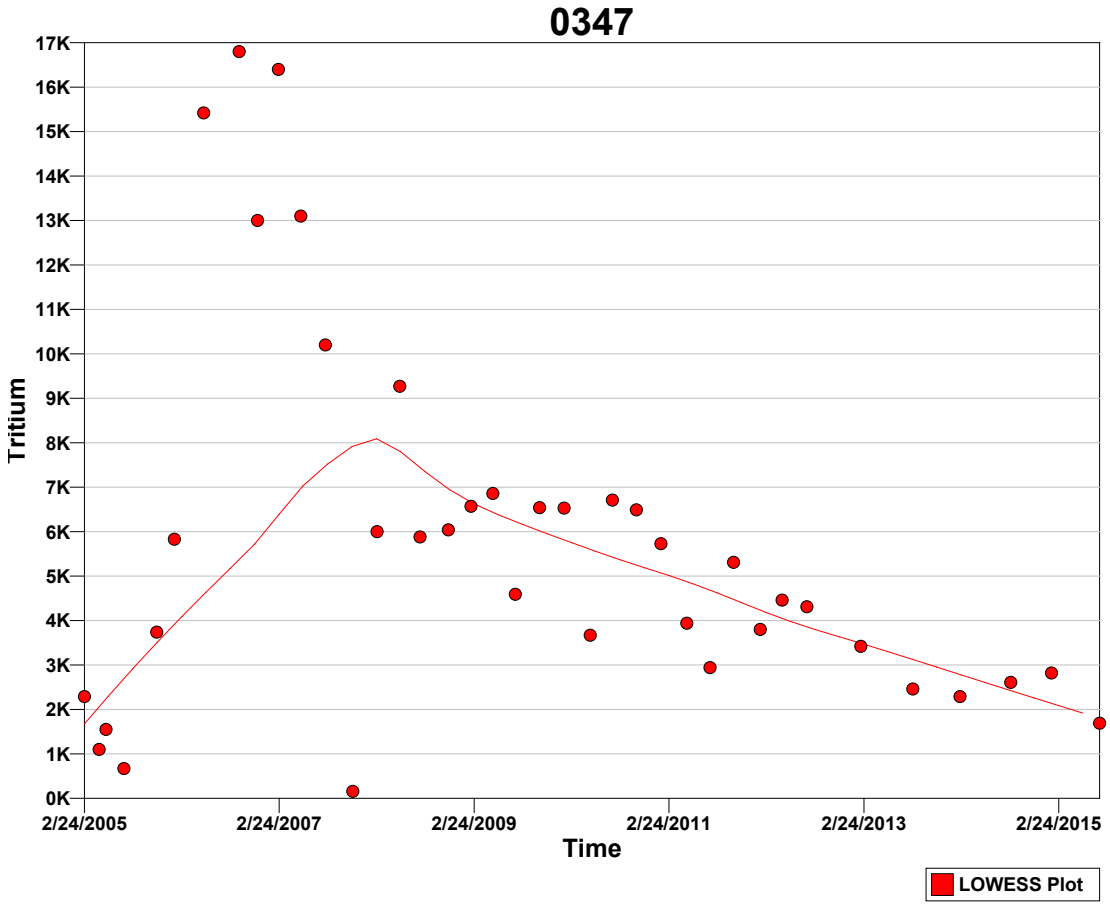
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=38) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.86327
Shapiro-Wilk 5% Critical Value	0.938

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-194	
MK Test Statistic	Z_{MK}	-2.42657	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Trichloroethene

Analysis was performed on the data that was entered for the location labeled "0315. The following table lists the data points that were used in the analysis.

0315							
Time	**Trichloroethene**		**Time**	**Trichloroethene**		**Time**	**Trichloroethene**
3/4/2005	10		2/12/2009	11.7		10/23/2012	16.6
5/19/2005	11		5/5/2009	12.5		2/12/2013	12.5
7/22/2005	13		7/28/2009	11.8		5/28/2013	7.23
1/27/2006	5.2		10/27/2009	14.1		8/26/2013	10.1
5/17/2006	7.2		1/26/2010	11.8		10/28/2013	12.9
9/26/2006	6.3		5/5/2010	11.1		2/19/2014	8.7
12/6/2006	3.79		7/26/2010	9.48		5/12/2014	8.99
2/21/2007	11.6		10/25/2010	15.2		8/28/2014	10.5
5/16/2007	13.2		1/25/2011	13.6		10/27/2014	11.7
8/20/2007	12.2		5/2/2011	8.1		1/28/2015	9.62
11/27/2007	16.8		7/28/2011	6.23		4/27/2015	6.07
2/26/2008	9.38		10/24/2011	10.7		7/27/2015	6.39
5/21/2008	11.2		2/1/2012	10.3		10/28/2015	8.24
8/5/2008	9.65		4/23/2012	12.3			
11/18/2008	17.2		7/25/2012	10.8			

SUMMARY STATISTICS for Trichloroethene								
n				43				
Min				3.79				
Max				17.2				
Range				13.41				
Mean				10.627				
Median				10.8				
Variance				9.4191				
StdDev				3.069				
Std Error				0.46803				
Skewness				0.020712				
Interquartile Range				3.8				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
3.79	5.374	6.258	8.7	10.8	12.5	14.76	16.76	17.2

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. The LOWESS method did not detect any outliers for the current data set.

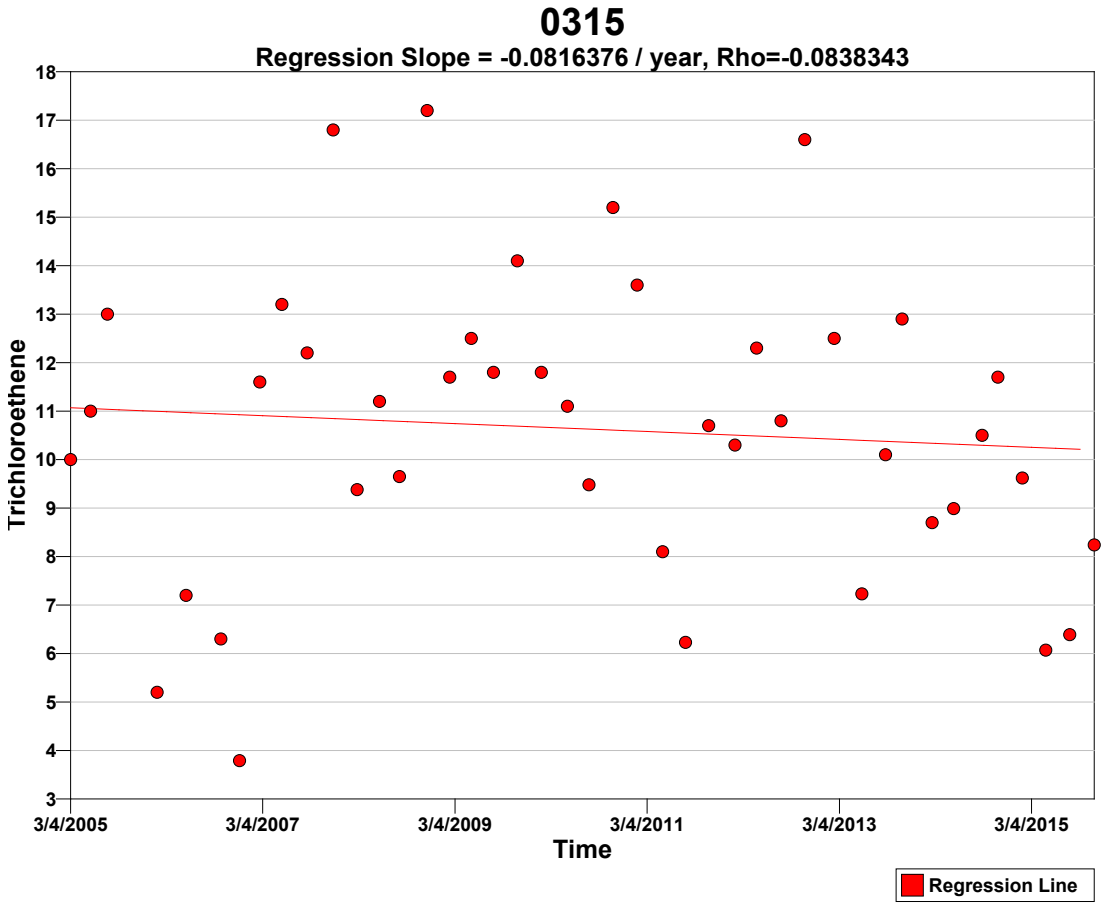
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

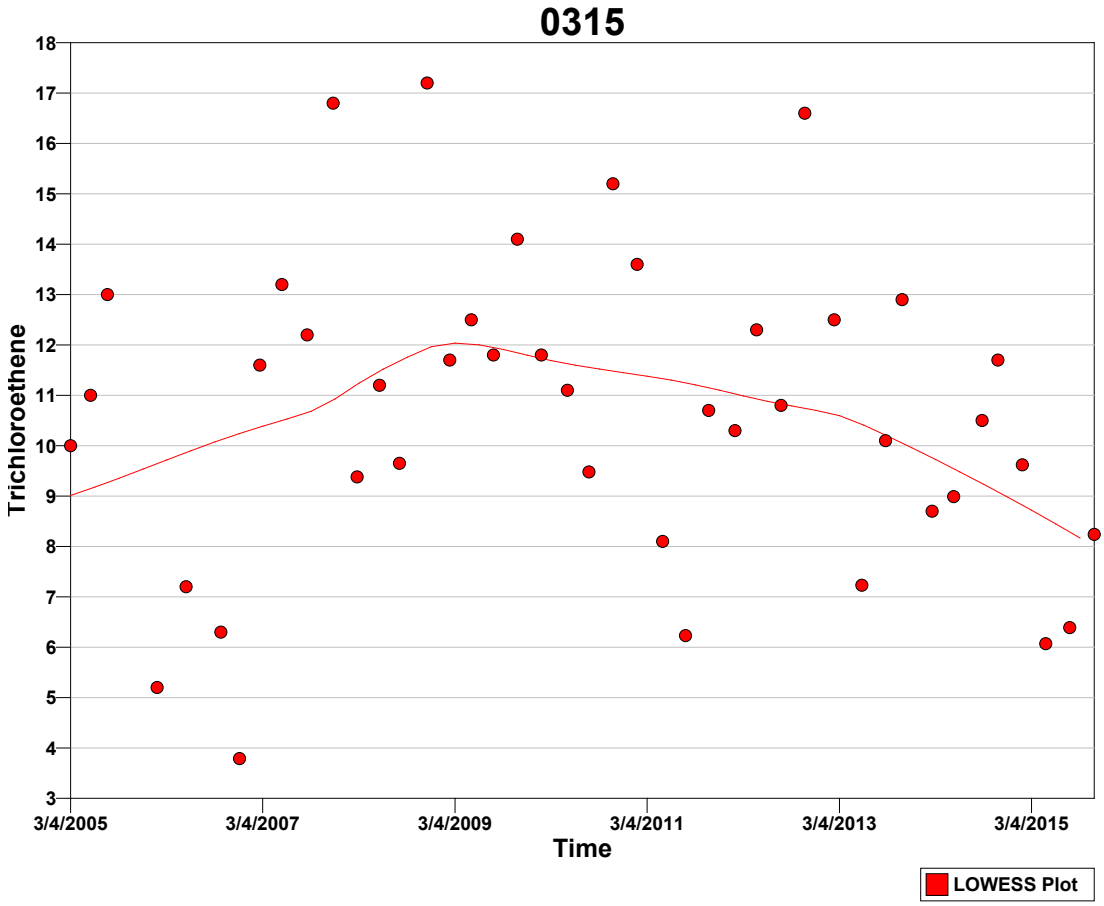
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots
The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the

value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=43) is less than 50.

Normal Distribution Test for Trichloroethene	
Shapiro-Wilk Test Statistic	0.98037
Shapiro-Wilk 5% Critical Value	0.943

The calculated test statistic exceeds the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-86	
MK Test Statistic	Z_{MK}	-0.889707	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	**Accept**
Alternative Hypothesis	H_a	A downward monotonic trend exists	Reject
Conclude with 95% confidence that a downward monotonic trend does not exist.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

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Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0346. The following table lists the data points that were used in the analysis.

0346							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
3/2/2005	33770		8/16/2007	1760		1/25/2011	1280
4/19/2005	15100		11/28/2007	2610		5/3/2011	987
4/27/2005	14900		2/26/2008	2090		7/27/2011	1470
5/16/2005	7850		5/20/2008	2260		10/24/2011	919
6/21/2005	5220		8/5/2008	1200		2/1/2012	943
7/22/2005	2130		11/18/2008	1830		4/24/2012	1050
11/3/2005	4460		2/11/2009	1810		7/25/2012	856
12/14/2005	4520		5/5/2009	1780		2/12/2013	494
1/25/2006	2320		7/28/2009	2030		8/26/2013	665
5/22/2006	2050		10/27/2009	2000		2/24/2014	196
9/26/2006	3490		1/26/2010	1320		8/28/2014	1020
12/5/2006	4750		5/6/2010	1830		1/28/2015	18.6
2/21/2007	2120		7/27/2010	1730		7/28/2015	736
5/16/2007	1830		10/26/2010	1710			

SUMMARY STATISTICS for Tritium								
n				41				
Min				18.6				
Max				33770				
Range				33751				
Mean				3441.6				
Median				1830				
Variance				3.3778e+007				
StdDev				5811.9				
Std Error				907.66				
Skewness				4.1174				
Interquartile Range				1430				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
18.6	225.8	679.2	1035	1830	2465	7324	1.508e+004	3.377e+004

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
3/2/2005	33770
4/19/2005	15100
4/27/2005	14900
5/16/2005	7850
7/22/2005	2130
1/25/2006	2320
12/5/2006	4750

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme

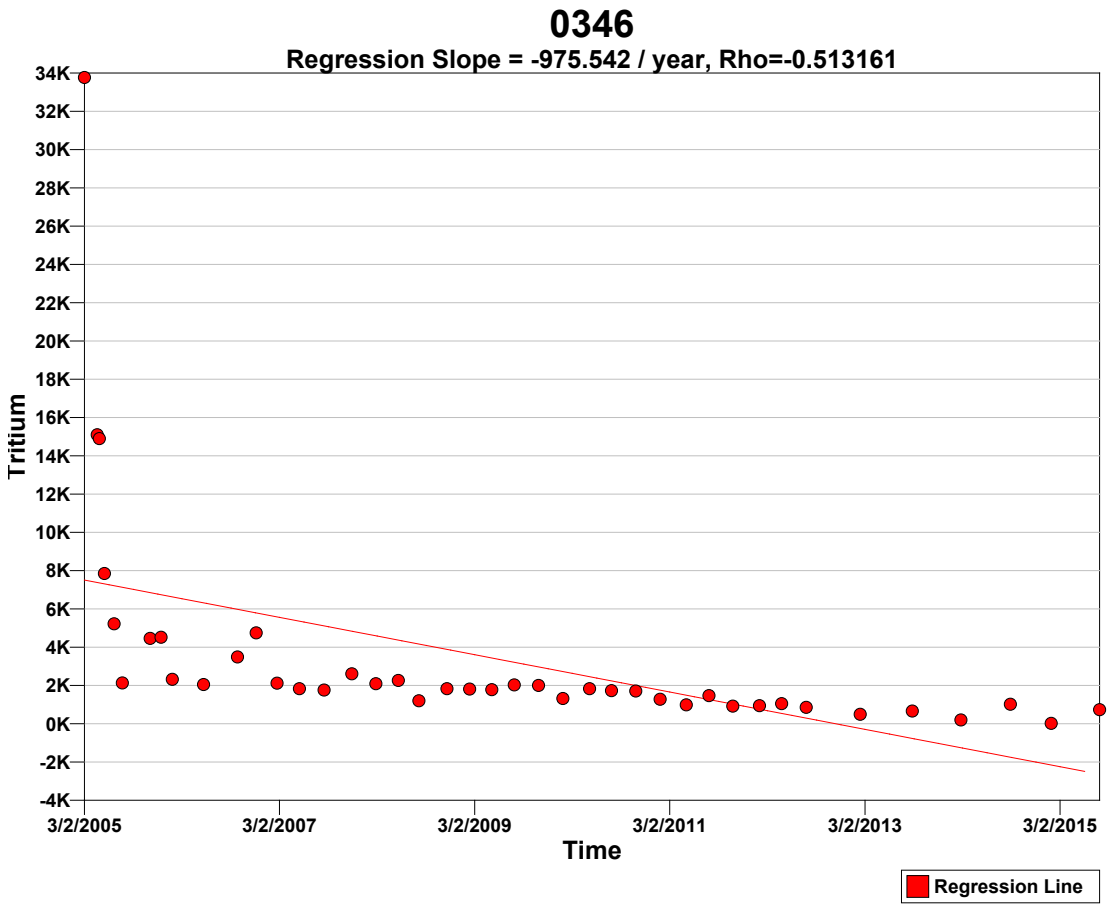
cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

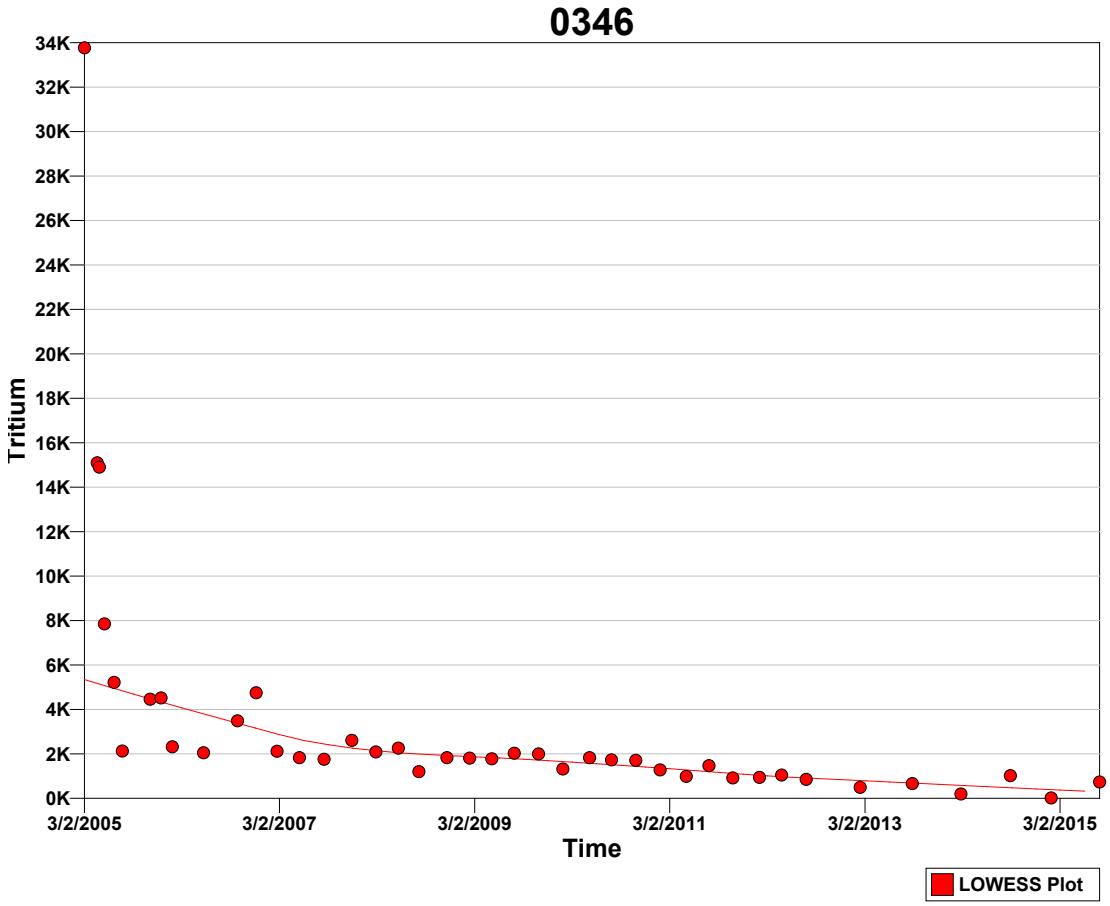
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=41) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.48854
Shapiro-Wilk 5% Critical Value	0.941

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-661	
MK Test Statistic	Z_{MK}	-7.41479	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0138. The following table lists the data points that were used in the analysis.

0138							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
4/27/2005	10490		11/29/2007	1390		1/24/2011	479
5/11/2005	8380		2/26/2008	1690		5/2/2011	1600
6/21/2005	12870		5/21/2008	3710		7/26/2011	1600
7/20/2005	13190		8/4/2008	3470		10/24/2011	914
8/29/2005	14570		11/18/2008	1680		1/31/2012	1170
11/2/2005	8920		2/9/2009	873		4/25/2012	1170
1/25/2006	6680		5/11/2009	1400		7/23/2012	1040
5/19/2006	14630		7/27/2009	2500		2/11/2013	281
9/25/2006	10000		10/26/2009	1590		8/27/2013	1190
12/4/2006	6910		1/25/2010	1200		2/18/2014	628
2/26/2007	7370		5/5/2010	1570		8/27/2014	862
5/15/2007	6810		7/26/2010	1770		1/27/2015	430
8/17/2007	4290		10/25/2010	880		7/28/2015	1060

SUMMARY STATISTICS for Tritium								
n				39				
Min				281				
Max				14630				
Range				14349				
Mean				4134.8				
Median				1600				
Variance				1.9398e+007				
StdDev				4404.4				
Std Error				705.26				
Skewness				1.2282				
Interquartile Range				5850				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
281	430	628	1060	1600	6910	1.287e+004	1.457e+004	1.463e+004

Outliers
One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
5/11/2005	8380
8/29/2005	14570
1/25/2006	6680
5/19/2006	14630
11/29/2007	1390

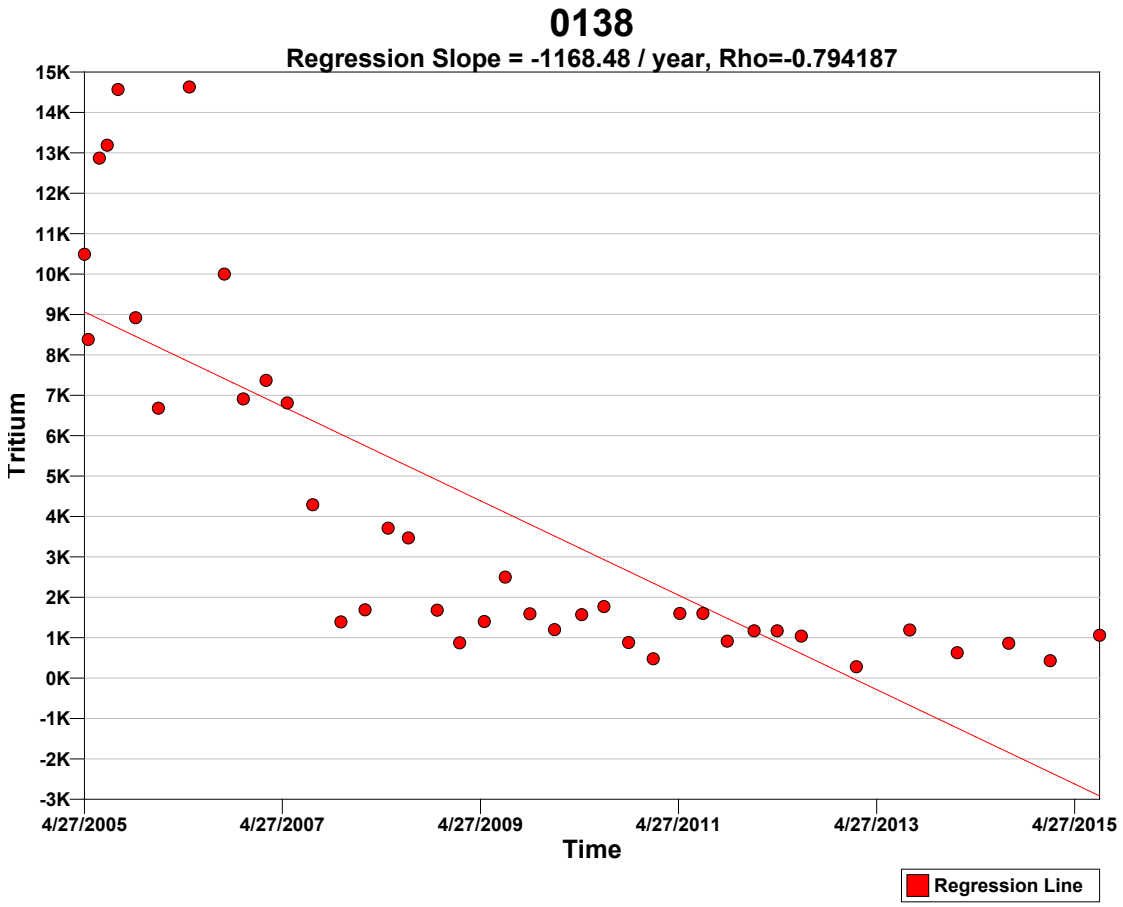
Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

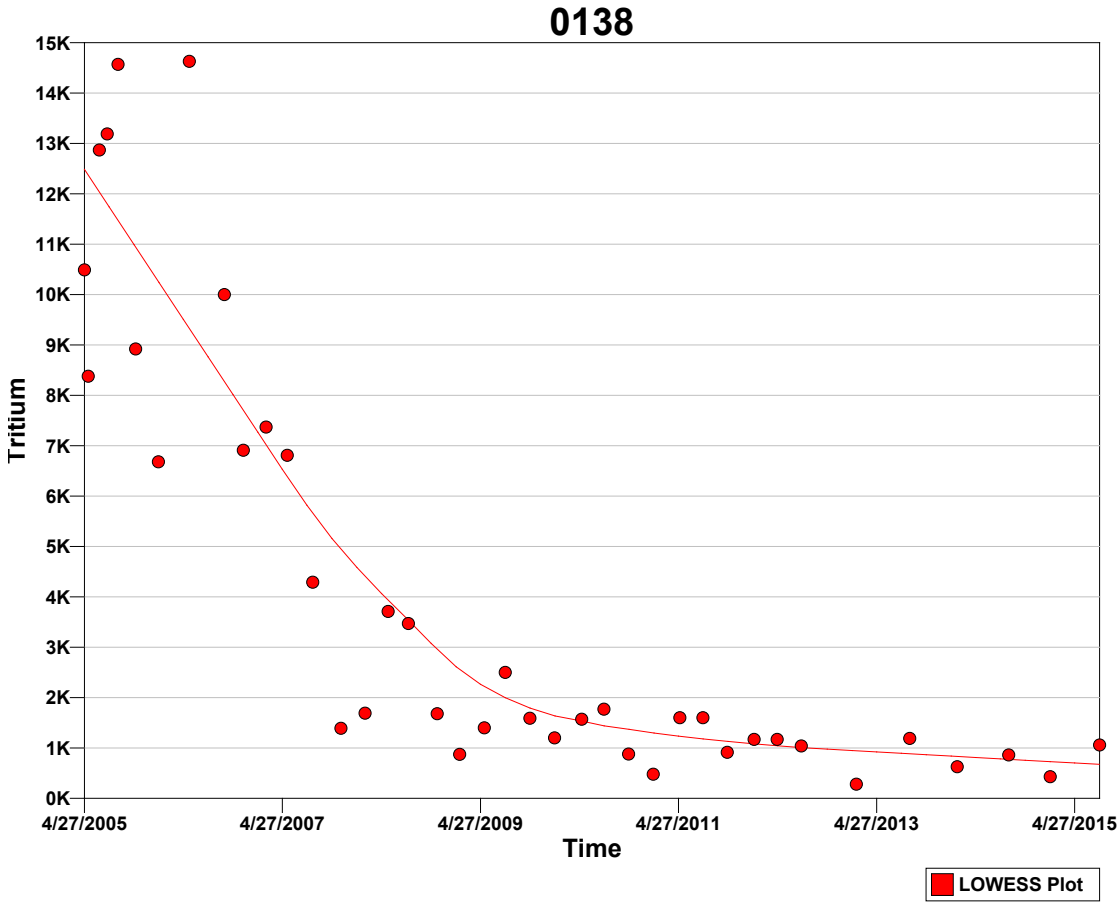
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=39) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.76747
Shapiro-Wilk 5% Critical Value	0.939

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-523	
MK Test Statistic	Z_{MK}	-6.31549	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

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Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

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Mann-Kendall Test for Monotonic Trend

Summary

This report summarizes the sampling design used, associated statistical assumptions, and the method of data analysis. Sampling plan components presented here include the data quality objectives and how many samples are needed to detect a monotonic trend while meeting those objectives.

The following table summarizes the sampling design developed.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Determine if there is a monotonic trend over time
Type of Test for Trend	Nonparametric
Working (Null) Hypothesis	There is no monotonic trend
Alternative Hypothesis	A downward monotonic trend exists
Method for detecting whether a trend exists	Mann-Kendall Nonparametric Test
Method of calculating number of samples needed to detect a trend	Monte-Carlo simulation using Mann-Kendall test
Time between samples (Sample Period)	1 months
Number of samples needed to detect a trend of -1 per year within tolerable error limits [a]	53

[a] See *Calculation of Number of Samples Required to Detect a Trend* section below for details.

Primary Sampling Objective

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

Selected Statistical Testing Approach

The MK test can be used in place of a parametric linear regression analysis that is used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test. Hence, the MK test is a non-parametric (distribution-free) test.

Hirsch, Slack and Smith (1982, page 107) indicate that the MK test is best viewed as an exploratory analysis and is most appropriately used to identify and quantify changes over time at sampling stations.

Calculations to Determine Whether a Trend Exists

The MK test is used to decide whether to reject the null hypothesis (H_o) that no monotonic trend exists in favor of the alternative hypothesis (H_a) that a monotonic trend exists.

One of three alternative hypotheses is chosen:

1. A monotonic downward trend exists
2. Either a monotonic upward or monotonic downward trend exists
3. A monotonic upward trend exists

For the current design, the 1st option (a downward trend) was chosen.

The data obtained over time must be convincing beyond a reasonable doubt before the MK test will reject the H_o and accept the H_a.

The MK test is conducted as follows (from Gilbert 1987, pp. 209-213):

1. List the data in the order in which they were collected over time, $x_1, x_2, \ldots, x_n$, which denote the measurements obtained at times 1, 2, ï¿½, n, respectively. The data are not necessarily (and need not be) collected at equally spaced time intervals, although equally spaced sampling over time is often preferred.

2. Determine the sign of all *n(n-1)/2* possible differences $x_j - x_k$, where j > k. These differences are

$x_2-x_1, x_3-x_1, \ldots, x_n-x_1, x_3-x_2, x_4-x_2, \ldots, x_n-x_{n-2}, x_n-x_{n-1}$

3. Let $\mathrm{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$, that is,

$\mathrm{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$
$\mathrm{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$, or if the sign of $x_j - x_k$ cannot be determined due to non-detects
$\mathrm{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

For example, if $x_j - x_k > 0$, then the observation at time j, denoted by x_j, is greater than the observation at time k, denoted by x_k.

4. Compute

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \qquad (1)$$

which is the number of positive differences minus the number of negative differences. If S is a positive number, observations obtained later in time tend to be *larger* than observations made earlier. If S is a negative number, then observations made later in time tend to be *smaller* than observations made earlier.

5. If $n \leq 10$, follow the procedure described in Gilbert (1987, page 209, Section 16.4.1) by looking up S in a table of probabilities (Gilbert 1987, Table A18, page 272). If this probability is less than α (the probability of concluding a trend exists when there is none), then reject the null hypothesis and conclude the trend exists. If *n* cannot be found in the table of probabilities (which can happen if there are tied data values), the next value farther from zero in the table is used. For example, if S=12 and there is no value for S=12 in the table, it is handled the same as S=13.

If $n > 10$, continue with steps 6 through 8 to determine whether a trend exists. This follows the procedure described in Gilbert (1987, page 211, Section 16.4.2).

6. Compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (2)$$

where g is the number of tied groups and t_p is the number of observations in the pth group. For example, in the sequence of measurements in time (23, 24, 29, 6, 29, 24, 24, 29, 23) we have g = 3 tied groups, for which t_1=2 for the tied value 23, t_2=3 for the tied value 24, and t_3=3 for the tied value 29.

7. Compute the MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad \text{if} \quad S > 0$$

$$= 0 \quad \text{if} \quad S = 0 \qquad (3)$$

$$= \frac{S+1}{\sqrt{VAR(S)}} \quad \text{if} \quad S < 0$$

A positive value of Z_{MK} indicates that the data tend to increase with time; a negative value of Z_{MK} indicates that the data tend to decrease with time.

8. Finally, the hypothesis is tested. H_o is rejected and H_a is accepted if $Z_{MK} \leq -Z_{1-\alpha}$ where:

H_o (null hypothesis): no monotonic trend exists

H_a (alternative hypothesis): a downward monotonic trend exists

Alpha (α) is the Type I error rate, which is the user-specified small probability that can be tolerated that the MK test will falsely reject the null hypothesis (i.e. will conclude a trend exists when there is none)

$Z_{1-\alpha}$ is the $100(1-\alpha)^{th}$ percentile of the standard normal distribution. For example, if $\alpha = 0.05$, then $Z_{1-\alpha} = 1.64485$. Values of $Z_{1-\alpha}$ are provided in many statistics books (for example Gilbert 1987, Table A1, page 254) and statistical software packages.

Calculation of Number of Samples Required to Detect a Trend

VSP uses a Monte-Carlo simulation to determine the required number of points in time, n, to take a measurement in order to detect a trend for specified small probabilities that the MK test will make decision errors. If a non-linear trend is actually present, then the value of n computed by VSP is only an approximation to the correct n. The simulation, which is a binary search on the number of samples needed, proceeds as follows:

1. The required probability of detecting a trend (if present) is set at $1-\beta$ where β is the user-specified probability of falsely accepting the null hypothesis.

2. The required number of samples, n, is initially set to 4, which is the minimum number of samples that can be analyzed using the Mann-Kendall test.

3. A set of n random numbers is created that conforms to the linear trend (change per unit time) that the VSP user indicates needs to be detected and to the standard deviation of normally distributed residuals about that trend line. This standard deviation is also specified by the VSP user.
   a. A set of n numbers is randomly chosen from a normal distribution having a mean of zero and the specified standard deviation of the residuals. Call this set of random numbers ($r_1, r_2, r_3, \ldots, r_n$).
   b. The change per sample period, i.e., the change that occurs between two adjacent sampling times, Δ, is calculated based on the user-specified trend slope and sample period.
   c. A multiple of Δ is added to each random number to create the necessary slope. The resulting numbers are ($x_1=r_1, x_2=r_2+\Delta, x_3=r_3+2\Delta, \ldots, x_n=r_n+(n-1)\Delta$)

4. The MK test (described above) is conducted on the set of numbers (x_1, x_2, ... , x_n) using the user-specified alpha error rate (α). If the null hypothesis is rejected, which indicates that the MK test detected a trend, then one is added to the count of trend detections.

5. Steps 3 and 4 are repeated 1000 times. The count of trend detections is then divided by 1000 to compute an estimate of the probability, P_d, that the MK test will detect a trend of the magnitude specified in Step 3 above.

6. P_d is compared to 1-β. If P_d equals 1-β then the target probability of detection has been achieved with n samples. In that case the simulation ends and VSP reports that n samples are required. If P_d < 1-β then n is increased and steps 3 through 6 are repeated. If P_d > 1-β then n is decreased and steps 3 through 6 are repeated. The process continues until P_d equals 1-β or n does not change.

The following table summarizes the parameters used, as specified by the VSP user, and the results of the simulation:

Trend	
Change of interest to detect	-1 / year
Time between samples (Sample Period)	1 months
Change (per sample period) of interest to detect	-0.0833333
Parameters	
Alpha (α)	0.05 (5%)
Beta (β)	0.1 (10%)
Standard deviation of residuals from trend line	3
Results	
Samples required, n (Sampling every 1 months)	53

Assumptions

The following assumptions underlie the MK test:

1. When no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time.
2. The observations obtained over time are representative of the true conditions at sampling times.
3. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

The MK test does not require that the measurements or the residuals about a trend tine be normally distributed or that the trend, if present, be linear. However, when VSP computes the number of samples required to detect a linear trend, VSP assumes that the residuals about an assumed linear trend line are normally distributed as explained previously.

The MK test can be computed if there are missing values (no measurements for some sampling times), but the performance of the test will be adversely affected. The assumption of independence requires that the time between samples be sufficiently long so that there is no correlation between measurements collected at different times. Consult Helsel (2005, pages 209-215) for doing nonparametric regression (trend) analyses when data are less than one or more detection limits.

Data Analysis for Tritium

Analysis was performed on the data that was entered for the location labeled "0608. The following table lists the data points that were used in the analysis.

0608							
Time	**Tritium**		**Time**	**Tritium**		**Time**	**Tritium**
2/17/2005	600		5/19/2008	20600		5/10/2011	8770
5/17/2005	13730		8/4/2008	21500		7/27/2011	9210
7/28/2005	16550		12/29/2008	15100		10/25/2011	10200
11/3/2005	21410		2/9/2009	18300		1/31/2012	8660
1/30/2006	26210		5/5/2009	15900		4/25/2012	9220
5/19/2006	41570		7/29/2009	16900		2/11/2013	8170
9/26/2006	54000		10/26/2009	19500		8/27/2013	6140
12/5/2006	41700		1/25/2010	10800		2/19/2014	6330
2/27/2007	29100		5/5/2010	11800		8/26/2014	5840
5/17/2007	31200		7/26/2010	14900		1/29/2015	5790
11/29/2007	30300		10/25/2010	12800		7/29/2015	6170
2/28/2008	26400		1/25/2011	11900			

SUMMARY STATISTICS for Tritium								
n				35				
Min				600				
Max				54000				
Range				53400				
Mean				17351				
Median				14900				
Variance				1.3875e+008				
StdDev				11779				
Std Error				1991				
Skewness				1.331				
Interquartile Range				12730				
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
600	4752	6020	8770	1.49e+004	2.15e+004	3.535e+004	4.416e+004	5.4e+004

Outliers

One of the trend data plots in VSP uses the LOWESS method to fit a non-linear trend line through the data while giving little weight to values that appear to be out of place and that donï¿½t follow the trend. These values with low weights can be considered possible outliers and are listed in the table below.

SUSPECTED OUTLIERS	
Date/Time	**Value**
2/17/2005	600
5/19/2006	41570
9/26/2006	54000
12/5/2006	41700

Data should not be excluded from analysis solely on the basis of the results of this method or any other outlier detection method. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them. Additionally, the default LOWESS parameters are robust for most datasets, but in some extreme cases some additional points besides the obvious outliers may be flagged as outliers while appearing to fit the fitted line rather well.

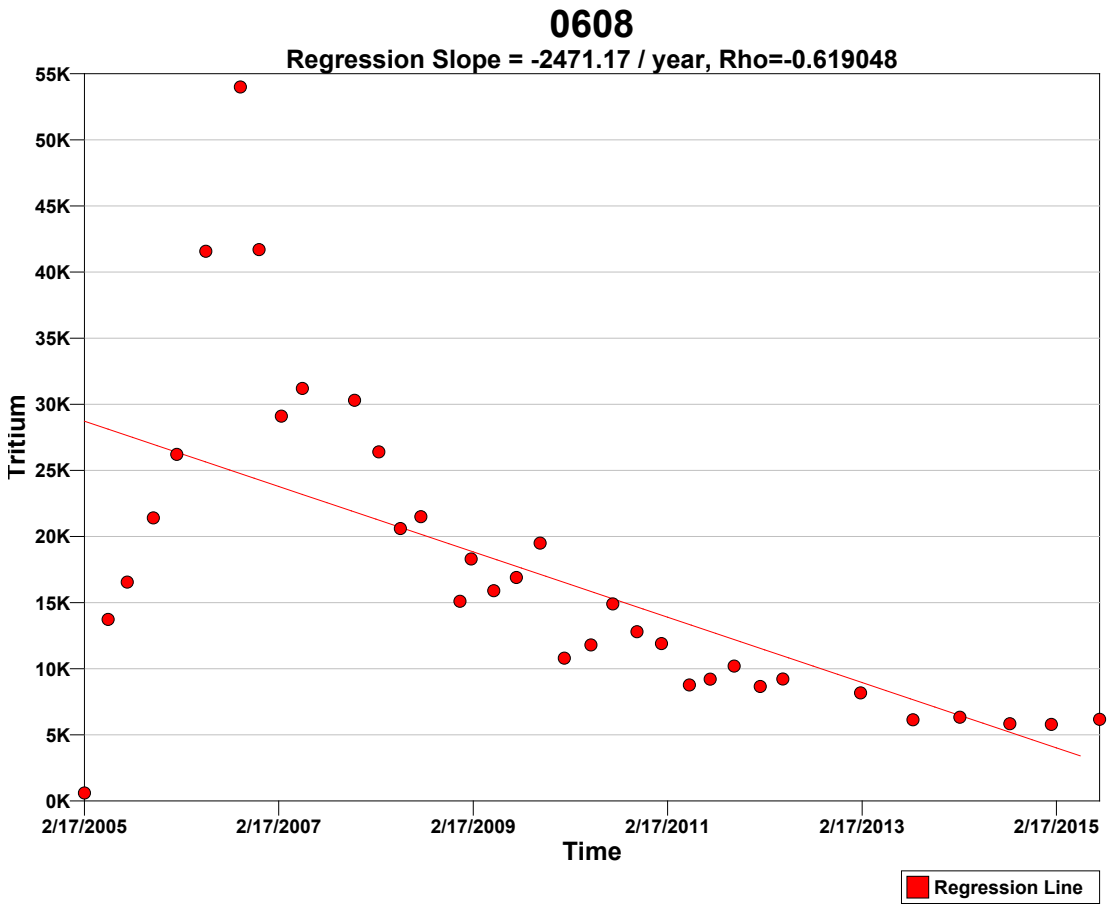
It is also recommended that the trend data plots be studied in depth to identify potential outliers and that the raw data be checked by an expert. No outlier detection method can replace a thorough and diligent

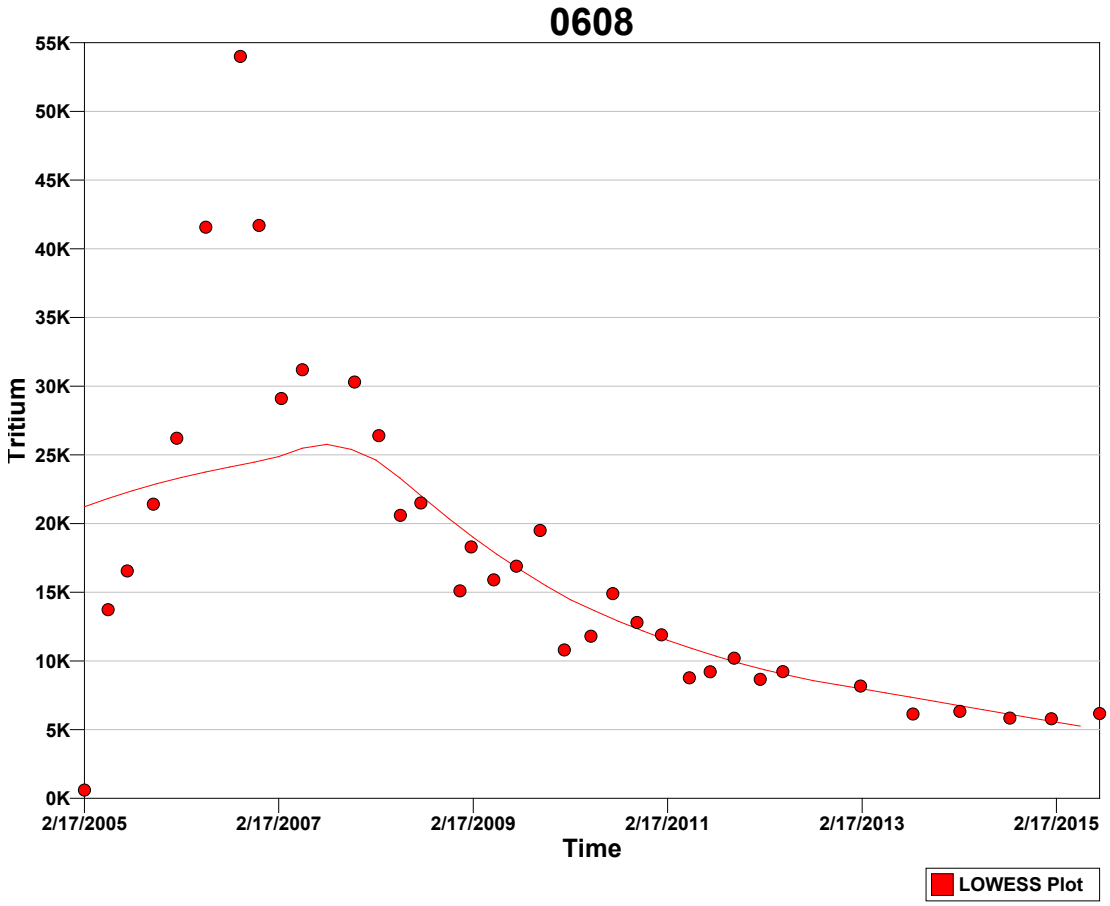
examination by someone familiar with the data. Ideally, data plots are examined and the obvious erroneous values are addressed before relying on an outlier test.

Data Plots

The Time vs. Measured Values Plot shows the best fitting 'least squares' linear line to the observed n data values plotted against time. The x-axis is the time when data were collected and the y-axis is the value of each datum. The slope of the linear line estimates the change in the data per unit time. If the linear line is a good fit to the data, then the slope of the line is an estimate of the linear trend over time in the data. If a linear line is not a good fit to the data, but an upward (or downward) tendency in the data is present, then a nonparametric estimator of monotonic change over time may be preferred to the estimated ï¿½least squaresï¿½ slope obtained assuming that a linear change over time is occurring.

The last plot is a Locally Weighted Smoothed Scatterplot (LOWESS Plot) developed by William S. Cleveland that shows a fitted line through the data that tends to eliminate the distortion that comes from deviant points.





Tests

A goodness-of-fit test was performed to test whether the values are normally distributed. The Shapiro-Wilk test was determined most appropriate for this VSP application because the size of the data set (n=35) is less than 50.

Normal Distribution Test for Tritium	
Shapiro-Wilk Test Statistic	0.88964
Shapiro-Wilk 5% Critical Value	0.934

The calculated test statistic does not exceed the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the values are normally distributed, or in other words the values do not appear to follow a normal distribution at the 5% level of significance. A Q-Q plot of values (displayed above) should be used to further assess the normality of the data.

Mann-Kendall Test

The Mann-Kendall Test for trend was performed on the data as outlined in the *Calculations to Determine Whether a Trend Exists* section above. The results are as follows:

Mann-Kendall Test			
Sum of Signs	S	-371	
MK Test Statistic	Z_{MK}	-5.25453	
Alpha	α	0.05	
Critical Value	$- Z_{1-\alpha}$	-1.64485	
Null Hypothesis	H_o	No trend exists	Reject
Alternative Hypothesis	H_a	A downward monotonic trend exists	**Accept**
Conclude with 95% confidence that a downward monotonic trend exists.			

References

Cleveland, William S., **Robust Locally Weighted Regression and Smoothing Scatterplots**, 1979, *Journal of the American Statistical Association*, Vol. 74, No. 368. p. 829-836.

Gilbert, R.O., 1987. **Statistical Methods for Environmental Pollution Monitoring**, Wiley & Sons, New York.

Helsel, D.R. 2005. **Nondetects and Data Analysis, Statistics for Censored Environmental Data**, Wiley & Sons, New York.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. **Techniques of trend analysis for monthly water quality data,** *Water Resources Research* 18(1):107-121.

Kendall, M.G. 1975. **Rank Correlation Methods,** 4th edition, Charles Griffin, London.

Mann, H.B. 1945. **Non-parametric tests against trend,** *Econometrica* 13:163-171.

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This design was last modified 2/22/2016 12:07:41 PM.

Software and documentation available at http://vsp.pnnl.gov

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Appendix C

2015 Groundwater Elevations

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Table C-1. Phase I Groundwater Elevations

Location ID	Date	Elevation of Top of Casing	Depth from Top of Casing	Groundwater Elevation
0353	1/26/2015	745.33	1.93	743.40
0353	7/29/2015	745.33	2.75	742.58
0400	1/26/2015	705.11	24.55	680.56
0400	7/29/2015	705.11	22.50	682.61
0402	1/5/2015	704.02	23.55	680.65
0402	1/26/2015	704.02	23.37	682.62
0402	2/2/2015	704.02	23.36	680.66
0402	3/2/2015	704.02	24.07	679.95
0402	4/6/2015	704.02	21.70	682.32
0402	5/5/2015	704.02	21.80	682.22
0402	7/29/2015	704.02	21.40	682.62
0402	8/11/2015	704.02	22.73	681.29
0402	8/19/2015	704.02	23.31	680.71
0402	9/9/2015	704.02	24.31	679.71
0402	10/12/2015	704.02	25.30	678.72
0402	11/2/2015	704.02	24.88	679.14
0402	11/16/15	704.02	24.59	679.43
0402	12/8/15	704.02	24.20	679.82
0411	1/27/2015	836.57	20.42	816.15
0411	7/29/2015	836.57	20.02	816.55
0443	1/27/2015	858.78	33.66	825.12
0443	7/29/2015	858.78	34.30	824.48
0444	1/27/2015	773.00	21.71	751.29
0444	7/29/2015	773.00	22.45	750.55
0445	1/26/2015	743.43	13.67	729.76
0445	7/29/2015	743.43	15.48	727.95
P033	1/26/2015	705.83	25.27	680.56
P033	7/29/2015	705.83	23.28	682.55

Table C-2. Parcels 6, 7, and 8 Groundwater Elevations

Location ID	Date	Elevation of Top of Casing	Depth from Top of Casing	Groundwater Elevation
0118	1/27/2015	704.86	22.95	681.91
0118	4/27/2015	704.86	21.39	683.47
0118	7/27/2015	704.86	21.38	683.48
0118	10/26/2015	704.86	24.92	679.94
0124	1/27/2015	705.12	24.15	680.97
0124	4/29/2015	705.12	22.19	682.93
0124	7/27/2015	705.12	22.16	682.96
0124	10/26/2015	705.12	26.25	678.87
0126	1/27/2015	705.54	24.59	680.95
0126	4/29/2015	705.54	22.61	682.93
0126	7/27/2015	705.54	22.59	682.95
0126	10/26/2015	705.54	26.70	678.84
0138	1/27/2015	697.76	16.10	681.66
0138	4/27/2015	697.76	14.60	683.16
0138	7/28/2015	697.76	14.82	682.94
0138	10/26/2015	697.76	18.18	679.58
0315	1/28/2015	723.99	43.08	680.91
0315	4/27/2015	723.99	40.93	683.06
0315	7/27/2015	723.99	41.03	682.96
0315	10/28/2015	723.99	45.04	678.95
0346	1/28/2015	742.97	15.92	727.05
0346	4/29/2015	742.97	13.63	729.34
0346	7/28/2015	742.97	14.16	728.81
0346	10/26/2015	742.97	16.48	726.49
0347	1/28/2015	725.20	44.31	680.89
0347	4/27/2015	725.20	42.13	683.07
0347	7/27/2015	725.20	42.28	682.92
0347	10/28/2015	725.20	46.21	678.99
0379	1/6/2015	716.11	35.14	680.97
0379	1/29/2015	716.11	35.21	680.90
0379	2/4/2015	716.11	35.17	680.94
0379	3/4/2015	716.11	35.86	680.25
0379	4/7/2015	716.11	33.69	682.42
0379	4/29/2015	716.11	33.18	682.93
0379	5/5/2015	716.11	33.79	682.32
0379	7/28/2015	716.11	33.40	682.71

Table C-2 (continued). Parcels 6, 7, and 8 Groundwater Elevations

Location ID	Date	Elevation of Top of Casing	Depth from Top of Casing	Groundwater Elevation
0379	8/11/2015	716.11	34.66	681.45
0379	10/26/2015	716.11	37.28	678.83
0379	11/2/2015	716.11	36.38	679.73
0386	1/28/2015	724.79	43.90	680.89
0386	4/27/2015	724.79	41.73	683.06
0386	7/28/2015	724.79	42.01	682.78
0386	10/27/2015	724.79	45.97	678.82
0387	1/29/2015	720.89	40.00	680.89
0387	4/27/2015	720.89	37.87	683.02
0387	7/28/2015	720.89	38.14	682.75
0387	10/27/2015	720.89	42.12	678.77
0389	1/28/2015	724.65	43.74	680.91
0389	4/27/2015	724.65	41.58	683.07
0389	7/28/2015	724.65	41.87	682.78
0389	10/27/2015	724.65	45.83	678.82
0392	1/29/2015	720.84	39.84	681.00
0392	4/27/2015	720.84	37.68	683.16
0392	7/28/2015	720.84	37.93	682.91
0392	10/27/2015	720.84	41.93	678.91

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Appendix D

Well Sealing Reports

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DNR 7810.12e

WATER WELL SEALING REPORT e-FORM
OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Soil and Water Resources
2045 Morse Road, Bldg B
Columbus, OH 43229-6693
Voice: (614) 265-6740 Fax: (614) 265-6767

309909

LOCATION

County MONTGOMERY Township MIAMI Section No. 15 Lot No.

Owner D.O.E. MOUND LAB

Address of Well Location ARTHUR AVE

City MIAMISBURG Zip Code

Well Location Description (120 Characters): LOCATED NORTH OF ARTHUR AVENUE, NEXT TO CITY WATER WORKS FACILITY DEPARTMENT OF ENERGY WELL DESIGNATED: 0311

Location of Well in either: State Plane N ☐ S ☒ X 1494187.71 +/- ft. Y 597873.25 +/- ft.
OR
Latitude/Longitude Latitude 0 Longitude 0

Elevation of Well 695.60 +/- ft. Datum Plane: ☐ NAD27 ☒ NAD83

Source of Coordinates: ☐ GPS ☒ Survey ☐ Other
Source of Elevation: ☐ GPS ☒ Survey ☐ Other

WELL IDENTIFICATION ODNR Well Log Number 707688 Project Well ID

MEASURED CONSTRUCTION DETAILS

Date of measurements
Depth of Well 35 ft. Static Water Level ft.
Borehole Depth ft. Borehole Diameter 6 in.
Casing Diameter 4 in. Casing Length 21 ft. Casing Type

SEALING PROCEDURE

Placement:		Sealing Material	Volume/Weight Used Units Required	Placement Method
From 0 ft.	To 19 ft.	Bentonite pellets/chunks	9.0 GALLONS	Poured (gravity)
From 19 ft.	To 29 ft.	Sand	9.0 GALLONS	Poured (gravity)
From 29 ft.	To 35 ft.	Sand and Gravel	9.0 GALLONS	Poured (gravity)
From ft.	To ft.			

Condition of Casing Was Casing Removed? ☐ Yes or ☒ No (check one)

If casing **Not Removed**, was it Perforated? ☒ Yes or ☐ No (check one) Perforations: From 0 ft. To 20 ft.

Date Sealing Performed 8/31/2015

Comments/Reason for Sealing: WELL DE-CONTAMINATED DUE TO CONSTRUCTION
BOTTOM OF WELL WAS SET AT 29 FT. BGS. NATURAL COLLAPSE OF ORIGINAL BOREHOLE 35-29 FT. BGS.
FLUSH MOUNT MONUMENT AND CONCRETE REMOVED. FILLED THE SCREEN/FILTER PACK INTERVAL OF THE WELL WITH #7 WELL SAND, THEN PLACED A 2 FT. BENTONITE CHIP PLUG FROM 19 TO 17 FT. BGS. ATTEMPT TO PULL THE WELL BROKE IT AT THE FIRST JOINT AT 20 FT. BGS. BROKEN RISER SECTION WAS REMOVED AND THE REMAINDER OF THE BOREHOLE WAS FILLED WITH BENTONITE CHIPS TO GROUND SURFACE

CONTRACTOR

Name SM STOLLER ODH Registration #
Address 1725 Vanguard RD
City/State/Zip MIAMISBURG, OH 45342

e-Signature REBECCA CATO Filed electronically on 9/9/2015
I hereby certify the information given is accurate and correct to the best of my knowledge.

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of sealing.
Distribute additional copies to: Customer, Driller and Local Health Department.

DNR 7810.12e

WATER WELL SEALING REPORT e-FORM
OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Soil and Water Resources
2045 Morse Road, Bldg B
Columbus, OH 43229-6693
Voice: (614) 265-6740 Fax: (614) 265-6767

309910

LOCATION

County MONTGOMERY Township MIAMI Section No. 15 Lot No.

Owner D.O.E. MOUND LAB

Address of Well Location ARTHUR AVE

City MIAMISBURG Zip Code

Well Location Description (120 Characters): LOCATED NORTH OF ARTHUR AVENUE, NEXT TO CITY WATER WORKS FACILITY DEPARTMENT OF ENERGY WELL DESIGNATED: 0301

Location of Well in either: State Plane N ☐ S ☒ X 1494179.84 +/- ft. Y 597872.78 +/- ft.
OR
Latitude/Longitude Latitude 0 Longitude 0

Elevation of Well 695.10 +/- ft. Datum Plane: ☐ NAD27 ☒ NAD83

Source of Coordinates: ☐ GPS ☒ Survey ☐ Other
Source of Elevation: ☐ GPS ☒ Survey ☐ Other

WELL IDENTIFICATION ODNR Well Log Number 707690 Project Well ID

MEASURED CONSTRUCTION DETAILS

Date of measurements
Depth of Well 88 ft. Static Water Level ft.
Borehole Depth ft. Borehole Diameter 6 in.
Casing Diameter 4 in. Casing Length 76 ft. Casing Type

SEALING PROCEDURE

Placement: From ft.	To ft.	Sealing Material	Volume/Weight Used Units Required	Placement Method
0	1	Bentonite pellets/chunks	1.5 GALLONS	Poured (gravity)
1	72	Bentonite slurry	30.0 GALLONS	Pumped w/ tremie pipe
72	75	Bentonite pellets/chunks	3.5 GALLONS	Poured (gravity)
75	88	Sand	9.0 GALLONS	Poured (gravity)

Condition of Casing Was Casing Removed? ☐ Yes or ☒ No (check one)

If casing **Not Removed**, was it Perforated? ☐ Yes or ☒ No (check one) Perforations: From ft. To ft.

Date Sealing Performed 9/2/2015

Comments/Reason for Sealing: WELL DECOMMISSIONED DUE TO CITY CONSTRUCTION
50' FROM OF WELL WAS SET AT 86.5 FT. BGS. NATURAL COLLAPSE OF ORIGINAL BOREHOLE 86.5-88 FT. BGS
FLUSH MOUNT AND CONCRETE REMOVED. WELL ABANDONED IN-PLACE, UNABLE TO PULL CASING. FILLED SCREEN WITH #4 SAND, THEN PLACED A 3 FT BENTONITE CHIP PLUS TREMIED BENTONITE SLURRY AT ~7.4 LBS./GAL. TO FILL WELL. GRADED OFF WITH BROKEN CONCRETE AND BENTONITE CHIPS.

CONTRACTOR

Name SM STOLLER ODH Registration #
Address 1725 Vanguard RD
City/State/Zip MIAMISBURG, OH 45342

e-Signature REBECCA CATO Filed electronically on 9/9/2015
I hereby certify the information given is accurate and correct to the best of my knowledge.

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of sealing.
Distribute additional copies to: Customer, Driller and Local Health Department.

DNR 7810.12e

WATER WELL SEALING REPORT e-FORM
OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Soil and Water Resources
2045 Morse Road, Bldg B
Columbus, OH 43229-6693
Voice: (614) 265-6740 Fax: (614) 265-6767

310131

LOCATION

County MONTGOMERY Township MIAMI Section No. ____ Lot No. ____

Owner STOLLER NEWPORT NEWS NUCLEAR (SN3)

Address of Well Location OLD MAIN ST

City MIAMISBURG Zip Code

Well Location Description (120 Characters): MOUND (OU9) MONITORING WELL: #0334
INSTALLATION DATE: 4/2/1993
ON OLD MAIN NEXT TO RIVER BETWEEN CENTER ST AND MAYS AVE

Location of Well in either: State Plane N [X] S [ ] X 1494850.09 +/- ____ ft. Y 6005401.81 +/- ____ ft.
OR
Latitude/Longitude Latitude 0 Longitude 0

Elevation of Well 700.50 +/- ____ ft. Datum Plane: [ ] NAD27 [X] NAD83

Source of Coordinates: [ ] GPS [X] Survey [ ] Other ____
Source of Elevation: [ ] GPS [X] Survey [ ] Other

WELL IDENTIFICATION ODNR Well Log Number ____ Project Well ID ____

MEASURED CONSTRUCTION DETAILS

Date of measurements 9/21/2015
Depth of Well 29.5 ft. Static Water Level 17.6 ft.
Borehole Depth 29.5 ft. Borehole Diameter 8 in.
Casing Diameter 4 in. Casing Length 19.5 ft. Casing Type Steel

SEALING PROCEDURE

Placement:		Sealing Material	Volume/Weight Used (Units Required)	Placement Method
From 0 ft.	To 0.5 ft.	Topsoil	4.5 CUBIC FEET	Poured (gravity)
From 0.5 ft.	To 17.5 ft.	Bentonite pellets/chunks	20 GALLONS	Poured (gravity)
From 17.5 ft.	To 29.5 ft.	Sand	10 GALLONS	Poured (gravity)
From ____ ft.	To ____ ft.			

Condition of Casing ____ Was Casing Removed? [ ] Yes or [X] No (check one)

If casing **Not Removed**, was it Perforated? [ ] Yes or [X] No (check one) Perforations: From ____ ft. To ____ ft.

Date Sealing Performed 9/22/2015

Comments/Reason for Sealing: MONITORING WELL NO LONGER USED/NEEDED
SCREEN PORTION OF WELL (19.5 TO 29.5) FILLED WITH SAND (GLOBAL #5)

CONTRACTOR

Name SM STOLLER ODH Registration # ____
Address 1725 Vanguard RD
City/State/Zip MIAMISBURG, OH 45342

e-Signature REBECCA CATO Filed electronically on 10/6/2015
I hereby certify the information given is accurate and correct to the best of my knowledge.

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of sealing.
Distribute additional copies to: Customer, Driller and Local Health Department.

DNR 7810.12e

WATER WELL SEALING REPORT e-FORM
OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Soil and Water Resources
2045 Morse Road, Bldg B
Columbus, OH 43229-6693
Voice: (614) 265-6740 Fax: (614) 265-6767

310132

LOCATION

County MONTGOMERY Township MIAMI Section No. ____ Lot No. ____

Owner STOLLER NEWPORT NEWS NUCLEAR (SN3)

Address of Well Location OLD MAIN ST

City MIAMISBURG Zip Code ____

Well Location Description (120 Characters): MOUND (OU9) MONITORING WELL: #0333
INSTALLATION DATE: 4/7/1993
ON OLD MAIN NEXT TO RIVER BETWEEN CENTER ST AND MAYS AVE

Location of Well in either: State Plane N [X] S [ ] X 1494851.90 +/- ____ ft. Y 6005471.19 +/- ____ ft.
OR
Latitude/Longitude Latitude 0 Longitude 0

Elevation of Well 700.30 +/- ____ ft. Datum Plane: [ ] NAD27 [X] NAD83

Source of Coordinates: [ ] GPS [X] Survey [ ] Other ____
Source of Elevation: [ ] GPS [X] Survey [ ] Other ____

WELL IDENTIFICATION ODNR Well Log Number ____ Project Well ID ____

MEASURED CONSTRUCTION DETAILS

Date of measurements 9/22/2015
Depth of Well 75 ft. Static Water Level 17.5 ft.
Borehole Depth ____ ft. Borehole Diameter 8 in.
Casing Diameter 4 in. Casing Length 65 ft. Casing Type Steel

SEALING PROCEDURE

Placement:		Sealing Material	Volume/Weight Used (Units Required)	Placement Method
From 0 ft.	To 0.5 ft.	Topsoil	4.5 CUBIC FEET	Poured (gravity)
From 0.5 ft.	To 63.5 ft.	Bentonite pellets/chunks	40 GALLONS	Poured (gravity)
From 63.5 ft.	To 75 ft.	Sand	10 GALLONS	Poured (gravity)
From ____ ft.	To ____ ft.			

Condition of Casing ____ Was Casing Removed? [ ] Yes or [X] No (check one)

If casing **Not Removed**, was it Perforated? [ ] Yes or [X] No (check one) Perforations: From ____ ft. To ____ ft.

Date Sealing Performed 9/22/2015

Comments/Reason for Sealing: MONITORING WELL NO LONGER USED/NEEDED
SCREEN PORTION OF WELL (65 TO 75) FILLED WITH SAND (GLOBAL #5)

CONTRACTOR

Name SM STOLLER ODH Registration # ____
Address 1725 Vanguard RD
City/State/Zip MIAMISBURG, OH 45342

e-Signature REBECCA CATO Filed electronically on 10/6/2015
I hereby certify the information given is accurate and correct to the best of my knowledge.

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of sealing.
Distribute additional copies to: Customer, Driller and Local Health Department.

Appendix E

2015 Groundwater and Seep Data Table

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Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0118	Parcels 6-7-8	cis-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	cis-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	cis-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0118	Parcels 6-7-8	Dissolved Oxygen	1/27/2015	5.77	mg/L			F	F
0118	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	5.39	mg/L			F	F
0118	Parcels 6-7-8	Dissolved Oxygen	7/27/2015	5.27	mg/L			F	F
0118	Parcels 6-7-8	Dissolved Oxygen	10/26/2015	6.9	mg/L				F
0118	Parcels 6-7-8	Oxidation Reduction Potential	1/27/2015	173	mV			F	F
0118	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	149.9	mV			F	F
0118	Parcels 6-7-8	Oxidation Reduction Potential	7/27/2015	53.2	mV			F	F
0118	Parcels 6-7-8	Oxidation Reduction Potential	10/26/2015	56.4	mV				F
0118	Parcels 6-7-8	pH	1/27/2015	7.16	s.u.			F	F
0118	Parcels 6-7-8	pH	4/27/2015	7.07	s.u.			F	F
0118	Parcels 6-7-8	pH	7/27/2015	7.2	s.u.			F	F
0118	Parcels 6-7-8	pH	10/26/2015	7.01	s.u.				F
0118	Parcels 6-7-8	Temperature	1/27/2015	12.63	C			F	F
0118	Parcels 6-7-8	Temperature	4/27/2015	13.26	C			F	F
0118	Parcels 6-7-8	Temperature	7/27/2015	14.74	C			F	F
0118	Parcels 6-7-8	Temperature	10/26/2015	13.7	C				F
0118	Parcels 6-7-8	Tetrachloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Tetrachloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Tetrachloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0118	Parcels 6-7-8	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	trans-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	trans-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0118	Parcels 6-7-8	Trichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Trichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Trichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0118	Parcels 6-7-8	Trichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0118	Parcels 6-7-8	Tritium	1/27/2015	-35.4	pCi/L	360	U	F	F
0118	Parcels 6-7-8	Tritium	7/27/2015	209	pCi/L	319	U	F	F
0118	Parcels 6-7-8	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Vinyl chloride	7/27/2015	0.16	ug/L	0.16	U	F	F
0118	Parcels 6-7-8	Vinyl chloride	10/26/2015	0.16	ug/L	0.16	U		F
0124	Parcels 6-7-8	cis-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	cis-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	cis-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	cis-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0124	Parcels 6-7-8	Dissolved Oxygen	1/27/2015	0.42	mg/L			F	F
0124	Parcels 6-7-8	Dissolved Oxygen	4/29/2015	3.02	mg/L			F	F
0124	Parcels 6-7-8	Dissolved Oxygen	7/27/2015	6.04	mg/L			F	F
0124	Parcels 6-7-8	Dissolved Oxygen	10/26/2015	3.39	mg/L				F
0124	Parcels 6-7-8	Oxidation Reduction Potential	1/27/2015	135	mV			F	F
0124	Parcels 6-7-8	Oxidation Reduction Potential	4/29/2015	123.9	mV			F	F
0124	Parcels 6-7-8	Oxidation Reduction Potential	7/27/2015	70.2	mV			F	F
0124	Parcels 6-7-8	Oxidation Reduction Potential	10/26/2015	153.1	mV				F
0124	Parcels 6-7-8	pH	1/27/2015	7.03	s.u.			F	F
0124	Parcels 6-7-8	pH	4/29/2015	6.83	s.u.			F	F
0124	Parcels 6-7-8	pH	7/27/2015	7.07	s.u.			F	F
0124	Parcels 6-7-8	pH	10/26/2015	6.87	s.u.				F
0124	Parcels 6-7-8	Temperature	1/27/2015	12.81	C			F	F
0124	Parcels 6-7-8	Temperature	4/29/2015	14.01	C			F	F
0124	Parcels 6-7-8	Temperature	7/27/2015	15.71	C			F	F
0124	Parcels 6-7-8	Temperature	10/26/2015	14.1	C				F
0124	Parcels 6-7-8	Tetrachloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Tetrachloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Tetrachloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Tetrachloroethene	10/26/2015	0.16	ug/L	0.16	U		F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0124	Parcels 6-7-8	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	trans-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	trans-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	trans-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0124	Parcels 6-7-8	Trichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Trichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Trichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Trichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0124	Parcels 6-7-8	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Vinyl chloride	4/29/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Vinyl chloride	7/27/2015	0.16	ug/L	0.16	U	F	F
0124	Parcels 6-7-8	Vinyl chloride	10/26/2015	0.16	ug/L	0.16	U		F
0126	Parcels 6-7-8	cis-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	cis-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	cis-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	cis-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0126	Parcels 6-7-8	Dissolved Oxygen	1/27/2015	1.08	mg/L			F	F
0126	Parcels 6-7-8	Dissolved Oxygen	4/29/2015	2.78	mg/L			F	F
0126	Parcels 6-7-8	Dissolved Oxygen	7/27/2015	0.78	mg/L			F	F
0126	Parcels 6-7-8	Dissolved Oxygen	10/26/2015	0.48	mg/L				F
0126	Parcels 6-7-8	Oxidation Reduction Potential	1/27/2015	126.7	mV			F	F
0126	Parcels 6-7-8	Oxidation Reduction Potential	4/29/2015	96.5	mV			F	F
0126	Parcels 6-7-8	Oxidation Reduction Potential	7/27/2015	27.2	mV			F	F
0126	Parcels 6-7-8	Oxidation Reduction Potential	10/26/2015	113.1	mV				F
0126	Parcels 6-7-8	pH	1/27/2015	6.98	s.u.			F	F
0126	Parcels 6-7-8	pH	4/29/2015	6.88	s.u.			F	F
0126	Parcels 6-7-8	pH	7/27/2015	7.15	s.u.			F	F
0126	Parcels 6-7-8	pH	10/26/2015	6.9	s.u.				F
0126	Parcels 6-7-8	Temperature	1/27/2015	12.37	C			F	F
0126	Parcels 6-7-8	Temperature	4/29/2015	14.09	C			F	F
0126	Parcels 6-7-8	Temperature	7/27/2015	15.79	C			F	F
0126	Parcels 6-7-8	Temperature	10/26/2015	13.9	C				F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0126	Parcels 6-7-8	Tetrachloroethene	1/27/2015	1.01	ug/L	0.16		F	F
0126	Parcels 6-7-8	Tetrachloroethene	4/29/2015	0.88	ug/L	0.16	J	F	F
0126	Parcels 6-7-8	Tetrachloroethene	7/27/2015	0.9	ug/L	0.16	J	F	F
0126	Parcels 6-7-8	Tetrachloroethene	10/26/2015	0.88	ug/L	0.16	J		F
0126	Parcels 6-7-8	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	trans-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	trans-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	trans-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0126	Parcels 6-7-8	Trichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	Trichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	Trichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	Trichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0126	Parcels 6-7-8	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	Vinyl chloride	4/29/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	Vinyl chloride	7/27/2015	0.16	ug/L	0.16	U	F	F
0126	Parcels 6-7-8	Vinyl chloride	10/26/2015	0.16	ug/L	0.16	U		F
0138	Parcels 6-7-8	cis-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	cis-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0138	Parcels 6-7-8	Dissolved Oxygen	1/27/2015	3.4	mg/L			F	F
0138	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	3.99	mg/L			F	F
0138	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	6.73	mg/L			F	F
0138	Parcels 6-7-8	Dissolved Oxygen	10/26/2015	6.93	mg/L				F
0138	Parcels 6-7-8	Oxidation Reduction Potential	1/27/2015	201.5	mV			F	F
0138	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	133.7	mV			F	F
0138	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	4.2	mV			F	F
0138	Parcels 6-7-8	Oxidation Reduction Potential	10/26/2015	243.2	mV				F
0138	Parcels 6-7-8	pH	1/27/2015	7.11	s.u.			F	F
0138	Parcels 6-7-8	pH	4/27/2015	7.02	s.u.			F	F
0138	Parcels 6-7-8	pH	7/28/2015	7.35	s.u.			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0138	Parcels 6-7-8	pH	10/26/2015	6.82	s.u.				F
0138	Parcels 6-7-8	Temperature	1/27/2015	11.47	C			F	F
0138	Parcels 6-7-8	Temperature	4/27/2015	12.26	C			F	F
0138	Parcels 6-7-8	Temperature	7/28/2015	13.9	C			F	F
0138	Parcels 6-7-8	Temperature	10/26/2015	12.9	C				F
0138	Parcels 6-7-8	Tetrachloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Tetrachloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0138	Parcels 6-7-8	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	trans-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0138	Parcels 6-7-8	Trichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Trichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Trichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Trichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0138	Parcels 6-7-8	Tritium	1/27/2015	430	pCi/L	346		JF	F
0138	Parcels 6-7-8	Tritium	7/28/2015	1060	pCi/L	321		F	F
0138	Parcels 6-7-8	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0138	Parcels 6-7-8	Vinyl chloride	10/26/2015	0.16	ug/L	0.16	U		F
0315	Parcels 6-7-8	cis-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	cis-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0315	Parcels 6-7-8	Dissolved Oxygen	1/28/2015	0.9	mg/L			F	F
0315	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	1.25	mg/L			F	F
0315	Parcels 6-7-8	Dissolved Oxygen	7/27/2015	1.04	mg/L			F	F
0315	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	0.94	mg/L				F
0315	Parcels 6-7-8	Oxidation Reduction Potential	1/28/2015	14.6	mV			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0315	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	111.1	mV			F	F
0315	Parcels 6-7-8	Oxidation Reduction Potential	7/27/2015	16.4	mV			F	F
0315	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	5.2	mV				F
0315	Parcels 6-7-8	pH	1/28/2015	7.1	s.u.			F	F
0315	Parcels 6-7-8	pH	4/27/2015	6.99	s.u.			F	F
0315	Parcels 6-7-8	pH	7/27/2015	7.19	s.u.			F	F
0315	Parcels 6-7-8	pH	10/28/2015	6.92	s.u.				F
0315	Parcels 6-7-8	Temperature	1/28/2015	13.15	C			F	F
0315	Parcels 6-7-8	Temperature	4/27/2015	14.23	C			F	F
0315	Parcels 6-7-8	Temperature	7/27/2015	16.84	C			F	F
0315	Parcels 6-7-8	Temperature	10/28/2015	14.2	C				F
0315	Parcels 6-7-8	Tetrachloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	Tetrachloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0315	Parcels 6-7-8	trans-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	trans-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0315	Parcels 6-7-8	Trichloroethene	1/28/2015	9.62	ug/L	0.16		F	F
0315	Parcels 6-7-8	Trichloroethene	4/27/2015	6.07	ug/L	0.16		F	F
0315	Parcels 6-7-8	Trichloroethene	7/27/2015	6.39	ug/L	0.16		F	F
0315	Parcels 6-7-8	Trichloroethene	10/28/2015	8.24	ug/L	0.16			F
0315	Parcels 6-7-8	Vinyl chloride	1/28/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	Vinyl chloride	7/27/2015	0.16	ug/L	0.16	U	F	F
0315	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0346	Parcels 6-7-8	cis-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	cis-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	cis-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0346	Parcels 6-7-8	Dissolved Oxygen	1/28/2015	8.92	mg/L			F	F
0346	Parcels 6-7-8	Dissolved Oxygen	4/29/2015	1.56	mg/L			F	F
0346	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	3.1	mg/L			F	F
0346	Parcels 6-7-8	Dissolved Oxygen	10/26/2015	0.61	mg/L				F
0346	Parcels 6-7-8	Oxidation Reduction Potential	1/28/2015	213.3	mV			F	F
0346	Parcels 6-7-8	Oxidation Reduction Potential	4/29/2015	-27.7	mV			F	F
0346	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	-17.6	mV			F	F
0346	Parcels 6-7-8	Oxidation Reduction Potential	10/26/2015	9.5	mV				F
0346	Parcels 6-7-8	pH	1/28/2015	8.01	s.u.			F	F
0346	Parcels 6-7-8	pH	4/29/2015	7.08	s.u.			F	F
0346	Parcels 6-7-8	pH	7/28/2015	7.3	s.u.			F	F
0346	Parcels 6-7-8	pH	10/26/2015	7.11	s.u.				F
0346	Parcels 6-7-8	Temperature	1/28/2015	12.2	C			F	F
0346	Parcels 6-7-8	Temperature	4/29/2015	13.25	C			F	F
0346	Parcels 6-7-8	Temperature	7/28/2015	15.2	C			F	F
0346	Parcels 6-7-8	Temperature	10/26/2015	14.3	C				F
0346	Parcels 6-7-8	Tetrachloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Tetrachloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Tetrachloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0346	Parcels 6-7-8	trans-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	trans-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	trans-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0346	Parcels 6-7-8	Trichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Trichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Trichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Trichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0346	Parcels 6-7-8	Tritium	1/28/2015	18.6	pCi/L	366	U	F	F
0346	Parcels 6-7-8	Tritium	7/28/2015	736	pCi/L	322		JF	F
0346	Parcels 6-7-8	Vinyl chloride	1/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Vinyl chloride	4/29/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0346	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0346	Parcels 6-7-8	Vinyl chloride	10/26/2015	0.16	ug/L	0.16	U		F
0347	Parcels 6-7-8	cis-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	cis-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	D
0347	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	cis-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0347	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		D
0347	Parcels 6-7-8	Dissolved Oxygen	1/28/2015	0.61	mg/L			F	F
0347	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	0.47	mg/L			F	F
0347	Parcels 6-7-8	Dissolved Oxygen	7/27/2015	0.97	mg/L			F	F
0347	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	0.59	mg/L				F
0347	Parcels 6-7-8	Oxidation Reduction Potential	1/28/2015	-37.3	mV			F	F
0347	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	-33	mV			F	F
0347	Parcels 6-7-8	Oxidation Reduction Potential	7/27/2015	-34.2	mV			F	F
0347	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	-48.9	mV				F
0347	Parcels 6-7-8	pH	1/28/2015	6.89	s.u.			F	F
0347	Parcels 6-7-8	pH	4/27/2015	6.81	s.u.			F	F
0347	Parcels 6-7-8	pH	7/27/2015	7.11	s.u.			F	F
0347	Parcels 6-7-8	pH	10/28/2015	6.75	s.u.				F
0347	Parcels 6-7-8	Temperature	1/28/2015	12.21	C			F	F
0347	Parcels 6-7-8	Temperature	4/27/2015	13.79	C			F	F
0347	Parcels 6-7-8	Temperature	7/27/2015	15.87	C			F	F
0347	Parcels 6-7-8	Temperature	10/28/2015	14.4	C				F
0347	Parcels 6-7-8	Tetrachloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	Tetrachloroethene	1/28/2015	0.16	ug/L	0.16	U	F	D
0347	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	Tetrachloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0347	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		D
0347	Parcels 6-7-8	trans-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0347	Parcels 6-7-8	trans-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	D
0347	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	trans-1,2-Dichloroethene	7/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0347	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		D
0347	Parcels 6-7-8	Trichloroethene	1/28/2015	25.4	ug/L	0.16		F	F
0347	Parcels 6-7-8	Trichloroethene	1/28/2015	25.9	ug/L	0.16		F	D
0347	Parcels 6-7-8	Trichloroethene	4/27/2015	24.5	ug/L	0.16		F	F
0347	Parcels 6-7-8	Trichloroethene	7/27/2015	17.6	ug/L	0.16		F	F
0347	Parcels 6-7-8	Trichloroethene	10/28/2015	19.6	ug/L	0.16			F
0347	Parcels 6-7-8	Trichloroethene	10/28/2015	21.3	ug/L	0.16			D
0347	Parcels 6-7-8	Tritium	1/28/2015	2820	pCi/L	368		F	F
0347	Parcels 6-7-8	Tritium	1/28/2015	2880	pCi/L	373		F	D
0347	Parcels 6-7-8	Tritium	7/27/2015	1690	pCi/L	320		F	F
0347	Parcels 6-7-8	Vinyl chloride	1/28/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	Vinyl chloride	1/28/2015	0.16	ug/L	0.16	U	F	D
0347	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	Vinyl chloride	7/27/2015	0.16	ug/L	0.16	U	F	F
0347	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0347	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		D
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	1/6/2015	341	mg/L	0.725			F
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	2/4/2015	343	mg/L	0.725		F	F
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	3/4/2015	378	mg/L	0.725		F	F
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	4/7/2015	359	mg/L	0.725		F	F
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	5/5/2015	357	mg/L	0.725		F	F
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	8/11/2015	368	mg/L	0.725		F	F
0379	Parcels 6-7-8	Alkalinity, Total (As CaCO3)	11/2/2015	382	mg/L	0.725			F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	1/6/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	2/4/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	3/4/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	4/7/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	D
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	5/5/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	8/11/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	cis-1,2-Dichloroethene	11/2/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	Dissolved Oxygen	1/6/2015	1.1	mg/L				F
0379	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	0.88	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	2/4/2015	0.69	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	3/4/2015	0.81	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	4/7/2015	0.66	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	4/29/2015	2.1	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	5/5/2015	2.22	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	4.32	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	8/11/2015	2.43	mg/L			F	F
0379	Parcels 6-7-8	Dissolved Oxygen	10/26/2015	0.93	mg/L				F
0379	Parcels 6-7-8	Dissolved Oxygen	11/2/2015	1.27	mg/L				F
0379	Parcels 6-7-8	Oxidation Reduction Potential	1/6/2015	71.8	mV				F
0379	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	184.9	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	2/4/2015	-6.3	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	3/4/2015	98.4	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	4/7/2015	-46.5	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	4/29/2015	-38.2	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	5/5/2015	41.3	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	-13	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	8/11/2015	-8.9	mV			F	F
0379	Parcels 6-7-8	Oxidation Reduction Potential	10/26/2015	80.1	mV				F
0379	Parcels 6-7-8	Oxidation Reduction Potential	11/2/2015	179.4	mV				F
0379	Parcels 6-7-8	pH	1/6/2015	7.04	s.u.				F
0379	Parcels 6-7-8	pH	1/29/2015	7.12	s.u.			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0379	Parcels 6-7-8	pH	2/4/2015	7.06	s.u.			F	F
0379	Parcels 6-7-8	pH	3/4/2015	7	s.u.			F	F
0379	Parcels 6-7-8	pH	4/7/2015	7	s.u.			F	F
0379	Parcels 6-7-8	pH	4/29/2015	7.08	s.u.			F	F
0379	Parcels 6-7-8	pH	5/5/2015	7.07	s.u.			F	F
0379	Parcels 6-7-8	pH	7/28/2015	7.33	s.u.			F	F
0379	Parcels 6-7-8	pH	8/11/2015	7.14	s.u.			F	F
0379	Parcels 6-7-8	pH	10/26/2015	7.08	s.u.				F
0379	Parcels 6-7-8	pH	11/2/2015	7.12	s.u.				F
0379	Parcels 6-7-8	Temperature	1/6/2015	12.86	C				F
0379	Parcels 6-7-8	Temperature	1/29/2015	13.39	C			F	F
0379	Parcels 6-7-8	Temperature	2/4/2015	13.47	C			F	F
0379	Parcels 6-7-8	Temperature	3/4/2015	13.16	C			F	F
0379	Parcels 6-7-8	Temperature	4/7/2015	14.78	C			F	F
0379	Parcels 6-7-8	Temperature	4/29/2015	14.5	C			F	F
0379	Parcels 6-7-8	Temperature	5/5/2015	15.55	C			F	F
0379	Parcels 6-7-8	Temperature	7/28/2015	17.1	C			F	F
0379	Parcels 6-7-8	Temperature	8/11/2015	15.4	C			F	F
0379	Parcels 6-7-8	Temperature	10/26/2015	14.7	C				F
0379	Parcels 6-7-8	Temperature	11/2/2015	14.4	C				F
0379	Parcels 6-7-8	Tetrachloroethene	1/6/2015	0.42	ug/L	0.16	J		F
0379	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.32	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	2/4/2015	0.35	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	3/4/2015	0.28	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	4/7/2015	0.29	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	4/29/2015	0.34	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	4/29/2015	0.29	ug/L	0.16	J	F	D
0379	Parcels 6-7-8	Tetrachloroethene	5/5/2015	0.32	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.25	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	8/11/2015	0.29	ug/L	0.16	J	F	F
0379	Parcels 6-7-8	Tetrachloroethene	10/26/2015	0.35	ug/L	0.16	J		F
0379	Parcels 6-7-8	Tetrachloroethene	11/2/2015	0.4	ug/L	0.16	J		F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	1/6/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	2/4/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	3/4/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	4/7/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	4/29/2015	0.16	ug/L	0.16	U	F	D
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	5/5/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	8/11/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	10/26/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	trans-1,2-Dichloroethene	11/2/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	Trichloroethene	1/6/2015	1.82	ug/L	0.16			F
0379	Parcels 6-7-8	Trichloroethene	1/29/2015	1.68	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	2/4/2015	1.77	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	3/4/2015	1.54	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	4/7/2015	1.78	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	4/29/2015	1.52	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	4/29/2015	1.41	ug/L	0.16		F	D
0379	Parcels 6-7-8	Trichloroethene	5/5/2015	1.5	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	7/28/2015	1.31	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	8/11/2015	1.71	ug/L	0.16		F	F
0379	Parcels 6-7-8	Trichloroethene	10/26/2015	1.77	ug/L	0.16			F
0379	Parcels 6-7-8	Trichloroethene	11/2/2015	1.7	ug/L	0.16			F
0379	Parcels 6-7-8	Tritium	1/29/2015	1030	pCi/L	365		JF	F
0379	Parcels 6-7-8	Tritium	7/28/2015	954	pCi/L	317		F	F
0379	Parcels 6-7-8	Vinyl chloride	1/6/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	2/4/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	3/4/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	4/7/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0379	Parcels 6-7-8	Vinyl chloride	4/29/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	4/29/2015	0.16	ug/L	0.16	U	F	D
0379	Parcels 6-7-8	Vinyl chloride	5/5/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	8/11/2015	0.16	ug/L	0.16	U	F	F
0379	Parcels 6-7-8	Vinyl chloride	10/26/2015	0.16	ug/L	0.16	U		F
0379	Parcels 6-7-8	Vinyl chloride	11/2/2015	0.16	ug/L	0.16	U		F
0386	Parcels 6-7-8	cis-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	cis-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0386	Parcels 6-7-8	Dissolved Oxygen	1/28/2015	3.63	mg/L			F	F
0386	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	5.86	mg/L			F	F
0386	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	2.73	mg/L			F	F
0386	Parcels 6-7-8	Dissolved Oxygen	10/27/2015	3.61	mg/L				F
0386	Parcels 6-7-8	Oxidation Reduction Potential	1/28/2015	94.9	mV			F	F
0386	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	131.6	mV			F	F
0386	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	16.8	mV			F	F
0386	Parcels 6-7-8	Oxidation Reduction Potential	10/27/2015	45.8	mV				F
0386	Parcels 6-7-8	pH	1/28/2015	6.87	s.u.			F	F
0386	Parcels 6-7-8	pH	4/27/2015	6.71	s.u.			F	F
0386	Parcels 6-7-8	pH	7/28/2015	7.17	s.u.			F	F
0386	Parcels 6-7-8	pH	10/27/2015	6.82	s.u.				F
0386	Parcels 6-7-8	Temperature	1/28/2015	11.66	C			F	F
0386	Parcels 6-7-8	Temperature	4/27/2015	12.91	C			F	F
0386	Parcels 6-7-8	Temperature	7/28/2015	14	C			F	F
0386	Parcels 6-7-8	Temperature	10/27/2015	12.6	C				F
0386	Parcels 6-7-8	Tetrachloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	J	F	F
0386	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	Tetrachloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0386	Parcels 6-7-8	trans-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0386	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	trans-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0386	Parcels 6-7-8	Trichloroethene	1/28/2015	2.35	ug/L	0.16		F	F
0386	Parcels 6-7-8	Trichloroethene	4/27/2015	2.11	ug/L	0.16		F	F
0386	Parcels 6-7-8	Trichloroethene	7/28/2015	1.94	ug/L	0.16		F	F
0386	Parcels 6-7-8	Trichloroethene	10/27/2015	2.14	ug/L	0.16			F
0386	Parcels 6-7-8	Vinyl chloride	1/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0386	Parcels 6-7-8	Vinyl chloride	10/27/2015	0.16	ug/L	0.16	U		F
0387	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	cis-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0387	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	3.03	mg/L			F	F
0387	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	1	mg/L			F	F
0387	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	2.65	mg/L			F	F
0387	Parcels 6-7-8	Dissolved Oxygen	10/27/2015	0.92	mg/L				F
0387	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	192.1	mV			F	F
0387	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	104.9	mV			F	F
0387	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	-16.1	mV			F	F
0387	Parcels 6-7-8	Oxidation Reduction Potential	10/27/2015	118.9	mV				F
0387	Parcels 6-7-8	pH	1/29/2015	6.99	s.u.			F	F
0387	Parcels 6-7-8	pH	4/27/2015	6.85	s.u.			F	F
0387	Parcels 6-7-8	pH	7/28/2015	7.4	s.u.			F	F
0387	Parcels 6-7-8	pH	10/27/2015	6.8	s.u.				F
0387	Parcels 6-7-8	Temperature	1/29/2015	11.87	C			F	F
0387	Parcels 6-7-8	Temperature	4/27/2015	13.77	C			F	F
0387	Parcels 6-7-8	Temperature	7/28/2015	14.6	C			F	F
0387	Parcels 6-7-8	Temperature	10/27/2015	13.1	C				F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0387	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.24	ug/L	0.16	J	F	F
0387	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.22	ug/L	0.16	J	F	F
0387	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.3	ug/L	0.16	J	F	F
0387	Parcels 6-7-8	Tetrachloroethene	10/27/2015	0.26	ug/L	0.16	J		F
0387	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	trans-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0387	Parcels 6-7-8	Trichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	Trichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	Trichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	Trichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0387	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0387	Parcels 6-7-8	Vinyl chloride	10/27/2015	0.16	ug/L	0.16	U		F
0389	Parcels 6-7-8	cis-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	cis-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0389	Parcels 6-7-8	Dissolved Oxygen	1/28/2015	2.84	mg/L			F	F
0389	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	3.08	mg/L			F	F
0389	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	4.02	mg/L			F	F
0389	Parcels 6-7-8	Dissolved Oxygen	10/27/2015	1.17	mg/L				F
0389	Parcels 6-7-8	Oxidation Reduction Potential	1/28/2015	124.2	mV			F	F
0389	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	86.8	mV			F	F
0389	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	22.4	mV			F	F
0389	Parcels 6-7-8	Oxidation Reduction Potential	10/27/2015	120.9	mV				F
0389	Parcels 6-7-8	pH	1/28/2015	6.88	s.u.			F	F
0389	Parcels 6-7-8	pH	4/27/2015	6.69	s.u.			F	F
0389	Parcels 6-7-8	pH	7/28/2015	7.23	s.u.			F	F
0389	Parcels 6-7-8	pH	10/27/2015	6.83	s.u.				F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0389	Parcels 6-7-8	Temperature	1/28/2015	11.46	C			F	F
0389	Parcels 6-7-8	Temperature	4/27/2015	13.5	C			F	F
0389	Parcels 6-7-8	Temperature	7/28/2015	15.4	C			F	F
0389	Parcels 6-7-8	Temperature	10/27/2015	12.4	C				F
0389	Parcels 6-7-8	Tetrachloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Tetrachloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0389	Parcels 6-7-8	trans-1,2-Dichloroethene	1/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	trans-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0389	Parcels 6-7-8	Trichloroethene	1/28/2015	0.23	ug/L	0.16	J	F	F
0389	Parcels 6-7-8	Trichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Trichloroethene	7/28/2015	0.18	ug/L	0.16	J	F	F
0389	Parcels 6-7-8	Trichloroethene	10/27/2015	0.29	ug/L	0.16	J		F
0389	Parcels 6-7-8	Vinyl chloride	1/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0389	Parcels 6-7-8	Vinyl chloride	10/27/2015	0.16	ug/L	0.16	U		F
0392	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	cis-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	cis-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0392	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	3.71	mg/L			F	F
0392	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	1.89	mg/L			F	F
0392	Parcels 6-7-8	Dissolved Oxygen	7/28/2015	2.45	mg/L			F	F
0392	Parcels 6-7-8	Dissolved Oxygen	10/27/2015	3.85	mg/L				F
0392	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	225.5	mV			F	F
0392	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	119	mV			F	F
0392	Parcels 6-7-8	Oxidation Reduction Potential	7/28/2015	17.3	mV			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0392	Parcels 6-7-8	Oxidation Reduction Potential	10/27/2015	105.6	mV				F
0392	Parcels 6-7-8	pH	1/29/2015	6.9	s.u.			F	F
0392	Parcels 6-7-8	pH	4/27/2015	6.73	s.u.			F	F
0392	Parcels 6-7-8	pH	7/28/2015	7.16	s.u.			F	F
0392	Parcels 6-7-8	pH	10/27/2015	6.61	s.u.				F
0392	Parcels 6-7-8	Temperature	1/29/2015	10.91	C			F	F
0392	Parcels 6-7-8	Temperature	4/27/2015	13.8	C			F	F
0392	Parcels 6-7-8	Temperature	7/28/2015	16.1	C			F	F
0392	Parcels 6-7-8	Temperature	10/27/2015	13.1	C				F
0392	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.29	ug/L	0.16	J	F	F
0392	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.29	ug/L	0.16	J	F	F
0392	Parcels 6-7-8	Tetrachloroethene	7/28/2015	0.27	ug/L	0.16	J	F	F
0392	Parcels 6-7-8	Tetrachloroethene	10/27/2015	0.25	ug/L	0.16	J		F
0392	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	trans-1,2-Dichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	trans-1,2-Dichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0392	Parcels 6-7-8	Trichloroethene	1/29/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	Trichloroethene	4/27/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	Trichloroethene	7/28/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	Trichloroethene	10/27/2015	0.16	ug/L	0.16	U		F
0392	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	Vinyl chloride	7/28/2015	0.16	ug/L	0.16	U	F	F
0392	Parcels 6-7-8	Vinyl chloride	10/27/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.57	ug/L	0.16	J		F
0601	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.73	ug/L	0.16	J		F
0601	Parcels 6-7-8	cis-1,2-Dichloroethene	7/29/2015	0.62	ug/L	0.16	J		F
0601	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	4.71	mg/L				F
0601	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	3.45	mg/L				F
0601	Parcels 6-7-8	Dissolved Oxygen	7/29/2015	8.59	mg/L				F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0601	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	6.25	mg/L				F
0601	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	95.6	mV				F
0601	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	73.5	mV				F
0601	Parcels 6-7-8	Oxidation Reduction Potential	7/29/2015	146.9	mV				F
0601	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	102.6	mV				F
0601	Parcels 6-7-8	pH	1/29/2015	7.11	s.u.				F
0601	Parcels 6-7-8	pH	4/27/2015	7.16	s.u.				F
0601	Parcels 6-7-8	pH	7/29/2015	7.32	s.u.				F
0601	Parcels 6-7-8	pH	10/28/2015	7.12	s.u.				F
0601	Parcels 6-7-8	Specific Conductance	1/29/2015	1512	umhos/cm				F
0601	Parcels 6-7-8	Specific Conductance	4/27/2015	1317	umhos/cm				F
0601	Parcels 6-7-8	Specific Conductance	7/29/2015	1450	umhos/cm				F
0601	Parcels 6-7-8	Specific Conductance	10/28/2015	710	umhos/cm				F
0601	Parcels 6-7-8	Tetrachloroethene	1/29/2015	14.9	ug/L	0.16			F
0601	Parcels 6-7-8	Tetrachloroethene	4/27/2015	12.8	ug/L	0.16			F
0601	Parcels 6-7-8	Tetrachloroethene	7/29/2015	12.2	ug/L	0.16			F
0601	Parcels 6-7-8	Tetrachloroethene	10/28/2015	1.31	ug/L	0.16			F
0601	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	Trichloroethene	1/29/2015	6.68	ug/L	0.16			F
0601	Parcels 6-7-8	Trichloroethene	4/27/2015	3.98	ug/L	0.16			F
0601	Parcels 6-7-8	Trichloroethene	7/29/2015	6.94	ug/L	0.16			F
0601	Parcels 6-7-8	Trichloroethene	10/28/2015	1.04	ug/L	0.16			F
0601	Parcels 6-7-8	Tritium	1/29/2015	22300	pCi/L	389			F
0601	Parcels 6-7-8	Tritium	7/29/2015	29000	pCi/L	321			F
0601	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		F
0601	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0602	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	9.89	ug/L	0.16			F
0602	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	7.5	ug/L	0.16			F
0602	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	4.56	ug/L	0.16			F
0602	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	6.63	mg/L				F
0602	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	6.07	mg/L				F
0602	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	10.16	mg/L				F
0602	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	73	mV				F
0602	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	111.2	mV				F
0602	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	156.5	mV				F
0602	Parcels 6-7-8	pH	1/29/2015	7.55	s.u.				F
0602	Parcels 6-7-8	pH	4/27/2015	7.05	s.u.				F
0602	Parcels 6-7-8	pH	10/28/2015	7.41	s.u.				F
0602	Parcels 6-7-8	Specific Conductance	1/29/2015	1683	umhos/cm				F
0602	Parcels 6-7-8	Specific Conductance	4/27/2015	1615	umhos/cm				F
0602	Parcels 6-7-8	Specific Conductance	10/28/2015	1350	umhos/cm				F
0602	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0602	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0602	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0602	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.67	ug/L	0.16	J		F
0602	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.45	ug/L	0.16	J		F
0602	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0602	Parcels 6-7-8	Trichloroethene	1/29/2015	19	ug/L	0.16			F
0602	Parcels 6-7-8	Trichloroethene	4/27/2015	21.4	ug/L	0.16			F
0602	Parcels 6-7-8	Trichloroethene	10/28/2015	14.7	ug/L	0.16			F
0602	Parcels 6-7-8	Tritium	1/29/2015	7280	pCi/L	370			F
0602	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F
0602	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U		F
0602	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0605	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	3.56	ug/L	0.16			F
0605	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	1.86	ug/L	0.16			F
0605	Parcels 6-7-8	cis-1,2-Dichloroethene	7/29/2015	1.09	ug/L	0.16			F
0605	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	2.19	ug/L	0.16			F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0605	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	8.96	mg/L				F
0605	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	7.03	mg/L				F
0605	Parcels 6-7-8	Dissolved Oxygen	7/29/2015	7.22	mg/L				F
0605	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	6.92	mg/L				F
0605	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	120	mV				F
0605	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	101	mV				F
0605	Parcels 6-7-8	Oxidation Reduction Potential	7/29/2015	-94.9	mV				F
0605	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	24.6	mV				F
0605	Parcels 6-7-8	pH	1/29/2015	6.83	s.u.				F
0605	Parcels 6-7-8	pH	4/27/2015	7.26	s.u.				F
0605	Parcels 6-7-8	pH	7/29/2015	7.45	s.u.				F
0605	Parcels 6-7-8	pH	10/28/2015	7.62	s.u.				F
0605	Parcels 6-7-8	Specific Conductance	1/29/2015	2433	umhos/cm				F
0605	Parcels 6-7-8	Specific Conductance	4/27/2015	2140	umhos/cm				F
0605	Parcels 6-7-8	Specific Conductance	7/29/2015	1890	umhos/cm				F
0605	Parcels 6-7-8	Specific Conductance	10/28/2015	1210	umhos/cm				F
0605	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.23	ug/L	0.16	J		F
0605	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.26	ug/L	0.16	J		F
0605	Parcels 6-7-8	Tetrachloroethene	7/29/2015	0.28	ug/L	0.16	J		F
0605	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0605	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.22	ug/L	0.16	J		F
0605	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0605	Parcels 6-7-8	trans-1,2-Dichloroethene	7/29/2015	0.24	ug/L	0.16	J		F
0605	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0605	Parcels 6-7-8	Trichloroethene	1/29/2015	13	ug/L	0.16			F
0605	Parcels 6-7-8	Trichloroethene	4/27/2015	10.9	ug/L	0.16			F
0605	Parcels 6-7-8	Trichloroethene	7/29/2015	12.3	ug/L	0.16			F
0605	Parcels 6-7-8	Trichloroethene	10/28/2015	7.23	ug/L	0.16			F
0605	Parcels 6-7-8	Tritium	1/29/2015	7910	pCi/L	354			F
0605	Parcels 6-7-8	Tritium	7/29/2015	8340	pCi/L	320			F
0605	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0605	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U		F
0605	Parcels 6-7-8	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		F
0605	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.18	ug/L	0.16	J		F
0606	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	cis-1,2-Dichloroethene	7/29/2015	0.7	ug/L	0.16	J		F
0606	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.5	ug/L	0.16	J		F
0606	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	9.14	mg/L				F
0606	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	6.59	mg/L				F
0606	Parcels 6-7-8	Dissolved Oxygen	7/29/2015	8.13	mg/L				F
0606	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	5.43	mg/L				F
0606	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	72	mV				F
0606	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	78.2	mV				F
0606	Parcels 6-7-8	Oxidation Reduction Potential	7/29/2015	24.2	mV				F
0606	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	0.8	mV				F
0606	Parcels 6-7-8	pH	1/29/2015	7.32	s.u.				F
0606	Parcels 6-7-8	pH	4/27/2015	7.37	s.u.				F
0606	Parcels 6-7-8	pH	7/29/2015	7.54	s.u.				F
0606	Parcels 6-7-8	pH	10/28/2015	7.48	s.u.				F
0606	Parcels 6-7-8	Specific Conductance	1/29/2015	1531	umhos/cm				F
0606	Parcels 6-7-8	Specific Conductance	4/27/2015	1398	umhos/cm				F
0606	Parcels 6-7-8	Specific Conductance	7/29/2015	2100	umhos/cm				F
0606	Parcels 6-7-8	Specific Conductance	10/28/2015	2470	umhos/cm				F
0606	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Tetrachloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Trichloroethene	1/29/2015	1	ug/L	0.16			F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0606	Parcels 6-7-8	Trichloroethene	4/27/2015	0.61	ug/L	0.16	J		F
0606	Parcels 6-7-8	Trichloroethene	7/29/2015	6.99	ug/L	0.16			F
0606	Parcels 6-7-8	Trichloroethene	10/28/2015	4.08	ug/L	0.16			F
0606	Parcels 6-7-8	Tritium	1/29/2015	2480	pCi/L	371			F
0606	Parcels 6-7-8	Tritium	7/29/2015	5580	pCi/L	321			F
0606	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		F
0606	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.71	ug/L	0.16	J		F
0607	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.52	ug/L	0.16	J		F
0607	Parcels 6-7-8	cis-1,2-Dichloroethene	7/29/2015	0.9	ug/L	0.16	J		F
0607	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.28	ug/L	0.16	J		F
0607	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	8.03	mg/L				F
0607	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	6.13	mg/L				F
0607	Parcels 6-7-8	Dissolved Oxygen	7/29/2015	11.64	mg/L				F
0607	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	7.63	mg/L				F
0607	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	140	mV				F
0607	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	88.6	mV				F
0607	Parcels 6-7-8	Oxidation Reduction Potential	7/29/2015	61.4	mV				F
0607	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	72.8	mV				F
0607	Parcels 6-7-8	pH	1/29/2015	7.01	s.u.				F
0607	Parcels 6-7-8	pH	4/27/2015	7.37	s.u.				F
0607	Parcels 6-7-8	pH	7/29/2015	7.55	s.u.				F
0607	Parcels 6-7-8	pH	10/28/2015	7.47	s.u.				F
0607	Parcels 6-7-8	Specific Conductance	1/29/2015	2018	umhos/cm				F
0607	Parcels 6-7-8	Specific Conductance	4/27/2015	1578	umhos/cm				F
0607	Parcels 6-7-8	Specific Conductance	7/29/2015	1670	umhos/cm				F
0607	Parcels 6-7-8	Specific Conductance	10/28/2015	1380	umhos/cm				F
0607	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.2	ug/L	0.16	J		F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0607	Parcels 6-7-8	Tetrachloroethene	7/29/2015	0.18	ug/L	0.16	J		F
0607	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	Trichloroethene	1/29/2015	4.86	ug/L	0.16			F
0607	Parcels 6-7-8	Trichloroethene	4/27/2015	4.38	ug/L	0.16			F
0607	Parcels 6-7-8	Trichloroethene	7/29/2015	6.67	ug/L	0.16			F
0607	Parcels 6-7-8	Trichloroethene	10/28/2015	3.25	ug/L	0.16			F
0607	Parcels 6-7-8	Tritium	1/29/2015	2760	pCi/L	369			F
0607	Parcels 6-7-8	Tritium	7/29/2015	3900	pCi/L	320			F
0607	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		F
0607	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	cis-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	cis-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	cis-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Dissolved Oxygen	1/29/2015	10.76	mg/L				F
0608	Parcels 6-7-8	Dissolved Oxygen	4/27/2015	9.9	mg/L				F
0608	Parcels 6-7-8	Dissolved Oxygen	7/29/2015	7.51	mg/L				F
0608	Parcels 6-7-8	Dissolved Oxygen	10/28/2015	8.54	mg/L				F
0608	Parcels 6-7-8	Oxidation Reduction Potential	1/29/2015	62	mV				F
0608	Parcels 6-7-8	Oxidation Reduction Potential	4/27/2015	93.5	mV				F
0608	Parcels 6-7-8	Oxidation Reduction Potential	7/29/2015	54.5	mV				F
0608	Parcels 6-7-8	Oxidation Reduction Potential	10/28/2015	69.4	mV				F
0608	Parcels 6-7-8	pH	1/29/2015	7.89	s.u.				F
0608	Parcels 6-7-8	pH	4/27/2015	7.9	s.u.				F
0608	Parcels 6-7-8	pH	7/29/2015	8.15	s.u.				F
0608	Parcels 6-7-8	pH	10/28/2015	8.18	s.u.				F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0608	Parcels 6-7-8	Specific Conductance	1/29/2015	1717	umhos/cm				F
0608	Parcels 6-7-8	Specific Conductance	4/27/2015	1846	umhos/cm				F
0608	Parcels 6-7-8	Specific Conductance	7/29/2015	2110	umhos/cm				F
0608	Parcels 6-7-8	Specific Conductance	10/28/2015	1930	umhos/cm				F
0608	Parcels 6-7-8	Tetrachloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Tetrachloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Tetrachloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Tetrachloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	trans-1,2-Dichloroethene	4/27/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	trans-1,2-Dichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Trichloroethene	1/29/2015	1.45	ug/L	0.16			F
0608	Parcels 6-7-8	Trichloroethene	4/27/2015	1.42	ug/L	0.16			F
0608	Parcels 6-7-8	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Trichloroethene	10/28/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Tritium	1/29/2015	5790	pCi/L	371			F
0608	Parcels 6-7-8	Tritium	7/29/2015	6170	pCi/L	322			F
0608	Parcels 6-7-8	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Vinyl chloride	4/27/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		F
0608	Parcels 6-7-8	Vinyl chloride	10/28/2015	0.16	ug/L	0.16	U		F
0353	Phase I	cis-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	Dissolved Oxygen	1/26/2015	4.53	mg/L			FQ	F
0353	Phase I	Dissolved Oxygen	7/29/2015	0.8	mg/L			FQ	F
0353	Phase I	Oxidation Reduction Potential	1/26/2015	34.5	mV			FQ	F
0353	Phase I	Oxidation Reduction Potential	7/29/2015	47.3	mV			FQ	F
0353	Phase I	pH	1/26/2015	7.45	s.u.			FQ	F
0353	Phase I	pH	7/29/2015	6.98	s.u.			FQ	F
0353	Phase I	Specific Conductance	1/26/2015	1465	umhos/cm			FQ	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0353	Phase I	Specific Conductance	7/29/2015	1380	umhos/cm			FQ	F
0353	Phase I	Temperature	1/26/2015	5.44	C			FQ	F
0353	Phase I	Temperature	7/29/2015	20.8	C			FQ	F
0353	Phase I	trans-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	Trichloroethene	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	Vinyl chloride	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0353	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0400	Phase I	cis-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	Dissolved Oxygen	1/26/2015	1.13	mg/L			F	F
0400	Phase I	Dissolved Oxygen	7/29/2015	3	mg/L			F	F
0400	Phase I	Oxidation Reduction Potential	1/26/2015	79.3	mV			F	F
0400	Phase I	Oxidation Reduction Potential	7/29/2015	49.7	mV			F	F
0400	Phase I	pH	1/26/2015	7.01	s.u.			F	F
0400	Phase I	pH	7/29/2015	7.06	s.u.			F	F
0400	Phase I	Specific Conductance	1/26/2015	1266	umhos/cm			F	F
0400	Phase I	Specific Conductance	7/29/2015	1300	umhos/cm			F	F
0400	Phase I	Temperature	1/26/2015	11.34	C			F	F
0400	Phase I	Temperature	7/29/2015	14.6	C			F	F
0400	Phase I	trans-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	Trichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	Vinyl chloride	1/26/2015	0.16	ug/L	0.16	U	F	F
0400	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Alkalinity, Total (As CaCO3)	1/5/2015	459	mg/L	0.725			F
0402	Phase I	Alkalinity, Total (As CaCO3)	2/2/2015	402	mg/L	0.725		F	F
0402	Phase I	Alkalinity, Total (As CaCO3)	3/2/2015	426	mg/L	0.725		F	F
0402	Phase I	Alkalinity, Total (As CaCO3)	4/6/2015	444	mg/L	0.725		F	F
0402	Phase I	Alkalinity, Total (As CaCO3)	5/5/2015	431	mg/L	0.725		F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0402	Phase I	Alkalinity, Total (As CaCO3)	8/11/2015	406	mg/L	0.725		F	F
0402	Phase I	Alkalinity, Total (As CaCO3)	11/2/2015	420	mg/L	0.725			F
0402	Phase I	cis-1,2-Dichloroethene	1/5/2015	0.16	ug/L	0.16	U		F
0402	Phase I	cis-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	2/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	3/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	4/6/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	5/5/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	8/11/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	cis-1,2-Dichloroethene	11/2/2015	0.4	ug/L	0.16	J		F
0402	Phase I	Dissolved Oxygen	1/5/2015	2.75	mg/L				F
0402	Phase I	Dissolved Oxygen	1/26/2015	1.31	mg/L			F	F
0402	Phase I	Dissolved Oxygen	2/2/2015	3.81	mg/L			F	F
0402	Phase I	Dissolved Oxygen	3/2/2015	0.34	mg/L			F	F
0402	Phase I	Dissolved Oxygen	4/6/2015	4.04	mg/L			F	F
0402	Phase I	Dissolved Oxygen	5/5/2015	4.42	mg/L			F	F
0402	Phase I	Dissolved Oxygen	7/29/2015	3.15	mg/L			F	F
0402	Phase I	Dissolved Oxygen	8/11/2015	4.22	mg/L			F	F
0402	Phase I	Dissolved Oxygen	11/2/2015	0.39	mg/L				F
0402	Phase I	Oxidation Reduction Potential	1/5/2015	246.9	mV				F
0402	Phase I	Oxidation Reduction Potential	1/26/2015	182.1	mV			F	F
0402	Phase I	Oxidation Reduction Potential	2/2/2015	116.5	mV			F	F
0402	Phase I	Oxidation Reduction Potential	3/2/2015	95.8	mV			F	F
0402	Phase I	Oxidation Reduction Potential	4/6/2015	124.3	mV			F	F
0402	Phase I	Oxidation Reduction Potential	5/5/2015	126.7	mV			F	F
0402	Phase I	Oxidation Reduction Potential	7/29/2015	71.9	mV			F	F
0402	Phase I	Oxidation Reduction Potential	8/11/2015	63.4	mV			F	F
0402	Phase I	Oxidation Reduction Potential	11/2/2015	152.5	mV				F
0402	Phase I	pH	1/5/2015	6.84	s.u.				F
0402	Phase I	pH	1/26/2015	7.03	s.u.			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0402	Phase I	pH	2/2/2015	6.86	s.u.			F	F
0402	Phase I	pH	3/2/2015	6.88	s.u.			F	F
0402	Phase I	pH	4/6/2015	6.77	s.u.			F	F
0402	Phase I	pH	5/5/2015	6.7	s.u.			F	F
0402	Phase I	pH	7/29/2015	7.17	s.u.			F	F
0402	Phase I	pH	8/11/2015	7.01	s.u.			F	F
0402	Phase I	pH	11/2/2015	7.04	s.u.				F
0402	Phase I	Specific Conductance	1/5/2015	1284	umhos/cm				F
0402	Phase I	Specific Conductance	1/26/2015	1257	umhos/cm			F	F
0402	Phase I	Specific Conductance	2/2/2015	1297.8	umhos/cm			F	F
0402	Phase I	Specific Conductance	3/2/2015	1259	umhos/cm			F	F
0402	Phase I	Specific Conductance	4/6/2015	1264	umhos/cm			F	F
0402	Phase I	Specific Conductance	5/5/2015	1438	umhos/cm			F	F
0402	Phase I	Specific Conductance	7/29/2015	1360	umhos/cm			F	F
0402	Phase I	Specific Conductance	8/11/2015	1380	umhos/cm			F	F
0402	Phase I	Specific Conductance	11/2/2015	1360	umhos/cm				F
0402	Phase I	Temperature	1/5/2015	10.75	C				F
0402	Phase I	Temperature	1/26/2015	11.41	C			F	F
0402	Phase I	Temperature	2/2/2015	11.35	C			F	F
0402	Phase I	Temperature	3/2/2015	11.83	C			F	F
0402	Phase I	Temperature	4/6/2015	13.59	C			F	F
0402	Phase I	Temperature	5/5/2015	13.78	C			F	F
0402	Phase I	Temperature	7/29/2015	15.6	C			F	F
0402	Phase I	Temperature	8/11/2015	15.2	C			F	F
0402	Phase I	Temperature	11/2/2015	14	C				F
0402	Phase I	trans-1,2-Dichloroethene	1/5/2015	0.16	ug/L	0.16	U		F
0402	Phase I	trans-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	trans-1,2-Dichloroethene	2/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	trans-1,2-Dichloroethene	3/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	trans-1,2-Dichloroethene	4/6/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	trans-1,2-Dichloroethene	5/5/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0402	Phase I	trans-1,2-Dichloroethene	8/11/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	trans-1,2-Dichloroethene	11/2/2015	0.16	ug/L	0.16	U		F
0402	Phase I	Trichloroethene	1/5/2015	0.32	ug/L	0.16	J		F
0402	Phase I	Trichloroethene	1/26/2015	0.43	ug/L	0.16	J	F	F
0402	Phase I	Trichloroethene	2/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Trichloroethene	3/2/2015	0.52	ug/L	0.16	J	F	F
0402	Phase I	Trichloroethene	4/6/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Trichloroethene	5/5/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Trichloroethene	8/11/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Trichloroethene	11/2/2015	0.81	ug/L	0.16	J		F
0402	Phase I	Vinyl chloride	1/5/2015	0.16	ug/L	0.16	U		F
0402	Phase I	Vinyl chloride	1/26/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	2/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	3/2/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	4/6/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	5/5/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	8/11/2015	0.16	ug/L	0.16	U	F	F
0402	Phase I	Vinyl chloride	11/2/2015	0.16	ug/L	0.16	U		F
0411	Phase I	cis-1,2-Dichloroethene	1/27/2015	3.34	ug/L	0.16		F	F
0411	Phase I	cis-1,2-Dichloroethene	1/27/2015	3.3	ug/L	0.16		F	D
0411	Phase I	cis-1,2-Dichloroethene	7/29/2015	1.69	ug/L	0.16		F	F
0411	Phase I	Dissolved Oxygen	1/27/2015	0.72	mg/L			F	F
0411	Phase I	Dissolved Oxygen	7/29/2015	6.23	mg/L			F	F
0411	Phase I	Oxidation Reduction Potential	1/27/2015	29.9	mV			F	F
0411	Phase I	Oxidation Reduction Potential	7/29/2015	76.1	mV			F	F
0411	Phase I	pH	1/27/2015	5.67	s.u.			F	F
0411	Phase I	pH	7/29/2015	7	s.u.			F	F
0411	Phase I	Specific Conductance	1/27/2015	1417	umhos/cm			F	F
0411	Phase I	Specific Conductance	7/29/2015	1410	umhos/cm			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0411	Phase I	Temperature	1/27/2015	9.12	C			F	F
0411	Phase I	Temperature	7/29/2015	16.5	C			F	F
0411	Phase I	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0411	Phase I	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	D
0411	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0411	Phase I	Trichloroethene	1/27/2015	10.8	ug/L	0.16		F	F
0411	Phase I	Trichloroethene	1/27/2015	10.6	ug/L	0.16		F	D
0411	Phase I	Trichloroethene	7/29/2015	10.3	ug/L	0.16		F	F
0411	Phase I	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0411	Phase I	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	D
0411	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	F	F
0443	Phase I	cis-1,2-Dichloroethene	1/27/2015	0.27	ug/L	0.16	J	F	F
0443	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.33	ug/L	0.16	J	F	F
0443	Phase I	Dissolved Oxygen	1/27/2015	2.73	mg/L			F	F
0443	Phase I	Dissolved Oxygen	7/29/2015	4.13	mg/L			F	F
0443	Phase I	Oxidation Reduction Potential	1/27/2015	-89.5	mV			F	F
0443	Phase I	Oxidation Reduction Potential	7/29/2015	116.5	mV			F	F
0443	Phase I	pH	1/27/2015	10.46	s.u.			F	F
0443	Phase I	pH	7/29/2015	7.22	s.u.			F	F
0443	Phase I	Specific Conductance	1/27/2015	1359	umhos/cm			F	F
0443	Phase I	Specific Conductance	7/29/2015	1280	umhos/cm			F	F
0443	Phase I	Temperature	1/27/2015	11.07	C			F	F
0443	Phase I	Temperature	7/29/2015	16.5	C			F	F
0443	Phase I	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0443	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
0443	Phase I	Trichloroethene	1/27/2015	6.03	ug/L	0.16		F	F
0443	Phase I	Trichloroethene	7/29/2015	5.87	ug/L	0.16		F	F
0443	Phase I	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0443	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	F	F
0444	Phase I	cis-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0444	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0444	Phase I	Dissolved Oxygen	1/27/2015	1.33	mg/L			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0444	Phase I	Dissolved Oxygen	7/29/2015	1.99	mg/L			FQ	F
0444	Phase I	Oxidation Reduction Potential	1/27/2015	-43.4	mV			F	F
0444	Phase I	Oxidation Reduction Potential	7/29/2015	34.1	mV			FQ	F
0444	Phase I	pH	1/27/2015	8.38	s.u.			F	F
0444	Phase I	pH	7/29/2015	7.38	s.u.			FQ	F
0444	Phase I	Specific Conductance	1/27/2015	1251	umhos/cm			F	F
0444	Phase I	Specific Conductance	7/29/2015	1290	umhos/cm			FQ	F
0444	Phase I	Temperature	1/27/2015	8.96	C			F	F
0444	Phase I	Temperature	7/29/2015	18.8	C			FQ	F
0444	Phase I	trans-1,2-Dichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0444	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0444	Phase I	Trichloroethene	1/27/2015	0.16	ug/L	0.16	U	F	F
0444	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0444	Phase I	Vinyl chloride	1/27/2015	0.16	ug/L	0.16	U	F	F
0444	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	cis-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	Dissolved Oxygen	1/26/2015	0.95	mg/L			FQ	F
0445	Phase I	Dissolved Oxygen	7/29/2015	0.98	mg/L			FQ	F
0445	Phase I	Oxidation Reduction Potential	1/26/2015	-76.4	mV			FQ	F
0445	Phase I	Oxidation Reduction Potential	7/29/2015	-100.5	mV			FQ	F
0445	Phase I	pH	1/26/2015	6.87	s.u.			FQ	F
0445	Phase I	pH	7/29/2015	6.97	s.u.			FQ	F
0445	Phase I	Specific Conductance	1/26/2015	22540	umhos/cm			FQ	F
0445	Phase I	Specific Conductance	7/29/2015	18910	umhos/cm			FQ	F
0445	Phase I	Temperature	1/26/2015	7.83	C			FQ	F
0445	Phase I	Temperature	7/29/2015	18.7	C			FQ	F
0445	Phase I	trans-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	Trichloroethene	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	FQ	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
0445	Phase I	Vinyl chloride	1/26/2015	0.16	ug/L	0.16	U	FQ	F
0445	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	FQ	F
0617	Phase I	cis-1,2-Dichloroethene	1/29/2015	1.94	ug/L	0.16			F
0617	Phase I	cis-1,2-Dichloroethene	7/29/2015	1.86	ug/L	0.16		J	F
0617	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	J	D
0617	Phase I	Dissolved Oxygen	1/29/2015	7.44	mg/L				F
0617	Phase I	Dissolved Oxygen	7/29/2015	8.64	mg/L				F
0617	Phase I	Oxidation Reduction Potential	1/29/2015	89	mV				F
0617	Phase I	Oxidation Reduction Potential	7/29/2015	63.8	mV				F
0617	Phase I	pH	1/29/2015	7.55	s.u.				F
0617	Phase I	pH	7/29/2015	6.91	s.u.				F
0617	Phase I	Specific Conductance	1/29/2015	1519	umhos/cm				F
0617	Phase I	Specific Conductance	7/29/2015	1670	umhos/cm				F
0617	Phase I	Tetrachloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0617	Phase I	Tetrachloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0617	Phase I	Tetrachloroethene	7/29/2015	0.16	ug/L	0.16	U		D
0617	Phase I	trans-1,2-Dichloroethene	1/29/2015	0.16	ug/L	0.16	U		F
0617	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		F
0617	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U		D
0617	Phase I	Trichloroethene	1/29/2015	8.26	ug/L	0.16			F
0617	Phase I	Trichloroethene	7/29/2015	8.05	ug/L	0.16		J	F
0617	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	J	D
0617	Phase I	Vinyl chloride	1/29/2015	0.16	ug/L	0.16	U		F
0617	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		F
0617	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U		D
P033	Phase I	cis-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	cis-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	Dissolved Oxygen	1/26/2015	1.98	mg/L			F	F
P033	Phase I	Dissolved Oxygen	7/29/2015	3.58	mg/L			F	F
P033	Phase I	Oxidation Reduction Potential	1/26/2015	144.4	mV			F	F
P033	Phase I	Oxidation Reduction Potential	7/29/2015	47.8	mV			F	F
P033	Phase I	pH	1/26/2015	7	s.u.			F	F

Sample ID	Area	Analyte	Sample Date	Value	Units	Detection Limit	Lab Qualifier	Validation Qualifier	Sample Type
P033	Phase I	pH	7/29/2015	7.12	s.u.			F	F
P033	Phase I	Specific Conductance	1/26/2015	1232	umhos/cm			F	F
P033	Phase I	Specific Conductance	7/29/2015	1530	umhos/cm			F	F
P033	Phase I	Temperature	1/26/2015	11.91	C			F	F
P033	Phase I	Temperature	7/29/2015	14.9	C			F	F
P033	Phase I	trans-1,2-Dichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	trans-1,2-Dichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	Trichloroethene	1/26/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	Trichloroethene	7/29/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	Vinyl chloride	1/26/2015	0.16	ug/L	0.16	U	F	F
P033	Phase I	Vinyl chloride	7/29/2015	0.16	ug/L	0.16	U	F	F

Appendix F

Data Assessment Reports

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Data Review and Validation Report

General Information

Requisition No. (RIN):	15016744
Sample Event:	January 26 – 29, 2015
Site(s):	Mound, Ohio; Groundwater
Laboratory:	GEL Laboratories, Charleston, South Carolina
Work Order No.:	366065
Analysis:	Volatiles
Validator:	Alison Kuhlman
Review Date:	April 9, 2015

This validation was performed according to the *Environmental Procedures Catalog* (LMS/POL/S04325), *"Standard Practice for Validation of Environmental Data."* The procedure was applied at Level 2, Data Deliverables Verification. See attached Data Validation Worksheets for supporting documentation on the data review and validation. All analyses were successfully completed. The samples were prepared and analyzed using accepted procedures based on methods specified by line item code, which are listed in Table 1.

Table 1. Analytes and Methods

Analyte	Line Item Code	Prep Method	Analytical Method
Volatile Organics, VOA	VOA-A-007	SW-846 5030B	SW-846 8260 LL

Data Qualifier Summary

None of the analytical results required qualification.

Sample Shipping/Receiving

GEL Laboratories in Charleston, South Carolina, received 12 water samples on January 29, 2015 and January 30, 2015, accompanied by Chain of Custody (COC) forms. The COC forms were checked to confirm that all of the samples were listed with sample collection dates and times, and that signatures and dates were present indicating sample relinquishment and receipt. The COC forms were complete with no errors or omissions. The air waybill numbers were listed on the receiving documentation.

Preservation and Holding Times

The sample shipment was received intact with the temperature inside the iced coolers at 3.3°C and 1.4°C, which complies with requirements. All samples were received in the correct container types and had been preserved correctly for the requested analyses. Sample analysis was completed within the applicable holding times.

Detection and Quantitation Limits

The method detection limit (MDL) was reported for all analytes as required. The MDL, as defined in 40 CFR 136, is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The practical quantitation limit (PQL) for these analytes is the lowest concentration that can be reliably measured, and is defined as 5 times the MDL. The reported MDLs for all analytes demonstrate compliance with contractual requirements.

Laboratory Instrument Calibration

Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable qualitative and quantitative data for all analytes. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning of the analytical run. Compliance requirements for continuing calibration checks are established to ensure that the instrument continues to be capable of producing acceptable qualitative and quantitative data. All laboratory instrument calibrations were performed correctly in accordance with the cited methods. All calibration and laboratory spike standards were prepared from independent sources.

The Continuing Calibration Verification standards associated with the samples exhibited percent difference values within acceptance criteria for all compounds.

Volatiles Internal Standards and Surrogates

The volatile internal standard recoveries and surrogate recoveries were within the acceptance ranges for all samples.

Method Blanks

Method blanks are analyzed to assess any contamination that may have occurred during sample preparation. The method blank results were below the MDL for all target compounds.

Trip Blank

Two trip blanks were prepared and analyzed to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organic samples. 2-Butanone, acetone, and toluene (all common laboratory contaminants) were detected in the trip blank. All associated sample results were less than the MDL, requiring no further action.

Matrix Spike Analysis

Matrix spike and matrix spike duplicate (MS/MSD) samples are used to measure method performance in the sample matrix. The MS/MSD analyses results met the acceptance criteria for all analytes.

Laboratory Replicate Analysis

Laboratory replicate analyses are used to determine laboratory precision for each sample matrix. The relative percent difference for organic replicate results should be less than the laboratory-derived control limits. All replicate results met these criteria, demonstrating acceptable precision.

Laboratory Control Sample

Laboratory control samples were analyzed at the correct frequency to provide information on the accuracy of the analytical method and the overall laboratory performance, including sample preparation. All control sample results were acceptable.

Field Duplicate

Field duplicate samples are collected and analyzed as an indication of overall precision of the measurement process. The precision observed includes both field and laboratory precision and has more variability than laboratory duplicates, which measure only laboratory performance. Duplicate samples were collected from location 0411 (field duplicate ID 9411). The relative percent difference for duplicate results that are greater than 5 times the PQL should be less than 20 percent. For results that are less than 5 times the PQL, the range should be no greater than the PQL. The duplicate results met the criteria, demonstrating acceptable overall precision.

Completeness

Results were reported in the correct units for all analytes requested using contract-required laboratory qualifiers.

Electronic Data Deliverable File

The EDD file arrived on February 27, 2015. The Sample Management System EDD validation module was used to verify that the EDD file was complete and in compliance with requirements. The module compares the contents of the file to the requested analyses to ensure all and only the requested data are delivered. The contents of the EDD were manually examined to verify that the sample results accurately reflect the data contained in the sample data package.

Sampling Protocol

Sample results for all monitoring wells met either the Category I and Category III low-flow sampling criteria and were qualified with an “F” flag in the database, indicating the wells were purged and sampled using the low-flow sampling method. Sample results for monitoring wells 0353 and 0445 met the Category III low-flow sampling criteria and were further qualified with a “Q” flag in the database. The turbidity values for locations 0400 and 0444 were greater than 50

NTU. The pH values for location 0444 did not meet the stability criterion, nor did the water level stability criteria.

Outliers Report

Potential outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected. Potential outliers may result from transcription errors, data-coding errors, or measurement system problems. However, outliers may also represent true extreme values of a distribution and indicate more variability in the population than was expected.

Statistical outlier tests give probabilistic evidence that an extreme value does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to identify data points that require further investigation. The tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set.

There are three steps involved in identifying extreme values or outliers:

1. Identify extreme values that may be potential outliers by generating the Outliers Report using the Sample Management System from data in the environmental database. The application compares the new data set (in standard environmental database units) with historical data and lists the new data that fall outside the historical data range. A determination is also made if the data are normally distributed using the Shapiro-Wilk Test.
2. Apply the appropriate statistical test. Dixon's Extreme Value test is used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test is valid only if the data without the suspected outlier are normally distributed. Rosner's Test is a parametric test that is used to detect outliers for sample sizes of 25 or more. This test also assumes that the data without the suspected outliers are normally distributed.
3. Scientifically review statistical outliers and decide on their disposition. The review should include an evaluation of any notable trends in the data that may indicate the outliers represent true extreme values.

No results from this sampling event were identified as potential outliers.

Report Prepared By: _____

Alison Kuhlman
Data Validator

SAMPLE MANAGEMENT SYSTEM
General Data Validation Report

RIN: 15016744 **Lab Code:** GEN **Validator:** Alison Kuhlman **Validation Date:** 4/9/2015

Project: Mound LTS&M Ground Water **Analysis Type:** ☐ Metals ☐ General Chem ☐ Rad ☑ Organics

# of Samples: 12 **Matrix:** Water **Requested Analysis Completed:** Yes

Chain of Custody

Present: OK **Signed:** OK **Dated:** OK

Sample

Integrity: OK **Preservation:** OK **Temperature:** OK

Select Quality Parameters

☑ Holding Times	All analyses were completed within the applicable holding times.
☑ Detection Limits	The reported detection limits are equal to or below contract requirements.
☑ Field/Trip Blanks	There were 2 trip/equipment blanks evaluated.
☑ Field Duplicates	There was 1 duplicate evaluated.

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15016744 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 4/9/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366065005	EPA 8260 Low Level	2-Butanone (Lab Contaminant)	0.730	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366065001	NCQ 194	0353	0.500	1.00	U	
366065002	NCQ 195	0400	0.500	1.00	U	
366065003	NCQ 196	0402	0.500	1.00	U	
366065004	NCQ 200	0445	0.500	1.00	U	
366065006	NCQ 203	P033	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366065005	EPA 8260 Low Level	Acetone (Lab Contaminant)	3.74	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366065001	NCQ 194	0353	0.500	1.00	U	
366065002	NCQ 195	0400	0.500	1.00	U	
366065003	NCQ 196	0402	0.500	1.00	U	
366065004	NCQ 200	0445	0.500	1.00	U	
366065006	NCQ 203	P033	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366065010	EPA 8260 Low Level	2-Butanone (Lab Contaminant)	1.08	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366065007	NCQ 197	0411	0.500	1.00	U	
366065008	NCQ 198	0443	0.500	1.00	U	
366065009	NCQ 199	0444	0.500	1.00	U	
366065011	NCQ 202	9411	0.500	1.00	U	
366065012	NCQ 201	0617	0.500	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15016744 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 4/9/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366065010	EPA 8260 Low Level	Acetone (Lab Contaminant)	4.75	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366065007	NCQ 197	0411	0.500	1.00	U	
366065008	NCQ 198	0443	0.500	1.00	U	
366065009	NCQ 199	0444	0.500	1.00	U	
366065011	NCQ 202	9411	0.500	1.00	U	
366065012	NCQ 201	0617	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366065010	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.250	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366065007	NCQ 197	0411	0.160	1.00	U	
366065008	NCQ 198	0443	0.160	1.00	U	
366065009	NCQ 199	0444	0.160	1.00	U	
366065011	NCQ 202	9411	0.160	1.00	U	
366065012	NCQ 201	0617	0.160	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15016744 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 4/9/2015

Duplicate: 9411 **Sample:** 0411

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
1,1,1,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,1-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2-Trichloro-1,2,2-trifluoroethane	1.50	U		1.00	1.50	U		1.00			ug/L
1,1,2-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,3-Trichlorobenzene	0.200	U		1.00	0.200	U		1.00			ug/L
1,2,3-Trichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromo-3-chloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromoethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,3,5-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,4-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
2,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
2-Butanone	0.500	U		1.00	0.500	U		1.00			ug/L
2-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
2-Hexanone	0.500	U		1.00	0.500	U		1.00			ug/L
4-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Isopropyltoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Methyl-2-pentanone	0.500	U		1.00	0.500	U		1.00			ug/L
Acetone	0.500	U		1.00	0.500	U		1.00			ug/L
Benzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromodichloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromoform	0.160	U		1.00	0.160	U		1.00			ug/L
Bromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Carbon Disulfide	0.500	U		1.00	0.500	U		1.00			ug/L
Carbon Tetrachloride	0.160	U		1.00	0.160	U		1.00			ug/L
Chlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Chloroethane	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15016744 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 4/9/2015

Duplicate: 9411 **Sample:** 0411

Analyte	Sample Result	Sample Flag	Sample Error	Sample Dilution	Duplicate Result	Duplicate Flag	Duplicate Error	Duplicate Dilution	RPD	RER	Units
Chloroform	0.160	U		1.00	0.160	U		1.00			ug/L
Chloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,2-Dichloroethene	3.34			1.00	3.30			1.00	1.20		ug/L
cis-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dichlorodifluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Ethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Hexachlorobutadiene	0.160	U		1.00	0.160	U		1.00			ug/L
Isopropylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Methylene Chloride	0.160	U		1.00	0.160	U		1.00			ug/L
Naphthalene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Propylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
sec-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Styrene	0.160	U		1.00	0.160	U		1.00			ug/L
tert-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Tetrachloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
Toluene	0.160	U		1.00	0.160	U		1.00			ug/L
Total Xylenes	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Trichloroethene	10.8			1.00	10.6			1.00	1.87		ug/L
Trichlorofluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Vinyl Chloride	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM
Organics Data Validation Summary

RIN: 15016744 **Project:** Mound LTS&M Ground Water **Lab Code:** GEN **Validation Date:** 4/9/2015

LCS Recovery: All LCS recoveries were within the laboratory acceptance limits.

Method Blank(s): All method blanks results were below the method detection limit.

MS/MSD Recovery: All MS/MSD recoveries were within the laboratory acceptance limits.

Surrogate Recovery: All surrogate recoveries were within the laboratory acceptance limits.

Data Review and Validation Report

General Information

Requisition No. (RIN):	15016745
Sample Event:	January 27-29, 2015
Site(s):	Mound, Ohio; Groundwater
Laboratory:	GEL Laboratories, Charleston, South Carolina
Work Order No.:	366119
Analysis:	Radiochemistry, Volatiles
Validator:	Gretchen Baer
Review Date:	May 14, 2015

This validation was performed according to the *Environmental Procedures Catalog* (LMS/POL/S04325), *"Standard Practice for Validation of Environmental Data."* The procedure was applied at Level 2, Data Deliverables Verification. See attached Data Validation Worksheets for supporting documentation on the data review and validation. All analyses were successfully completed. The samples were prepared and analyzed using accepted procedures based on methods specified by line item code, which are listed in Table 1.

Table 1. Analytes and Methods

Analyte	Line Item Code	Prep Method	Analytical Method
Tritium	LSC-A-001	EPA 906.0 Mod	EPA 906.0 Mod
Volatile Organics, VOA	VOA-A-007	SW-846 5030B	SW-846 8260 LL

Data Qualifier Summary

Analytical results were qualified as listed in Table 2. Refer to the sections below for an explanation of the data qualifiers applied.

Table 2. Data Qualifier Summary

Sample Number	Location	Analyte(s)	Flag	Reason
366119-004	0138	Tritium	J	Less than the determination limit
366119-021	0379	Tritium	J	Less than the determination limit

Sample Shipping/Receiving

GEL Laboratories in Charleston, South Carolina, received 24 water samples on January 30, 2015, accompanied by Chain of Custody (COC) forms. The COC forms were checked to confirm that all of the samples were listed with sample collection dates and times, and that signatures and dates were present indicating sample relinquishment and receipt. The COC forms were complete with no errors or omissions. The air waybill numbers were listed on the receiving documentation.

Preservation and Holding Times

The sample shipment was received intact with the temperature inside the iced cooler at 1.4 °C, which complies with requirements. All samples were received in the correct container types and had been preserved correctly for the requested analyses. Sample analysis was completed within the applicable holding times.

Detection and Quantitation Limits

The method detection limit (MDL) was reported for all organic analytes as required. The MDL, as defined in 40 CFR 136, is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The practical quantitation limit (PQL) for these analytes is the lowest concentration that can be reliably measured, and is defined as 5 times the MDL.

For radiochemical analytes (those measured by radiometric counting) the MDL and PQL are not applicable, and these results are evaluated using the minimum detectable concentration (MDC), Decision Level Concentration (DLC), and Determination Limit (DL). The MDC is a measure of radiochemical method performance and was calculated and reported as specified in the *Quality Systems Manual*. The DLC is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero, and is estimated as 3 times the one-sigma total propagated uncertainty. Results that are greater than the MDC, but less than the DLC are qualified with a “U” flag (not detected). The DL for radiochemical results is the lowest concentration that can be reliably measured, and is defined as 3 times the MDC. Results not previously “U” qualified that are less than the DL are qualified with a “J” flag as estimated values.

The reported MDLs for all organic analytes and MDCs for radiochemical analytes demonstrate compliance with contractual requirements.

Laboratory Instrument Calibration

Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable qualitative and quantitative data for all analytes. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning of the analytical run. Compliance requirements for continuing calibration checks are established to ensure that the instrument continues to be capable of producing acceptable qualitative and quantitative data. All laboratory instrument calibrations were performed correctly in accordance with the cited methods. All calibration and laboratory spike standards were prepared from independent sources.

The Continuing Calibration Verification standards associated with the samples exhibited percent difference values within acceptance criteria for all compounds, with the following exceptions. 2-Hexanone had percent drift values greater than 20 percent. There were no sample results greater than the MDL associated with this calibration verification compound, so no qualification is necessary.

Volatiles Internal Standards and Surrogates

The volatile internal standard recoveries and surrogate recoveries were within the acceptance ranges for all samples.

Method Blanks

Method blanks are analyzed to assess any contamination that may have occurred during sample preparation. The method blank results were below the MDL for all target volatile compounds. The tritium method blank result was less than the DLC.

Trip Blank

Trip blanks were prepared and analyzed to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organic samples. Acetone, 2-butanone, and toluene were detected in some trip blanks. These analytes were not detected in the associated samples.

Matrix Spike Analysis

Matrix spike and matrix spike duplicate (MS/MSD) samples are used to measure method performance in the sample matrix. The MS/MSD analyses results met the acceptance criteria for all analytes with the following exceptions. Spike recoveries for two volatile compounds were outside the acceptance range. There were no results above the detection limit for these compounds.

Laboratory Replicate Analysis

Laboratory replicate analyses are used to determine laboratory precision for each sample matrix. The relative percent difference for organic replicate results should be less than the laboratory-derived control limits. For radiochemical measurements, the relative error ratio (the ratio of the

absolute difference between the sample and duplicate results and the sum of the 1-sigma uncertainties) is used to evaluate duplicate results and should be less than 3. All replicate results met these criteria, demonstrating acceptable precision.

Laboratory Control Sample

Laboratory control samples were analyzed at the correct frequency to provide information on the accuracy of the analytical method and the overall laboratory performance, including sample preparation. All control sample results were acceptable.

Field Duplicate

Field duplicate samples are collected and analyzed as an indication of overall precision of the measurement process. The precision observed includes both field and laboratory precision and has more variability than laboratory duplicates, which measure only laboratory performance. Duplicate samples were collected from location 0347 (field duplicate ID 9347). For non-radiochemical measurements, the relative percent difference for duplicate results that are greater than 5 times the PQL should be less than 20 percent. For results less than 5 times the PQL, the range should be no greater than the PQL. For radiochemical measurements, the relative error ratio (the ratio of the absolute difference between the sample and duplicate results and the sum of the 1-sigma uncertainties) is used to evaluate duplicate results and should be less than 3. All duplicate results met these criteria, demonstrating acceptable precision.

Completeness

Results were reported in the correct units for all analytes requested using contract-required laboratory qualifiers.

Electronic Data Deliverable File

The EDD file arrived on March 2, 2015. The Sample Management System EDD validation module was used to verify that the EDD file was complete and in compliance with requirements. The module compares the contents of the file to the requested analyses to ensure all and only the requested data are delivered. The contents of the EDD were manually examined to verify that the sample results accurately reflect the data contained in the sample data package.

Sampling Protocol

Sample results for all monitoring wells met the Category I low-flow sampling criteria and were qualified with an “F” flag in the database, indicating the wells were purged and sampled using the low-flow sampling method. The turbidity values for locations 0315 and 0389 were greater than 50 NTU.

Outliers Report

Potential outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected. Potential outliers may result from transcription errors, data-coding errors, or

measurement system problems. However, outliers may also represent true extreme values of a distribution and indicate more variability in the population than was expected.

Statistical outlier tests give probabilistic evidence that an extreme value does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to identify data points that require further investigation. The tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set.

There are three steps involved in identifying extreme values or outliers:

1. Identify extreme values that may be potential outliers by generating the Outliers Report using the Sample Management System from data in the environmental database. The application compares the new data set (in standard environmental database units) with historical data and lists the new data that fall outside the historical data range. A determination is also made if the data are normally distributed using the Shapiro-Wilk Test.
2. Apply the appropriate statistical test. Dixon's Extreme Value test is used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test is valid only if the data without the suspected outlier are normally distributed. Rosner's Test is a parametric test that is used to detect outliers for sample sizes of 25 or more. This test also assumes that the data without the suspected outliers are normally distributed.
3. Scientifically review statistical outliers and decide on their disposition. The review should include an evaluation of any notable trends in the data that may indicate the outliers represent true extreme values.

No results from this sampling event were identified as potential outliers.

Report Prepared By: _____

Gretchen Baer
Data Validator

Data Validation Outliers Report - No Field Parameters
Comparison: All historical Data Beginning 1/1/2005
Laboratory: GEL Laboratories
RIN: 15016745
Report Date: 5/14/2015

					Current			**Historical Maximum**			**Historical Minimum**			**Number of Data Points**		**Statistical Outlier**
						Qualifiers			*Qualifiers*			*Qualifiers*				
Site Code	Location Code	Sample ID	Sample Date	Analyte	Result	*Lab*	*Data*	Result	*Lab*	*Data*	Result	*Lab*	*Data*	N	N Below Detect	
MND01	0606	N001	01/29/2015	Tritium	2480			14600			3020			15	0	No
MND01	0608	N001	01/29/2015	Tritium	5790			54000			5840			27	0	NA

STATISTICAL TESTS:
The distribution of the data is tested for normality or lognormality using the Shapiro-Wilk Test
Outliers are identified using Dixon's Test when there are 25 or fewer data points.
Outliers are identified using Rosner's Test when there are 26 or more data points.
See Data Quality Assessment: Statistical Methods for Practitioners, EPA QC/G-9S, February 2006.

NA: Data are not normally or lognormally distributed.

SAMPLE MANAGEMENT SYSTEM
General Data Validation Report

RIN: 15016745 **Lab Code:** GEN **Validator:** Gretchen Baer **Validation Date:** 5/14/2015

Project: Mound LTS&M Ground Water **Analysis Type:** ☐ Metals ☐ General Chem ☑ Rad ☑ Organics

# of Samples: 24 **Matrix:** Water **Requested Analysis Completed:** Yes

Chain of Custody

Present: OK **Signed:** OK **Dated:** OK

Sample

Integrity: OK **Preservation:** OK **Temperature:** OK

Select Quality Parameters

☑ Holding Times	All analyses were completed within the applicable holding times.
☑ Detection Limits	The reported detection limits are equal to or below contract requirements.
☑ Field/Trip Blanks	There were 3 trip/equipment blanks evaluated.
☑ Field Duplicates	There was 1 duplicate evaluated.

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15016745 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 5/14/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119007	EPA 8260 Low Level	Acetone (Lab Contaminant)	3.53	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119001	NCQ 213	0118	0.500	1.00	U	
366119002	NCQ 218	0124	0.500	1.00	U	
366119003	NCQ 219	0126	0.500	1.00	U	
366119004	NCQ 205	0138	0.500	1.00	U	
366119005	NCQ 210	0301	0.500	1.00	U	
366119006	NCQ 211	0311	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119007	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.160	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119001	NCQ 213	0118	0.160	1.00	U	
366119002	NCQ 218	0124	0.160	1.00	U	
366119003	NCQ 219	0126	0.160	1.00	U	
366119004	NCQ 205	0138	0.160	1.00	U	
366119005	NCQ 210	0301	0.160	1.00	U	
366119006	NCQ 211	0311	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119019	EPA 8260 Low Level	2-Butanone (Lab Contaminant)	0.820	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119014	NCQ 217	0315	0.500	1.00	U	
366119015	NCQ 214	0346	0.500	1.00	U	
366119016	NCQ 216	0347	0.500	1.00	U	
366119017	NCQ 206	0386	0.500	1.00	U	
366119018	NCQ 208	0389	0.500	1.00	U	
366119020	NCQ 225	9347	0.500	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15016745 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 5/14/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119019	EPA 8260 Low Level	Acetone (Lab Contaminant)	3.97	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119014	NCQ 217	0315	0.500	1.00	U	
366119015	NCQ 214	0346	0.500	1.00	U	
366119016	NCQ 216	0347	0.500	1.00	U	
366119017	NCQ 206	0386	0.500	1.00	U	
366119018	NCQ 208	0389	0.500	1.00	U	
366119020	NCQ 225	9347	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119019	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.270	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119014	NCQ 217	0315	0.160	1.00	U	
366119015	NCQ 214	0346	0.160	1.00	U	
366119016	NCQ 216	0347	0.160	1.00	U	
366119017	NCQ 206	0386	0.160	1.00	U	
366119018	NCQ 208	0389	0.160	1.00	U	
366119020	NCQ 225	9347	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119024	EPA 8260 Low Level	Acetone (Lab Contaminant)	2.10	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119008	NCQ 222	0601	0.500	1.00	U	
366119009	NCQ 226	0602	0.500	1.00	U	
366119010	NCQ 220	0605	0.500	1.00	U	
366119011	NCQ 223	0606	0.500	1.00	U	
366119012	NCQ 221	0607	0.500	1.00	U	
366119013	NCQ 224	0608	0.500	1.00	U	
366119021	NCQ 215	0379	0.500	1.00	U	
366119022	NCQ 207	0387	0.500	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15016745 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 5/14/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	366119024		Acetone (Lab Contaminant)				

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
366119023	NCQ 209	0392	0.500	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15016745 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 5/14/2015

Duplicate: 9347 **Sample:** 0347

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
1,1,1,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,1-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2-Trichloro-1,2,2-trifluoroethane	1.50	U		1.00	1.50	U		1.00			ug/L
1,1,2-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,3-Trichlorobenzene	0.200	U		1.00	0.200	U		1.00			ug/L
1,2,3-Trichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromo-3-chloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromoethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,3,5-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,4-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
2,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
2-Butanone	0.500	U		1.00	0.500	U		1.00			ug/L
2-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
2-Hexanone	0.500	U		1.00	0.500	U		1.00			ug/L
4-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Isopropyltoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Methyl-2-pentanone	0.500	U		1.00	0.500	U		1.00			ug/L
Acetone	0.500	U		1.00	0.500	U		1.00			ug/L
Benzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromodichloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromoform	0.160	U		1.00	0.160	U		1.00			ug/L
Bromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Carbon Disulfide	0.500	U		1.00	0.500	U		1.00			ug/L
Carbon Tetrachloride	2.24			1.00	2.19			1.00	2.26		ug/L
Chlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Chloroethane	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15016745 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 5/14/2015

Duplicate: 9347 **Sample:** 0347

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
Chloroform	0.950	J		1.00	0.950	J		1.00	0		ug/L
Chloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dichlorodifluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Ethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Hexachlorobutadiene	0.160	U		1.00	0.160	U		1.00			ug/L
Isopropylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Methylene Chloride	0.160	U		1.00	0.160	U		1.00			ug/L
Naphthalene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Propylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
sec-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Styrene	0.160	U		1.00	0.160	U		1.00			ug/L
tert-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Tetrachloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
Toluene	0.160	U		1.00	0.160	U		1.00			ug/L
Total Xylenes	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Trichloroethene	25.4			1.00	25.9			1.00	1.95		ug/L
Trichlorofluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Tritium	2820		638	1.00	2880		651	1.00	2.11	0.1	pCi/L
Vinyl Chloride	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM
Organics Data Validation Summary

RIN: 15016745 **Project:** Mound LTS&M Ground Water **Lab Code:** GEN **Validation Date:** 5/14/2015

LCS Recovery: All LCS recoveries were within the laboratory acceptance limits.

Method Blank(s): All method blanks results were below the method detection limit.

MS/MSD Recovery: There were 2 MS/MSD failures.

Surrogate Recovery: All surrogate recoveries were within the laboratory acceptance limits.

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: MS/MSD Performance

RIN: 15016745 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 5/14/2015

MS/MSD	Date Analyzed	Method	Analyte	Recovery MS	Recovery MSD	Lower Limit	Upper Limit	MSD RPD	RPD Limit
NCQ 216	02/06/2015	EPA 8260 Low Level	Chloromethane	128.0	112.0	51.0	126.0		
NCQ 216	02/06/2015	EPA 8260 Low Level	Vinyl Chloride	135.0	120.0	63.0	121.0		

SAMPLE MANAGEMENT SYSTEM
Radiochemistry Data Validation Worksheet

RIN: 15016745 **Lab Code:** GEN **Date Due:** 2/27/2015

Matrix: Water **Site Code:** MND03 **Date Completed:** 3/6/2015

Sample	Analyte	Date Analyzed	Result	Flag	Tracer %R	LCS %R	MS %R	Duplicate RER
Blank	Tritium	02/14/2015	101.0000	U				
0347	Tritium	02/14/2015						0.07
Blank_Spike	Tritium	02/14/2015				83.50		
0347	Tritium	02/14/2015					102.0	

Data Review and Validation Report

General Information

Requisition No. (RIN):	15046952
Sample Event:	April 27 – 29, 2015
Site(s):	Mound, Ohio; Groundwater
Laboratory:	GEL Laboratories, Charleston, South Carolina
Work Order No.:	372119
Analysis:	Volatiles
Validator:	Alison Kuhlman
Review Date:	June 30, 2015

This validation was performed according to the Environmental Procedures Catalog (LMS/POL/S04325), "Standard Practice for Validation of Environmental Data." The procedure was applied at Level 2, Data Deliverables Verification. See attached Data Validation Worksheets for supporting documentation on the data review and validation. All analyses were successfully completed. The samples were prepared and analyzed using accepted procedures based on methods specified by line item code, which are listed in Table 1.

Table 1. Analytes and Methods

Analyte	Line Item Code	Prep Method	Analytical Method
Volatile Organics, VOA	VOA-A-007	SW-846 5030B	SW-846 8260 LL

Data Qualifier Summary

Analytical results were qualified as listed in Table 2. Refer to the attached validation worksheets and the sections below for an explanation of the data qualifiers applied.

Table 2. Data Qualifiers

Sample Number	Location	Analyte	Flag	Reason
372119006	0301	Methylene Chloride	U	Less than 10 times the trip blank
372119007	0311	Methylene Chloride	U	Less than 10 times the trip blank
372119010	0346	Methylene Chloride	U	Less than 10 times the trip blank
372119011	0379	Methylene Chloride	U	Less than 10 times the trip blank
372119014	0124	Methylene Chloride	U	Less than 10 times the trip blank
372119015	0126	Methylene Chloride	U	Less than 10 times the trip blank
372119021	9379	Methylene Chloride	U	Less than 10 times the trip blank

Sample Shipping/Receiving

GEL Laboratories in Charleston, South Carolina, received 23 water samples on April 30, 2015, accompanied by Chain of Custody (COC) forms. The COC forms were checked to confirm that all of the samples were listed with sample collection dates and times, and that signatures and dates were present indicating sample relinquishment and receipt. The COC forms were complete with no errors or omissions. The air waybill numbers were listed on the receiving documentation.

Preservation and Holding Times

The sample shipment was received intact with the temperature inside the iced coolers at 3.4°C, which complies with requirements. All samples were received in the correct container types and had been preserved correctly for the requested analyses. Sample analysis was completed within the applicable holding times.

Detection and Quantitation Limits

The method detection limit (MDL) was reported for all analytes as required. The MDL, as defined in 40 CFR 136, is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The practical quantitation limit (PQL) for these analytes is the lowest concentration that can be reliably measured, and is defined as 5 times the MDL. The reported MDLs for all analytes demonstrate compliance with contractual requirements.

Laboratory Instrument Calibration

Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable qualitative and quantitative data for all analytes. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning of the analytical run. Compliance requirements for continuing calibration checks are established to ensure that the instrument continues to be capable of producing acceptable qualitative and quantitative data. All laboratory instrument calibrations were performed correctly in accordance with the cited methods. All calibration and laboratory spike standards were prepared from independent sources.

The Continuing Calibration Verification (CCV) standard associated with the samples exhibited percent difference values outside acceptance criteria for 2-hexanone and 2-butanone. All associated sample results for these compounds are less than the MDL, requiring no further action.

Volatiles Internal Standards and Surrogates

The volatile internal standard recoveries and surrogate recoveries were within the acceptance ranges for all samples.

Method Blanks

Method blanks are analyzed to assess any contamination that may have occurred during sample preparation. The method blank results were below the MDL for all target compounds.

Trip Blank

Two trip blanks were prepared and analyzed to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organic samples. Methylene chloride (a common laboratory contaminant) was detected in one of the trip blanks. All associated sample results are qualified with a "U" flag (not detected) when the sample result is greater than the MDL, but less than ten times the blank concentration.

Matrix Spike Analysis

Matrix spike and matrix spike duplicate (MS/MSD) samples are used to measure method performance in the sample matrix. The MS/MSD analyses results met the acceptance criteria for all analytes, with the exception of vinyl chloride. The MS analyses for vinyl chloride did not meet acceptance criteria, biased high. All associated sample results were below the MDL, requiring no further action.

Laboratory Replicate Analysis

Laboratory replicate analyses are used to determine laboratory precision for each sample matrix. The relative percent difference for organic replicate results should be less than the laboratory-derived control limits. All replicate results met these criteria, demonstrating acceptable precision.

Laboratory Control Sample

Laboratory control samples were analyzed at the correct frequency to provide information on the accuracy of the analytical method and the overall laboratory performance, including sample preparation. All control sample results were acceptable, with the following exception. The laboratory control sample for dichlorodifluoromethane was outside the acceptance limit, biased high. All associated sample results were below the MDL, requiring no further action.

Field Duplicate

Field duplicate samples are collected and analyzed as an indication of overall precision of the measurement process. The precision observed includes both field and laboratory precision and has more variability than laboratory duplicates, which measure only laboratory performance. Duplicate samples were collected from location 0379 (field duplicate ID 9379). The relative percent difference for duplicate results that are greater than 5 times the PQL should be less than 20 percent. For results that are less than 5 times the PQL, the range should be no greater than the PQL. The duplicate results met the criteria, demonstrating acceptable overall precision.

Completeness

Results were reported in the correct units for all analytes requested using contract-required laboratory qualifiers.

Electronic Data Deliverable File

The EDD file arrived on May 28, 2015. The Sample Management System EDD validation module was used to verify that the EDD file was complete and in compliance with requirements. The module compares the contents of the file to the requested analyses to ensure all and only the requested data are delivered. The contents of the EDD were manually examined to verify that the sample results accurately reflect the data contained in the sample data package.

Sampling Protocol

Sample results for all monitoring wells met the Category I low-flow sampling criteria and were qualified with an “F” flag in the database, indicating the wells were purged and sampled using the low-flow sampling method. The turbidity value for location 0351 was greater than 50 NTU. The dissolved oxygen value for location 0351 did not meet the stability criterion.

Outliers Report

Potential outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected. Potential outliers may result from transcription errors, data-coding errors, or measurement system problems. However, outliers may also represent true extreme values of a distribution and indicate more variability in the population than was expected.

Statistical outlier tests give probabilistic evidence that an extreme value does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to identify data points that require further investigation. The tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set.

There are three steps involved in identifying extreme values or outliers:

1. Identify extreme values that may be potential outliers by generating the Outliers Report using the Sample Management System from data in the environmental database. The application compares the new data set (in standard environmental database units) with historical data and lists the new data that fall outside the historical data range. A determination is also made if the data are normally distributed using the Shapiro-Wilk Test.
2. Apply the appropriate statistical test. Dixon's Extreme Value test is used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test is valid only if the data without the suspected outlier are normally distributed. Rosner's Test is a parametric test that is used to detect outliers for sample sizes of 25 or more. This test also assumes that the data without the suspected outliers are normally distributed.
3. Scientifically review statistical outliers and decide on their disposition. The review should include an evaluation of any notable trends in the data that may indicate the outliers represent true extreme values.

No results from this sampling event were identified as potential outliers.

Report Prepared By: _____

Alison Kuhlman
Data Validator

Data Validation Outliers Report - No Field Parameters
Comparison: All historical Data Beginning 1/1/2005
Laboratory: GEL Laboratories
RIN: 15046952
Report Date: 6/30/2015

					Current			**Historical Maximum**			**Historical Minimum**			**Number of Data Points**		**Statistical Outlier**
						Qualifiers			*Qualifiers*			*Qualifiers*				
Site Code	Location Code	Sample ID	Sample Date	Analyte	Result	*Lab*	*Data*	Result	*Lab*	*Data*	Result	*Lab*	*Data*	N	N Below Detect	
MND01	0379	N002	04/29/2015	Trichloroethene	1.41			2.56	J		1.42		F	47	0	No
MND01	0602	N001	04/27/2015	cis-1,2-Dichloroethene	7.50			42.3			8.11			23	0	No

STATISTICAL TESTS:
The distribution of the data is tested for normality or lognormality using the Shapiro-Wilk Test
Outliers are identified using Dixon's Test when there are 25 or fewer data points.
Outliers are identified using Rosner's Test when there are 26 or more data points.
See Data Quality Assessment: Statistical Methods for Practitioners, EPA QC/G-9S, February 2006.

SAMPLE MANAGEMENT SYSTEM
General Data Validation Report

RIN: 15046952 **Lab Code:** GEN **Validator:** Alison Kuhlman **Validation Date:** 6/30/2015

Project: Mound LTS&M Ground Water **Analysis Type:** ☐ Metals ☐ General Chem ☐ Rad ☑ Organics

# of Samples: 23 **Matrix:** Water **Requested Analysis Completed:** Yes

Chain of Custody

Present: OK **Signed:** OK **Dated:** OK

Sample

Integrity: OK **Preservation:** OK **Temperature:** OK

Select Quality Parameters

☑ Holding Times	All analyses were completed within the applicable holding times.
☑ Detection Limits	The reported detection limits are equal to or below contract requirements.
☑ Field/Trip Blanks	There were 2 trip/equipment blanks evaluated.
☑ Field Duplicates	There was 1 duplicate evaluated.

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15046952 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 6/30/2015

Duplicate: 9379 **Sample:** 0379

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
1,1,1,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,1-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2-Trichloro-1,2,2-trifluoroethane	1.50	U		1.00	1.50	U		1.00			ug/L
1,1,2-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,3-Trichlorobenzene	0.200	U		1.00	0.200	U		1.00			ug/L
1,2,3-Trichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromo-3-chloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromoethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,3,5-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,4-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
2,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
2-Butanone	0.500	U		1.00	0.500	U		1.00			ug/L
2-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
2-Hexanone	0.500	U		1.00	0.500	U		1.00			ug/L
4-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Isopropyltoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Methyl-2-pentanone	0.500	U		1.00	0.500	U		1.00			ug/L
Acetone	0.500	U		1.00	0.500	U		1.00			ug/L
Benzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromodichloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromoform	0.160	U		1.00	0.160	U		1.00			ug/L
Bromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Carbon Disulfide	0.500	U		1.00	0.500	U		1.00			ug/L
Carbon Tetrachloride	0.600	J		1.00	0.630	J		1.00			ug/L
Chlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Chloroethane	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15046952 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 6/30/2015

Duplicate: 9379 **Sample:** 0379

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
Chloroform	0.160	U		1.00	0.160	U		1.00			ug/L
Chloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dichlorodifluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Ethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Hexachlorobutadiene	0.160	U		1.00	0.160	U		1.00			ug/L
Isopropylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Methylene Chloride	2.50	J		1.00	2.57	J		1.00	2.76		ug/L
Naphthalene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Propylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
sec-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Styrene	0.160	U		1.00	0.160	U		1.00			ug/L
tert-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Tetrachloroethene	0.340	J		1.00	0.290	J		1.00			ug/L
Toluene	0.160	U		1.00	0.160	U		1.00			ug/L
Total Xylenes	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Trichloroethene	1.52			1.00	1.41			1.00	7.51		ug/L
Trichlorofluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Vinyl Chloride	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15046952 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 6/30/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	372119023	EPA 8260 Low Level	Methylene Chloride (Lab Contaminant)	2.65	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
372119001	NFY 707	0138	0.160	1.00	U	
372119002	NFY 708	0386	0.160	1.00	U	
372119003	NFY 709	0387	0.160	1.00	U	
372119004	NFY 710	0389	0.160	1.00	U	
372119005	NFY 711	0392	0.160	1.00	U	
372119006	NFY 712	0301	2.52	1.00	J	U
372119007	NFY 713	0311	2.83	1.00	J	U
372119009	NFY 715	0118	0.160	1.00	U	
372119010	NFY 716	0346	2.94	1.00	J	U
372119011	NFY 717	0379	2.50	1.00	J	U
372119012	NFY 718	0347	0.160	1.00	U	
372119013	NFY 719	0315	0.160	1.00	U	
372119014	NFY 720	0124	2.83	1.00	J	U
372119015	NFY 721	0126	2.65	1.00	J	U
372119016	NFY 722	0605	0.160	1.00	U	
372119017	NFY 723	0607	0.160	1.00	U	
372119018	NFY 724	0601	0.160	1.00	U	
372119019	NFY 725	0606	0.160	1.00	U	
372119020	NFY 726	0608	2.59	1.00	J	U
372119021	NFY 727	9379	2.57	1.00	J	U
372119022	NFY 728	0602	2.63	1.00	J	U

SAMPLE MANAGEMENT SYSTEM
Organics Data Validation Summary

RIN: 15046952 **Project:** Mound LTS&M Ground Water **Lab Code:** GEN **Validation Date:** 6/30/2015

LCS Recovery: There was 1 LCS failure.

Method Blank(s): All method blanks results were below the method detection limit.

MS/MSD Recovery: There was 1 MS/MSD failure.

Surrogate Recovery: All surrogate recoveries were within the laboratory acceptance limits.

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: LCS Recovery

RIN: 15046952 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 6/30/2015

LCS/LCSD	Date Analyzed	Method	Analyte	Recovery	Lower Limit	Upper Limit
LCS	05/08/2015	EPA 8260 Low Level	Dichlorodifluoromethane	135.0	54.0	133.0

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: MS/MSD Performance

RIN: 15046952 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 6/30/2015

MS/MSD	Date Analyzed	Method	Analyte	Recovery MS	Recovery MSD	Lower Limit	Upper Limit	MSD RPD	RPD Limit
NFY 707	05/08/2015	EPA 8260 Low Level	Vinyl Chloride	123.0	111.0	63.0	121.0		

Data Review and Validation Report

General Information

Requisition No. (RIN):	15077238
Sample Event:	July 27-29, 2015
Site(s):	Mound, Ohio; Groundwater
Laboratory:	GEL Laboratories, Charleston, South Carolina
Work Order No.:	378378
Analysis:	Organics and Radiochemistry
Validator:	Gretchen Baer
Review Date:	November 18, 2015

This validation was performed according to the *Environmental Procedures Catalog* (LMS/POL/S04325), *"Standard Practice for Validation of Environmental Data."* The procedure was applied at Level 2, Data Deliverables Verification. See attached Data Validation Worksheets for supporting documentation on the data review and validation. All analyses were successfully completed. The samples were prepared and analyzed using accepted procedures based on methods specified by line item code, which are listed in Table 1.

Table 1. Analytes and Methods

Analyte	Line Item Code	Prep Method	Analytical Method
Tritium	LSC-A-001	EPA 906.0 Mod	EPA 906.0 Mod
Volatile Organics, VOA	VOA-A-007	SW-846 5030B	SW-846 8260 LL

Data Qualifier Summary

Analytical results were qualified as listed in Table 2. Refer to the sections below for an explanation of the data qualifiers applied.

Table 2. Data Qualifier Summary

Sample Number	Location	Analyte(s)	Flag	Reason
All	All	Methylene chloride	U	Less than 10 times the method blank
378378002	0124	Acetone	U	Less than 10 times the trip blank
378378004	0301	Acetone	U	Less than 10 times the trip blank
378378005	0311	Acetone	U	Less than 10 times the trip blank
378378005	0311	Choroform	U	Less than 5 times the trip blank
378378006	0315	Acetone	U	Less than 10 times the trip blank
378378007	0347	Choroform	U	Less than 5 times the trip blank
378378009	0601	Acetone	U	Less than 10 times the trip blank
378378010	0605	Acetone	U	Less than 10 times the trip blank
378378010	0605	Choroform	U	Less than 5 times the trip blank
378378010	0605	Toluene	U	Less than 10 times the trip blank
378378011	0606	Acetone	U	Less than 10 times the trip blank
378378011	0606	Choroform	U	Less than 5 times the trip blank
378378013	0608	Acetone	U	Less than 10 times the trip blank
378378015	0138	Acetone	U	Less than 10 times the trip blank
378378016	0346	Acetone	U	Less than 10 times the trip blank
378378016	0346	Tritium	J	Less than the determination limit
378378017	0379	Acetone	U	Less than 10 times the trip blank
378378018	0386	Acetone	U	Less than 10 times the trip blank
378378019	0387	Acetone	U	Less than 10 times the trip blank
378378020	0389	Acetone	U	Less than 10 times the trip blank
378378021	0392	Acetone	U	Less than 10 times the trip blank

Sample Shipping/Receiving

GEL Laboratories in Charleston, South Carolina, received 22 water samples on July 31, 2015, accompanied by Chain of Custody (COC) forms. The COC forms were checked to confirm that all of the samples were listed with sample collection dates and times, and that signatures and dates were present indicating sample relinquishment and receipt. The COC forms were complete with no errors or omissions. The air waybill numbers were listed on the receiving documentation.

The client cancelled the analyses for sample 9607 because of a sampling error.

Preservation and Holding Times

The sample shipment was received intact with the temperature inside the iced cooler at 3.3 °C, which complies with requirements. All samples were received in the correct container types and had been preserved correctly for the requested analyses. Sample analysis was completed within the applicable holding times.

Detection and Quantitation Limits

The method detection limit (MDL) was reported for all organic analytes as required. The MDL, as defined in 40 CFR 136, is the minimum concentration of an analyte that can be measured and

reported with 99 percent confidence that the analyte concentration is greater than zero. The practical quantitation limit (PQL) for these analytes is the lowest concentration that can be reliably measured, and is defined as 5 times the MDL.

For radiochemical analytes (those measured by radiometric counting) the MDL and PQL are not applicable, and these results are evaluated using the minimum detectable concentration (MDC), Decision Level Concentration (DLC), and Determination Limit (DL). The MDC is a measure of radiochemical method performance and was calculated and reported as specified in the *Quality Systems Manual*. The DLC is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero, and is estimated as 3 times the one-sigma total propagated uncertainty. Results that are greater than the MDC, but less than the DLC are qualified with a "U" flag (not detected). The DL for radiochemical results is the lowest concentration that can be reliably measured, and is defined as 3 times the MDC. Results not previously "U" qualified that are less than the DL are qualified with a "J" flag as estimated values.

The reported MDLs for all organic analytes and MDCs for radiochemical analytes demonstrate compliance with contractual requirements.

Laboratory Instrument Calibration

Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable qualitative and quantitative data for all analytes. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning of the analytical run. Compliance requirements for continuing calibration checks are established to ensure that the instrument continues to be capable of producing acceptable qualitative and quantitative data. All laboratory instrument calibrations were performed correctly in accordance with the cited methods. All calibration and laboratory spike standards were prepared from independent sources.

The Continuing Calibration Verification standards associated with the samples exhibited percent difference values within acceptance criteria for all compounds, with the following exceptions. Acetone and 2-hexanone had percent drift values greater than 20 percent. There were no sample results greater than the MDL associated with these calibration verification compounds, so no qualification is necessary.

Volatiles Internal Standards and Surrogates

The volatile internal standard recoveries and surrogate recoveries were within the acceptance ranges for all samples.

Method Blanks

Method blanks are analyzed to assess any contamination that may have occurred during sample preparation. Methylene chloride (a common laboratory contaminant) was detected in the volatiles method blanks at concentrations above the MDL. Associated samples with results less than 10 times the blank concentrations are qualified with a "U" flag (not detected). The tritium method blank result was less than the DLC.

Trip Blank

Trip blanks were prepared and analyzed to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organic samples. Acetone, 2-butanone, choroform, and toluene were detected in some trip blanks. Sample results for these compounds that are less than 5 times the trip blank concentration (and less than 10 times the blank concentration for common laboratory contaminants) are qualified with a "U" flag as not detected.

Matrix Spike Analysis

Matrix spike and matrix spike duplicate (MS/MSD) samples are used to measure method performance in the sample matrix. The spike recoveries met the acceptance criteria for all analytes evaluated.

Laboratory Replicate Analysis

Laboratory replicate analyses are used to determine laboratory precision for each sample matrix. The relative percent difference (RPD) for organic replicate results should be less than the laboratory-derived control limits. For radiochemical measurements, the relative error ratio (the ratio of the absolute difference between the sample and duplicate results and the sum of the 1-sigma uncertainties) is used to evaluate duplicate results and should be less than 3. All replicate results met these criteria, with the following exception. The RPD for four volatiles compounds exceeded the criteria in a matrix spike sample. These compounds were not detected in the associated sample and no further qualification is necessary.

Laboratory Control Sample

Laboratory control samples were analyzed at the correct frequency to provide information on the accuracy of the analytical method and the overall laboratory performance, including sample preparation. All control sample results were acceptable.

Field Duplicate

Field duplicate samples are collected and analyzed as an indication of overall precision of the measurement process. The precision observed includes both field and laboratory precision and has more variability than laboratory duplicates, which measure only laboratory performance. Duplicate samples were collected from location 0607 (field duplicate ID 9607).

The client cancelled the analysis for sample 9607 because of a sampling error.

Completeness

Results were reported in the correct units for all analytes requested using contract-required laboratory qualifiers.

Electronic Data Deliverable (EDD) File

The EDD file arrived on August 28, 2015. The Sample Management System EDD validation module was used to verify that the EDD file was complete and in compliance with requirements. The module compares the contents of the file to the requested analyses to ensure all and only the requested data are delivered. The contents of the EDD were manually examined to verify that the sample results accurately reflect the data contained in the sample data package.

Sampling Protocol

Sample results for all monitoring wells met the Category I low-flow sampling criteria and were qualified with an “F” flag in the database, indicating the wells were purged and sampled using the low-flow sampling method. The turbidity values for locations 0311, 0315, and 0389 were greater than 50 NTU. The percent difference for the final three dissolved oxygen measurements at 0387 were greater than 10 percent. The percent difference for the final three specific conductance measurements at 0346 were greater than 10 percent.

Outliers Report

Potential outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected. Potential outliers may result from transcription errors, data-coding errors, or measurement system problems. However, outliers may also represent true extreme values of a distribution and indicate more variability in the population than was expected.

Statistical outlier tests give probabilistic evidence that an extreme value does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to identify data points that require further investigation. The tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set.

There are three steps involved in identifying extreme values or outliers:

1. Identify extreme values that may be potential outliers by generating the Outliers Report using the Sample Management System from data in the environmental database. The application compares the new data set (in standard environmental database units) with historical data and lists the new data that fall outside the historical data range. A determination is also made if the data are normally distributed using the Shapiro-Wilk Test.
2. Apply the appropriate statistical test. Dixon's Extreme Value test is used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test is valid only if the data without the suspected outlier are normally distributed. Rosner's Test is a parametric test that is used to detect outliers for sample sizes of 25 or more. This test also assumes that the data without the suspected outliers are normally distributed.

3. Scientifically review statistical outliers and decide on their disposition. The review should include an evaluation of any notable trends in the data that may indicate the outliers represent true extreme values.

No results from this sampling event were identified as potential outliers.

Report Prepared By: _____

Gretchen Baer
Data Validator

Data Validation Outliers Report - No Field Parameters
Comparison: All historical Data Beginning 1/1/2005
Laboratory: GEL Laboratories
RIN: 15077238
Report Date: 11/18/2015

					Current			**Historical Maximum**			**Historical Minimum**			**Number of Data Points**		**Statistical Outlier**
						Qualifiers			*Qualifiers*			*Qualifiers*				
Site Code	Location Code	Sample ID	Sample Date	Analyte	Result	*Lab*	*Data*	Result	*Lab*	*Data*	Result	*Lab*	*Data*	N	N Below Detect	
MND01	0379	N001	07/28/2015	Trichloroethene	1.31		F	2.56	J		1.41		F	50	0	No
MND01	0605	N001	07/29/2015	cis-1,2-Dichloroethene	1.09			32.2			1.27			37	0	NA

STATISTICAL TESTS:
The distribution of the data is tested for normality or lognormality using the Shapiro-Wilk Test
Outliers are identified using Dixon's Test when there are 25 or fewer data points.
Outliers are identified using Rosner's Test when there are 26 or more data points.
See Data Quality Assessment: Statistical Methods for Practitioners, EPA QC/G-9S, February 2006.

NA: Data are not normally or lognormally distributed.

SAMPLE MANAGEMENT SYSTEM
General Data Validation Report

RIN: 15077238 **Lab Code:** GEN **Validator:** Gretchen Baer **Validation Date:** 11/18/2015

Project: Mound LTS&M Ground Water **Analysis Type:** ☐ Metals ☐ General Chem ☑ Rad ☑ Organics

# of Samples: 21 **Matrix:** Water **Requested Analysis Completed:** Yes

Chain of Custody

Present: OK **Signed:** OK **Dated:** OK

Sample

Integrity: OK **Preservation:** OK **Temperature:** OK

Select Quality Parameters

☑ Holding Times	All analyses were completed within the applicable holding times.
☑ Detection Limits	The reported detection limits are equal to or below contract requirements.
☑ Field/Trip Blanks	There were 2 trip/equipment blanks evaluated.
☐ Field Duplicates	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15077238 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378008	EPA 8260 Low Level	2-Butanone (Lab Contaminant)	3.07	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378001	NIZ 593	0118	0.500	1.00	U	
378378002	NIZ 598	0124	0.500	1.00	U	
378378003	NIZ 599	0126	0.500	1.00	U	
378378004	NIZ 590	0301	0.500	1.00	U	
378378005	NIZ 591	0311	0.500	1.00	U	
378378006	NIZ 597	0315	0.500	1.00	U	
378378007	NIZ 596	0347	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378008	EPA 8260 Low Level	Acetone (Lab Contaminant)	23.4		0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378001	NIZ 593	0118	0.500	1.00	U	
378378002	NIZ 598	0124	1.55	1.00	J	U
378378003	NIZ 599	0126	0.500	1.00	U	
378378004	NIZ 590	0301	1.63	1.00	J	U
378378005	NIZ 591	0311	1.99	1.00	J	U
378378006	NIZ 597	0315	2.84	1.00	J	U
378378007	NIZ 596	0347	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378008	EPA 8260 Low Level	Chloroform	0.220	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378001	NIZ 593	0118	0.160	1.00	U	
378378002	NIZ 598	0124	0.160	1.00	U	
378378003	NIZ 599	0126	0.160	1.00	U	
378378004	NIZ 590	0301	0.160	1.00	U	
378378005	NIZ 591	0311	0.230	1.00	J	U
378378006	NIZ 597	0315	0.160	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15077238 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378008		Chloroform				

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378007	NIZ 596	0347	0.240	1.00	J	U

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378008	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.290	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378001	NIZ 593	0118	0.160	1.00	U	
378378002	NIZ 598	0124	0.160	1.00	U	
378378003	NIZ 599	0126	0.160	1.00	U	
378378004	NIZ 590	0301	0.160	1.00	U	
378378005	NIZ 591	0311	0.160	1.00	U	
378378006	NIZ 597	0315	0.160	1.00	U	
378378007	NIZ 596	0347	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378022	EPA 8260 Low Level	2-Butanone (Lab Contaminant)	3.12	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378009	NIZ 602	0601	0.500	1.00	U	
378378010	NIZ 600	0605	0.500	1.00	U	
378378011	NIZ 603	0606	0.500	1.00	U	
378378012	NIZ 601	0607	0.500	1.00	U	
378378013	NIZ 604	0608	0.500	1.00	U	
378378015	NIZ 585	0138	0.500	1.00	U	
378378016	NIZ 594	0346	0.500	1.00	U	
378378017	NIZ 595	0379	0.500	1.00	U	
378378018	NIZ 586	0386	0.500	1.00	U	
378378019	NIZ 587	0387	0.500	1.00	U	
378378020	NIZ 588	0389	0.500	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15077238 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378022		2-Butanone (Lab Contaminant)				

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378021	NIZ 589	0392	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378022	EPA 8260 Low Level	Acetone (Lab Contaminant)	24.6		0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378009	NIZ 602	0601	1.51	1.00	J	U
378378010	NIZ 600	0605	2.02	1.00	J	U
378378011	NIZ 603	0606	2.31	1.00	J	U
378378012	NIZ 601	0607	0.500	1.00	U	
378378013	NIZ 604	0608	6.16	1.00	J	U
378378015	NIZ 585	0138	2.89	1.00	J	U
378378016	NIZ 594	0346	2.87	1.00	J	U
378378017	NIZ 595	0379	5.04	1.00	J	U
378378018	NIZ 586	0386	2.04	1.00	J	U
378378019	NIZ 587	0387	5.08	1.00	J	U
378378020	NIZ 588	0389	4.34	1.00	J	U
378378021	NIZ 589	0392	2.21	1.00	J	U

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378022	EPA 8260 Low Level	Chloroform	0.230	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378009	NIZ 602	0601	0.160	1.00	U	
378378010	NIZ 600	0605	0.770	1.00	J	U
378378011	NIZ 603	0606	0.250	1.00	J	U
378378012	NIZ 601	0607	0.160	1.00	U	
378378013	NIZ 604	0608	0.160	1.00	U	
378378015	NIZ 585	0138	0.160	1.00	U	
378378016	NIZ 594	0346	0.160	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15077238 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378022		Chloroform				

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378017	NIZ 595	0379	0.160	1.00	U	
378378018	NIZ 586	0386	0.160	1.00	U	
378378019	NIZ 587	0387	0.160	1.00	U	
378378020	NIZ 588	0389	0.160	1.00	U	
378378021	NIZ 589	0392	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378378022	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.320	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378378009	NIZ 602	0601	0.160	1.00	U	
378378010	NIZ 600	0605	0.270	1.00	J	U
378378011	NIZ 603	0606	0.160	1.00	U	
378378012	NIZ 601	0607	0.160	1.00	U	
378378013	NIZ 604	0608	0.160	1.00	U	
378378015	NIZ 585	0138	0.160	1.00	U	
378378016	NIZ 594	0346	0.160	1.00	U	
378378017	NIZ 595	0379	0.160	1.00	U	
378378018	NIZ 586	0386	0.160	1.00	U	
378378019	NIZ 587	0387	0.160	1.00	U	
378378020	NIZ 588	0389	0.160	1.00	U	
378378021	NIZ 589	0392	0.160	1.00	U	

SAMPLE MANAGEMENT SYSTEM
Organics Data Validation Summary

RIN: 15077238 **Project:** Mound LTS&M Ground Water **Lab Code:** GEN **Validation Date:** 11/18/2015

LCS Recovery: All LCS recoveries were within the laboratory acceptance limits.

Method Blank(s): There were 3 method blank results above the MDL.

MS/MSD Recovery: There were 4 MS/MSD failures.

Surrogate Recovery: All surrogate recoveries were within the laboratory acceptance limits.

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: MS/MSD Performance

RIN: 15077238 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 11/18/2015

MS/MSD	Date Analyzed	Method	Analyte	Recovery MS	Recovery MSD	Lower Limit	Upper Limit	MSD RPD	RPD Limit
NIZ 601	08/11/2015	EPA 8260 Low Level	2-Butanone	100.0	78.9	29.0	143.0	24.00	20.0
NIZ 601	08/11/2015	EPA 8260 Low Level	2-Hexanone	103.0	80.7	46.0	120.0	24.00	20.0
NIZ 601	08/11/2015	EPA 8260 Low Level	4-Methyl-2-pentanone	108.0	87.2	70.0	116.0	21.00	20.0
NIZ 601	08/11/2015	EPA 8260 Low Level	Acetone	88.7	70.9	23.0	171.0	22.00	20.0

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: Method Blanks

RIN: 15077238 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 11/18/2015

Method Blank	Date Analyzed	Method	Analyte	Result	Flag(s)	MDL
1203366890	8/4/2015	EPA 8260 Low Level	Methylene Chloride	0.76	J	0.16
1203369157	8/6/2015	EPA 8260 Low Level	Methylene Chloride	0.47	J	0.16
1203371578	8/11/2015	EPA 8260 Low Level	Methylene Chloride	1.57	J	0.16

SAMPLE MANAGEMENT SYSTEM
Radiochemistry Data Validation Worksheet

RIN: 15077238 **Lab Code:** GEN **Date Due:** 8/28/2015

Matrix: Water **Site Code:** MND03 **Date Completed:** 8/28/2015

Sample	Analyte	Date Analyzed	Result	Flag	Tracer %R	LCS %R	MS %R	Duplicate RER
0607	Tritium	08/14/2015						0.15
Blank_Spike	Tritium	08/14/2015				104.00		
0607	Tritium	08/14/2015					96.3	
Blank	Tritium	08/14/2015	140.0000	U				

Data Review and Validation Report

General Information

Requisition No. (RIN):	15107445
Sample Event:	October 26 - 28, 2015
Site(s):	Mound, Ohio; Groundwater
Laboratory:	GEL Laboratories, Charleston, South Carolina
Work Order No.:	384449
Analysis:	Organics
Validator:	Samantha Tigar
Review Date:	January 20, 2016

This validation was performed according to the *Environmental Procedures Catalog* (LMS/POL/S04325), *"Standard Practice for Validation of Environmental Data."* The procedure was applied at Level 2, Data Deliverables Verification. See attached Data Validation Worksheets for supporting documentation on the data review and validation. All analyses were successfully completed. The samples were prepared and analyzed using accepted procedures based on methods specified by line item code, which are listed in Table 1.

Table 1. Analytes and Methods

Analyte	Line Item Code	Prep Method	Analytical Method
Volatile Organics, VOA	VOA-A-007	SW-846 8260 LL	SW-846 8260 LL

Data Qualifier Summary

Analytical results were qualified as listed in Table 2. Refer to the sections below for an explanation of the data qualifiers applied.

Table 2. Data Qualifier Summary

Sample Number	Location	Analyte(s)	Flag	Reason
384449003	0126	Acetone	U	Less than 10 times the trip blank
384449008	0601	Acetone	U	Less than 10 times the trip blank
384449009	0602	Acetone	U	Less than 10 times the trip blank
384449011	0606	Acetone	U	Less than 10 times the trip blank
384449016	0389	Acetone	U	Less than 10 times the trip blank
384449009	0602	Chloromethane	U	Less than 5 times the trip blank
384449010	0605	Chloromethane	U	Less than 5 times the trip blank
384449011	0606	Chloromethane	U	Less than 5 times the trip blank
384449015	0387	Chloromethane	U	Less than 5 times the trip blank
384449001	0118	Methylene chloride	U	Less than 10 times the trip blank
384449002	0124	Methylene chloride	U	Less than 10 times the trip blank
384449003	0126	Methylene chloride	U	Less than 10 times the trip blank
384449004	0138	Methylene chloride	U	Less than 10 times the trip blank
384449005	0346	Methylene chloride	U	Less than 10 times the trip blank
384449006	0379	Methylene chloride	U	Less than 10 times the trip blank
384449008	0601	Methylene chloride	U	Less than 10 times the trip blank
384449009	0602	Methylene chloride	U	Less than 10 times the trip blank
384449010	0605	Methylene chloride	U	Less than 10 times the trip blank
384449011	0606	Methylene chloride	U	Less than 10 times the trip blank
384449012	0607	Methylene chloride	U	Less than 10 times the trip blank
384449013	0608	Methylene chloride	U	Less than 10 times the trip blank
384449014	0386	Methylene chloride	U	Less than 10 times the trip blank
384449015	0387	Methylene chloride	U	Less than 10 times the trip blank
384449020	0347	Methylene chloride	U	Less than 10 times the trip blank
384449021	0999	Methylene chloride	U	Less than 10 times the method blank
384449022	9347	Methylene chloride	U	Less than 10 times the method blank

Sample Shipping/Receiving

GEL Laboratories in Charleston, South Carolina, received 22 water samples on October 30, 2015, accompanied by Chain of Custody (COC) forms. The COC forms were checked to confirm that all of the samples were listed with sample collection dates and times, and that signatures and dates were present indicating sample relinquishment and receipt. The COC forms were complete with no errors or omissions. The air waybill numbers were listed on the receiving documentation.

Preservation and Holding Times

The sample shipment was received intact with the temperature inside the iced cooler at 2.6 °C, which complies with requirements. All samples were received in the correct container types and had been preserved correctly for the requested analyses. Sample analysis was completed within the applicable holding times.

Detection and Quantitation Limits

The method detection limit (MDL) was reported for all analytes as required. The MDL, as defined in 40 CFR 136, is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The practical quantitation limit (PQL) for these analytes is the lowest concentration that can be reliably measured, and is defined as 5 times the MDL. The reported MDLs for all analytes demonstrate compliance with contractual requirements.

Laboratory Instrument Calibration

Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable qualitative and quantitative data for all analytes. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning of the analytical run. Compliance requirements for continuing calibration checks are established to ensure that the instrument continues to be capable of producing acceptable qualitative and quantitative data. All laboratory instrument calibrations were performed correctly in accordance with the cited methods. All calibration and laboratory spike standards were prepared from independent sources. The Continuing Calibration Verification standards associated with the samples exhibited percent difference values within acceptance criteria for all compounds.

Volatiles Internal Standards and Surrogates

The volatile internal standard recoveries and surrogate recoveries were within the acceptance ranges for all samples. No surrogate recoveries were reported for dibromofluoromethane due to an industry shortage.

Method Blanks

Method blanks are analyzed to assess any contamination that may have occurred during sample preparation. Methylene chloride (a common laboratory contaminant) was detected in the volatiles method blanks at concentrations above the MDL. Associated samples with results less than 10 times the blank concentrations are qualified with a “U” flag (not detected).

Trip Blank

Trip blanks were prepared and analyzed to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organic samples. Acetone, chloromethane, methylene chloride, and toluene were detected in some trip blanks. Sample results for these compounds that are less than 5 times the trip blank concentration (and less than 10 times the blank concentration for common laboratory contaminants) are qualified with a “U” flag as not detected.

Matrix Spike Analysis

Matrix spike and matrix spike duplicate (MS/MSD) samples are used to measure method performance in the sample matrix. The spike recoveries met the acceptance criteria for all

analytes evaluated with the following exception. A MSD recovery for dichlorodifluoromethane was below the lower limit however, the sample was not associated with this RIN. No qualification is necessary.

Laboratory Replicate Analysis

Laboratory replicate analyses are used to determine laboratory precision for each sample matrix. The relative percent difference (RPD) for organic replicate results should be less than the laboratory-derived control limits. All replicate results met these criteria.

Laboratory Control Sample

Laboratory control samples were analyzed at the correct frequency to provide information on the accuracy of the analytical method and the overall laboratory performance, including sample preparation. All control sample results were acceptable.

Field Duplicate

Field duplicate samples are collected and analyzed as an indication of overall precision of the measurement process. The precision observed includes both field and laboratory precision and has more variability than laboratory duplicates, which measure only laboratory performance. A duplicate sample was collected from location 0347. The relative percent difference for duplicate results that are greater than 5 times the PQL should be less than 20 percent. For results that are less than 5 times the PQL, the range should be no greater than the PQL. The duplicate results met these criteria.

Completeness

Results were reported in the correct units for all analytes requested using contract-required laboratory qualifiers.

Electronic Data Deliverable (EDD) File

The EDD file arrived on November 30, 2015. The Sample Management System EDD validation module was used to verify that the EDD file was complete and in compliance with requirements. The module compares the contents of the file to the requested analyses to ensure all and only the requested data are delivered. The contents of the EDD were manually examined to verify that the sample results accurately reflect the data contained in the sample data package.

Sampling Protocol

Sample results for all monitoring wells with field documentation met the Category I low-flow sampling criteria and were qualified with an “F” flag in the database, indicating the wells were purged and sampled using the low-flow sampling method.

Note that locations 0601, 0602, 0605, 0606, 0607, and 0608 did not have field sheet documentation and have not been qualified.

Locations 0138 and 0386 did not have three readings taken after one pump/tubing volume had been purged. The turbidity value for location 0315 was greater than 50 and was not filtered. Dissolved oxygen at location 0347 did not meet criteria. These results are qualified with a “J” flag as estimated values.

Outliers Report

Potential outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected. Potential outliers may result from transcription errors, data-coding errors, or measurement system problems. However, outliers may also represent true extreme values of a distribution and indicate more variability in the population than was expected.

Statistical outlier tests give probabilistic evidence that an extreme value does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to identify data points that require further investigation. The tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set.

There are three steps involved in identifying extreme values or outliers:

1. Identify extreme values that may be potential outliers by generating the Outliers Report using the Sample Management System from data in the environmental database. The application compares the new data set (in standard environmental database units) with historical data and lists the new data that fall outside the historical data range. A determination is also made if the data are normally distributed using the Shapiro-Wilk Test.
2. Apply the appropriate statistical test. Dixon's Extreme Value test is used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test is valid only if the data without the suspected outlier are normally distributed. Rosner's Test is a parametric test that is used to detect outliers for sample sizes of 25 or more. This test also assumes that the data without the suspected outliers are normally distributed.
3. Scientifically review statistical outliers and decide on their disposition. The review should include an evaluation of any notable trends in the data that may indicate the outliers represent true extreme values.

No results from this sampling event were identified as potential outliers.

Report Prepared By: _____

Samantha Tigar
Data Validator

Data Validation Outliers Report - No Field Parameters
Comparison: All historical Data Beginning 1/1/2005
Laboratory: GEL Laboratories
RIN: 15107445

Report Date: 1/21/2016

					Current			**Historical Maximum**			**Historical Minimum**			**Number of**		**Statistical**
						Qualifiers			*Qualifiers*			*Qualifiers*		**Data Points**		**Outlier**
Site Code	Location Code	Sample ID	Sample Date	Analyte	Result	*Lab*	*Data*	Result	*Lab*	*Data*	Result	*Lab*	*Data*	N	N Below Detect	
MND01	0602	N001	10/28/2015	cis-1,2-Dichloroethene	4.56			42.3			7.50			24	0	No
MND01	0602	N001	10/28/2015	trans-1,2-Dichloroethene	0.160	U		5.00	U		0.200	J		24	5	NA
MND01	0605	N001	10/28/2015	Trichloroethene	7.23			24.7			8.69			38	0	NA
MND01	0607	N001	10/28/2015	cis-1,2-Dichloroethene	0.280	J		3.96	J		0.400	J		39	0	NA

STATISTICAL TESTS:
The distribution of the data is tested for normality or lognormality using the Shapiro-Wilk Test
Outliers are identified using Dixon's Test when there are 25 or fewer data points.
Outliers are identified using Rosner's Test when there are 26 or more data points.
See Data Quality Assessment: Statistical Methods for Practitioners, EPA QC/G-9S, February 2006.

NA: Data are not normally or lognormally distributed.

SAMPLE MANAGEMENT SYSTEM

General Data Validation Report

RIN: 15107445 **Lab Code:** GEN **Validator:** Samantha Tigar **Validation Date:** 1/20/2016

Project: Mound LTS&M Ground Water **Analysis Type:** ☐ Metals ☐ General Chem ☐ Rad ☑ Organics

# of Samples: 22 **Matrix:** Water **Requested Analysis Completed:** Yes

Chain of Custody

Present: OK **Signed:** OK **Dated:** OK

Sample

Integrity: OK **Preservation:** OK **Temperature:** OK

Select Quality Parameters

☑ Holding Times	All analyses were completed within the applicable holding times.
☑ Detection Limits	The reported detection limits are equal to or below contract requirements.
☑ Field/Trip Blanks	There were 3 trip/equipment blanks evaluated.
☑ Field Duplicates	There was 1 duplicate evaluated.

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15107445 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 1/20/2016

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449007	EPA 8260 Low Level	Acetone (Lab Contaminant)	2.39	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449001	NLW 068	0118	0.500	1.00	U	
384449002	NLW 073	0124	0.500	1.00	U	
384449003	NLW 074	0126	5.68	1.00	J	U
384449004	NLW 060	0138	0.500	1.00	U	
384449005	NLW 069	0346	0.500	1.00	U	
384449006	NLW 070	0379	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449007	EPA 8260 Low Level	Chloromethane	0.260	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449001	NLW 068	0118	0.160	1.00	U	
384449002	NLW 073	0124	0.160	1.00	U	
384449003	NLW 074	0126	0.160	1.00	U	
384449004	NLW 060	0138	0.160	1.00	U	
384449005	NLW 069	0346	0.160	1.00	U	
384449006	NLW 070	0379	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449007	EPA 8260 Low Level	Methylene Chloride (Lab Contaminant)	1.72	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449001	NLW 068	0118	1.76	1.00	J	U
384449002	NLW 073	0124	1.75	1.00	J	U
384449003	NLW 074	0126	1.89	1.00	J	U
384449004	NLW 060	0138	1.73	1.00	J	U
384449005	NLW 069	0346	1.66	1.00	J	U
384449006	NLW 070	0379	1.57	1.00	J	U

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15107445 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 1/20/2016

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449018	EPA 8260 Low Level	Acetone (Lab Contaminant)	2.75	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449014	NLW 061	0386	0.500	1.00	U	
384449015	NLW 062	0387	0.500	1.00	U	
384449016	NLW 063	0389	5.06	1.00	J	U
384449017	NLW 064	0392	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449018	EPA 8260 Low Level	Chloromethane	0.240	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449014	NLW 061	0386	0.160	1.00	U	
384449015	NLW 062	0387	0.190	1.00	J	U
384449016	NLW 063	0389	0.160	1.00	U	
384449017	NLW 064	0392	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449018	EPA 8260 Low Level	Methylene Chloride (Lab Contaminant)	0.360	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449014	NLW 061	0386	0.570	1.00	J	U
384449015	NLW 062	0387	0.200	1.00	J	U
384449016	NLW 063	0389	0.160	1.00	U	
384449017	NLW 064	0392	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449021	EPA 8260 Low Level	Acetone (Lab Contaminant)	2.03	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449008	NLW 077	0601	2.58	1.00	J	U
384449009	NLW 081	0602	2.49	1.00	J	U

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15107445 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 1/20/2016

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449021		Acetone (Lab Contaminant)				

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449010	NLW 075	0605	0.500	1.00	U	
384449011	NLW 078	0606	2.02	1.00	J	U
384449012	NLW 076	0607	0.500	1.00	U	
384449013	NLW 079	0608	0.500	1.00	U	
384449019	NLW 072	0315	0.500	1.00	U	
384449020	NLW 071	0347	0.500	1.00	U	
384449022	NLW 080	9347	0.500	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449021	EPA 8260 Low Level	Chloromethane	0.250	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449008	NLW 077	0601	0.160	1.00	U	
384449009	NLW 081	0602	0.180	1.00	J	U
384449010	NLW 075	0605	0.170	1.00	J	U
384449011	NLW 078	0606	0.190	1.00	J	U
384449012	NLW 076	0607	0.160	1.00	U	
384449013	NLW 079	0608	0.160	1.00	U	
384449019	NLW 072	0315	0.160	1.00	U	
384449020	NLW 071	0347	0.160	1.00	U	
384449022	NLW 080	9347	0.160	1.00	U	

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449021	EPA 8260 Low Level	Methylene Chloride (Lab Contaminant)	0.640	BJ	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449008	NLW 077	0601	1.31	1.00	J	U
384449009	NLW 081	0602	0.510	1.00	J	U
384449010	NLW 075	0605	0.620	1.00	J	U
384449011	NLW 078	0606	0.600	1.00	J	U

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15107445 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 1/20/2016

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449021		Methylene Chloride (Lab Contaminant)				

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449012	NLW 076	0607	0.540	1.00	J	U
384449013	NLW 079	0608	0.520	1.00	J	U
384449019	NLW 072	0315	0.160	1.00	U	
384449020	NLW 071	0347	0.180	1.00	J	U
384449022	NLW 080	9347	0.440	1.00	BJ	U

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	384449021	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.180	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
384449008	NLW 077	0601	0.160	1.00	U	
384449009	NLW 081	0602	0.160	1.00	U	
384449010	NLW 075	0605	0.160	1.00	U	
384449011	NLW 078	0606	0.160	1.00	U	
384449012	NLW 076	0607	0.160	1.00	U	
384449013	NLW 079	0608	0.160	1.00	U	
384449019	NLW 072	0315	0.160	1.00	U	
384449020	NLW 071	0347	0.160	1.00	U	
384449022	NLW 080	9347	0.160	1.00	U	

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15107445 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 1/20/2016

Duplicate: 9347 **Sample:** 0347

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
1,1,1,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,1-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2-Trichloro-1,2,2-trifluoroethane	1.50	U		1.00	1.50	U		1.00			ug/L
1,1,2-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,3-Trichlorobenzene	0.200	U		1.00	0.200	U		1.00			ug/L
1,2,3-Trichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromo-3-chloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromoethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,3,5-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,4-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
2,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
2-Butanone	0.500	U		1.00	0.500	U		1.00			ug/L
2-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
2-Hexanone	0.500	U		1.00	0.500	U		1.00			ug/L
4-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Isopropyltoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Methyl-2-pentanone	0.500	U		1.00	0.500	U		1.00			ug/L
Acetone	0.500	U		1.00	0.500	U		1.00			ug/L
Benzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromodichloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromoform	0.160	U		1.00	0.160	U		1.00			ug/L
Bromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Carbon Disulfide	0.500	U		1.00	0.500	U		1.00			ug/L
Carbon Tetrachloride	1.46			1.00	1.62			1.00	NA		ug/L
Chlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Chloroethane	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15107445 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 1/20/2016

Duplicate: 9347 **Sample:** 0347

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
Chloroform	0.510	J		1.00	0.550	J		1.00			ug/L
Chloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dichlorodifluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Ethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Hexachlorobutadiene	0.160	U		1.00	0.160	U		1.00			ug/L
Isopropylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Methylene Chloride	0.180	J		1.00	0.440	BJ		1.00			ug/L
Naphthalene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Propylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
sec-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Styrene	0.160	U		1.00	0.160	U		1.00			ug/L
tert-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Tetrachloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
Toluene	0.160	U		1.00	0.160	U		1.00			ug/L
Total Xylenes	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Trichloroethene	19.6			1.00	21.3			1.00	8.31		ug/L
Trichlorofluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Vinyl Chloride	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM
Organics Data Validation Summary

RIN: 15107445 **Project:** Mound LTS&M Ground Water **Lab Code:** GEN **Validation Date:** 1/21/2016

LCS Recovery: All LCS recoveries were within the laboratory acceptance limits.

Method Blank(s): There were 2 method blank results above the MDL.

MS/MSD Recovery: There was 1 MS/MSD failure.

Surrogate Recovery: All surrogate recoveries were within the laboratory acceptance limits.

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: Method Blanks

RIN: 15107445 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 1/21/2016

Method Blank	Date Analyzed	Method	Analyte	Result	Flag(s)	MDL
1203429754	11/9/2015	EPA 8260 Low Level	Methylene Chloride	0.39	J	0.16
1203435061	11/11/2015	EPA 8260 Low Level	Methylene Chloride	0.19	J	0.16

Data Review and Validation Report

General Information

Requisition No. (RIN):	15077239
Sample Event:	July 29, 2015
Site(s):	Mound, Ohio; Groundwater
Laboratory:	GEL Laboratories, Charleston, South Carolina
Work Order No.:	378396
Analysis:	Organics
Validator:	Gretchen Baer
Review Date:	November 18, 2015

This validation was performed according to the *Environmental Procedures Catalog* (LMS/POL/S04325), *"Standard Practice for Validation of Environmental Data."* The procedure was applied at Level 2, Data Deliverables Verification. See attached Data Validation Worksheets for supporting documentation on the data review and validation. All analyses were successfully completed. The samples were prepared and analyzed using accepted procedures based on methods specified by line item code, which are listed in Table 1.

Table 1. Analytes and Methods

Analyte	Line Item Code	Prep Method	Analytical Method
Volatile Organics, VOA	VOA-A-007	SW-846 5030B	SW-846 8260 LL

Data Qualifier Summary

Analytical results were qualified as listed in Table 2. Refer to the sections below for an explanation of the data qualifiers applied.

Table 2. Data Qualifier Summary

Sample Number	Location	Analyte(s)	Flag	Reason
378396010	0617	cis-1,2-Dichloroethene	J	Field duplicate range > PQL
378396010	0617	Trichloroethene	J	Field duplicate range > PQL
378396011	0617 Duplicate	2-Butanone	U	Less than 10 times the trip blank
378396011	0617 Duplicate	cis-1,2-Dichloroethene	J	Field duplicate range > PQL
378396011	0617 Duplicate	Toluene	U	Less than 10 times the trip blank
378396011	0617 Duplicate	Trichloroethene	J	Field duplicate range > PQL
All	All	Methylene chloride	U	Less than 10 times the method blank
All Field Samples	All Field Samples	Acetone	U	Less than 10 times the trip blank

Sample Shipping/Receiving

GEL Laboratories in Charleston, South Carolina, received 11 water samples on July 31, 2015, accompanied by Chain of Custody (COC) forms. The COC forms were checked to confirm that all of the samples were listed with sample collection dates and times, and that signatures and dates were present indicating sample relinquishment and receipt. The COC forms were complete with no errors or omissions. The air waybill numbers were listed on the receiving documentation.

Preservation and Holding Times

The sample shipment was received intact with the temperature inside the iced cooler at 3.3 °C, which complies with requirements. All samples were received in the correct container types and had been preserved correctly for the requested analyses. Sample analysis was completed within the applicable holding times.

Detection and Quantitation Limits

The method detection limit (MDL) was reported for all analytes as required. The MDL, as defined in 40 CFR 136, is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The practical quantitation limit (PQL) for these analytes is the lowest concentration that can be reliably measured, and is defined as 5 times the MDL. The reported MDLs for all analytes demonstrate compliance with contractual requirements.

Laboratory Instrument Calibration

Compliance requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable qualitative and quantitative data for all analytes. Initial calibration demonstrates that the instrument is capable of acceptable performance in the beginning of the analytical run. Compliance requirements for continuing calibration checks are established to ensure that the instrument continues to be capable of producing acceptable qualitative and quantitative data. All laboratory instrument calibrations were performed correctly in accordance with the cited methods. All calibration and laboratory spike standards were prepared from independent sources.

The Continuing Calibration Verification standards associated with the samples exhibited percent difference values within acceptance criteria for all compounds, with the following exceptions. Acetone, 2-butanone, and 2-hexanone had percent drift values greater than 20 percent. There were no sample results greater than the MDL associated with these calibration verification compounds, so no qualification is necessary.

Volatiles Internal Standards and Surrogates

The volatile internal standard recoveries and surrogate recoveries were within the acceptance ranges for all samples.

Method Blanks

Method blanks are analyzed to assess any contamination that may have occurred during sample preparation. Methylene chloride (a common laboratory contaminant) was detected in the volatiles method blanks at concentrations above the MDL. Associated samples with results less than 10 times the blank concentrations are qualified with a "U" flag (not detected).

Trip Blank

Trip blanks were prepared and analyzed to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organic samples. Acetone, 2-butanone, and toluene were detected in some trip blanks. Sample results for these compounds that are less than 5 times the trip blank concentration (and less than 10 times the blank concentration for common laboratory contaminants) are qualified with a "U" flag as not detected.

Matrix Spike Analysis

Matrix spike and matrix spike duplicate (MS/MSD) samples are used to measure method performance in the sample matrix. The spike recoveries met the acceptance criteria for all analytes evaluated.

Laboratory Replicate Analysis

Laboratory replicate analyses are used to determine laboratory precision for each sample matrix. The relative percent difference (RPD) for organic replicate results should be less than the laboratory-derived control limits. For radiochemical measurements, the relative error ratio (the ratio of the absolute difference between the sample and duplicate results and the sum of the 1-sigma uncertainties) is used to evaluate duplicate results and should be less than 3. All replicate results met these criteria, with the following exception. The RPD for four volatiles compounds exceeded the criteria in a matrix spike sample. These compounds were not detected in the associated sample and no further qualification is necessary.

Laboratory Control Sample

Laboratory control samples were analyzed at the correct frequency to provide information on the accuracy of the analytical method and the overall laboratory performance, including sample preparation. All control sample results were acceptable.

Field Duplicate

Field duplicate samples are collected and analyzed as an indication of overall precision of the measurement process. The precision observed includes both field and laboratory precision and has more variability than laboratory duplicates, which measure only laboratory performance. A duplicate sample was collected from location 0617. The relative percent difference for duplicate results that are greater than 5 times the PQL should be less than 20 percent. For results that are less than 5 times the PQL, the range should be no greater than the PQL. The duplicate results met the criteria with the exception of the range between results for cis-1,2-dichloroethene and trichloroethene. There were no analytical errors identified during the review of the data. The cis-1,2-dichloroethene and trichloroethene results for this location are qualified with a "J" flag as estimated values.

Completeness

Results were reported in the correct units for all analytes requested using contract-required laboratory qualifiers.

Electronic Data Deliverable (EDD) File

The EDD file arrived on August 28, 2015. The Sample Management System EDD validation module was used to verify that the EDD file was complete and in compliance with requirements. The module compares the contents of the file to the requested analyses to ensure all and only the requested data are delivered. The contents of the EDD were manually examined to verify that the sample results accurately reflect the data contained in the sample data package.

Sampling Protocol

Sample results for all monitoring wells met the Category I or II low-flow sampling criteria and were qualified with an "F" flag in the database, indicating the wells were purged and sampled using the low-flow sampling method. The groundwater sample results for the wells 0353, 0444, and 0445 were further qualified with a "Q" flag in the database indicating the data are considered qualitative because these are Category II wells.

Note that wells 0411 and 0443 were categorized as II, but were sampled using I criteria.

The turbidity value for location 0400 was greater than 50 NTU.

Outliers Report

Potential outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were

collected. Potential outliers may result from transcription errors, data-coding errors, or measurement system problems. However, outliers may also represent true extreme values of a distribution and indicate more variability in the population than was expected.

Statistical outlier tests give probabilistic evidence that an extreme value does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to identify data points that require further investigation. The tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set.

There are three steps involved in identifying extreme values or outliers:

1. Identify extreme values that may be potential outliers by generating the Outliers Report using the Sample Management System from data in the environmental database. The application compares the new data set (in standard environmental database units) with historical data and lists the new data that fall outside the historical data range. A determination is also made if the data are normally distributed using the Shapiro-Wilk Test.
2. Apply the appropriate statistical test. Dixon's Extreme Value test is used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test is valid only if the data without the suspected outlier are normally distributed. Rosner's Test is a parametric test that is used to detect outliers for sample sizes of 25 or more. This test also assumes that the data without the suspected outliers are normally distributed.
3. Scientifically review statistical outliers and decide on their disposition. The review should include an evaluation of any notable trends in the data that may indicate the outliers represent true extreme values.

No results from this sampling event were identified as potential outliers.

Report Prepared By: _____

Gretchen Baer
Data Validator

Data Validation Outliers Report - No Field Parameters
Comparison: All historical Data Beginning 1/1/2005
Laboratory: GEL Laboratories
RIN: 15077239
Report Date: 11/18/2015

					Current			Historical Maximum			Historical Minimum			Number of Data Points		Statistical Outlier
						Qualifiers			*Qualifiers*			*Qualifiers*				
Site Code	Location Code	Sample ID	Sample Date	Analyte	Result	*Lab*	*Data*	Result	*Lab*	*Data*	Result	*Lab*	*Data*	N	N Below Detect	
MND01	0617	N002	07/29/2015	cis-1,2-Dichloroethene	0.160	U	J	2.82	J		0.590	J		20	0	No
MND01	0617	N002	07/29/2015	Trichloroethene	0.160	U	J	10.4			1.84			20	0	No

STATISTICAL TESTS:
The distribution of the data is tested for normality or lognormality using the Shapiro-Wilk Test
Outliers are identified using Dixon's Test when there are 25 or fewer data points.
Outliers are identified using Rosner's Test when there are 26 or more data points.
See Data Quality Assessment: Statistical Methods for Practitioners, EPA QC/G-9S, February 2006.

SAMPLE MANAGEMENT SYSTEM
General Data Validation Report

RIN: 15077239 **Lab Code:** GEN **Validator:** Gretchen Baer **Validation Date:** 11/18/2015

Project: Mound LTS&M Ground Water **Analysis Type:** ☐ Metals ☐ General Chem ☐ Rad ☑ Organics

# of Samples: 11 **Matrix:** Water **Requested Analysis Completed:** Yes

Chain of Custody

Present: OK **Signed:** OK **Dated:** OK

Sample

Integrity: OK **Preservation:** OK **Temperature:** OK

Select Quality Parameters

☑ Holding Times	All analyses were completed within the applicable holding times.
☑ Detection Limits	The reported detection limits are equal to or below contract requirements.
☑ Field/Trip Blanks	There was 1 trip/equipment blank evaluated.
☑ Field Duplicates	There was 1 duplicate evaluated.

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15077239 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378396008	EPA 8260 Low Level	2-Butanone (Lab Contaminant)	3.85	J	0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378396001	NIZ 609	0353	0.500	1.00	U	
378396002	NIZ 610	0400	0.500	1.00	U	
378396003	NIZ 611	0402	0.500	1.00	U	
378396004	NIZ 612	0411	0.500	1.00	U	
378396005	NIZ 613	0443	0.500	1.00	U	
378396006	NIZ 614	0444	0.500	1.00	U	
378396007	NIZ 615	0445	0.500	1.00	U	
378396009	NIZ 618	P033	0.500	1.00	U	
378396010	NIZ 616	0617	0.500	1.00	U	
378396011	NIZ 617	9617	1.98	1.00	J	U

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378396008	EPA 8260 Low Level	Acetone (Lab Contaminant)	31.9		0.500	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378396001	NIZ 609	0353	5.54	1.00	J	U
378396002	NIZ 610	0400	1.94	1.00	J	U
378396003	NIZ 611	0402	3.93	1.00	J	U
378396004	NIZ 612	0411	3.22	1.00	J	U
378396005	NIZ 613	0443	2.61	1.00	J	U
378396006	NIZ 614	0444	2.45	1.00	J	U
378396007	NIZ 615	0445	2.19	1.00	J	U
378396009	NIZ 618	P033	4.25	1.00	J	U
378396010	NIZ 616	0617	3.82	1.00	J	U
378396011	NIZ 617	9617	15.1	1.00		U

SAMPLE MANAGEMENT SYSTEM

Validation Report: Equipment/Trip Blanks

RIN: 15077239 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Blank Data

Blank Type	Lab Sample ID	Lab Method	Analyte Name	Result	Qualifier	MDL	Units
Trip Blank	378396008	EPA 8260 Low Level	Toluene (Lab Contaminant)	0.270	J	0.160	ug/L

Sample ID	Sample Ticket	Location	Result	Dilution Factor	Lab Qualifier	Validation Qualifier
378396001	NIZ 609	0353	0.160	1.00	U	
378396002	NIZ 610	0400	0.160	1.00	U	
378396003	NIZ 611	0402	0.160	1.00	U	
378396004	NIZ 612	0411	0.160	1.00	U	
378396005	NIZ 613	0443	0.160	1.00	U	
378396006	NIZ 614	0444	0.160	1.00	U	
378396007	NIZ 615	0445	0.160	1.00	U	
378396009	NIZ 618	P033	0.160	1.00	U	
378396010	NIZ 616	0617	0.160	1.00	U	
378396011	NIZ 617	9617	0.200	1.00	J	U

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15077239 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Duplicate: 9617 **Sample:** 0617

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
1,1,1,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,1-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2,2-Tetrachloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1,2-Trichloro-1,2,2-trifluoroethane	1.50	U		1.00	1.50	U		1.00			ug/L
1,1,2-Trichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
1,1-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,3-Trichlorobenzene	0.200	U		1.00	0.200	U		1.00			ug/L
1,2,3-Trichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2,4-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromo-3-chloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dibromoethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloroethane	0.160	U		1.00	0.160	U		1.00			ug/L
1,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,3,5-Trimethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
1,3-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
1,4-Dichlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
2,2-Dichloropropane	0.160	U		1.00	0.160	U		1.00			ug/L
2-Butanone	0.500	U		1.00	1.98	J		1.00			ug/L
2-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
2-Hexanone	0.500	U		1.00	0.500	U		1.00			ug/L
4-Chlorotoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Isopropyltoluene	0.160	U		1.00	0.160	U		1.00			ug/L
4-Methyl-2-pentanone	0.500	U		1.00	0.500	U		1.00			ug/L
Acetone	3.82	J		1.00	15.1			1.00			ug/L
Benzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Bromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromodichloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Bromoform	0.160	U		1.00	0.160	U		1.00			ug/L
Bromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Carbon Disulfide	0.500	U		1.00	0.500	U		1.00			ug/L
Carbon Tetrachloride	0.160	U		1.00	0.160	U		1.00			ug/L
Chlorobenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Chloroethane	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM

Validation Report: Field Duplicates

RIN: 15077239 **Lab Code:** GEN **Project:** Mound LTS&M Ground Water **Validation Date:** 11/18/2015

Duplicate: 9617 **Sample:** 0617

	Sample				Duplicate						
Analyte	Result	Flag	Error	Dilution	Result	Flag	Error	Dilution	RPD	RER	Units
Chloroform	0.160	U		1.00	0.160	U		1.00			ug/L
Chloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
cis-1,2-Dichloroethene	1.86			1.00	0.160	U		1.00	>PQL		ug/L
cis-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromochloromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dibromomethane	0.160	U		1.00	0.160	U		1.00			ug/L
Dichlorodifluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Ethylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Hexachlorobutadiene	0.160	U		1.00	0.160	U		1.00			ug/L
Isopropylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Methylene Chloride	1.53	BJ		1.00	1.22	BJ		1.00			ug/L
Naphthalene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
n-Propylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
sec-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Styrene	0.160	U		1.00	0.160	U		1.00			ug/L
tert-Butylbenzene	0.160	U		1.00	0.160	U		1.00			ug/L
Tetrachloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
Toluene	0.160	U		1.00	0.200	J		1.00			ug/L
Total Xylenes	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,2-Dichloroethene	0.160	U		1.00	0.160	U		1.00			ug/L
trans-1,3-Dichloropropene	0.160	U		1.00	0.160	U		1.00			ug/L
Trichloroethene	8.05			1.00	0.160	U		1.00	>PQL		ug/L
Trichlorofluoromethane	0.160	U		1.00	0.160	U		1.00			ug/L
Vinyl Chloride	0.160	U		1.00	0.160	U		1.00			ug/L

SAMPLE MANAGEMENT SYSTEM
Organics Data Validation Summary

RIN: 15077239 **Project:** Mound LTS&M Ground Water **Lab Code:** GEN **Validation Date:** 11/18/2015

LCS Recovery: All LCS recoveries were within the laboratory acceptance limits.

Method Blank(s): There were 2 method blank results above the MDL.

MS/MSD Recovery: There were 4 MS/MSD failures.

Surrogate Recovery: All surrogate recoveries were within the laboratory acceptance limits.

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: MS/MSD Performance

RIN: 15077239 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 11/18/2015

MS/MSD	Date Analyzed	Method	Analyte	Recovery MS	Recovery MSD	Lower Limit	Upper Limit	MSD RPD	RPD Limit
NIZ 601	08/11/2015	EPA 8260 Low Level	2-Butanone	100.0	78.9	29.0	143.0	24.00	20.0
NIZ 601	08/11/2015	EPA 8260 Low Level	2-Hexanone	103.0	80.7	46.0	120.0	24.00	20.0
NIZ 601	08/11/2015	EPA 8260 Low Level	4-Methyl-2-pentanone	108.0	87.2	70.0	116.0	21.00	20.0
NIZ 601	08/11/2015	EPA 8260 Low Level	Acetone	88.7	70.9	23.0	171.0	22.00	20.0

SAMPLE MANAGEMENT SYSTEM

Non-Compliance Report: Method Blanks

RIN: 15077239 **Lab Code:** GEN

Project: Mound LTS&M Ground Water

Validation Date: 11/18/2015

Method Blank	Date Analyzed	Method	Analyte	Result	Flag(s)	MDL
1203371578	8/11/2015	EPA 8260 Low Level	Methylene Chloride	1.57	J	0.16
1203373907	8/12/2015	EPA 8260 Low Level	Methylene Chloride	0.91	J	0.16

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