

Chlorinated Organic Solvent Remediation Pilot Study

INTRODUCTION

This paper presents the results to date of a 5 month pilot scale study for the reduction of organic solvents including perchloroethene (PCE) and trichloroethene (TCE). The scope of services involved designing, building and operating a NEAT™ remediation system at an industrial facility in Fulton County, GA. A primary objective is to evaluate the effectiveness of gas infusion technology in the site's tight geologic formation, and determine optimal system design parameters for full scale remediation. The site has some challenging geologic conditions and two prior technologies were tested and failed; chemical oxidation injection, and slow-release hydrogen compound injection.

4 (four) injection wells were installed in the vicinity of the previous pilot studies. The injection wells were drilled to the top of bedrock, approximately 60 feet deep. They were constructed in a manner similar to the monitoring wells. Existing monitoring wells within the zone of influence were used to track the progress of the system. The initial assumption was that the radius of influence would be about 25 feet from each injection well. However, monitoring of a well 60 feet from the closest injection point indicated a clear pattern of reductive dechlorination, with anaerobic, reductive conditions achieved within 45 days of start up.



SUMMARY

In summary, the anaerobic pilot study has been successful in demonstrating that reductive dechlorination will occur under the aquifer conditions created by the eGeo system. Our system converted an oxidative environment, DO= 5 ppm, ORP=+280, to a reductive environment, DO=0 ppm, ORP= -190, in 30 days. In addition, we have optimized the flow rate to minimize gas supply costs, and determined through air monitoring that our system installation is safe and economical.

Results to date are illustrated graphically in figures 2-10. Although high concentrations of PCE and TCE continue to migrate into the pilot area, substantial quantities of daughter products (Cis - 1,2 -Dichloroethene) have been generated, indicating reductive dechlorination processes are converting the PCE. As the remediation program transitions to aerobic conditions, the daughter products such as vinyl chloride will be further degraded to carbon dioxide, ethene, and water.

PCE Pilot Study

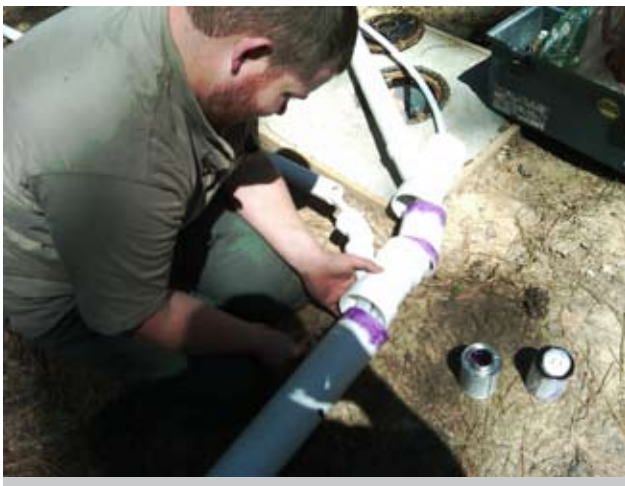
INSTALLATION

A NEAT™ trailer mounted remediation system was configured and mobilized to the site on April 4, 2011. The system injects methane gas, hydrogen gas and triethyl phosphate (TEP) vapor via a nitrogen gas carrier stream. Nitrogen is used rather than air to create anaerobic (low oxygen) conditions to facilitate dechlorination of the perchloroethylene (PCE).

After satisfactory reduction of PCE, the system will be transitioned to aerobic operation using compressed air as the carrier gas with nitrous oxide and TEP as nutrient sources.



A system of PVC carrier pipes and internal HDPE tubing was installed to safely distribute the gas from tanks in the trailer to each injection well. The system is sealed to minimize loss of gas and prevent intrusion. HDPE tubing is used because the ethyl group in triethyl phosphate vapor will degrade PVC over time. After installation and testing the system was turned on for continuous operation on April 7, 2011.



Gas Monitoring Program

We have monitored the wellhead in each injection well and in the 3 monitoring wells both to detect any buildup of potentially explosive gas, and to identify the by-products of PCE dechlorination.



The monitoring has been performed on site using a portable instrument shown at right, the MultiRAE Plus.

The gases that have been monitored are

- Cl₂ - Chlorine
- VOC - Volatile organic compounds
- CO₂ - Carbon Dioxide
- CH₄ - Methane
- O₂ - Oxygen

Daily data was recorded on site using the following format:

4/29/2011
9:30 AM

	initial	reset
Tank (psi)	1490	1490
Regulator (psi)	19	17.5
Flow (cfh)	2.2	2.1

IW	Cl ₂	VOC	CO ₂	CH ₄	O ₂
EG4	0	1	560	100	0.5
EG3	0	6	2250	6	20.7
EG2	0	11.4	700	100	0.7
EG1	0	32	800	9	19.5
BG 0	0	640	0	20.9	
PT-2	0.1	1	2430	2	20.9
PT-1	0.3	1.6	1440	2	20.9
PT-3	0.1	12.8	9420	2	20.1

GAS DIFFUSION

Each injection well is controlled by a valve to allow balancing of flow. A flow metering device is used to adjust the rate of gas flow to the header shown at right.

Operations to date have indicated a flow rate of approximately 3 standard cubic feet per hour (scfh) at 18 psi is sufficient to overcome the headloss from the tubing and the 28 foot column of water in the injection wells.

The delivery pressure is maintained by a 2 stage regulator (shown at right) that has a range of 0 - 50 psi. We have been operating the system with a working pressure in the range 16-24 psi.

During system start up and testing, the groundwater in the injection well was lifted to the surface, as illustrated in the photo below, when the pressure was set greater than 30 psi and a flowrate above 4 scfh.





Reductive Dechlorination

Anaerobic Reductive Dechlorination

Enhanced in situ anaerobic bioremediation can be an effective method of degrading various forms of chlorinated compounds dissolved in groundwater. The addition of an organic substrate to an aquifer has the potential to stimulate microbial growth and development, creating an anaerobic environment in which rates of anaerobic degradation of CAHs (chlorinated aliphatic hydrocarbons) may be greatly enhanced. Therefore, a variety of organic substrates in various engineering designs have been applied to the subsurface to promote anaerobic degradation of CAHs to innocuous end products. In some cases, microorganisms also may need to be added (bioaugmentation), but only if the natural microbial population is incapable of performing the required transformations.

The following three general reactions may degrade CAHs by reductive dechlorination:

Direct Anaerobic Reductive Dechlorination is a biological reaction in which bacteria gain energy and grow as one or more chlorine atoms on a CAH molecule are replaced with hydrogen in an anaerobic environment. In this reaction, the chlorinated compound serves as the electron acceptor and hydrogen serves as the direct electron donor. Hydrogen used in this reaction is typically supplied by fermentation of organic substrates. This reaction may also be referred to as halorespiration or dehalorespiration.

Cometabolic Anaerobic Reductive Dechlorination is a reaction in which a chlorinated compound is reduced by a non-specific enzyme or co-factor produced during microbial metabolism of another compound (i.e., the primary substrate) in an anaerobic environment. By definition, cometabolism of the chlorinated compound does not yield any energy or growth benefit for the microbe mediating the reaction. For the cometabolic process to be sustained, sufficient primary substrate is required to support growth of the transforming microorganisms.

Abiotic Reductive Dechlorination is a chemical degradation reaction not associated with biological activity where a chlorinated hydrocarbon is reduced by a reactive compound. Addition of an organic substrate and creation of an anaerobic environment may create reactive compounds such as iron-monosulfides that can degrade CAHs. In this case, substrate addition may indirectly cause abiotic reductive dechlorination.

In practice, it may not be possible to distinguish between these three different reactions at the field scale. All three reactions may be occurring, and abiotic reductive dechlorination may be enhanced indirectly by substrate addition. As described, anaerobic dechlorination refers to the biotic processes of direct and cometabolic anaerobic reductive dechlorination.

In general, anaerobic dechlorination occurs by sequential removal of chloride ions. For example, the chlorinated ethenes are transformed sequentially from PCE to TCE to the dichloroethene (DCE) isomers (cis-DCE or trans-DCE) to vinyl chloride (VC) to ethene as illustrated on Figure 1:

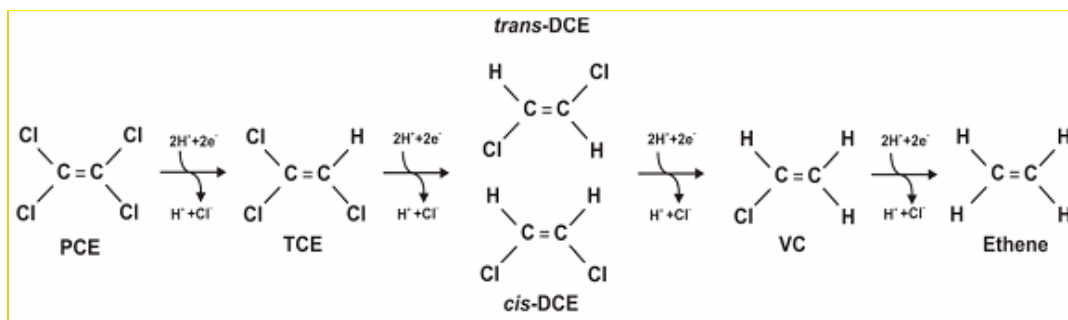


Figure 1. Sequential Reduction of PCE to Ethene by Anaerobic Reductive Dechlorination

In this reaction, hydrogen is the electron donor, which is oxidized. The chlorinated ethene molecule is the electron acceptor, which is reduced. While other fermentation products (e.g., acetate) may serve as an electron donor, hydrogen appears to be the most important electron donor for anaerobic dechlorination of CAHs.

This background information is provided here to support the logic behind using hydrogen and methane gases within the nitrogen carrier gas. The results during the first 5 months of operation are encouraging. The data is clearly trending in the direction that indicates the gas is diffusing from the injection wells throughout the study zone in sufficient quantities to facilitate reductive dechlorination.



Results

CONCLUSION

During the five month pilot operation approximately 12,000 cubic feet of nitrogen-methane-hydrogen gas mix was injected. The monitoring well labeled PT-2 is located within a 10 foot radius of 2 injection wells, and the monitoring well labeled PT-3 is approximately 60 feet down gradient of the 4 injection wells.

The results illustrated in figures 2 through 10 provide compelling evidence that sequential reduction of PCE to vinyl chloride has occurred in the pilot study zone of influence via Anaerobic Reductive Dechlorination. The dramatic increase in daughter products CIS-dichloroethene (DCE) and the intermediate vinyl chloride are directly and uniquely correlated with the relatively substantial reduction of PCE and TCE. Relative because this is a grossly contaminated site and the pilot study area is within the highest concentrations of PCE and TCE. During the injection process, it is suspected that slugs of PCE and TCE migrated into the injection zone, so the magnitude of reduction in PCE concentrations does not appear consistent with the higher magnitude of daughter product formation.

The pilot study has demonstrated that the NEAT™ anaerobic process is a safe and economical approach to remediation of sites impacted by chlorinated organic solvents. The data compiled during the 5 month period provides a sound basis for design of full scale remediation operations, and will prove invaluable in designing systems for similar projects in the future.

REFERENCE

eGeo Services teamed with the Corporate Owners' environmental consultant on the pilot study. We appreciate the opportunity to work with them and the assistance they provided. Our contact has been:

Mr. Jack A. Wintle, P.G., Environmental Services Manager
Oasis Environmental Services, LLC
678-739-2400 office 678-431-0130 mobile
jwintle@oasis-cs.com

Michael J. McJilton, P.E., Project Principal
eGeo Services, Inc.
Mike@egeoservices.com
770.335.3919



Figure 2: PT-2 40' Trends

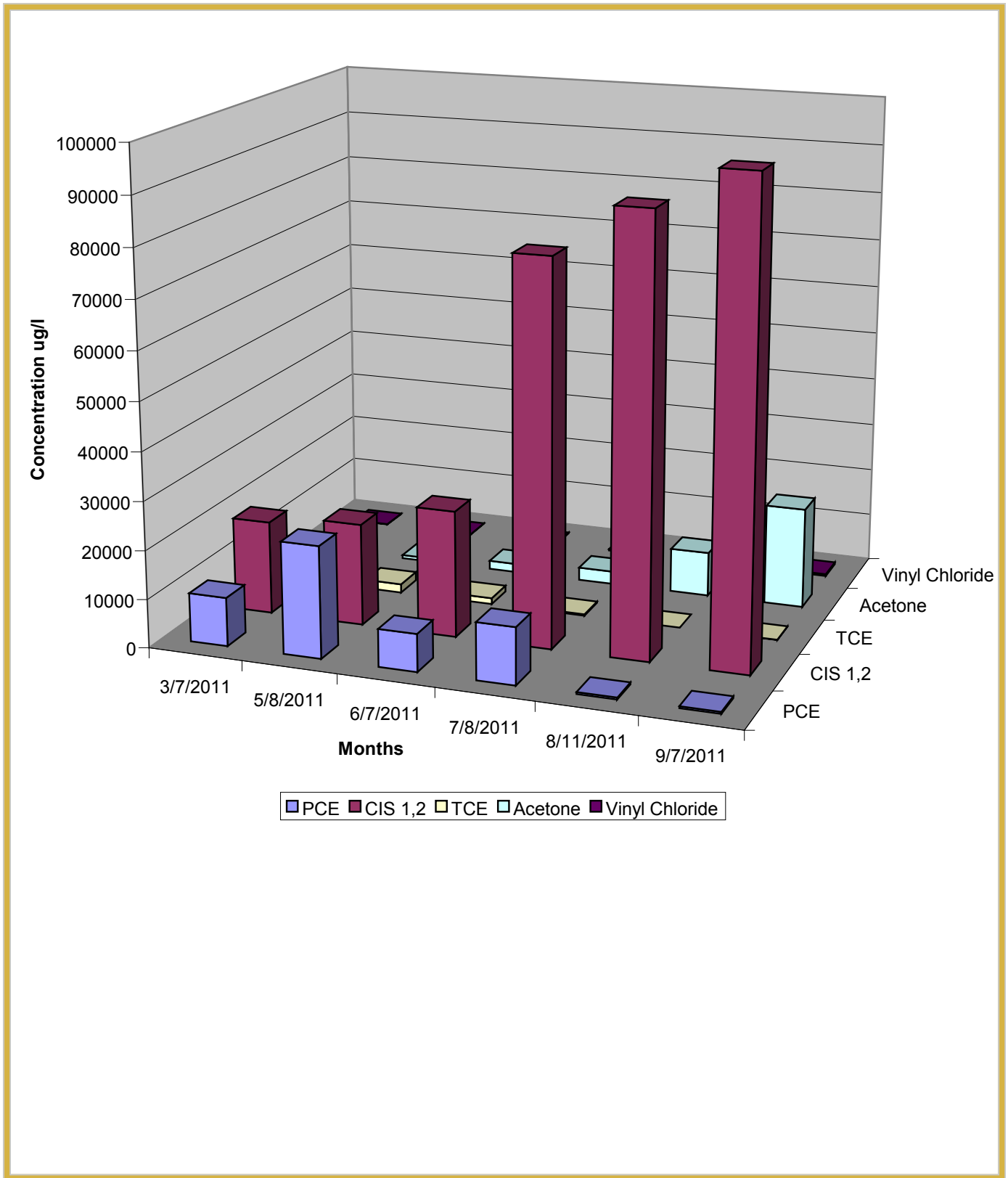


Figure 3: PT-2 60' Trends

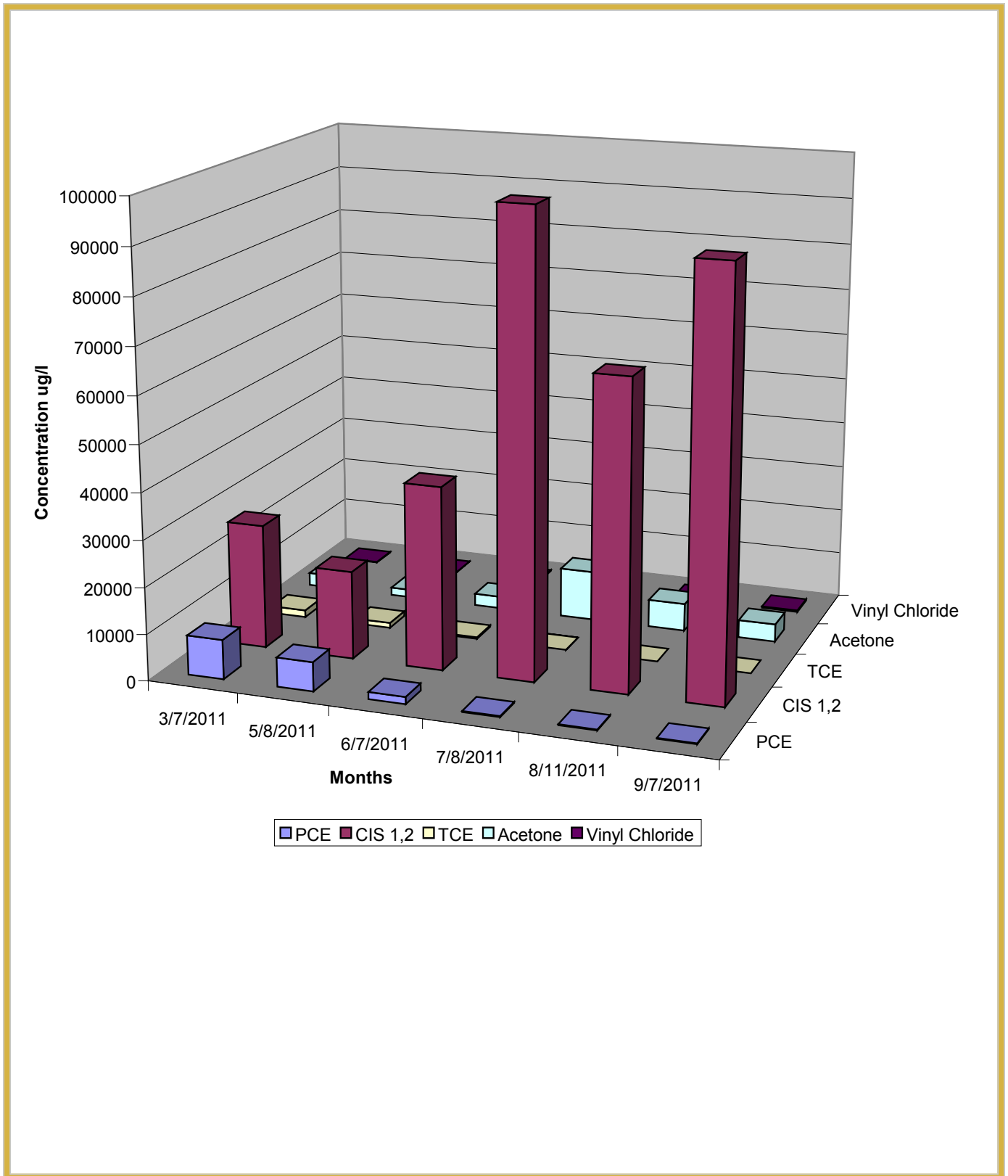




Figure 4: PT-3 40' Trends

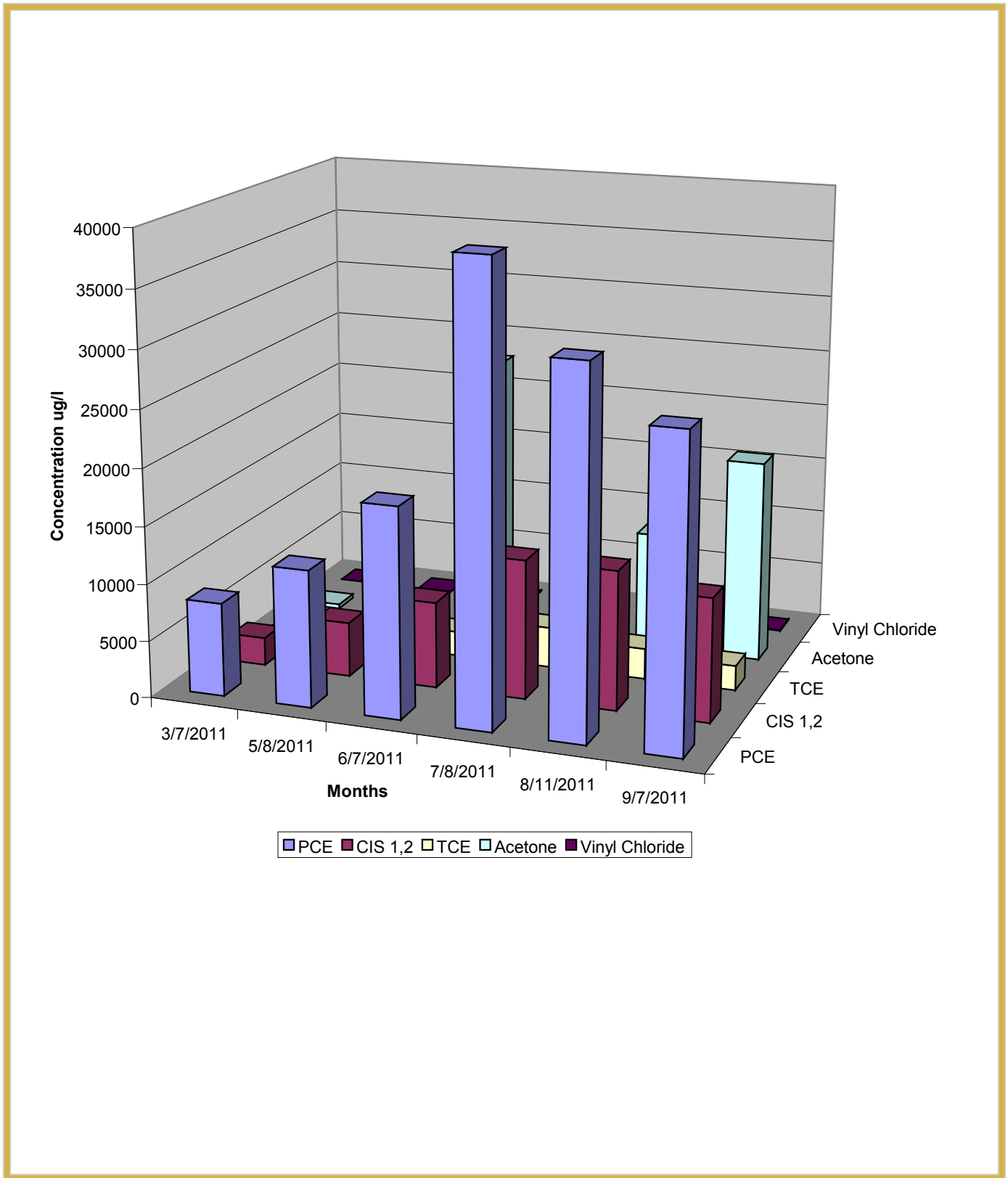




Figure 5: PT-3 60' Trends

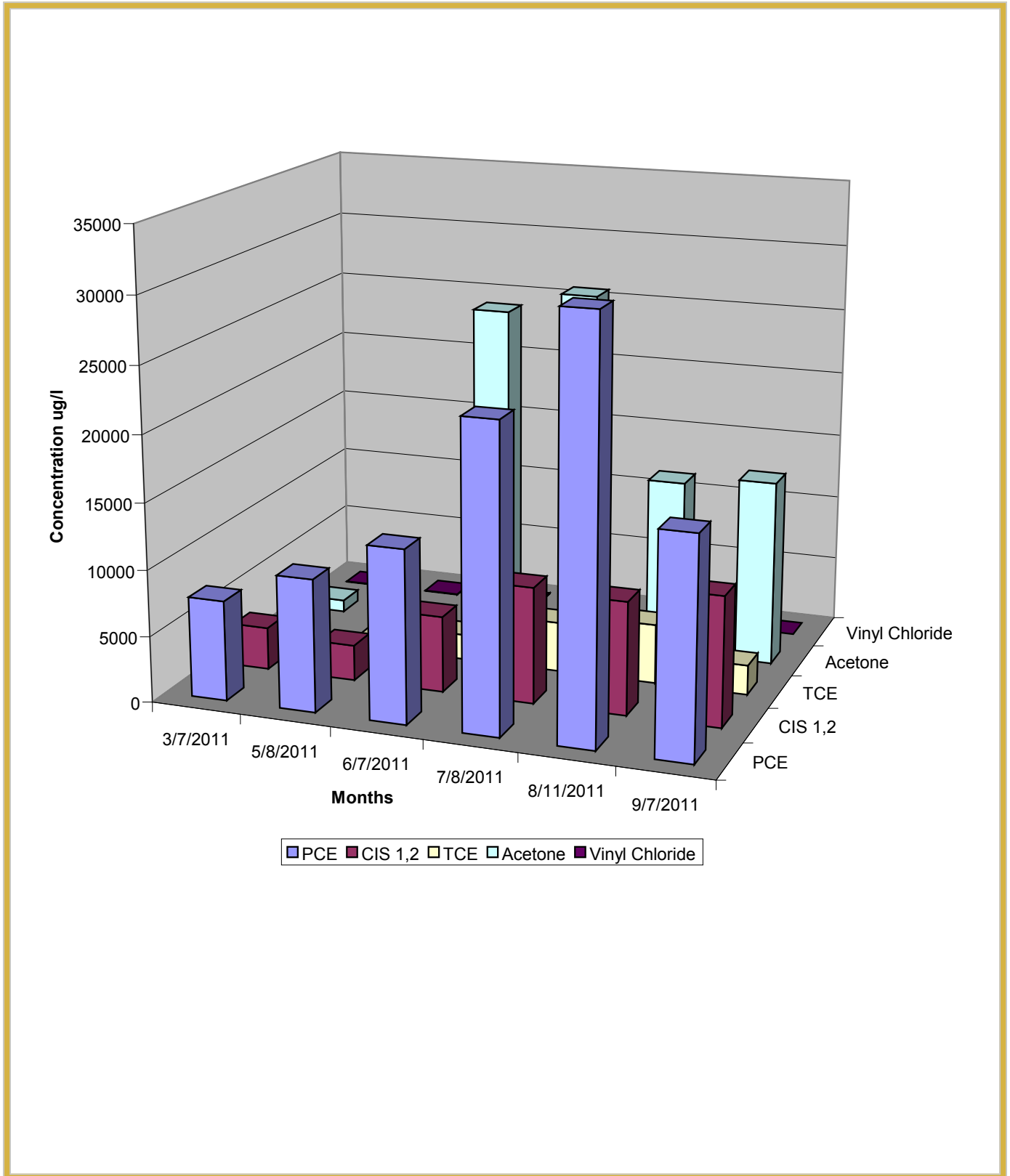




Figure 6: PCE Trends

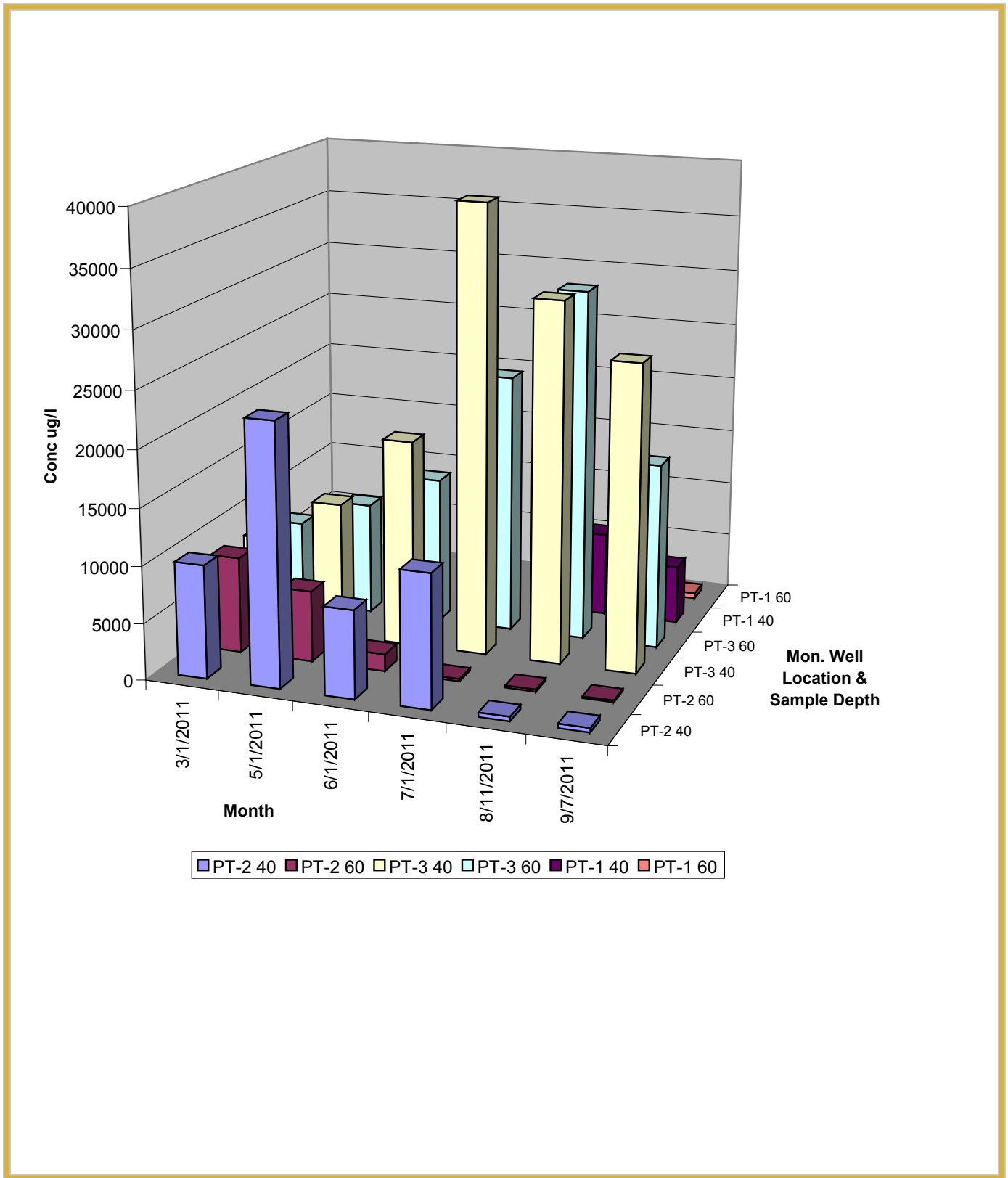




Figure 7:

CIS- 1,2 - Dichloroethene Trends

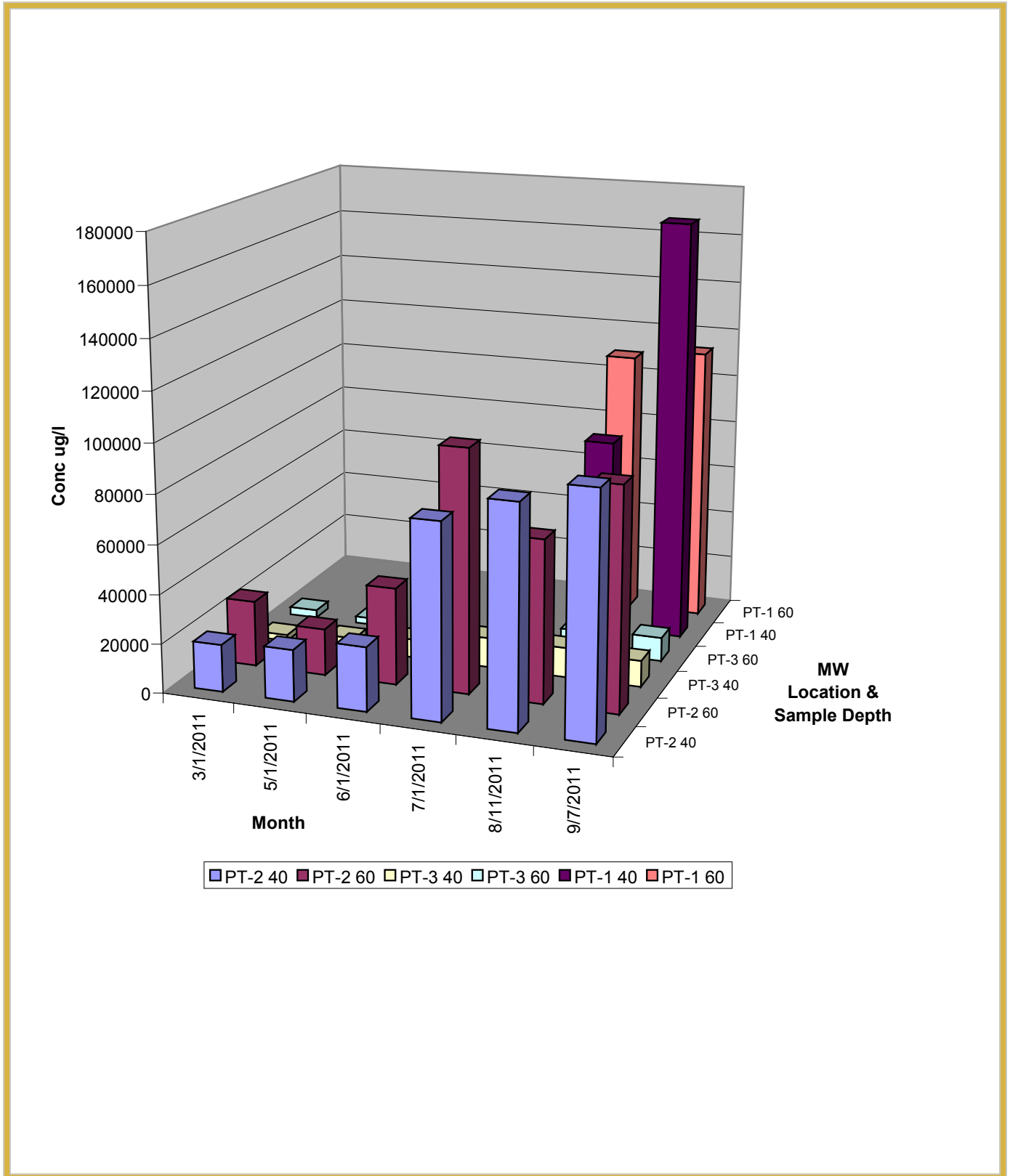




Figure 8: TCE Trends

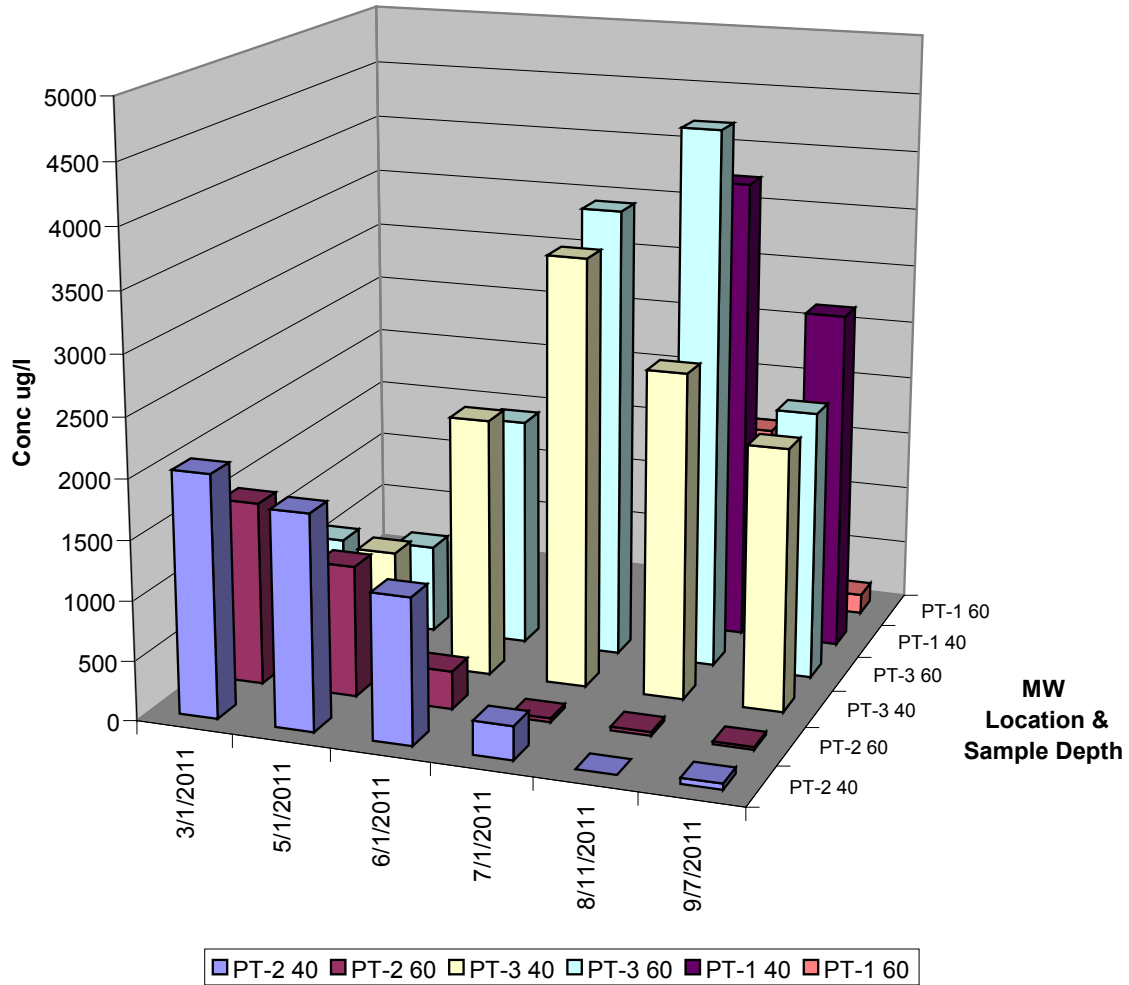


Figure 9: Acetone Trends

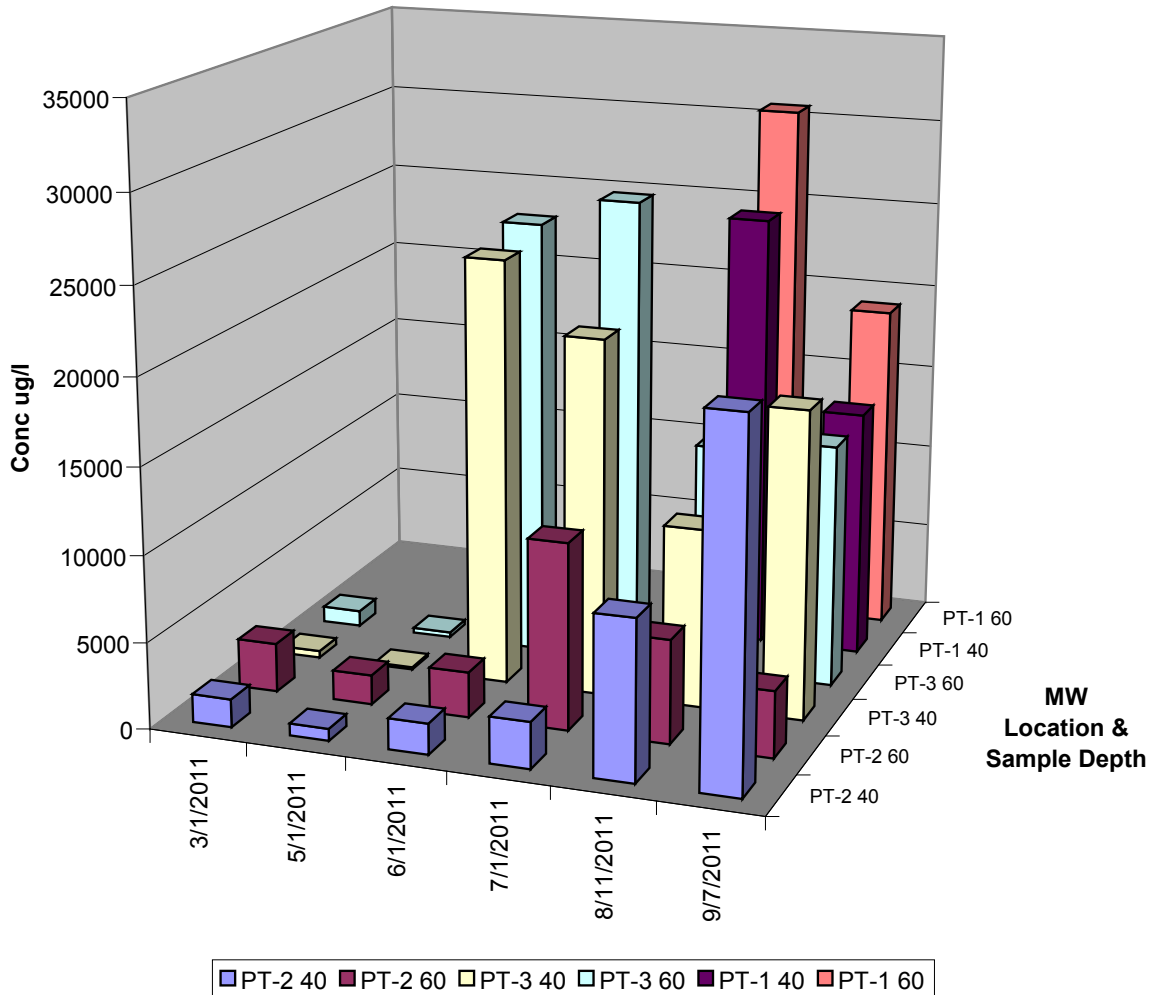




Figure 10: Vinyl Chloride Trends

