2007

LITHOLOGIC AND HYDROGEOLOGIC CONTROLS ON THE OCCURRENCE, TRANSPORT, AND FATE OF MTBE IN FINE GRAINED GLACIAL-LACUSTRINE SEDIMENTS

Mary Kathryn Sutherland
The University of Montana

Recommended Citation

Sutherland, Mary Kathryn, "LITHOLOGIC AND HYDROGEOLOGIC CONTROLS ON THE OCCURRENCE, TRANSPORT, AND FATE OF MTBE IN FINE GRAINED GLACIAL-LACUSTRINE SEDIMENTS" (2007). *Graduate Student Theses, Dissertations, & Professional Papers*. 1283.
https://scholarworks.umt.edu/etd/1283

LITHOLOGIC AND HYDROGEOLOGIC CONTROLS ON THE OCCURRENCE, TRANSPORT, AND FATE OF MTBE IN FINE GRAINED GLACIAL-LACUSTRINE SEDIMENTS

By

MARY KATHRYN SUTHERLAND

B.S. Geology, James Madison University, 2003

Thesis

presented in partial fulfillment of the of the requirements
for the degree of

Master of Science
Geosciences

The University of Montana
Missoula, Montana

May 2009

Approved By:
Perry Brown, Associate Provost for Graduate Education
Graduate School

William Woessner, Chair
Geosciences

Marc Hendrix
Geosciences

Scott Woods
College of Forestry and Conservation

Sutherland, Mary, M.S., May 2009 Geology

Lithologic and Hydrogeologic Controls on the Occurrence, Transport, and Fate of MTBE in Fine Grained Glacial-lacustrine Sediments

Chairperson: William Woessner

In April of 1994, a leaking 60,480L gasoline underground storage tank was removed from George's Conoco in Ronan, Montana. Investigations discovered a free product plume extending under Highway 93, with dissolved phase contamination (including MTBE) extending 460 m west to Spring Creek.

Though geochemical sampling has established the general plume extent, the influence of aquifer heterogeneities on plume position and transport behavior is poorly described. The purpose of this work is to characterize the physical controls on plume migration. In addition to standard well installation and geochemical sampling, geotechnical tools including cone penetration testing (CPT) and Membrane Interface Probe (MIP), were used to examine subtle changes in sand, silt and clay. These tests were supported by site coring, grain size analyses, and lab and field hydraulic conductivity testing.

CPT results revealed glacial diamict sediments, dominated by silt and fine sand with lenses of clay varying in thickness. It appears the plume preferentially travels in sequences of sand and silt in the water table aquifer between depths of 3 to 10 m, though some contamination has been discovered at greater depth and is believed to be passing underneath Spring Creek and traveling west, potentially impacting water users in the Flathead Valley.

Through field and laboratory analysis, the governing hydrogeologic controls on the ground water flow system were described. A model was developed to simulate the contaminant transport and compared to observed plume movement, and a heat transport model was developed for comparison with both the modeled ground water flow and the field-observed ground water flow characteristics.

It became evident that under the documented hydraulic conductivities for sediments found at this site, the velocity of plume movement was considerably more rapid than expected. This suggests that either an interconnected fracture network is responsible for the transport of hydrocarbons throughout the site, or the known date of contaminant release from George's Conoco is unreliable.

Acknowledgements

Without the grant provided by the American Petroleum Institute through the Montana Department of Environmental Quality this work would not have been possible. Thanks to Jeff Kuhn and Pat Skibicki of the DEQ for all the help, advice, and financial support.

Thanks to Anthony Farinacci for all the help with field work, none of which I could have done without his generous donation of many Saturdays.
Thanks to Anthony Berthelotte, Shandin Pete, and Michael Sperazza who all politely allowed me to beg, borrow and steal from their wealth of knowledge.

This work would not have been possible without the encouragement of Jeff Kuhn of the Montana DEQ. I am immensely grateful to him for his support, optimism, and patience while I plodded along.

And above all, thanks to Bill Woessner, who has helped in so many ways I could write another thesis.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Methyl tert-butyl ether (MTBE), an additive included in automotive gasoline since the 1980's, is used to help increase combustion efficiency and reduce engine knocking (Loustaunau 2003, Leal-Bautista 2006). Currently, more than 80% of the reformulated gasoline sold in the United States each year contains up to 15% MTBE by volume (Deeb 2000, Jacobs 2000, Herrick 2000, Schmidt 2003, Rong 2005). Despite regulations on the handling and storage of gasoline, leaks and spills associated with underground storage tank systems are common, and often impact surface water and ground water (Deeb 2000, Herrick 2000, Jacobs, 2000, Bradley 2001, Schmidt 2003, Schmidt 2004). In fact, MTBE is the second most common volatile organic compound found in shallow ground water (Squillace 1996, Cozzarelli 1999, Jacobs 2000, Hong 2001, Rossell, 2005, Bradley 2006, Stocking 1999, Leal-Bautista 2006, Chen 2006). Despite its presence as a major ground water contaminant, the behavior of MTBE in ground water is poorly understood (Conant 2000, Jacobs 2000, Rong 2005). Many states have begun to impose restrictions and even phase-out the use of MTBE in an effort to control ground water pollution, however, since it's introduction, MTBE has become a prevalent ground water contaminant that will require many years to remediate even after termination of its use (Jacobs 2000, Rong 2005).

Tertiary-butyl alcohol (TBA) is an octane booster used in gasoline as well as an impurity and degradation product of MTBE (Bay 2005, Rosell 2005, Chen 2006). Under aerobic conditions, the MTBE ether bond is cleaved and TBA is formed, which may then metabolize to form formaldehyde and acetone under specific conditions (Stocking 1999, Deeb 2000, Jacobs 2000, Kolhatkar 2000, Schmidt 2004). TBA acts as the rate limiting step in the degradation of MTBE (Deeb 2000). In conditions where benzene toluene ethylbenzene xylenes (BTEX) exists, microorganisms will utilize these compounds for carbon and energy, a process that requires oxygen and may create anaerobic conditions for MTBE and TBA degradation (Deeb 2000, Jacobs 2000, Schirmer 2003, Chen 2006). MTBE and TBA have been shown to biodegrade to CH_4 and CO_2 in the presence of Fe (II,III) and hydrogen sulfide when oxygen is not available (Finneran 2001, Hurt 1999). Due to TBA's recalcitrant nature, slow metabolism, and relative mobility, it is also a significant ground water pollutant that is commonly associated with MTBE contamination and often used as an indicator of MTBE biodegradation (Anthony 1999, Stocking 1999, Chen 2006). TBA is a known animal carcinogen, however, the effects on humans are uncertain (Williams 2003).

The California Environmental Protection Agency (EPA) has shown that consumption of trace quantities of MTBE can have negative impacts on human health, including nausea, headaches, and affects similar to drunkenness. At high enough levels, death can occur. Little is known about the affects of tertiary butyl alcohol (TBA) in humans, though in lab animals the central nervous system and the urinary tract are impacted (Williams 2003). People exposed to MTBE and TBA complained of sore nose and throats, headaches, dizziness, and nausea. In Montana, the ground water standard for MTBE is 30 μg/L, falling within the USEPA Drinking Water Health Advisory of 20-40 μg/L (Jacobs 2000). There is currently no national standard for TBA in water.

The purpose of this work was to determine hydrogeologic controls on the transport and fate of MTBE in a fine grained unconfined aquifer. Efforts emphasized describing the character and hydrologic properties of the geologic material and assimilating and analyzing source history and water quality data sets collected over the last twelve years.

Specific objectives included using existing data to:

1. Refine the site stratigraphy
2. Refine the ground water flow system by establishing a larger monitoring well network
3. Refine the hydraulic properties of the sediments
4. Determine key geologic and hydrologic controls on MTBE transport
5. Refine the vertical extent of the MTBE plume
6. Evaluate the transport process using ground water modeling

This work will provide a basis for generalizing conditions that control the fate of MTBE in fine grained sediments and provide a foundation for designing future monitoring and remediation efforts.

1.1 MTBE Occurrence and Fate

MTBE contamination in ground water occurs most commonly in urban areas with concentrations much higher than those found in agricultural areas (Squillace 1996). The United States Geological Survey's National Ground water Assessment Program determined that MTBE tends to occur most often in shallow ground water underlying urban areas (Jacobs 2000). This is attributed to two primary sources; the first and most common is a point source contamination zone such as a leaking pipeline, a spill, or a failed underground storage tank (Squillace 1999, Stocking 1999, Deeb 2000). The second most common is non point source, such as atmospheric deposition and stormwater runoff

(Squillace 1999). MTBE in surface water has also been attributed to exhaust and fueling emissions during recreational activities (Stocking 1999).

MTBE can be found in ground water anywhere it is used and is found in the environment worldwide (Squillace 1999, Rosell, 2005, Chen 2006). Its chemical structure is $C_5H_{12}O_6$ as shown in Figure 1 (Jacobs 2000). MTBE has a low organic carbon coefficient which prevents it from adsorbing to the organic matter in the soil (Stocking 1999, Jacobs 2000), and a low retardation factor (nearing 1) which causes MTBE to move at a velocity very close to that of the ground water (Anthony 1999, Jacobs 2000). MTBE is expected to partition into water more quickly than other gasoline components due to its high water solubility, which has been reported as anywhere from 23,200 – 54,000 mg/L at 25°C (Squillace 1996, Stocking 1999, Jacobs 2000). MTBE has a relatively low vapor pressure, 2.45mmHg at 25°C, which prevents large amounts of dissolved phase MTBE being lost to vaporization at the capillary fringe (Jacobs 2000, Fetter 1999). In the absence of any physical or biological retardation, MTBE will generally dissipate through natural dispersion (Jacobs 2000). In many cases, a small amount of MTBE is lost through soil vapor dissipation (Stocking 1999) while the remaining MTBE is discharged through ground water to a surface water body where it is commonly diluted below the detectable range (Jacobs 2000).

Table 1 shows a brief overview of the literature on MTBE spills, their locations, and effected sediments.

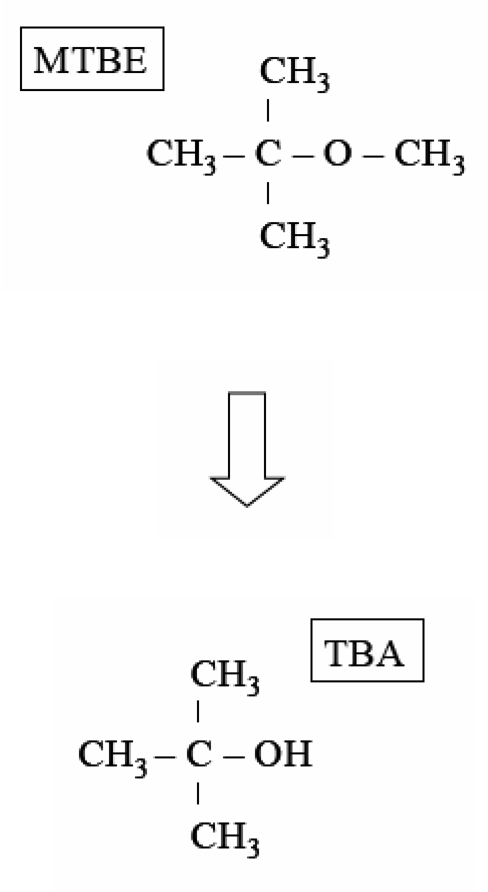


Figure 1. Chemical structure of MTBE and TBA (Jacobs 2000).

Location	**Sediments affected**	**Ground Water Flow**	**Plume Length**	**Timeframe**
Almena, Kansas	coarse to fine sands, silts, clays, alluvial deposits	N/A	N/A	N/A
southern Taiwan	silty sand, clayey silt	.2-1.4 m/d	>500 m	>2 years
Düsseldorf, Germany	fine sand, coarse sand, gravel, quaternary deposits	N/A	>160 m	>2 years
near Beufort, South Carolina	well sorted sand, clay	minimum 33 m/y	350 m (truncated)	>10 years
Port Hueneme, California	clayey silt, fine-medium sand (beach type), clay	90-180 m/y	1300 m	15 years
Orange County, California	fine to coarse channel sands	27 ft/y	N/A	7 years
Napa Valley, California	silty clay, sandy clay, (thin) sand/gravel	N/A	>450 ft	3 years
Laurens, South Carolina	poorly sorted coarse sand	N/A	N/A	N/A
Charleston, South Carolina	fine silt and clay	N/A	N/A	N/A
Galloway Township, New Jersey	clay-sand, medium sand	.04-.36 ft/d	>50 m	>2 years
south of Elizabeth City, South Carolina	silty clay, sandy clay, sand and clay	N/A	300 m (discharge to river)	N/A

Table 1. Overview of published MTBE sites (Bradley 2006, Chen 2006, Rossell 2005, Landmeyer 2000, Salanitro 2001, Sweeney 1999, Bradley 1999, Cozzarelli 1999, Hurt 1999).

1.2 Site Description and History

This research utilized the instrumented and studied Ronan MTBE Research Site in Ronan, Montana (Figure 2.) The site has been monitored and regulated for over 13 years by the Remediation Division of the Montana Department of Environmental Quality (DEQ) (HKM 2003, HKM 2004, HKM 2006). The town of Ronan is situated in the Mission Valley of northwest Montana at approximately 3,090 ft above sea level. Average daily temperatures range from -2°C in January to 28°C in July (Flathead Valley Visitor Information 2007). The area receives approximately 17 inches per year of precipitation (Flathead Valley Visitor Information 2007). The site is also wheel line irrigated for alfalfa production from late April to late September. The lithology is primarily composed of glacial lacustrine sediments, forming an unconfined aquifer of fine silts and sands that are bounded above and below by clay (MSE-HKM, 2002). Ground water is reported to flow in a west to southwest direction. Loustaunau (2003) suggested the upper 20-22 ft of the aquifer system discharged in a number of seeps and eventually flowed to adjacent Spring Creek (HKM 2002). Deeper portions of the flow system continue to travel west beyond the creek (Loustaunau 2003).

In April of 1994, an apparently ruptured underground storage tank (UST) was removed from George's Conoco on Highway 93 in Ronan, Montana (Figure 2). Subsequent investigations revealed a gasoline plume containing MTBE estimated at 11,000 gallons had been released into the underlying sediments (HKM 2003, HKM 2004, HKM 2006). The plume passed west under Highway 93 and now extends about 1,500 ft west of the source where MTBE, TBA, and BTEX have been observed discharging at springs, seeps, and directly into Spring Creek (MSE-HKM 1993). Dilution prevents

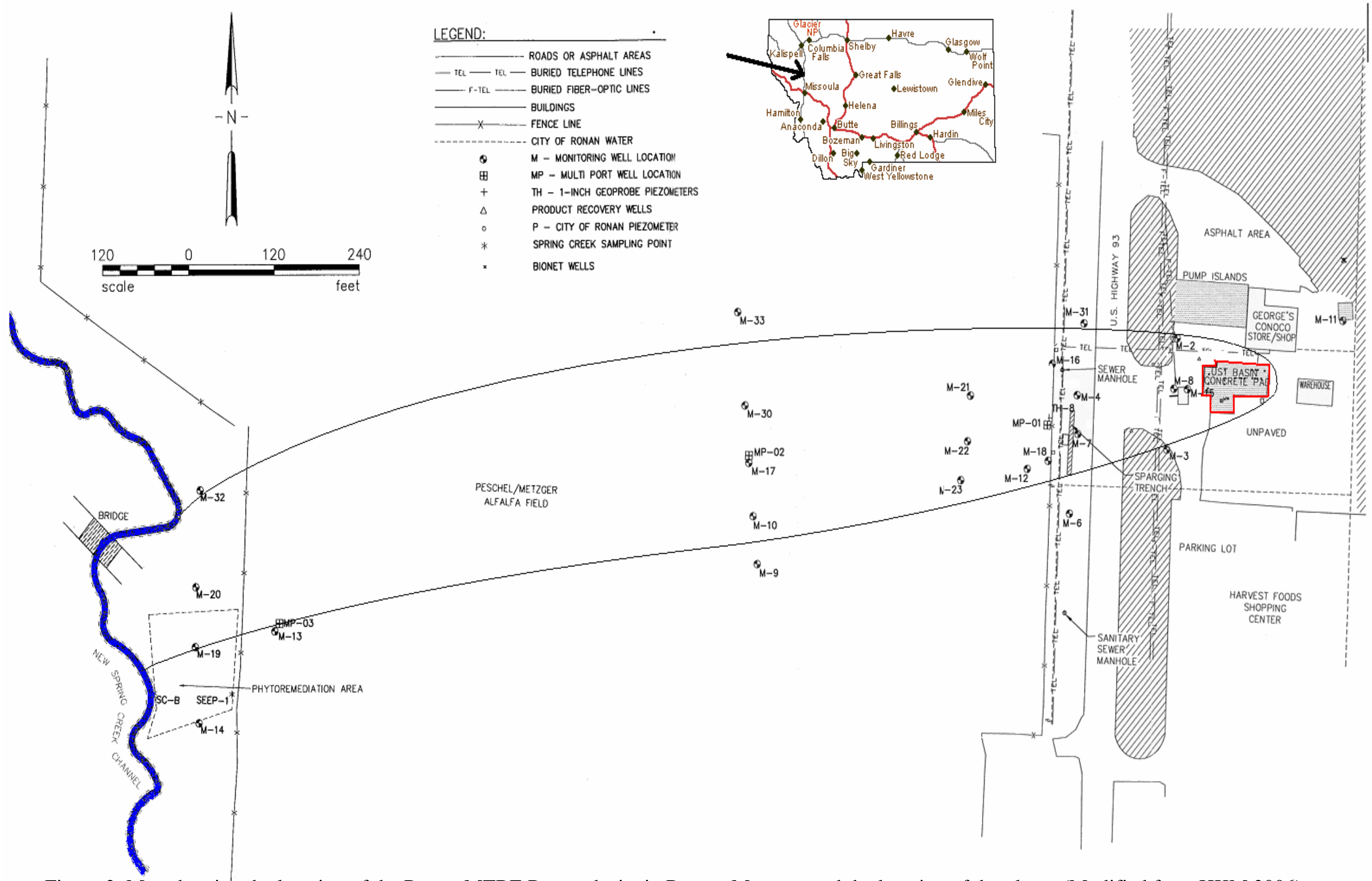


Figure 2. Map showing the location of the Ronan MTBE Research site in Ronan, Montana and the location of the plume (Modified from HKM 2006).

direct measurement of MTBE concentrations in the creek, though measurable amounts appear to be discharging to the channel hyproheic zone (Loustaunau 2003). The Ronan MTBE Research Site, which encompasses the area surrounding the release site extending to approximately 50 ft beyond Spring Creek, is the largest known MTBE plume in the state.

Thirty-one 2 to 4 inch diameter PVC monitoring wells having screen lengths of 3.25 to 20 ft were installed by DEQ contractors from 1994 to 2006 (HKM 2004). Three Solinst Continuous Multichannel Tubing (CMT) monitoring wells (MP-01, MP-02, and MP-03) were installed along the plume's longitudinal axis to depths of 72, 62, and 57 ft, respectively. The wells were completed with sand packs and sealed with bentonite clay (MSE-HKM 2003). These 2 inch diameter wells were installed using a 4 inch diameter hollow stem auger drill with an eight inch outer diameter. Split spoon sampling completed by DEQ contractors and driller's logs were used to interpret the lithology of the site. A cross section suggests four main hydrogeologic units composed of clay, silt, and fine sand (HKM 2003) (Figure 3). The water level monitoring and quarterly water quality sampling were used to establish a representation of the general direction of ground water flow and the position of the two-dimensional plume.

In 2002 the US EPA conducted an in situ bioremediation study using hydraulic fracturing to create 7 BioNets filled with silica or Isolite® in the west areas of the alfalfa field. These BioNets were utilized to introduce known MTBE degrading microbes, oxygen, and nutrients (Loustaunau 2003). In addition, further west on the floodplain of Spring Creek, a phytoremediation net of cottonwood, bulrush, and willow seedlings was

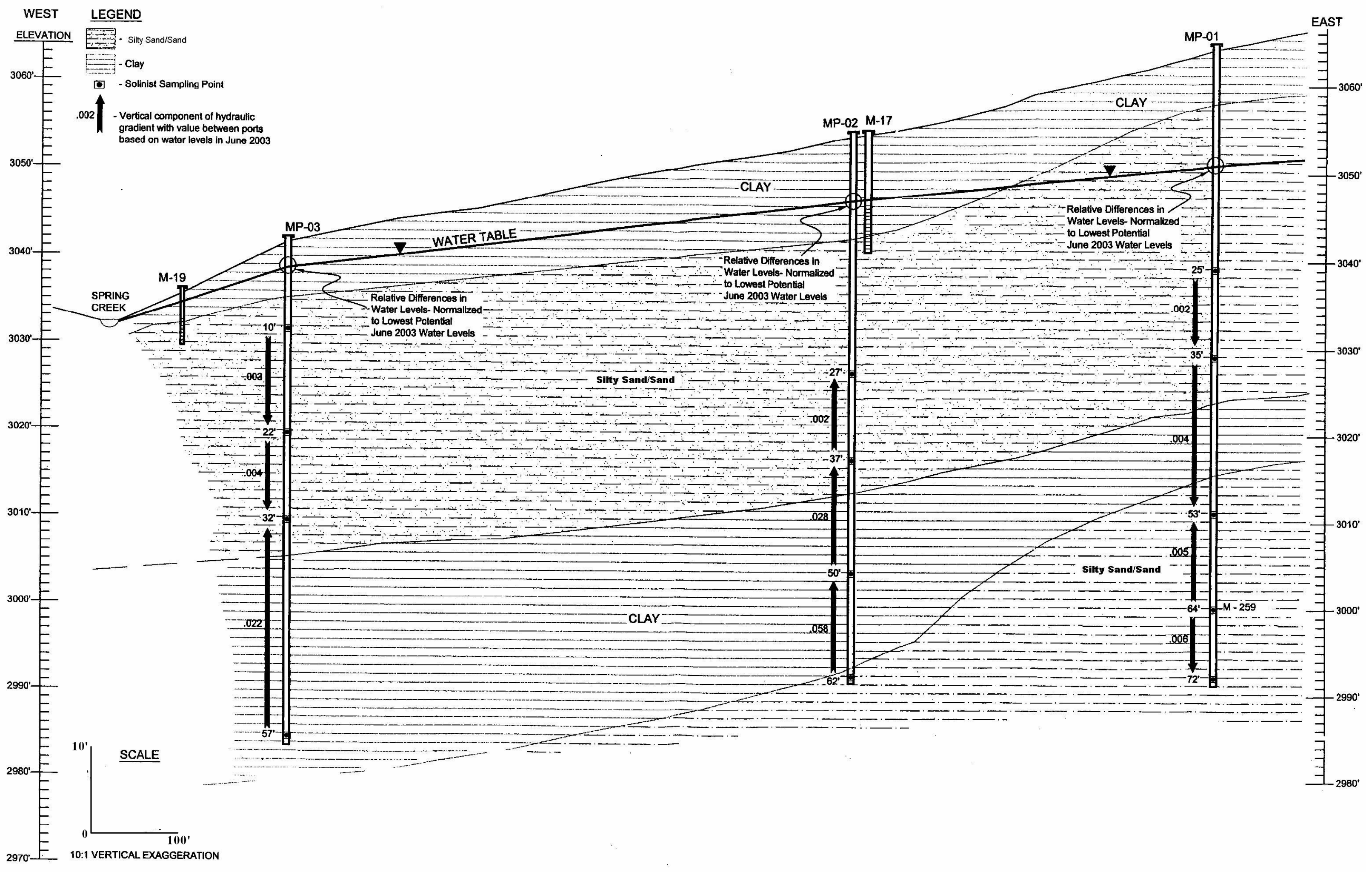


Figure 3. Original cross section along plume axis based on well logs from wells MP-01, MP-02, and MP-03. Water levels reflect June 2003 data. Transect location described on Figure 4 as "Plume Transect" (adapted from HKM 2003)

installed by the MT DEQ and the US Geological Survey (USGS) in 2001 (Loustaunau 2003).

Electrical resistance heating was performed as a remediation technology beneath Highway 93 between July 11 and November 30, 2003 (HKM 2003). The purpose of heating the ambient ground water was two-fold; the primary purpose being to elevate ground water temperatures to boil off excess hydrocarbons, which vaporize at a lower temperature than water, and secondly to increase the ambient ground water temperatures to enhance rates of possible natural microbial degradation. A network of temperature recording devices installed around the site indicate that the ambient ground water temperature is seasonally influenced, although slightly, and it remains between 5° and 10°C year round. Microbial action is generally believed to be reduced at cooler temperatures. Bradley (2006) reported rates of microbial degradation in laboratory microcosm studies of MTBE in the Ronan sediments may be reduced by low seasonal temperatures by up to 35%. During remediation the ground water temperature was raised to approximately 100°C, which allowed for the evaporation of a large volume of contamination (HKM 2004). The actual amount of MTBE vaporized is unknown.

Microbial breakdown of MTBE is also largely dependent on the presence of oxygen, therefore a soil vapor extraction (SVE) air sparging system was installed and operated in conjunction with the heating event (HKM 2003). SVE began in July 2003 and ran during the same period as the heating event. The air sparging system included twelve electrodes as sparge units. This system was started in August 2003 to allow for heating of the ground water (HKM 2003). Both the SVE and air sparging operated on pulse mode. In September 2003 an additional SVE/air sparging system was activated including a sparge trench parallel to Highway 93 extending the north-south width of the plume (HKM 2003). This trench was installed as part of the original remediation efforts and was in operation prior to the heating event. The air sparging/SVE system is still in operation.

2.0 Methods

Research efforts included applying a variety of methods to enhance analyses of the geologic framework and sediment complexity associated with the observed plume and overall site. In addition to re-examining historical drilling logs a series of cone penetration tests (CPT) were performed. Testing was calibrated by additional site coring and development of grain size distributions and estimates of hydraulic properties. Hydraulic conductivity characterization was conducted both in the field and lab using both traditional techniques and temperature transport evaluations. Additional wells were installed to improve interpretations of the overall ground water flow system. Three dimensional plume characterization was further defined by collecting membrane interface probe (MIP) data during CPT sampling. These additional data sets were used to refine the site conceptual model by developing and calibrating a site ground water model. The modeling effort was also used to further evaluate physical controls on the transport of MTBE in fine grained sediments.

2.1 Cone Penetration Testing

In February of 2005, ConeTec of Baltimore, Maryland was contracted by the Montana DEQ to perform twenty-two CPT west of the fence located along Highway 93 forming three transects perpendicular to the plume axis. Eight additional sites were evaluated in order fill in the data gaps between transects and to determine the lateral extent of the geology surrounding the plume (Figure 4). This work was performed in an attempt to refine the understanding of the area geology and create a more comprehensive stratigraphic profile of the plume sediments.

Components of the CPT include the following (Figure 5).

1. Piezocone, an electronic metal cone that acts as a drill bit driven into the sediment and monitoring the cone resistance (q_c)
2. Porous ring, the ring is saturated with silicone oil and it monitors the pore pressue (u) as the rod is driven and it sits directly above the piezocone in the u_2 position
3. Geophone, which measures the shear wave velocities (V_s)
4. Seismometer, which measures the compression wave velocities (V_p)
5. Friction sleeve with string guage, which measures the friction on the sleeve during a push
6. Ultra-Violet Induced Fluorescence (UVIF) with a sapphire lens, this recognizes the presence of hydrocarbons by emitting a high frequency light that excites the electrons of a compound and measures the fluorescence when the compound returns to a stable state, generally only effective in the presence of free product
7. Laser Induced Fluorescence (LIF) also detects free product, although it is not used in conjunction with the above method and was not utilized for this project

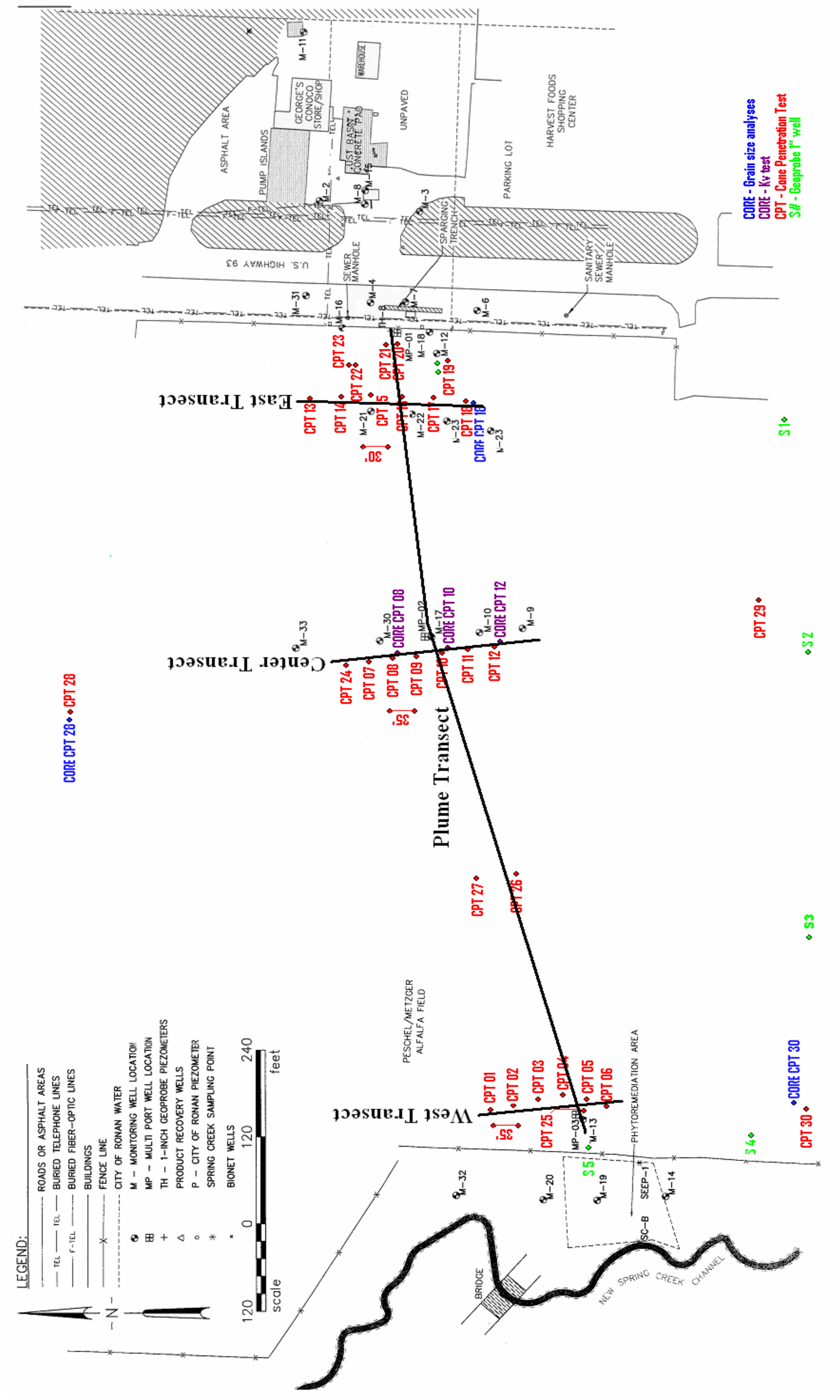


Figure 4. Basemap provided by HKM (2003) adapted to show locations of CPT points and geoprobe wells.

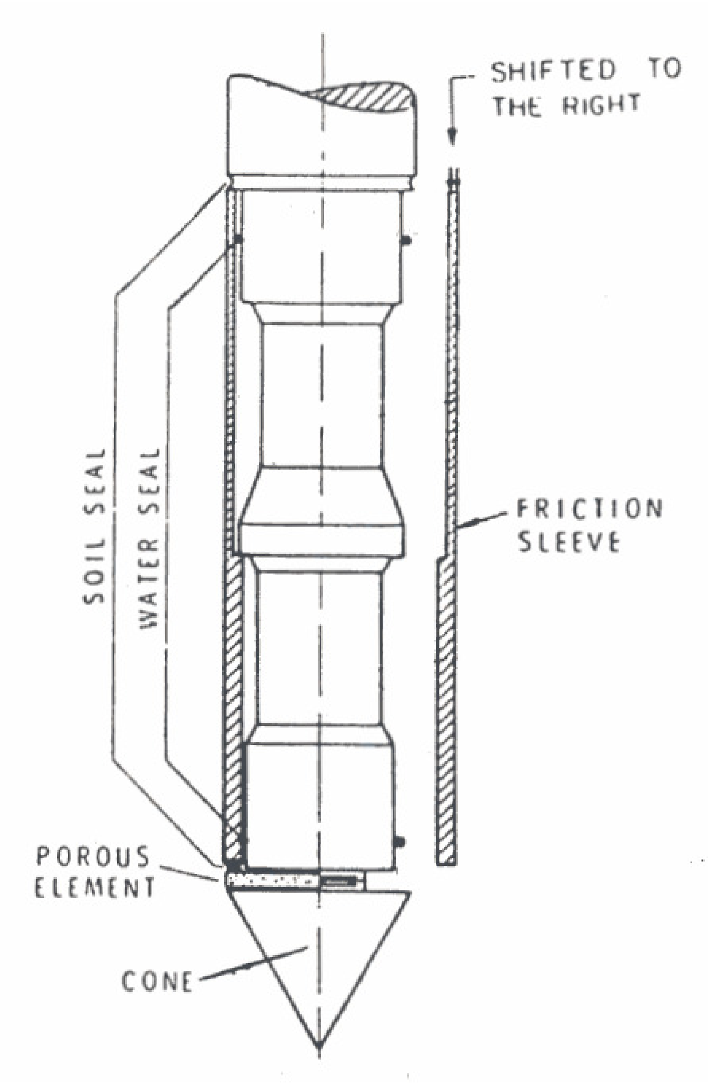


Figure 5. Components of the Cone Penetration Testing rod (adapted from Robertson, 1989)

2.2 Lithologic and Hydraulic Properties

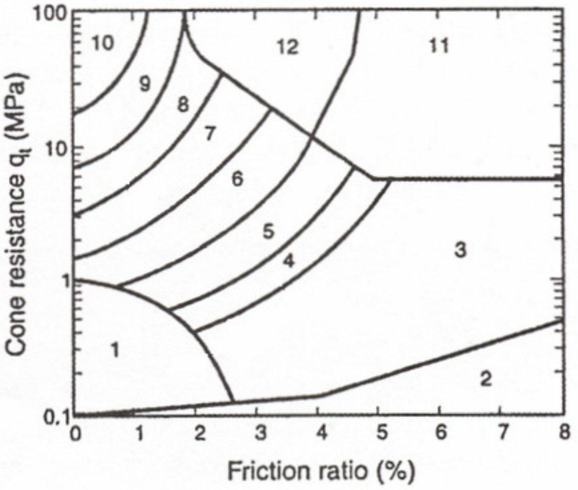
Cone Penetration Testing offers a continuous vertical stratigraphic profile by inferring the response of the subsurface strata to penetration resistance. CPT collects pore pressure, cone resistance, shear and wave velocities, and friction as a rod equipped with a specialized tip is driven into the sediments. During this test, sediment permeability was estimated from the dynamic pore pressure (u_d) as well as from a dissipation test measuring the time it takes for excess pore water pressure to reach equilibrium piezometric pressure ($T_{100\%}$) (Robertson, 2004). Cohesive soils such as clay have a greater $T_{100\%}$ than non-cohesive soils, such as sand.

In a few locations where more specific data were required, a pore pressure dissipation test (PPD) was performed on a static rod (Robertson, 2004). Rather than measuring the dynamic pore pressure, the PPD test measured the decay of excess pressure in conductive sediments or the time required to recharge the pores with water.

Testing results are then compared to instrument related soil property classifications. One of twelve sediment zones is selected as representative of instrumental response data (Soil Behavior Type or SBT). Specific information used to determine SBT is the corrected cone penetration resistance (q_t) and the friction ratio, defined as:

$$R_f = f_s/q_t$$

where R_f is the friction ratio and f_s is the sleeve friction stress (Figure 6). Typically, the cone penetration resistance is high in sands and low in clays while the friction ratio is low in sands and high in clays (Figure 7).



Zone	*Soil behaviour type*
1	*Sensitive fine grained*
2	*Organic material*
3	*Clay*
4	*Silty Clay to clay*
5	*Clayey silt to silty clay*
6	*Sandy silt to clayey silt*
7	*Silty sand to sandy silt*
8	*Sand to silty sand*
9	*Sand*
10	*Gravelly sand to sand*
11	*Very stiff fine grained**
12	*Sand to clayey sand**

** Overconsolidated or cemented*

Figure 6. Soil Behavior Type (SBT) diagram showing how sediments are classified under SBTs (adapted from Robertson 1986).

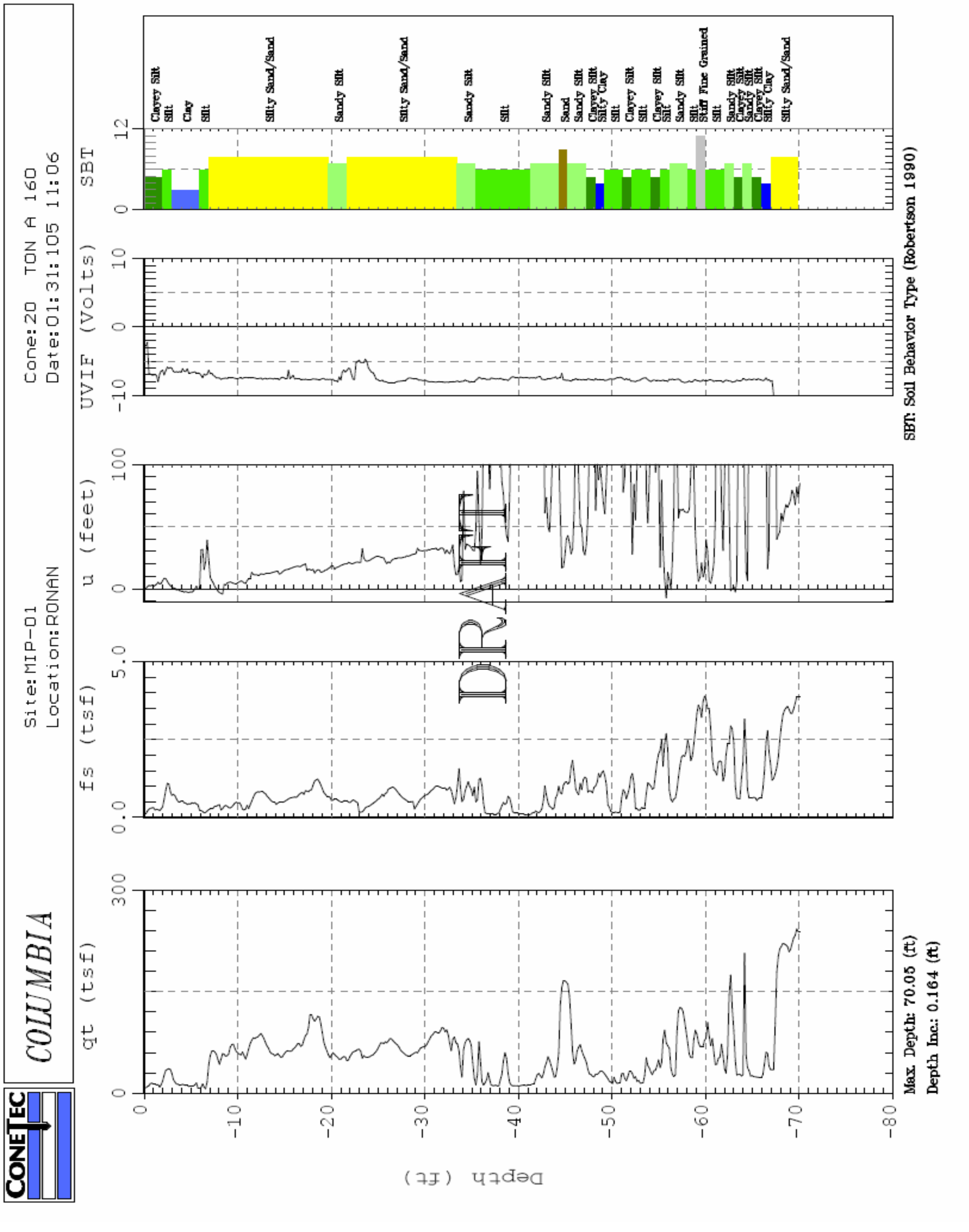


Figure 7. Report provided by ConeTec showing the results of CPT at site CPT01. The y axis of the graphs shows depth in feet with the first column indicating cone resistance (q_t), measured in tones per square foot. The second column denotes sleevefriction stress (fs), also in tones per square foot; the third column indicates uncorrected pore pressure (u) in feet; and the fourth column shows the UVIF results. This fourth column was disregarded for work at this site as the MIP provided a much finer tool for hydrocarbon analysis. The final column shows the SBT data, which is interpreted much like a stratigraphic column showing grain size analyses.

For comparison with the CPT interpreted geologic logs, three 1.5 in diameter cores were taken at CPT-18, CPT-28, and CPT-30 using a 5400 Geoprobe. These sites were chosen in order to sample each of the major lithological units represented in the CPT data (Appendix A). The cores were taken using a Geoprobe $1^1/_2$ inch Macro-core Soil Sampler at depths of 8, 12, and 16 ft, respectively. These cores were split and logged for comparison to SBT data at the corresponding CPT points. Based on visual examination representative samples of sediment types were assessed and grain size analyses performed.

2.3 Grain Size Analysis

Grain size distributions were obtained using the Malvern Mastersizer 2000, a low-angle laser light scattering (LALLS) system, commonly called a laser diffractometer. The Mastersizer 2000 was chosen for measuring sediment grain sizes over traditional methods (pipette, sieve analysis) because of the more rapid analyses time and the significant accuracy (up to a 95% confidence interval) (Sperazza, 2004). It measures particles in the .02-2000µm range (Sperazza, 2004). As described by Sperazza (2004) approximately 0.1g was placed in a 30mL bottle of a 5.5g/L solution of sodium hexametaphosphate, $(NaPO_3)_6$. The sediment was stored for 24 hours in order to allow for chemical dispersion and to prevent grains from aggregating after sonication.

The entire sample, once prepared, is introduced to the laser diffractometer through a dilution of deionized water. This solution was sonicated for 60 seconds, allowing the disaggregated particles to achieve maximum dispersion without flocculating the clays or breaking down larger grains (Sperazza, 2004). The grain size of each sample was measured by 52 sensors taking 1000 readings per second for twelve seconds. This analysis was performed three successive times, with the average result of the three tests reported in the statistical analyses (Sperazza, 2004). Data were compiled and reported using Malvern's Mastersizer 2000 software, version 5. Grain size distributions were prepared for each sample using the standard technique (Sperazza 2004). Grain size analysis results were plotted on ternary diagrams in order to show the classification by grain size and to compare results to the SBT obtained from analyses of the CPT data.

2.4 Ground Water Flow System

Historical reports of concentration data provided by HKM were compiled and analyzed in order to identify trends in plume movement. Graphs were compiled that illustrate the concentration of BTEX components, ground water elevation, dissolved oxygen (DO) and total petroleum hydrocarbons (TPH). These data were used in concert with the probing methods to characterize the three-dimensional distribution of site contaminants including MTBE and BTEX.

In order to place the established ground water flow regime in the context of the larger more regional flow system, seven wells (S#) were installed on the outskirts of the alfalfa field (Figure 4). These 1 inch diameter PVC wells were installed using the Geoprobe to a depth of 20-25 ft with a five foot screened interval. The wells were completed by allowing the formation to collapse around the well screen. The remaining well column was filled with coarse sand and a half foot cap of bentonite clay. The wells were monitored bi-monthly along with the established well network to determine the flow in the overall system. Data were analyzed by constructing water level hydrographs and water table maps (Fetter 2001).

2.5 Hydraulic Conductivity Analyses

In an attempt to further characterize the hydraulic properties of the site sediment, cores were taken at CPT-08, CPT-10, and CPT-12 and falling head permeameter tests were performed in the lab on undisturbed segments to determine vertical hydraulic conductivities (Fetter, 2001). The following equation was used:

$$K_v=(d_t^2L/d_c^2t)\ln(h_o/h)$$

Where K_v is the vertical conductivity in cm/s, L is the length of the sample, h_o is the initial head within the falling head tube, h is the final head in the falling head tube, t is the time it takes to go from h_o to h, d_t is the inside diameter of the falling head tube, and d_c is the inside diameter of the sample core. Cores were prepared by cutting the core barrel into six-inch intervals. Tests were completed on samples that occurred below the water table. The polycarbonate 2 inch diameter core tubes containing the undisturbed sediments were capped using rubber stoppers to seal the cores at the top. At the base, a plug of extra-fine steel wool held the sediments in place and allowed water to drain without impacting the flow rate. Samples of each analyzed core were taken from the bottom of the six-inch section prior to K_v testing for the purpose of grain size analysis. The average of three separate falling head tests is used to represent the core conductivity

Estimates of the horizontal conductivity were determined by performing slug tests on various existing and newly installed wells. Several one inch diameter PVC wells were installed at discreet depths in an attempt to isolate the hydraulic characteristics of a particular unit identified by the CPT (CPT-01, CPT-04, CPT-06, CPT-16, CPT-30). The well at CPT-01 was installed to 41 ft to isolate the silt unit, the well installed at CPT-04 was installed to 25 ft to isolate the silty sand/sand unit, the CPT-06 well was installed in the sandy silt unit at 19 ft depth, the CPT-16 well was installed to 25 ft within the sand unit, and the CPT-30 well was installed to 12 inches order to isolate the 'sensitive fines unit'. With the exception of the well installed near CPT-30, which had a 2 foot screen, the wells had a 5 foot screened interval with a 0.60 slot size screen (0.06 inch openings). The thickness of the sediments at CPT-30 required a three foot screen to ensure completion within the desired unit. All wells were installed within five feet of the CPT point.

Slug tests were performed both with a Geoprobe Pneumatic Slug Test Kit (Geoprobe 2002) and, in less conductive sediments requiring long recovery times, by using a continuous water level monitoring Solinst DataLogger operated for approximately one week (May and October 2006). The Hvorslev (1951) method was used to calculate horizontal conductivity:

$$K_h=[r^2\ln(L_e/R)]/(2L_e t^{37})$$

where K_h is the hydraulic conductivity, r is the radius of the well casing, R is the radius of the well screen, L_e is the screen length, and t^{37} is the time is takes for the water level to rise to 37% of the initial change.

2.6 Temperature Monitoring

The 2003 remediation heating event created a plume of warm ground water below Highway 93 that tracked out across the alfalfa field and began to reach well M12 in

October of 2003 peaking at just over 24°C. It was hoped that monitoring of the heat plume would contribute to understanding hydraulic conditions at this site (Su 2004). Ten temperature buttons (Johnson 2005) were installed below the water surface within well M12 at five foot intervals with two buttons at each location. Two one inch wells (T1 and T2) were constructed four and eight feet down hydrologic gradient from well M12 with two temperature buttons were installed at corresponding elevations to each set of buttons installed at well M12 (Figure 4). Both wells were screened the entire length of the saturated thickness. A Solinst water level/temperature logger was installed prior to the heating event in well M12 in order to monitor ambient ground water temperature throughout the entire remediation effort. Data from this logger showed ground water temperatures at this well were impacted by the heating event despite its interpreted position on the outskirts of the contaminant plume.

Heat can be used as a tracer to determine the hydraulic transport properties within an aquifer (Rath 2006, Anderson 2005, Constantz 2003, Land 2001) using a simple model to solve for three-dimensional advective transport. The three dimensional heat-transport equation is written as:

$$(K_e/\rho c)\nabla^2 T - (\rho_w c_w/\rho c)\nabla \cdot (Tq) = \delta T/\delta t$$

where T is temperature, t is time, ρ_w is the density and c_w is the specific heat of water, ρ is the density and c is the specific heat of the sediments, q is the discharge, and K_e is a term including the effective thermal conductivity of the sediments and the water (Anderson 2005).

The equation is solved by several models, although VS2DH for shallow aquifers is the model chosen for this study. Although this model is designed for tracking heat loss and gain in stream channels, the advantage is that the model uses iterative time steps to calculate the effect of the temperature on the viscosity of the fluid.

2.7 Delineating the Dissolved Phase Plume

In an attempt to refine the three dimensional distribution of the dissolved MTBE plume (and other site constituents) CPT testing was accompanied with Membrane Interface Probe data collection (McInnes, personal communication, 2005). This probe was operated with a ultra-violet induced fluorescence meter (UVIF). As this probe is advanced though the subsurface it provides a very coarse analysis of the presence or absence of hydrocarbons. The advantage of the MIP tool is that it provides a real-time quantitative estimate of speciated volatile organic hydrocarbons (VOCs). In particular, five VOCs were targeted: benzene, toluene, ethyl benzene, xylenes (BTEX), and methyl *tert* butyl ether (MTBE). For the purposes of this study, and due to operator and DEQ time limitations, the MIP was not used to speciate hydrocarbons on-site but rather to identify the presence or absence of low concentrations of contaminants.

The MIP tool was operated by attaching a heating element to the CPT rod above the piezocone and using a sampling port to draw gases up through a hose to a portable gas chromatograph mounted in the Columbia Technologies truck. By heating the water surrounding the sample port to a specified target temperature, the water would boil off and the VOCs would be collected and analyzed. Nitrogen and hydrogen were used as carrier gases for conveying hydrocarbons from the CPT rod to the three detectors used to identify the hydrocarbons. The methodology was described via verbal communication by

Doug McInnes of Columbia Technologies (personal communication, Doug McInnes, 2005).

In an attempt to collect data at a wide range of points, under the field time constraints, the rod was driven at a constant rate and the temperature remained at approximately 60°C. The limitations of operating the tool in this way only caused the MIP to indicate areas of high VOC concentrations (where gases were likely to be present naturally). In areas identified as ‘hot spots’ the probe was halted and allowed to heat to the target temperature of 120°C for a more accurate analysis. Three detectors were utilized for this purpose (McInnes, personal communication, 2005), a photo ionization detector (PID), an electron capture detector (ECD), and a flame ionization detector (FID). The PID was used to identify aromatic hydrocarbons, the ECD for halogenated compounds, and the FID was used for identifying organic hydrocarbons.

A ground water budget was calculated estimated for the selected model area. The ground water budget was calculated as:

$$GW_{in} = Gw_{out} - \text{Stream loss}$$

Darcy’s Law was used to calculate the flux of ground water through a cross section of the aquifer. Darcy’s Law states that the discharge, Q, through an aquifer is equal to the transmissivity, T, multiplied by the width of the aquifer, w (in this case, the width of the modeled section), and the ground water gradient, i. Transmissivity was calculated as the product of the estimated hydraulic conductivity, K, and the thickness of the aquifer, b. Hydraulic gradients were estimated using three wells to the east (M31, M11, and M6) and three wells to the west (M14, M13, M32). Recharge was not calculated from precipitation as the area receives only 16.5 inches per year, the majority of which never reaches the water table due to uptake by plants and evaporation.

The analyses completed as part of this work and data from previous works were evaluated and a generalized conceptual model of the hydrogeology of the site was developed (Anderson 1992). A key component of the conceptual site model is a steady state water balance. This was formulated as ground water in = ground water out. Because this was a steady state model, changes in storage were set equal to zero. Ground water entering the system is introduced through a constant head boundary set east of the site, which has been established at 3055 based on projected ground water gradients. Water is lost to the system at a constant head boundary to the west of the site, which is established at 3025 ft based on ground water gradients. In addition, ground water is allowed to discharge to surface water at Spring Creek. Recharge to the system is introduced only in portions of the balance area that extended beyond the alfalfa field area. It was assumed evapotranspiration in the alfalfa field prevented precipitation and irrigation water from reaching the ground water system in this area. The BioNet phreatophyte network installed along the east floodplain of the creek was not included in the water budget as a significant portion (<90%) was destroyed by after it's creation.

2.8 Numerical Modeling Parameters

A steady state three-dimensional site ground water flow model was formulated and calibrated using Waterloo Hydrologic's Visual Modflow v. 3.1 on May 3, 2007. The model was designed to simulate the steady state flow and to evaluate how physical factors likely control the advective transport of MTBE at the Ronan site. The model was comprised of three layers (35, 11 and 20 ft thick) representing the principal sediment types identified during this investigation. It covers an area of 0.16 mi^2 and extends to a depth of approximately 66 ft. The site was divided into a grid of 8000 cells each with dimensions of 18 by 30 ft. Model formulation considered the work of Loustaunau (2003) who constructed and calibrated a profile model representing ground water behavior along a flow line representing the centerline of the plume. The three-dimensional model was calibrated to reflect the measured values of hydraulic conductivities (field and laboratory analysis), the ground water discharge to the stream described by Loustaunau (2003) (Spring Creek), the movement and location of the MTBE plume, and the horizontal and vertical hydraulic gradients (MP-01, MP-02, and MP-03). The 14 water table elevations collected in June 2003 were used to calibrate the water table position.

The model boundaries included no-flow zones to the north and south of the site where ground water flow is parallel to the boundaries and constant head boundaries to the east and west. The east constant head boundary located 800 ft east of spill site allowed ground water to flow into the model domain creating the observed east-west flow system (HKM 2003, 2004, 2006). The west constant head boundary was positioned approximately 400 ft west of the stream (Loustaunau 2003). Figure 8 shows the model parameters including the well locations used for calibration and the model boundaries. Spring Creek was represented by the river package and creek bed properties were based on Loustaunau (2003) estimates.

Particle tracking was performed as a calibration technique by comparing particle paths and locations to observed plume behavior. In addition, advective flow of MTBE was examined by investigating the predicted location of particles relative to the known source history and observed plume center of mass as mapped based on mid-May to early June 2003 water quality sampling results.

Figure 8. Model parameters for Modflow model of Ronan site.

3.0 Results

The main objectives of this research were to gain an understanding of how the site lithology and corresponding hydrogeologic properties control the behavior of MTBE in fine-grained sediments. The site geology is first placed in the context of the geologic setting of the Mission Valley based on the literature and then described in detail relying on both historical and project related observations and interpretations. With this framework, the ground water system is assessed and current plume conditions are described. Finally, a conceptual model of the site hydrogeology and the controls on the transport and fate of MTBE are developed and tested.

3.1 Regional Geologic Setting

The Ronan MTBE site lies within the Mission Valley, which has previously been described as part of the glacial Lake Missoula depositional environment (Levish 1997). The Mission Valley was believed to be the deepest and largest valley inundated by glacial Lake Missoula during the late Wisconsin age (Levish 1997). The valley was flooded by impounding the Clark Fork River by the Purcell Trench lobe of the Cordilleran ice sheet, creating a glacial lacustrine depositional environment in which the Ronan site is located. Glacial lacustrine sediments have been described in detail along the Flathead River, where erosion by the river has created massive outcrops that can be mapped for several miles (Levish 1997, Smith 2004, Hofmann 2005, Edwards 2006).

Levish (1997) describes these sediments along Flathead River between Polson, 11 miles to the north, and Crow Creek 6.5 mi to the southwest of Ronan as a 492 ft outcropping of primarily laminated fines; including sands, silts and clays. Beds of clast-supported gravels are also observed in some outcrops. The vertical sequences described in Levish's work ranges from glacial diamict to incalated laminated silt and clay, to laminated fines containing no diamict. Laminations are described as anywhere from mm size to up to a meter in thickness. Levish further describes the color and bedding of the laminations as showing brownish colored clays and nearly white silts, often occurring with cross bedded ripples. Dropstones carried by floating ice were frequently recorded on a scale from mm to massive boulder sized, deposited within the bedded sediments. It has been interpreted that such glacial lacustrine sediments are found at this study site.

3.2. Site Lithology and Physical Framework- Ronan Site

The sediments types interpreted from the CPT, grain size analyses, and logging of Geoprobe coring data suggest sediments are fine grained and generally very similar to those described by Levish (1997). Cores of silts and sands contain distinct sequences of fine laminations disrupted by the presence of dropstones in nearly all core sections. While most laminations are on the mm scale some vary to as much as 3cm in size.

Site sediments are composed of brownish colored clays interlayered with lighter colored silts and sands. Color descriptions are listed on the lithologic columns for Geoprobe cores (Appendixb B). In addition, small scale ripples can be seen in the most distinct of the laminated beds within the cores. Dropstones were also observed in cores and range in size from 0.1to 1.2 in in diameter. Dropstones did not occur in all sections of sediment, and when present the quantity ranged from rare (a single stone) to multiple (nearing clast-supported). In one area only were clast-supported bedded gravels found, at CPT 30.

Grain size analyses typically showed a fairly distinct separation between a near surface layer of fine grained sediments and the underlying water-bearing silts and sands. The coarser sediments generally consisted of a high sand content, while the silt content ranged considerably and clay was consistently below 5%. The surface sediments generally showed significant clay content with little sand and high silt content. CPT 30 was the only location showing clay content greater than 50%, defining it simply as clay. This point is outside of the dissolved phase plume and so cannot be considered a confining unit preventing contamination from spreading to depth. At CPT 10, however, a coarse unit with greater than 90% sand was seen. This point is within the confines of the plume and may have influenced MTBE migration at rates larger than those attributed to the dominant silty sediments.

The SBT correlates very closely to corresponding cores with minor grain size fraction differences. The resolution of CPT data was about one foot leaving lesser bedding characteristics unidentified. The comparison of CPT 30 with the corresponding Geoprobe core shows very good correlation between CPT interpreted lithology and observed and lab characterized lithology over the eight feet of recovered core.

Core samples of the sediments were characterized, laminated bedding and the results of the grain size analyses were compared to the SBT and established properties of each unit were assigned to corresponding SBT units. CPT can not identify layered units where bedding may consist of alternating two inch thick layers. For such layers of alternating sand and silt, the entire section may be interpreted as silty sand. It is assumed that SBT interpretations are consistent throughout the site, that is to say, a silty sand lying at a depth of 35 ft is similar in its hydraulic properties to a silty sand lying at 65 ft.

Previous investigations at this site generated an east-west cross geologic section based on split spoon sampling performed during installation of the three CMT wells (HKM Engineering, 2003) (Figure 9). The interpretation of these data show an upper clay unit, ranging from 10-12 ft at land surface. Underlying this upper unit is a 30-40 ft silt and sand dominated unit that acts as the primary water-bearing unit. Underlying these sediments is a second clay unit of indeterminate thickness (10-25 ft). The contractor installed monitoring well network was established with the primary purpose of accessing the shallow ground water where contamination was assumed to be present. Most wells are completed in the near surface silt and sand dominated unit.

A Geoprobe was used to take three cores for comparison with the SBT data, although the practical depth using this method is much less than that achieved with the CPT. Coring depth was limited both by the equipment available and by flowing sands encountered below the water table that caused the borehole to fill with sediments between core extraction intervals. While the cores taken using this method offered significantly more detail than either split spoon cores or SBT, each core was taken a minimum of 5 ft from the CPT point. This was done in order to prevent the coring of bentonite backfill used to plug CPT boreholes or sediments disrupted by the CPT process. The complexity of the sedimentary deposits is such that this distance may result in differences between the profiles. Included are two profiles comparing SBT data in the left column and an expanded profile aligned with data described from the split Geoprobe cores on the right (Figures 10-12). By aligning the identified units and corresponding grain size analyses with the SBT data, it was possible to determine the representativeness of the SBT profiles.

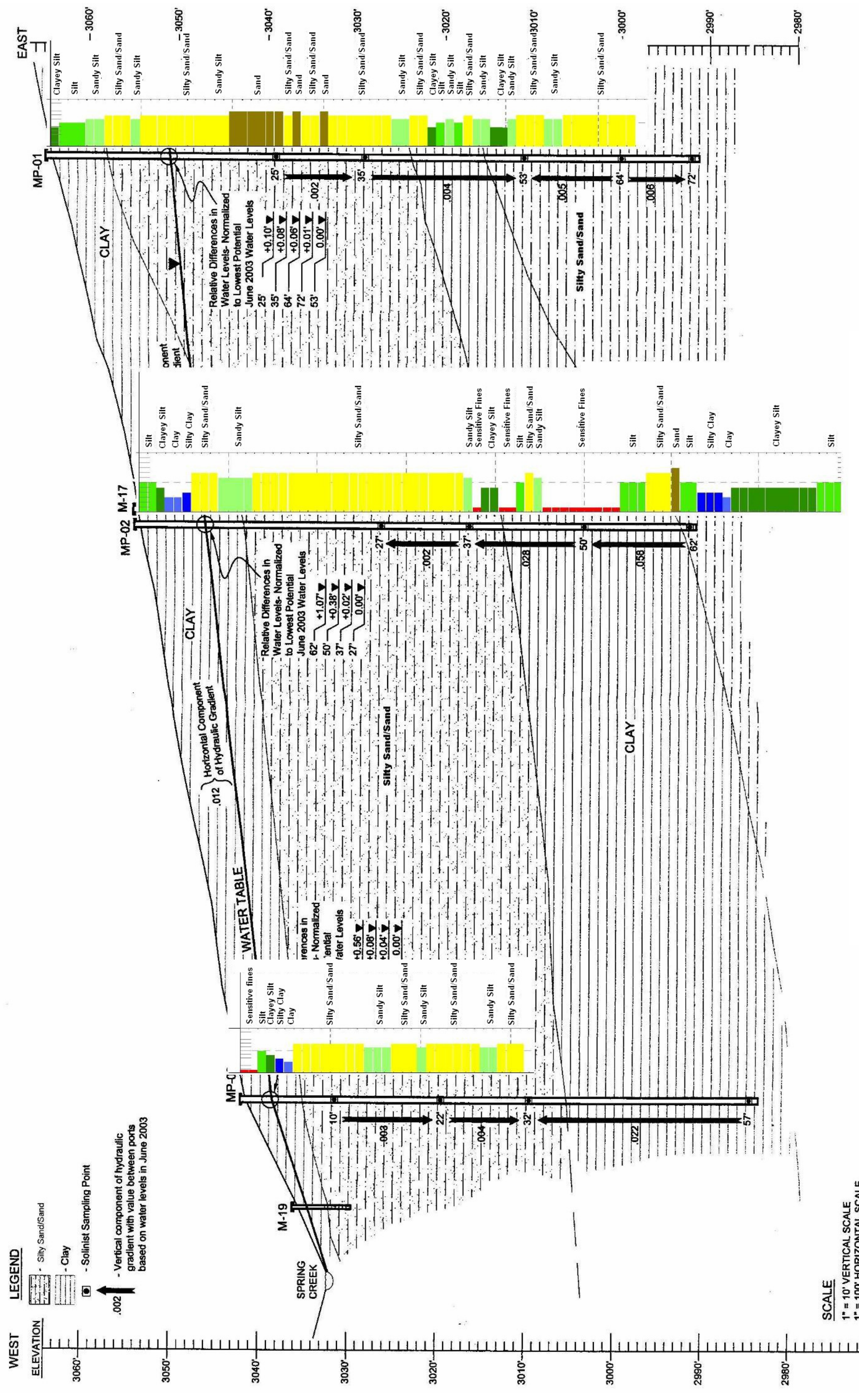
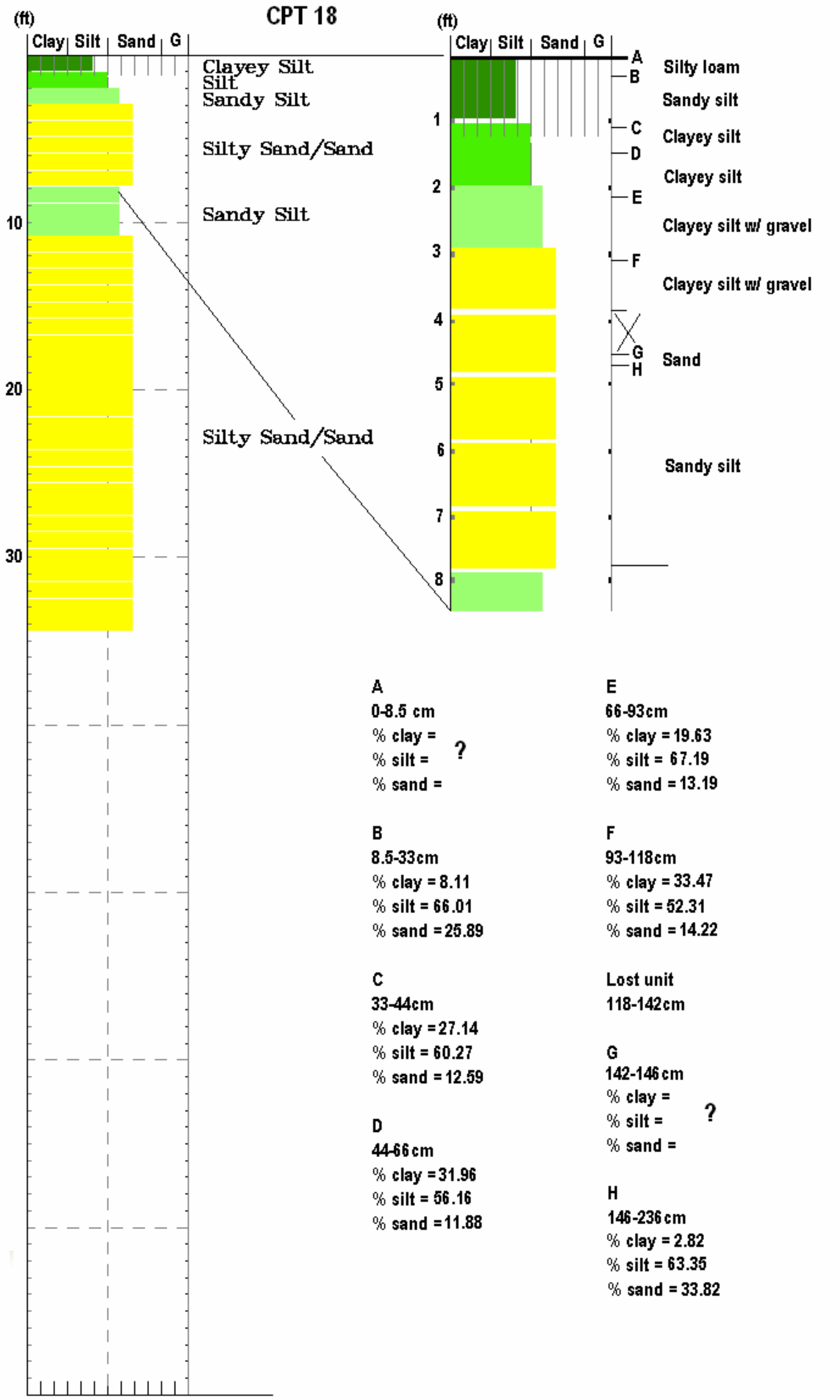


Figure 9. HKM cross section with CPT points overlaid (HKM 2003).



A
0-8.5 cm
% clay =
% silt =
% sand =
?

B
8.5-33cm
% clay = 8.11
% silt = 66.01
% sand = 25.89

C
33-44cm
% clay = 27.14
% silt = 60.27
% sand = 12.59

D
44-66cm
% clay = 31.96
% silt = 56.16
% sand = 11.88

E
66-93cm
% clay = 19.63
% silt = 67.19
% sand = 13.19

F
93-118cm
% clay = 33.47
% silt = 52.31
% sand = 14.22

Lost unit
118-142cm

G
142-146cm
% clay =
% silt =
% sand =
?

H
146-236cm
% clay = 2.82
% silt = 63.35
% sand = 33.82

Figure 10. CPT 18 SBT as compared to mapped Geoprobe core and grain size analysis

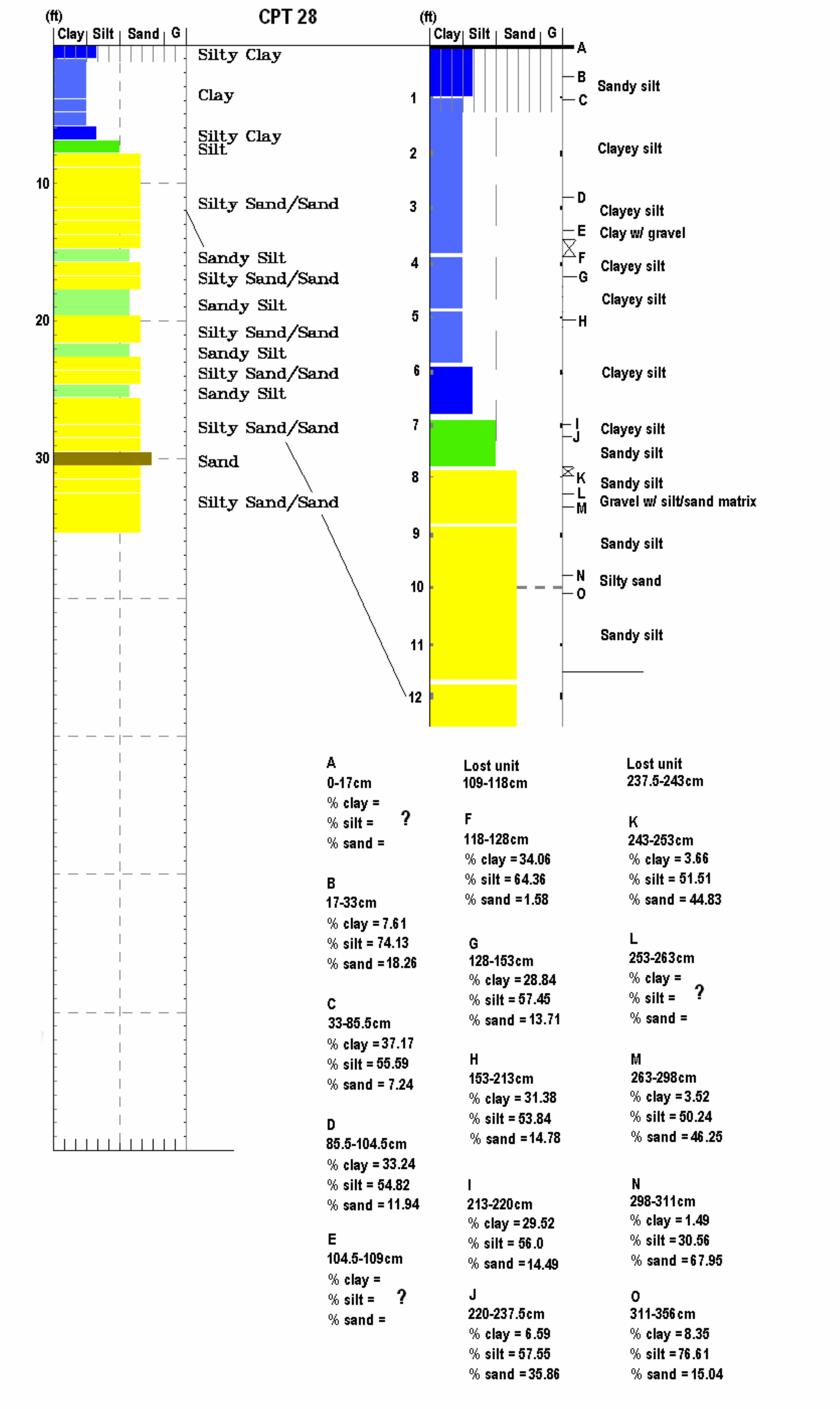
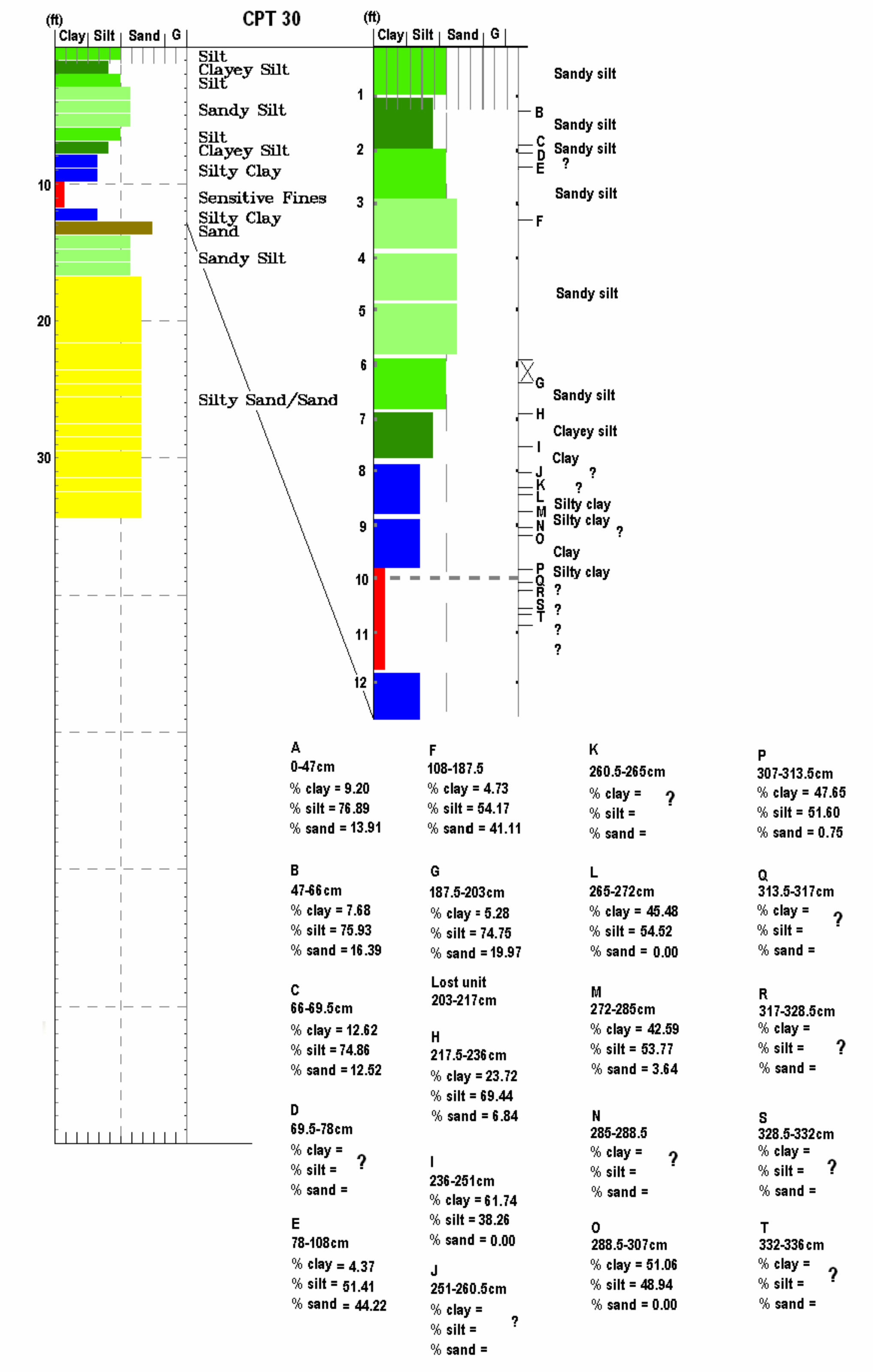


Figure 11. CPT 28 SBT as compared to mapped Geoprobe core and grain size analysis



A
0-47cm
% clay = 9.20
% silt = 76.89
% sand = 13.91

B
47-66cm
% clay = 7.68
% silt = 75.93
% sand = 16.39

C
66-69.5cm
% clay = 12.62
% silt = 74.86
% sand = 12.52

D
69.5-78cm
% clay =
% silt = ?
% sand =

E
78-108cm
% clay = 4.37
% silt = 51.41
% sand = 44.22

F
108-187.5
% clay = 4.73
% silt = 54.17
% sand = 41.11

G
187.5-203cm
% clay = 5.28
% silt = 74.75
% sand = 19.97

Lost unit
203-217cm

H
217.5-236cm
% clay = 23.72
% silt = 69.44
% sand = 6.84

I
236-251cm
% clay = 61.74
% silt = 38.26
% sand = 0.00

J
251-260.5cm
% clay =
% silt = ?
% sand =

K
260.5-265cm
% clay = ?
% silt =
% sand =

L
265-272cm
% clay = 45.48
% silt = 54.52
% sand = 0.00

M
272-285cm
% clay = 42.59
% silt = 53.77
% sand = 3.64

N
285-288.5
% clay = ?
% silt =
% sand =

O
288.5-307cm
% clay = 51.06
% silt = 48.94
% sand = 0.00

P
307-313.5cm
% clay = 47.65
% silt = 51.60
% sand = 0.75

Q
313.5-317cm
% clay = ?
% silt =
% sand =

R
317-328.5cm
% clay =
% silt = ?
% sand =

S
328.5-332cm
% clay =
% silt = ?
% sand =

T
332-336cm
% clay =
% silt = ?
% sand =

Figure 12. CPT 30 SBT as compared to mapped Geoprobe core and grain size analysis

Results of CPT logging and interpreted SBT revealed the original auger based three unit interpretation is likely over simplified (Figure 9). The interpreted SBT results showed that generally lenses of coarse sands are present in the eastern portion of the site and finer units composed of sandy silt dominate the western portion. In addition, the identified underlying clay unit is considerably thinner to the east than depicted by the CMT well logs. In addition it would appear this unit is not primarily comprised of clay, but rather a clay-rich silt. A fence diagram constructed down the centerline of the plume was prepared using interpreted SBT lithologies (Figure 13). The overall framework interpreted from the CPT and Geoprobe coring is similar to the HKM interpreted lithology; however, split spoon interpretations apparently missed subtle changes in sediment types. Records show that split spoon sampling below the water table encountered problems as fine sediments would flow up into the spoon, a condition that made the interpretation of lithologic breaks in these samples very hard to describe (HKM 2003).

In addition to interpreting an east-west profile, three transects were constructed perpendicular to the plume axis (north to south) (Figures 14-16). The east transect clearly identifies multiple sand lenses seen in the previously described fence diagram, as well as finer lenses of sandy silt. Sediment layers appear to pinch out and are often intersected by coarser units. Windows between the upper and lower sandy silt units may be present. Sediment types in the area closest to the road show a silt and sand dominated system, whereas cross sections farther west indicate fine sediment packages dominate the lithology.

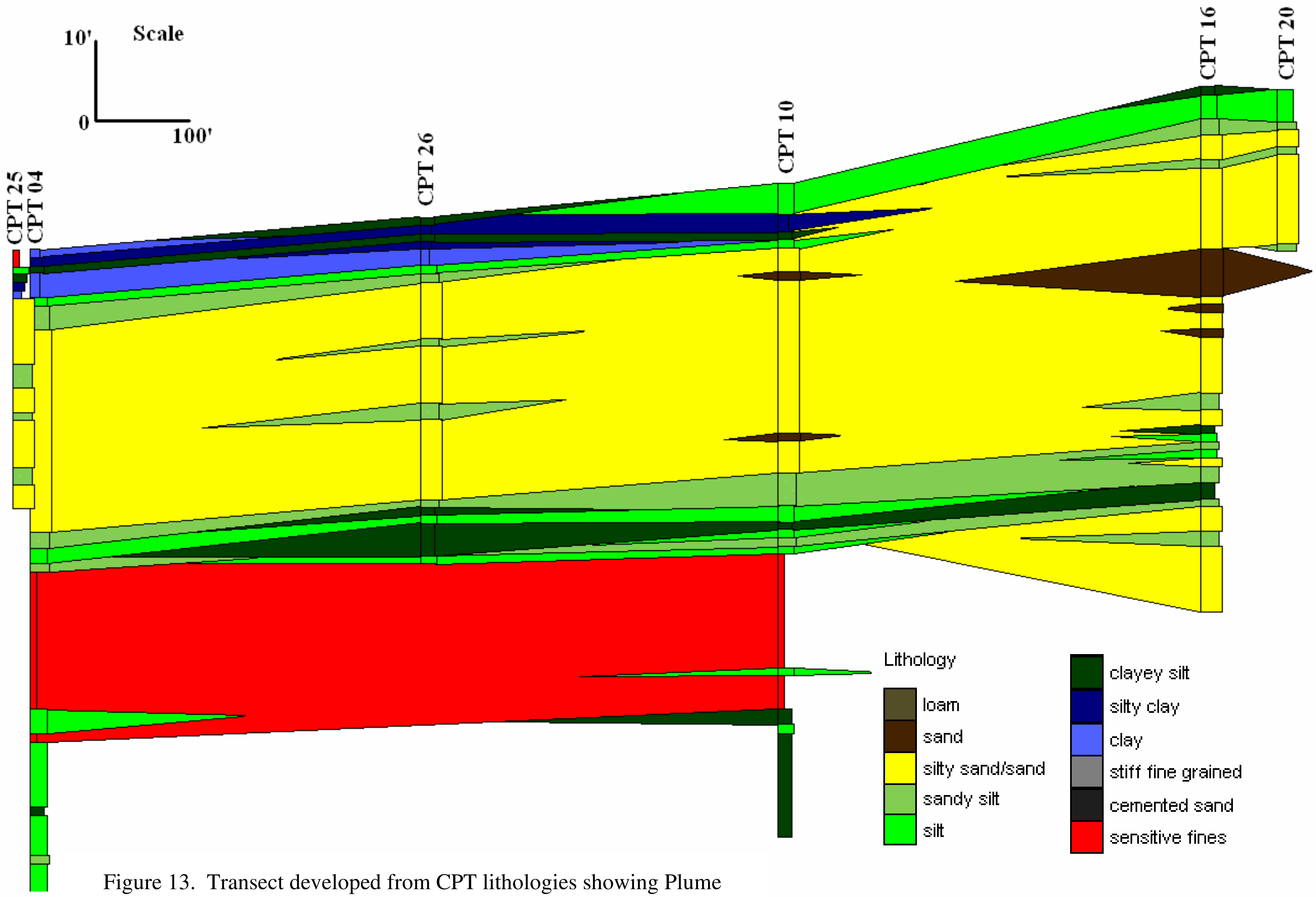


Figure 13. Transect developed from CPT lithologies showing Plume Transect along the plume axis. Location of the transect is shown on Figure 4.

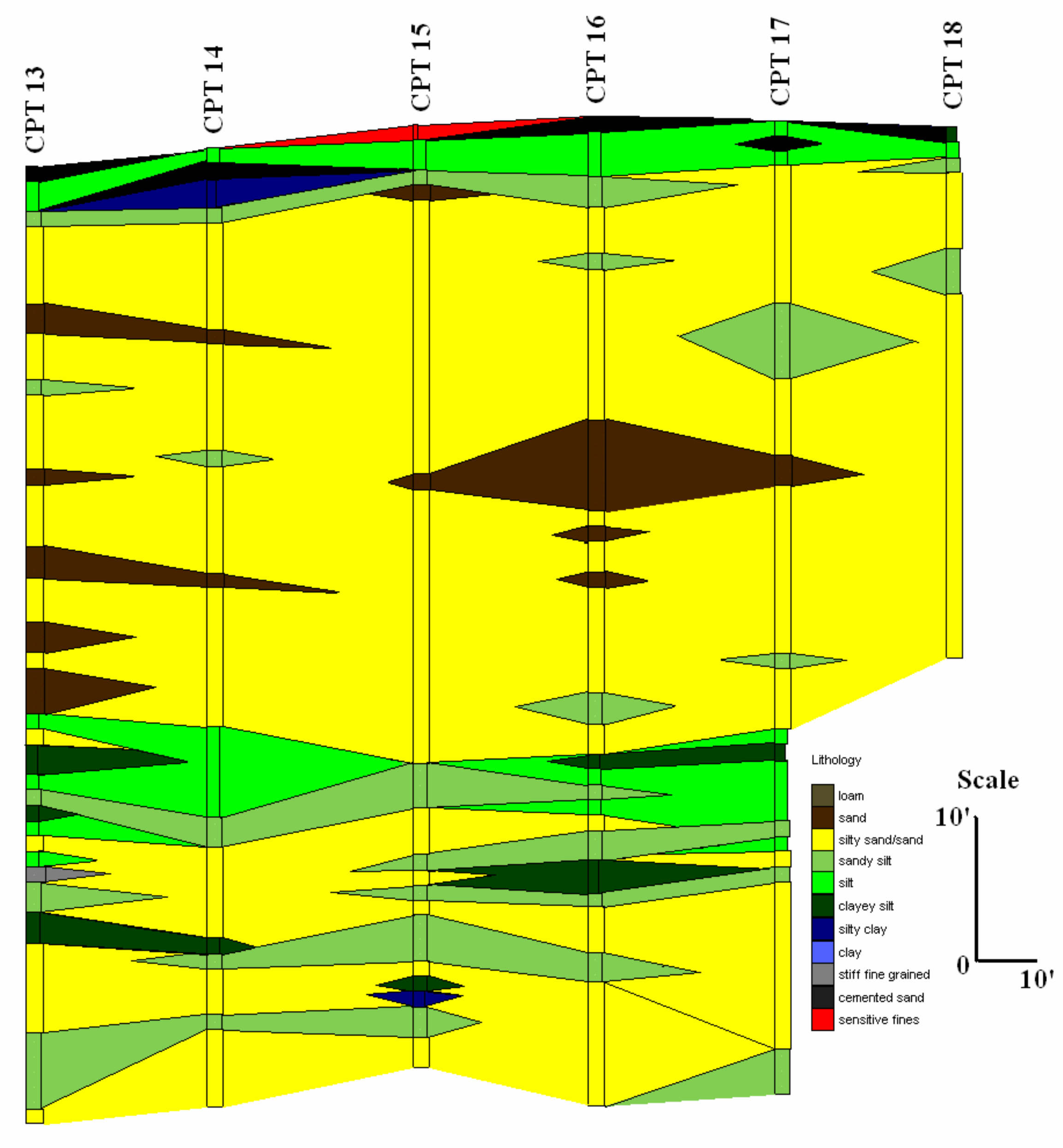


Figure 14. Transect developed from CPT lithologies showing East Transect perpendicular to the plume axis. The transect location is shown on Figure 4.

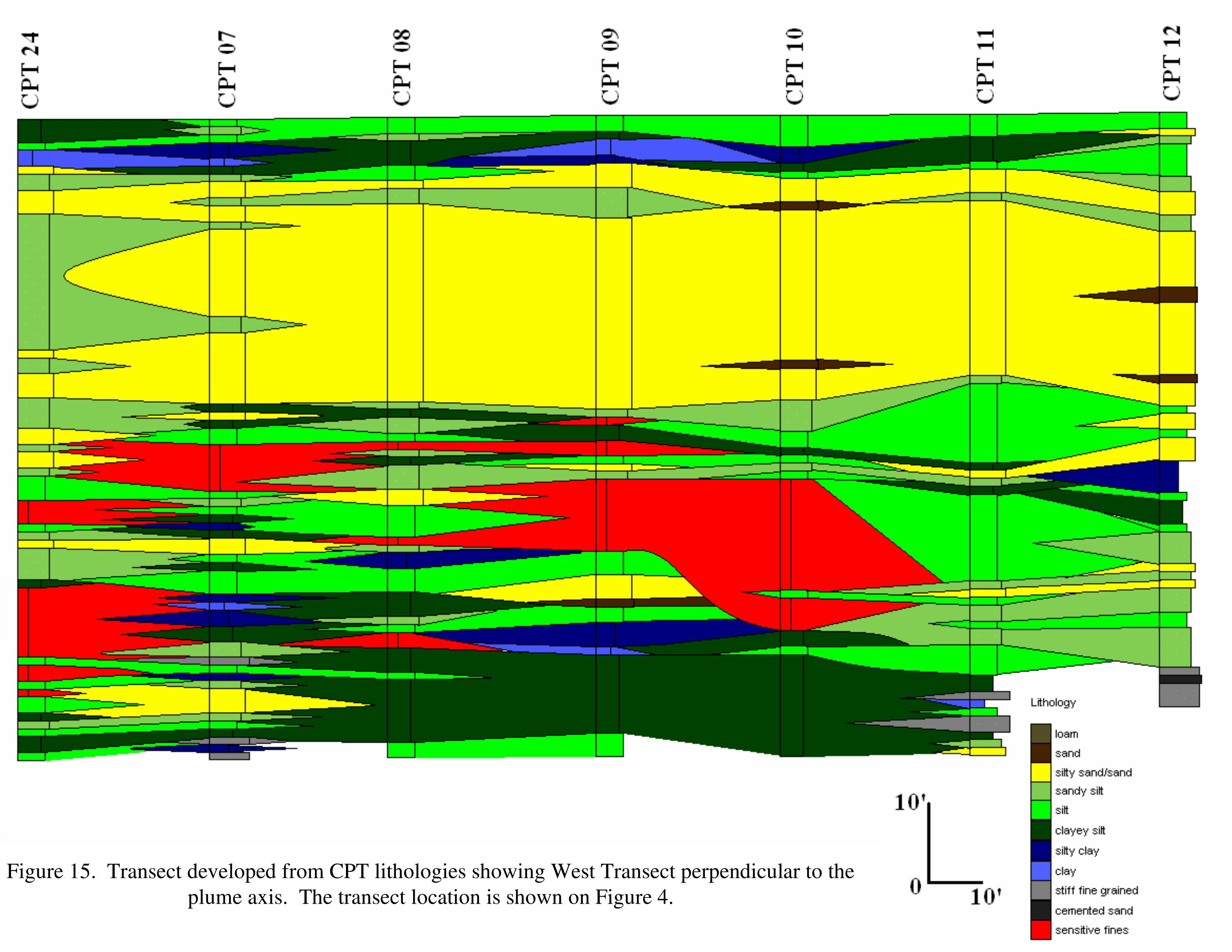


Figure 15. Transect developed from CPT lithologies showing West Transect perpendicular to the plume axis. The transect location is shown on Figure 4.

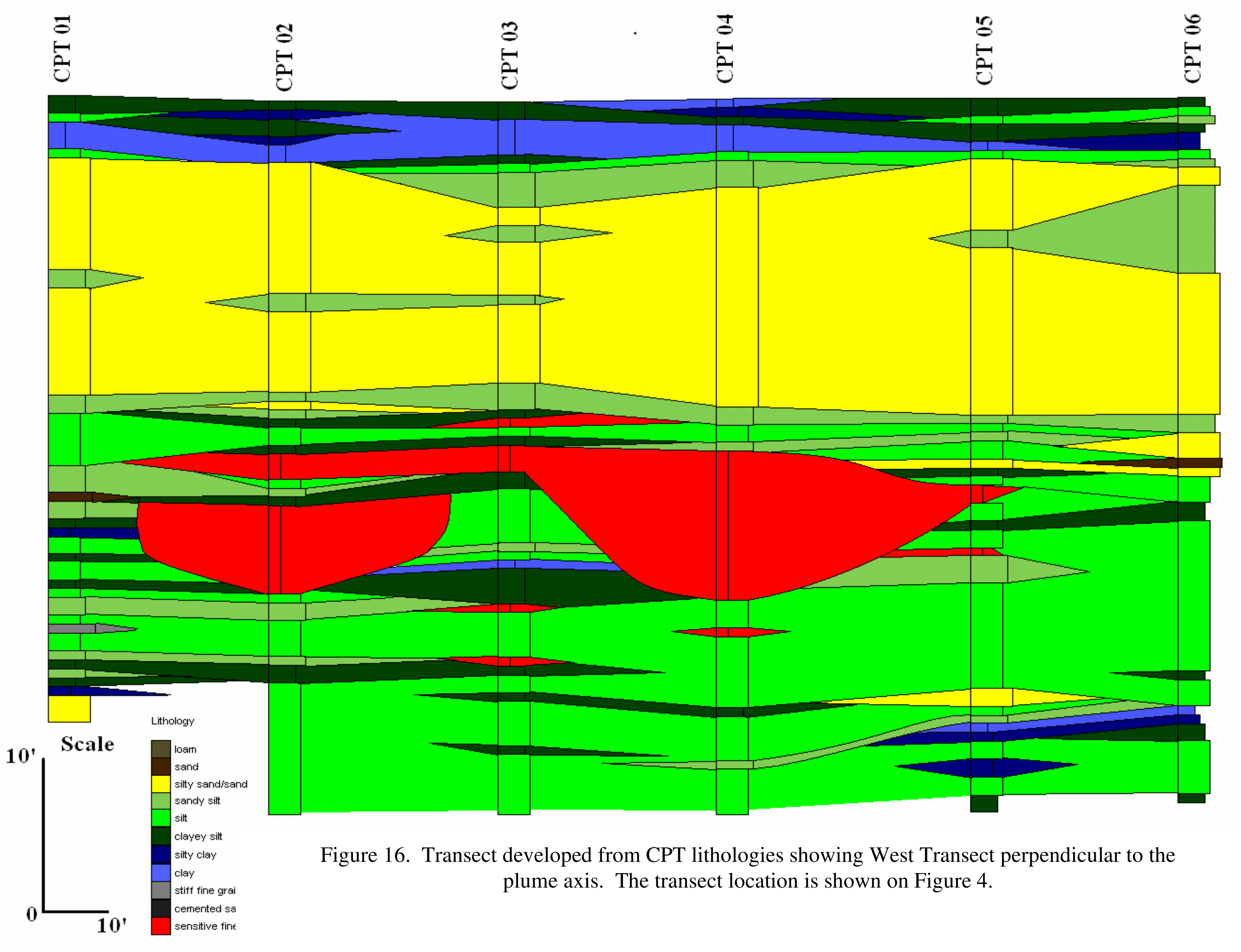


Figure 16. Transect developed from CPT lithologies showing West Transect perpendicular to the plume axis. The transect location is shown on Figure 4.

The center and west transects show an equally complex sedimentary relationship with the fine grained unit becoming more clay rich and significantly thicker. The center transect shows similar heterogeneity; suggesting the coarse grained units may be pinching out not only to the north and south but also to the west. Data below this fine grained unit are not available. The two upper and lower coarse grained units are essentially separated in this area by the clay rich unit; however, the eastern most cross section indicates the coarse grained units are connected.

The west transect is more homogeneous than the center transect, with the lower unit dominated almost entirely by clay-rich sediments. Lenses of coarse sediment are virtually absent and the water bearing unit shows more fine-grained lenses than in the more easterly transects. Beyond this section to the west, the land surface topography drops quickly to the first bench along the creek. A seepage face along this break in slope limited access to the coring equipment (Loustaunau 2003). To the west of the creek, however, the sandy silt dominant upper sediments are found immediately below the topsoil, suggesting the upper clay unit has been eroded and the creek bed includes coarse grained sediments.

3.3 Ground Water Flow

Data compiled by HKM Engineering (2003, 2004, 2006) and Loustaunau (2003) provide a consistent description of ground water movement from east to west with a slight trend to the south. Ground water is presumably recharged near the Mission Mountain range to the east and moves to the west. Shallow ground water at the site is discharged to Spring Creek while the deeper ground water is presumed to flow to the west past the creek (Loustaunau 2003). A local topographic high approximately 100 ft west of the creek likely sets up the reported and observed shallow ground water system that follows west to east discharging to Spring Creek (Loustaunau 2003).

Ground water flow in the vicinity of the site travels west of the highway and discharges to Spring Creek to the west, this system transports the MTBE and other contaminants at the site (Figure17). The water table is found typically 18 ft below land surface in the eastern portion of the site and 2-5 ft below land surface in the western area (Figure 18). The water level record of the continuous recording transducer located in well M12 shows seasonal variation in the water level tends to vary between 3058 ft and 3054 ft, being nearest the land surface in the April and at its deepest position in August. Though the field is typically irrigated using a side roll sprinkler from May to September no clear evidence of water percolating and recharging the underlying ground water system is observed (HKM 2004, Loustaunau 2003).

Seepage is observed on the slope just east of Spring Creek. Local ground water discharge occurs in Spring Creek with average seepage flux of 0.05 to 2.34 ft^3/ft^2d (Loustaunau 2003). Loustaunau (2003) reported the creek gains approximately 10 cfs over a 2,600 ft stream reach as the creek passes through the site.

Vertical movement of ground water at the site appears to be limited by the presence of fine grained sediments below the silty sand/sand unit. Reported vertical gradients are typically below 0.01 (HKM 2003, Loustaunau 2003, HKM 2004, HKM 2006). Vertical gradients are typically upwards where sediments of low permeability underlie higher permeability sediments, and gradients are slightly downward within the higher permeability units (Figure 2) (Loustaunau 2003, HKM 2006). At the stream interface, the ground water flow from depths up to 25 ft is upward and into the creek. Below about 25 ft, ground water generally appears to move horizontally and west beyond the site (Loustaunau 2003).

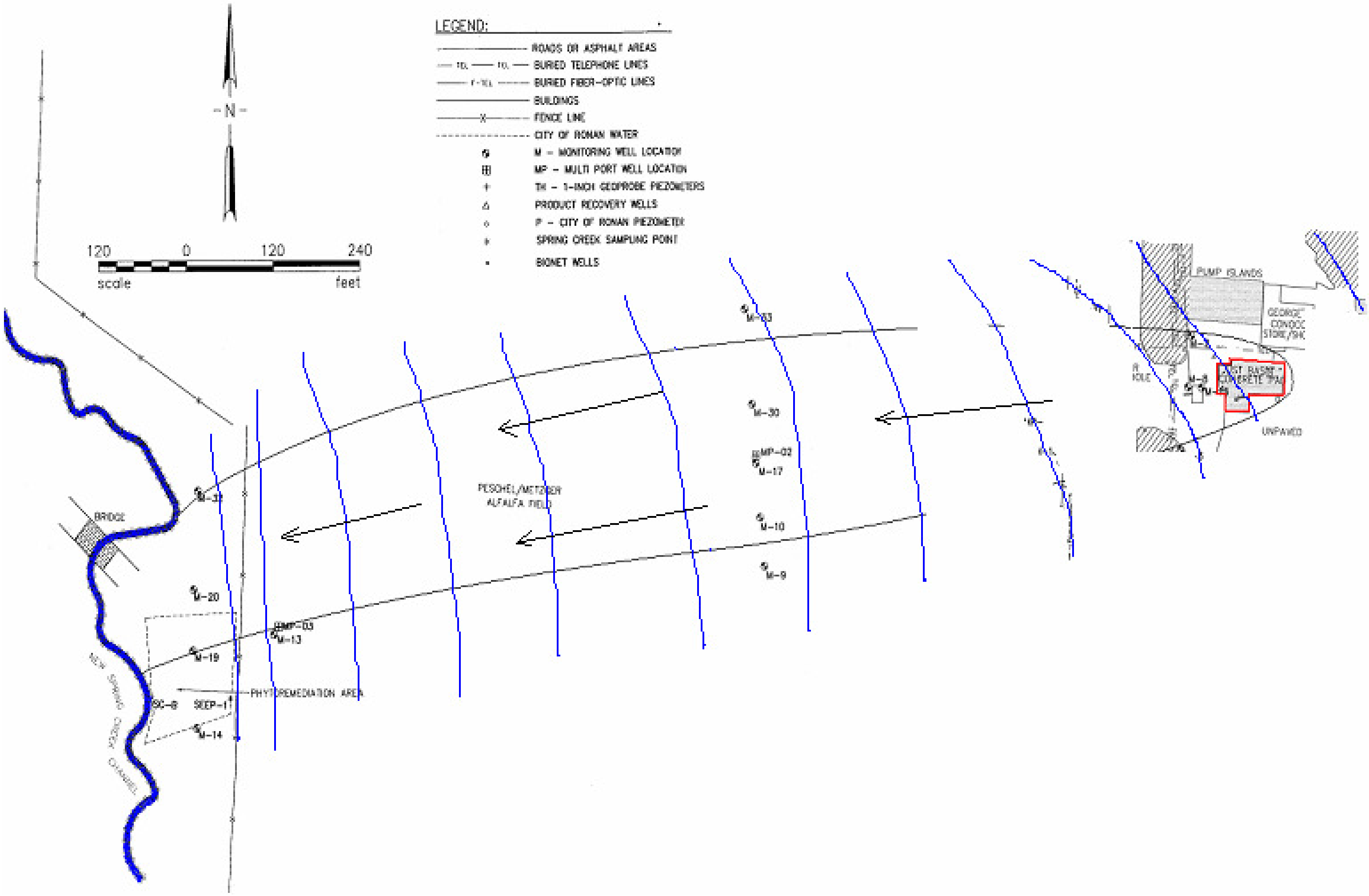
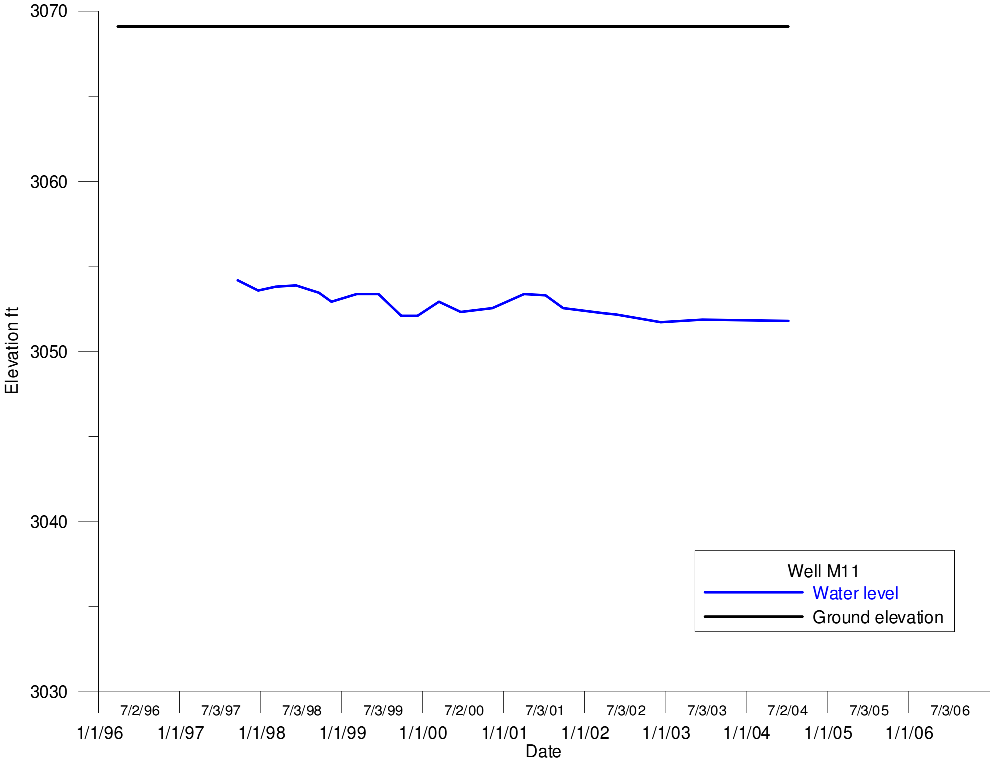


Figure 17. Map taken from HKM (2004) showing ground water flow direction at the Ronan MTBE site.



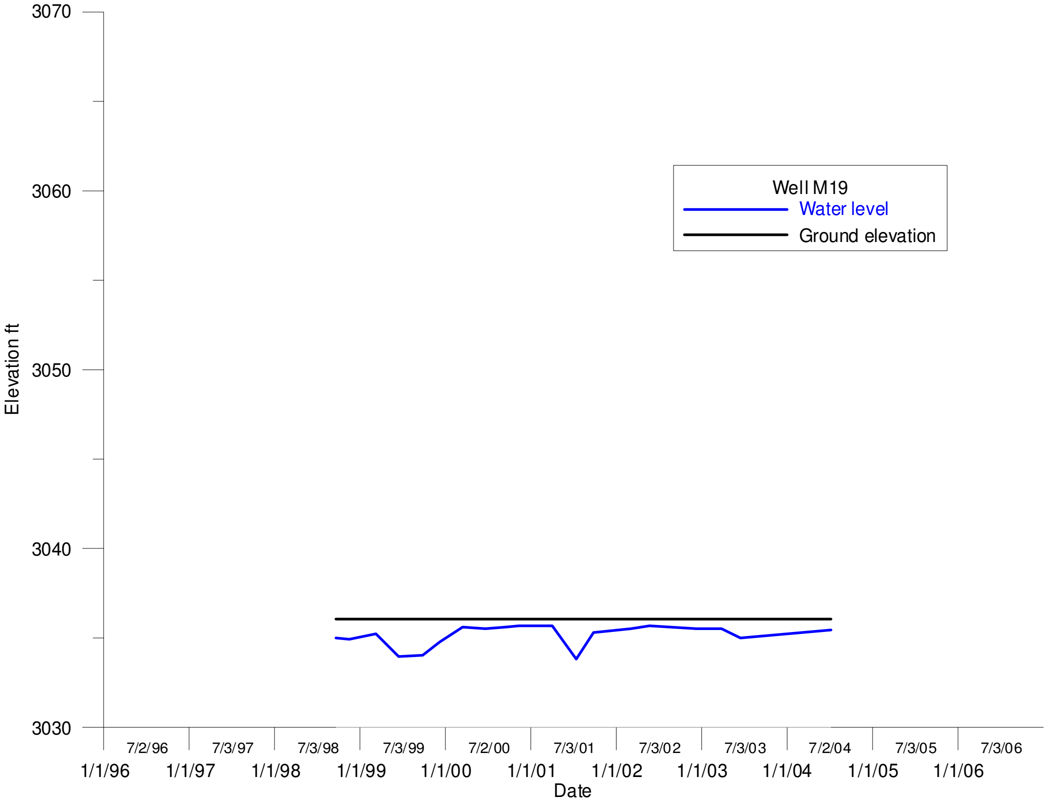


Figure 18. Hydrograph showing water levels at M11 and at M19.

3.4 Hydraulic Parameter Characterization

Laboratory permeability testing of segments of Geoprobe cores yielded a wide range of vertical hydraulic conductivity values for site sediments (Table 3). Characterization of the fine grained sediments located within 10 ft of the land surface indicated very low vertical hydraulic conductivity values. While the coring process tends to compact sediments and lowers the hydraulic conductivity, it is unlikely that the extremely low conductivities can be entirely attributed to this phenomenon. The lack of observable changes in permeameter water levels during testing prevented calculation of representative hydraulic conductivity values. Generally, horizontal hydraulic conductivitites are estimated from vertical values by assuming K_h/K_v is equal to 10 (Anderson and Woessner, 1992) (Table 3).

Field based determinations of horizontal hydraulic conductivities yield a wide range of values (1.7 ft/d to 1.4×10^{-4} ft/d) (Table 4). In an attempt to characterize general sediment types at the site four geologic units (sand, silty sand, sandy silt, and silty clay) were examined. The measured hydraulic conductivities were lumped and averaged for each unit to obtain a representative value (Table 5). The vertical hydraulic conductivity (K_v) values determined for the silty sand/sand sediments were approximately 3 orders of magnitude lower than field determined horizontal values (K_h) while the sandy silt sediment K_h and K_v values were separated by 5 orders of magnitude. The hydraulic conductivities of the clayey silt unit varied by 4 orders of magnitude. The sand sized sediment hydraulic conductivities varied by one order of magnitude difference (between K_h and K_v). All averaged vertical hydraulic conductivities were lower than the averaged horizontal hydraulic conductivities (Table 5).

Sample Name		K_v ave (ft/d)	Estimated K_h ave (ft/d)	Clay %	Silt %	Sand %	
CPT 08							
(102-108") - Average	**A**	1.94E-01	1.94E+00	20.787	72.445	6.766	clayey silt
(108-114") - Average	**B**	3.20E-01	3.20E+00	1.883	66.991	31.126	sandy silt
(114-120") - Average	**C**	7.42E-01	7.42E+00	1.728	60.139	38.134	sandy silt
(120-126") - Average	**D**	1.89E-01	1.89E+00	3.954	73.031	23.015	sandy silt
(126-132") - Average	**E**	2.98E-01	2.98E+00	2.564	75.949	21.487	sandy silt
(132-139") - Average	**F**	7.50E-01	7.50E+00	2.994	69.69	27.318	sandy silt
CPT 10							
(81-87") - Average	**A**	6.21E-02	6.21E-01	4.229	64.832	30.939	sandy silt
(87-93") - Average	**B**	1.44E-01	1.44E+00	3.447	73.063	23.491	sandy silt
(93-99") - Average	**C**	1.29E-01	1.29E+00	3.654	71.126	25.22	sandy silt
(99-105") - Average	**D**	2.01E-01	2.01E+00	2.827	67.835	29.338	sandy silt
(105-111") - Average	**E**	1.25E-01	1.25E+00	1.098	57.866	41.037	sandy silt
(111-117") - Average	**F**	9.78E-02	9.78E-01	3.498	73.232	23.271	sandy silt
(117-125") - Average	**G**	1.11E-01	1.11E+00	3.493	73.765	22.743	sandy silt
(131-137") - Average	**H**	6.13E-02	6.13E-01	3.489	75.96	20.55	sandy silt
(137-143") - Average	**I**	8.17E-01	8.17E+00	1.835	41.791	56.375	silty sand
(143-149") - Average	**J**	3.53E-01	3.53E+00	3.688	73.238	23.073	sandy silt
(149-155") - Average	**K**	2.43E+01	2.43E+02	0.662	11.434	87.905	sand
(155-161") - Average	**L**	7.37E+01	7.37E+02	0.282	5.414	94.305	sand
(161-167") - Average	**M**	8.12E+01	8.12E+02	0.423	7.252	92.324	sand
CPT 12							
(78-83") - Average	**A**	5.36E-02	5.36E-01	2.158	75.958	21.884	sandy silt
(83-89") - Average	**B**	1.00E-01	1.00E+00	3.854	74.491	21.656	sandy silt
(89-95") - Average	**C**	1.38E-01	1.38E+00	3.734	75.144	21.123	sandy silt
(95-101") - Average	**D**	7.05E-01	7.05E+00	2.889	72.257	24.855	sandy silt
(101-107") - Average	**E**	1.20E+00	1.20E+01	2.841	67.318	29.841	sandy silt
(107-113") - Average	**F**	8.17E-01	8.17E+00	2.677	53.554	43.769	sandy silt
(113-119") - Average	**G**	2.23E-01	2.23E+00	3.724	54.431	41.846	sandy silt
(119-125") - Average	**H**	1.68E-01	1.68E+00	2.847	79.312	17.84	sandy silt

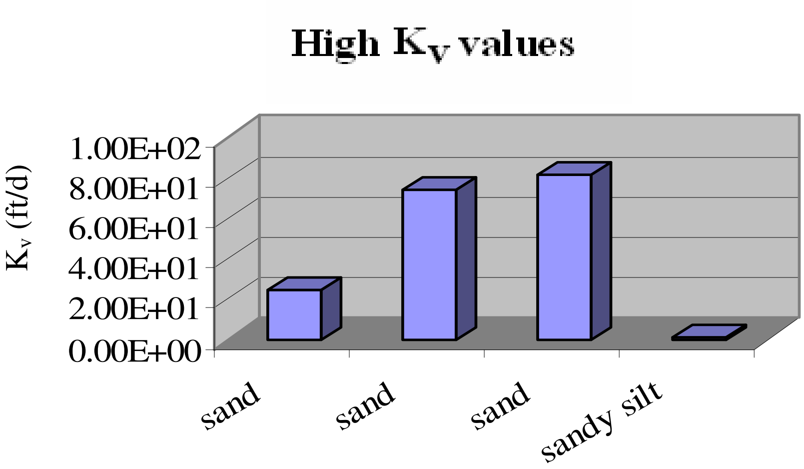
Table 2. Vertical conductivity and grain size analysis for CPT 08, CPT 10, and CPT 12.

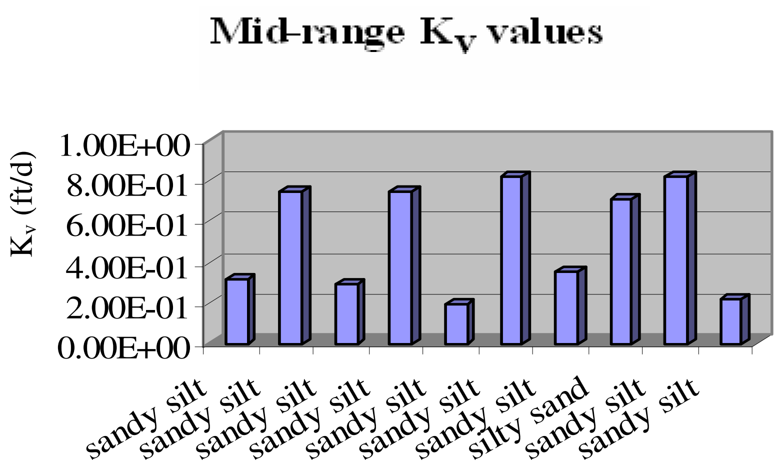
Well	**K_h ft/d**	**Unit**
M6*	1.25E-01	silty sand/sand
M9*	2.01E-03	silty sand/sand
M10*	3.97E-03	clayey silt
M11*	4.68E-02	silty sand/sand
M13*	3.97E-03	clayey silt
M14*	1.39E-02	silty clay
M17*	7.09E-02	silt
M19*	1.50E-02	clayey silt
M20*	3.12E-03	clayey silt
M30*	6.80E-02	silty sand/sand
M31*	4.54E-02	sandy silt
M32*	7.09E-03	silt
CPT 01	6.94E-01	silt
CPT 04	1.39E-01	silty sand/sand
CPT 06	7.23E-03	sandy silt
CPT 16	1.69E+00	sand
CPT 30	1.67E-04	sensitive fines
M34b	7.40E-05	unknown
M34c	7.40E-05	unknown
Average	1.54E-01	N/A

Table 3. Table of horizontal hydraulic conductivities.
*Taken from Loustaunau, 2002.

Sediment	K_v estimated K_h (ft/d)	K_h ave (ft/d)	K_v ave (ft/d)
clayey silt	1.85E+01	5.71E-03	1.94E-01
sandy silt	2.63E-02	4.30E+04	3.18E-01
sand	1.69E+00	3.10E+02	5.97E+01
silty sand/sand	7.61E-02	3.00E+02	8.17E-01

Table 4. Average vertical hydraulic conductivities (K_v) and horizontal hydraulic conductivities (K_h) for sediments described at the Ronan MTBE site.





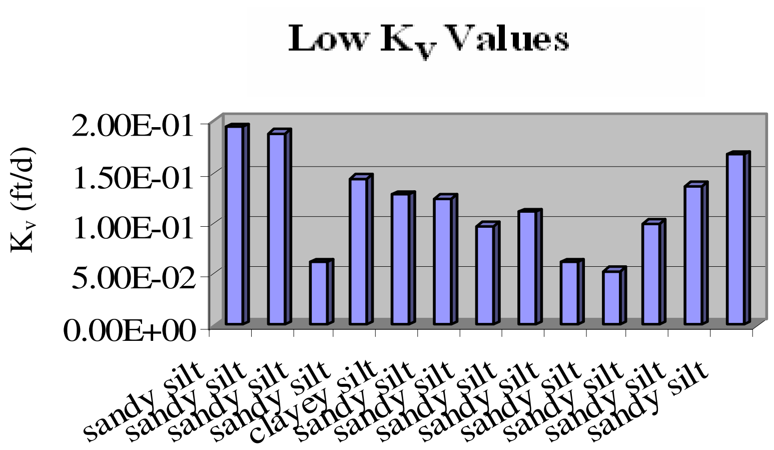


Figure 19. Bar graphs showing vertical hydraulic conductivity.

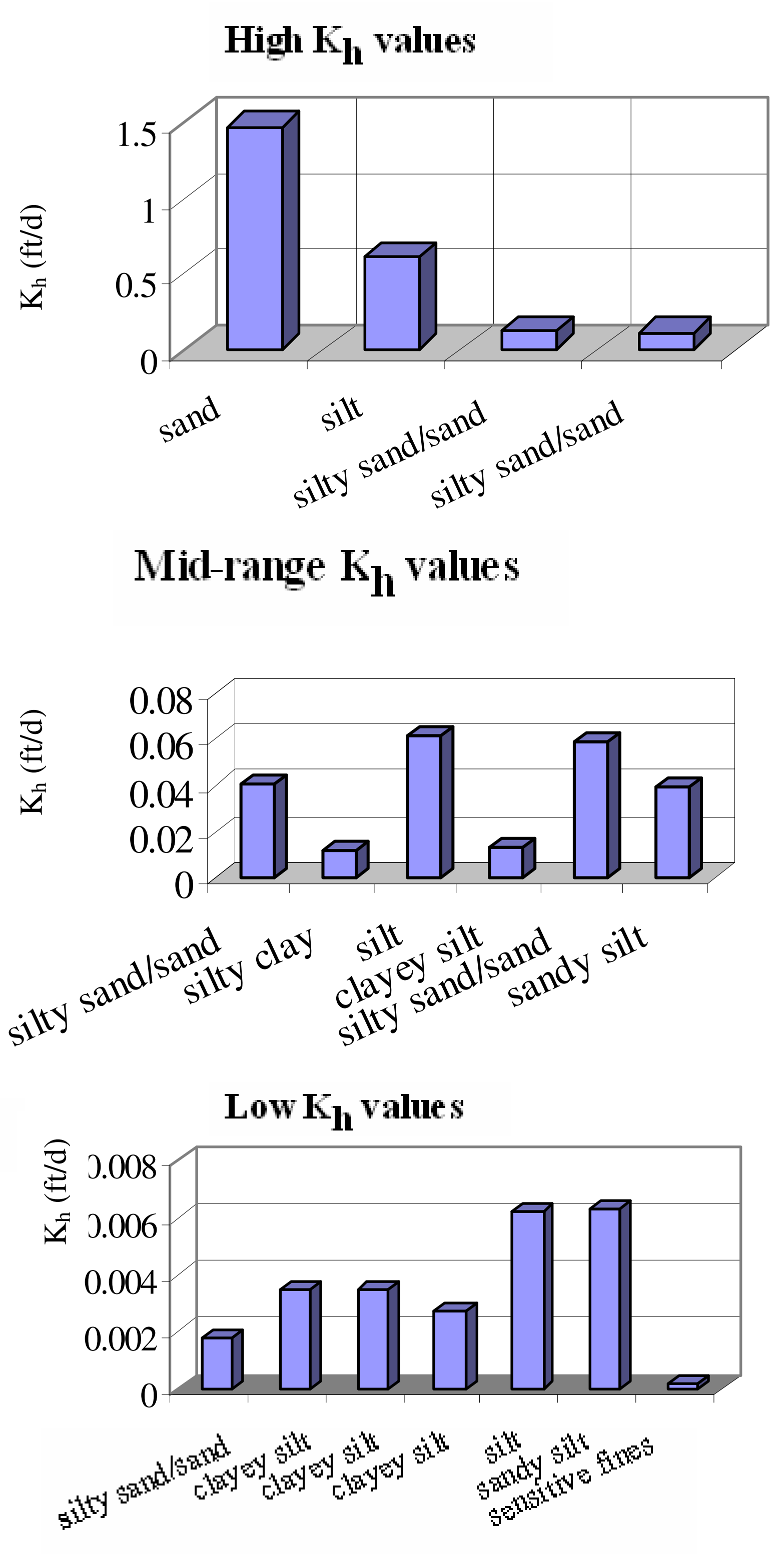


Figure 20. Bar graphs showing horizontal hydraulic conductivity

3.5 Temperature Monitoring

The well network established to assess the transport of heat near Highway 93 included instrumentation at wells M12 (Solinst water level/temperature logger) wells T1 and T2 (temperature buttons were installed at five foot intervals), and at well S1 (located outside of the heated plume where ambient ground water temperatures could be established). Well T2, the well spaced at eight feet from well M12, was destroyed prior to the first temperature monitoring.

The temperature monitoring revealed the temperature peak had already passed the instrumented location (Figure 21 amd 22). The records for the Solinst logger that was operated during the entire heating test shows the temperature history at well M12 located 75 ft from the western edge of the remediation project. This temperature record was evaluated using the USGS temperature model VS2DH (Healy, 1996). The model was set up as a rectangle starting at the heated area and extending 75 ft. The arrival of the temperature signal was calculated using ground water velocity values. The temperature plume moved at a rate of 0.16 ft/day and a final ground water velocity value of 0.3 ft/d was determined. The horizontal hydraulic conductivity in this portion of the site is estimated to be 0.2 ft/day.

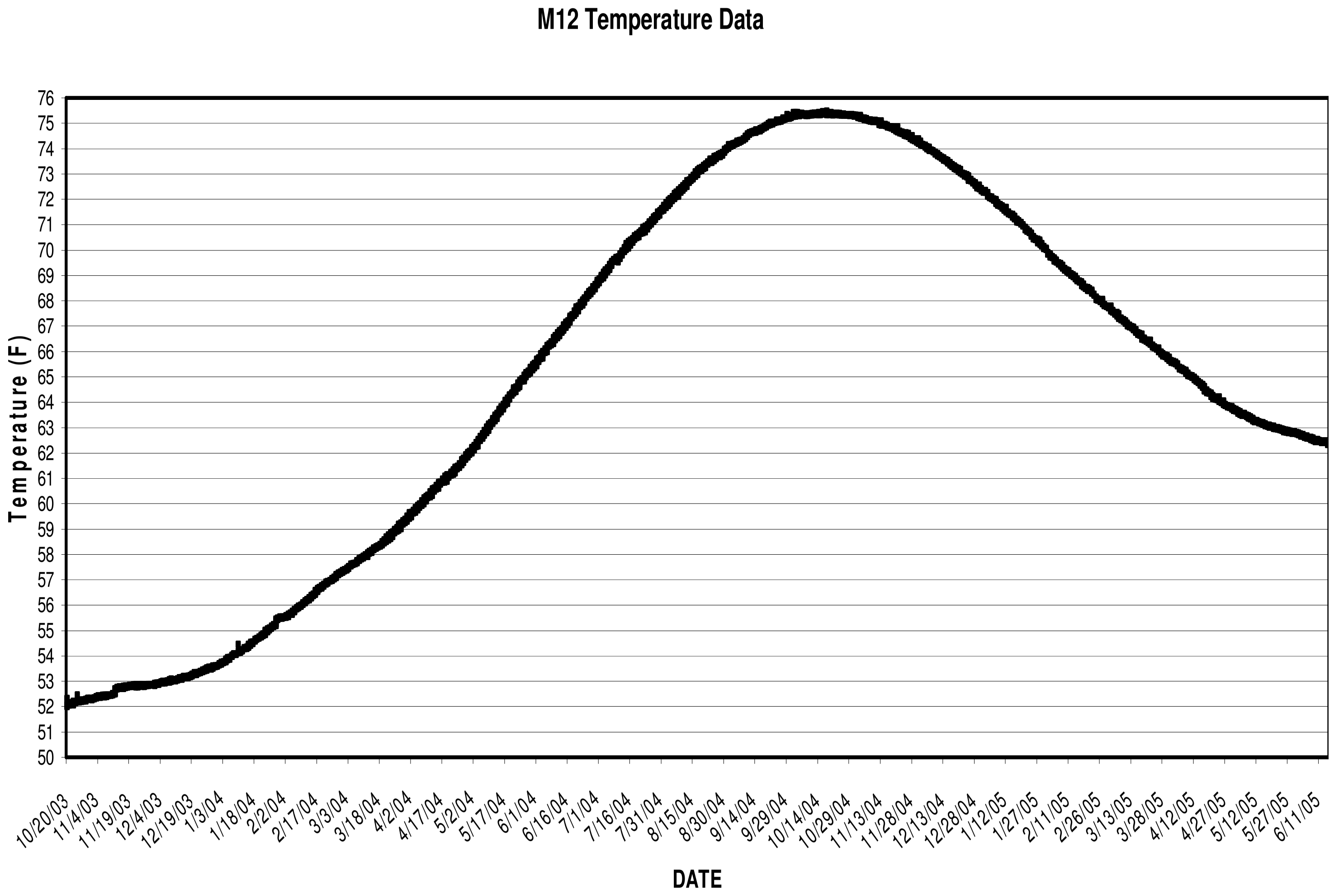


Figure 21. Ground water temperatures at well M12 taken by Solinst water level/temperature logger (courtesy of HKM Engineering). The line indicates monitoring by temperature button.

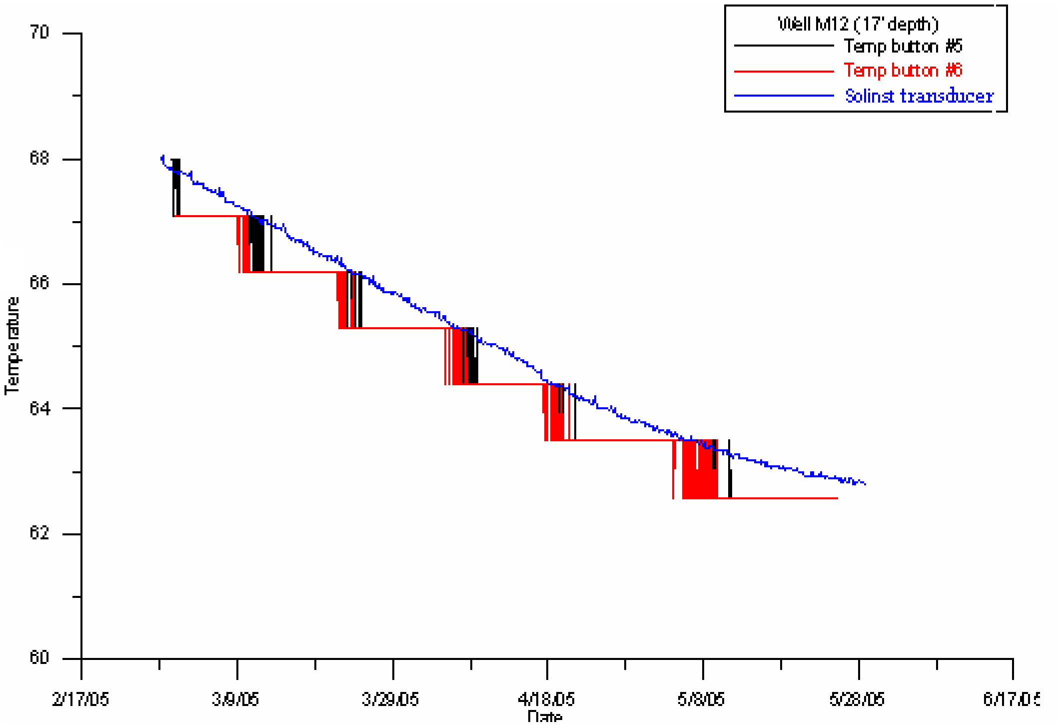


Figure 22. Graph showing recordings from two temperature buttons located at well T1 and temperature data from well M12 during the same time interval (courtesy of HKM Engineering, 2003)

3.6 Plume Delineation

Reports by the DEQ consultants and the work of Loustaunau (2003) recorded the horizontal distribution of the MTBE plume over time and the vertical depth to which the plume is believed to have migrated (HKM 2003, 2004, 2006). Based on the reported source release history (1994), it appears contamination spread quickly across the site in a longitudinal direction, with wells near the creek showing minor (≤5µg/L) concentrations of MTBE as soon as September of 1998. Appendix C includes a graphical analysis of MTBE over time. The highest MTBE concentrations have yet to reach the creek, however, the highest concentrations were recorded at the center transect in 2003 at well M30. Figure 23 shows the interpreted locations of the bulk MTBE center of mass over time (results compiled from HKM 2003, 2204, 2005).

The vertical extent of the plume was reported by HKM (2003, 2004, 2006) to be 72 ft in the east and 57 ft in the west based on CMT sampling of the MP wells (Figure 23). Loustaunau (2003) was the first to attempt to resolve the mechanisms that accounted for the observed concentrations. He hypothesized that the CMT wells may allow diffusion of MTBE through the well casing and thus reported concentrations at depth were suspect. Loustaunau (2003) concluded that the polyethylene casing used for the CMT wells (MP-01, MP-02, MP-03) was permeable to MTBE. For this reason, the MTBE concentrations found at depth in these wells are questioned.

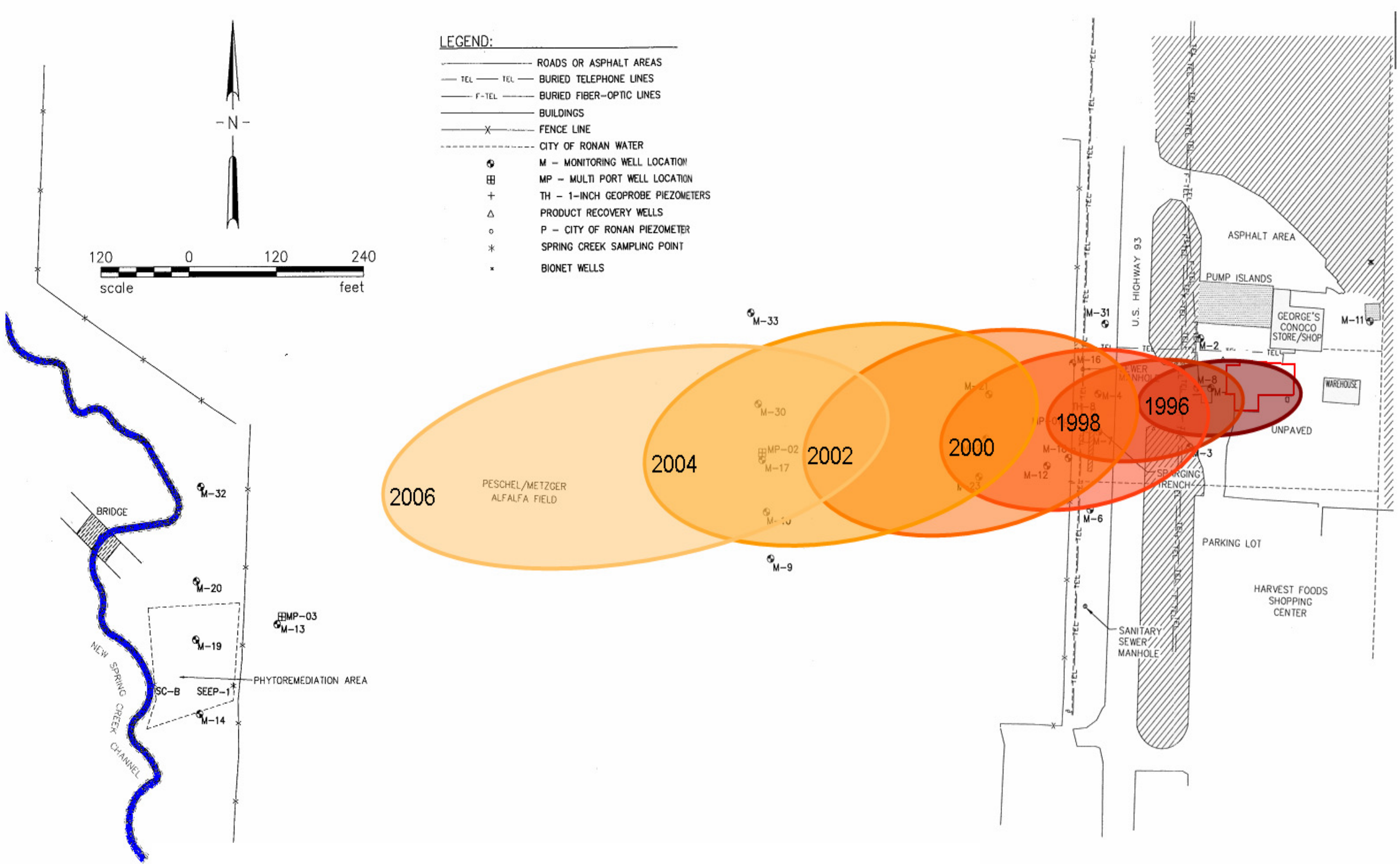


Figure 23. Interpreted location of bulk contamination. 1996-2006. Plume limits are estimated to be >1 ppb.

In an attempt to better resolve the vertical distribution of impacted ground water the MIP tool was employed. However, as applied it was only able to indicate areas of high concentrations of hydrocarbons.

Included in Appendix D are copies of the MIP output data. The six graphs show electrical conductivity (which was not measured), the speed at which the CPT rod was pushed, the PID, FID, and ECD readings, and the temperature of the water surrounding the probe. All of the temperature graphs show rhythmic spikes and decays in temperature, some more clearly than others. This is attributed to the push delay required as the drill clamp is raised to drive each additional section of rod. While the pause was generally 45 seconds or less, the delay allowed the MIP heating element to significantly increase the sampling water temperature. The decay occurs as the additional rod section is driven into the ground and the MIP moves beyond the heated water and returns to ambient water temperature. This occurred at approximately four foot intervals, the length of each section of drill rod added.

The PID and FID instrument measures hydrocarbons in their gaseous state, making the readings more accurate when the temperature is raised and gas is produced. Corresponding spikes in the UV wavelength can be noticed on both detectors in combination with the increased temperature, and responses to low level concentrations are more frequent during temperature spikes. For example, MIP-04 shows two temperature spikes between the depths of 16.0 and 21.4 ft. Analogous peaks can be seen in the PID and FID graphs, indicating the clear presence of targeted hydrocarbons. MIP-01 shows analogous FID peaks between 21 and 37 ft, however, the lack of

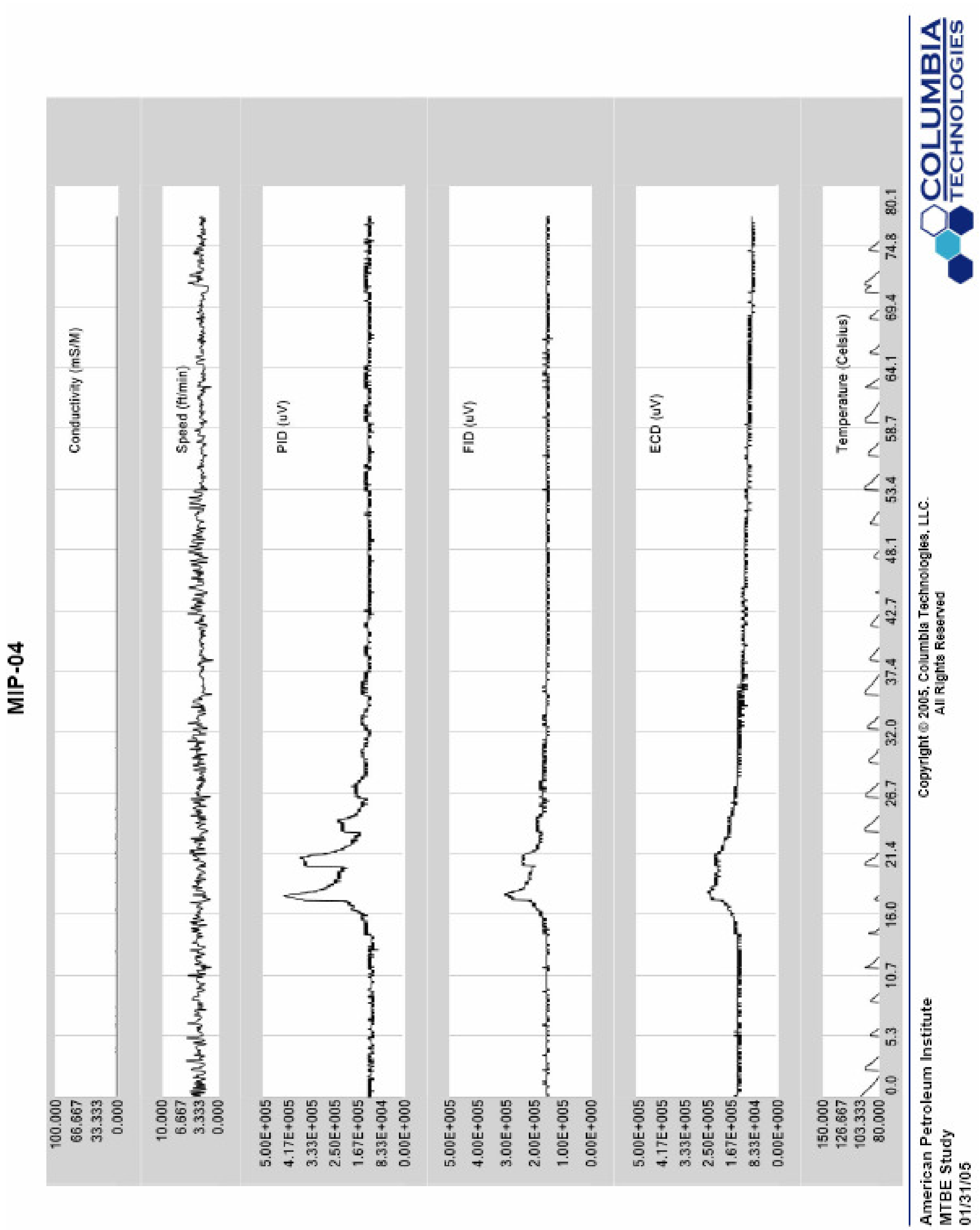


Figure 24. MIP results from location MIP-04 showing increased concentrations of hydrocarbons on the PID, FID, and ECD.

verification from the PID does not confirm the presence of hydrocarbons. The presence of hydrocarbons at specific depths was verified only when both detectors showed peaking UV wavelengths.

The locations with a measurable hydrocarbon concentration were recorded at CPT 04, 07, 08, 10, 11, 14-17, 20, 22, and 25 (Appendix D). All of these locations are found surrounding the longitudinal axis of the plume where concentrations have historically been highest (Figure 24). In the east transect, apparent contamination extends 90 ft laterally, and spreads to 140 ft at the center transect (HKM 2006). Only one point in the west transect indicated apparent contamination and therefore the lateral extent could not be determined from the MIP data. Concentrations found at depths below 35 ft were suggestedfound at four locations in the east transect but in other locations contamination was found only at shallower depths (Figure 24.)

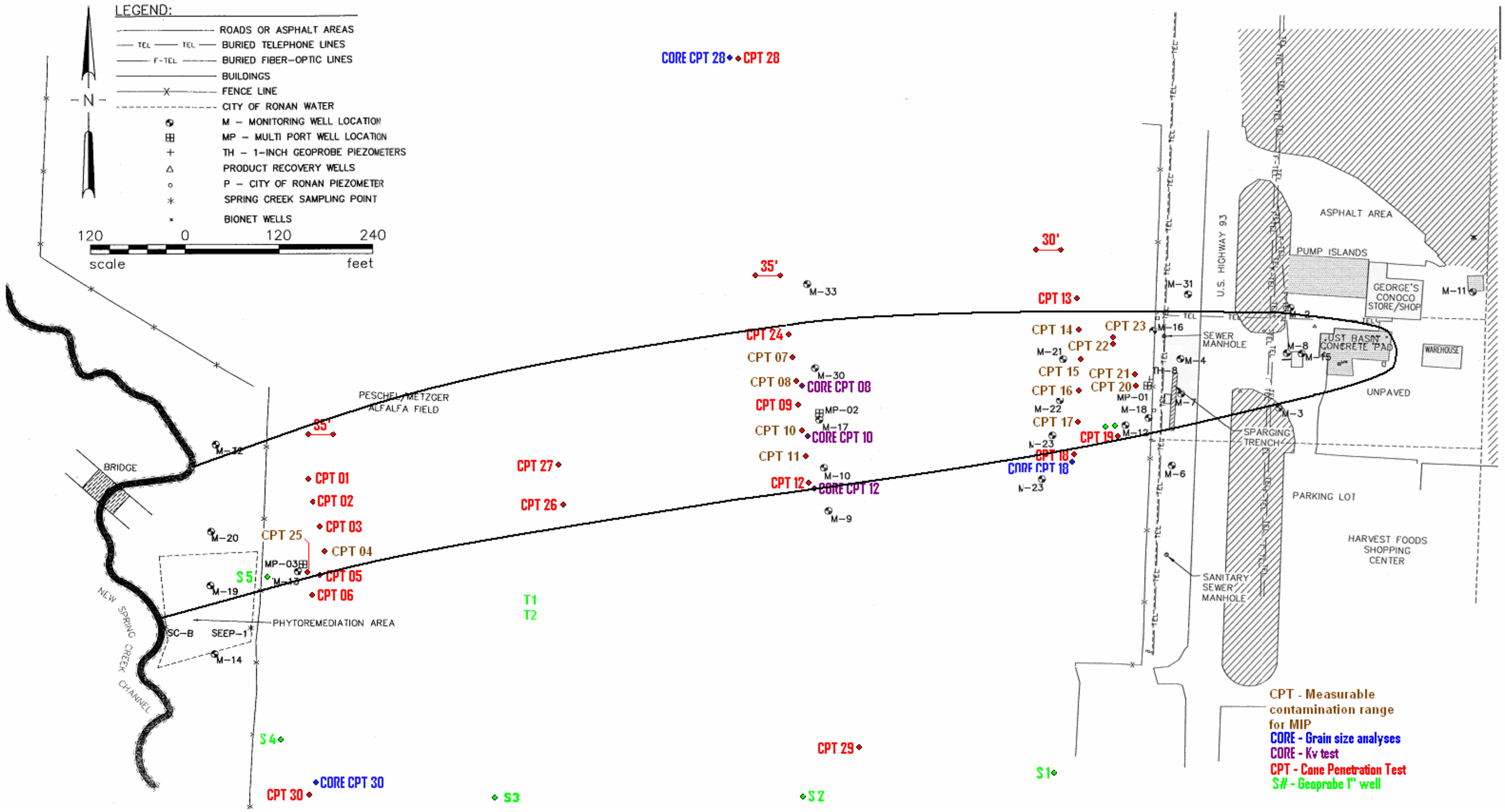


Figure 25. Shows location of the plume and CPT locations where MIP recorded contamination (8 brown CPT points). Plume limits are estimated to be >1 ppb.

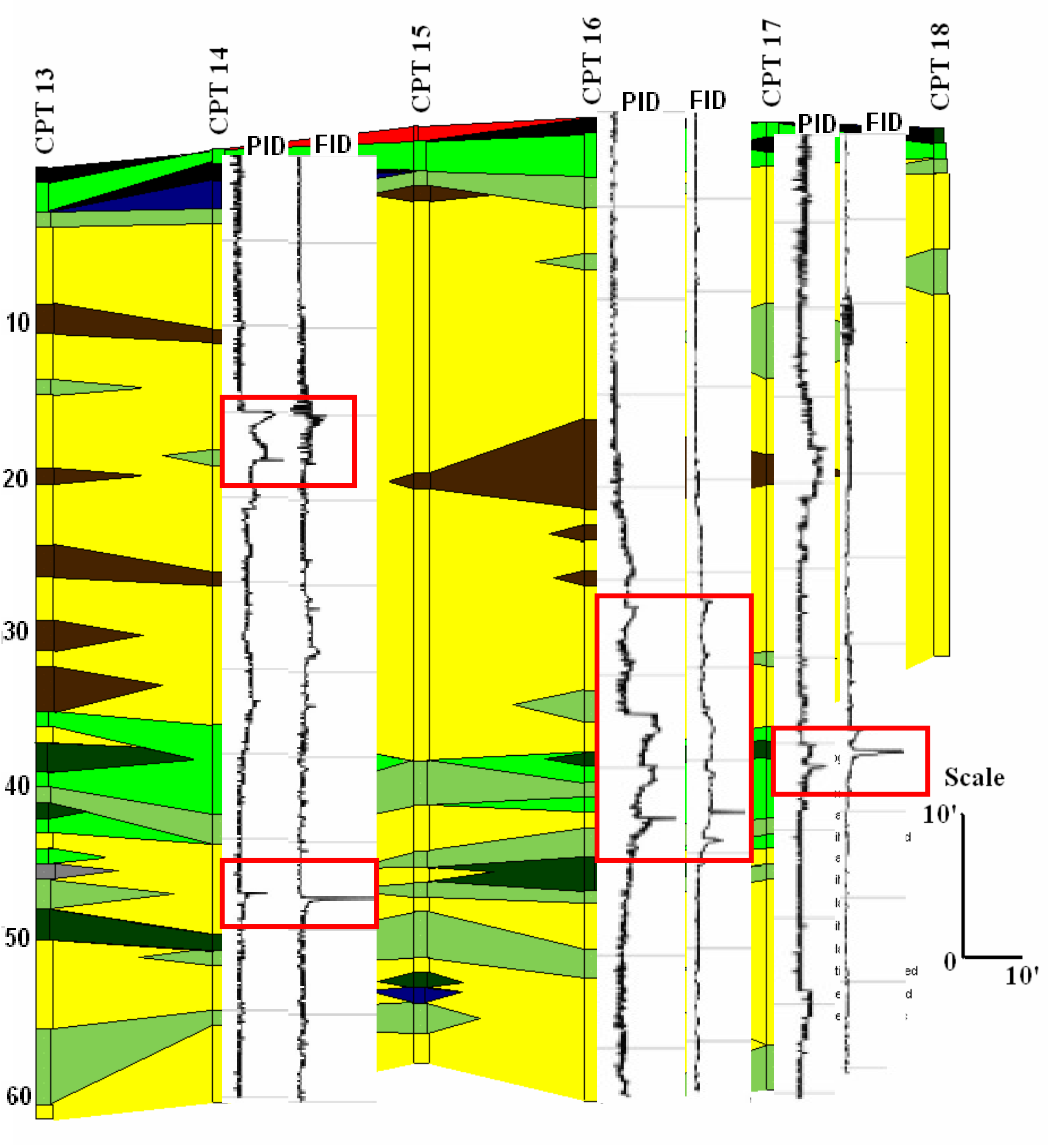


Figure 26. Diagram of east CPT/MIP transect showing areas of hydrocarbon contamination as evidenced by the MIP detectors (PID, FID). Boxed areas indicate contamination. Scale is in feet.

With very few exceptions, the instrument interpreted contamination appears to be confined to the defined shallow aquifer above the lower fine grained sediments. An indication of contamination is found closer to the surface in the west transect where the topography is lower and the water table is closer to the surface topography. MIP-11 shows hydrocarbons at an unusually shallow depth, which is a likely product of vapors rising into the soil above the water table since the point is not located in a topographic low and the two adjacent points do not show contaminants above the water table. In contrast, MIP-14 shows contaminants at a depth of approximately 47 ft, well below other locations. This anomalous spike is located in a silty sand lens beneath an 8 foot silt unit. MIP-16 shows a similar situation, although the hydrocarbons at this point are separated from the coarse material by a 2 foot unit of sandy silt and have reached a depth of only 40 ft (Figure 25).

3.7 Pre-model Water Budget

For comparison with the modeled ground water balance, the pre-model estimated ground water budget was computed. The ground water gradient into the study area was computed using a three point solution as 0.0045 and it was 0.0087 at the west out flow boundary. The cross sectional area for a 1400 foot width of the aquifer was computed to be 49000 ft^2 for the eastern boundary and 35000 ft^2 ft for the western boundary assuming a thickness of 35 ft and 25 ft, respectively. Based on lithology, the hydraulic conductivity was assumed to be 2.5 ft/d along the eastern boundary and 1.48 ft/d along the western boundary. The ground water discharge was estimated as:

$$GW_{in} = Tiw = (2.5ft/d \times 35ft)(.0045)(1400ft) = 551ft^3/d \ +/- \ 100\%$$

GW_{out} = Tiw = (1.48ft/d x 25ft)(.0087)(1400ft) = 450ft^3/d +/- 100%

As error in field measurements occur and the site conductivities are observed to be quite heterogeneous, uncertainty in estimated ground water discharge calculations may vary 50-100%

Stream flow estimated by Loustaunau's (2003) data suggests a flux into the creek between 70ft^3/d and 3276ft^3/d. Using the low flow calculations from Loustaunau's steam flow data, and variation in surface water discharges of +/- 50%, the stream could be gaining between 35ft^3/d and 4914ft^3/d.

The ground water discharge simulated by the steady state ground water model was lower than the field calculated ground water budget:

Q_{in} = 352 ft^3/d

Q_{out} = 279 ft^3/d

Stream gain = 59 ft^3/d

The discrepancy between the modeled water in and water out less than 3%.

Based on study analyses and results, the numerical model was used to generally evaluate the conceptual hydrogeologic model and the general transport and fate of MTBE. The physical framework of the site was generalized by simplifying the complex stratigraphy in to three layers (Figure 26). These layers were chosen based on drilling and CPT testing and data on site water quality. Constant head boundaries were assigned to all three layers at the eastern and western model boundaries. No flow boundaries are assigned to the north and south extent of the model. The no- flow boundaries were placed well away from the plume to avoid any affects on the plume movement.

Spring Creek was represented using river cells which allow ground water to exchange with the stream. Hydraulic conductivities were assigned to replicate the horizontal and vertical conductivities described by Loustaunau (2003).

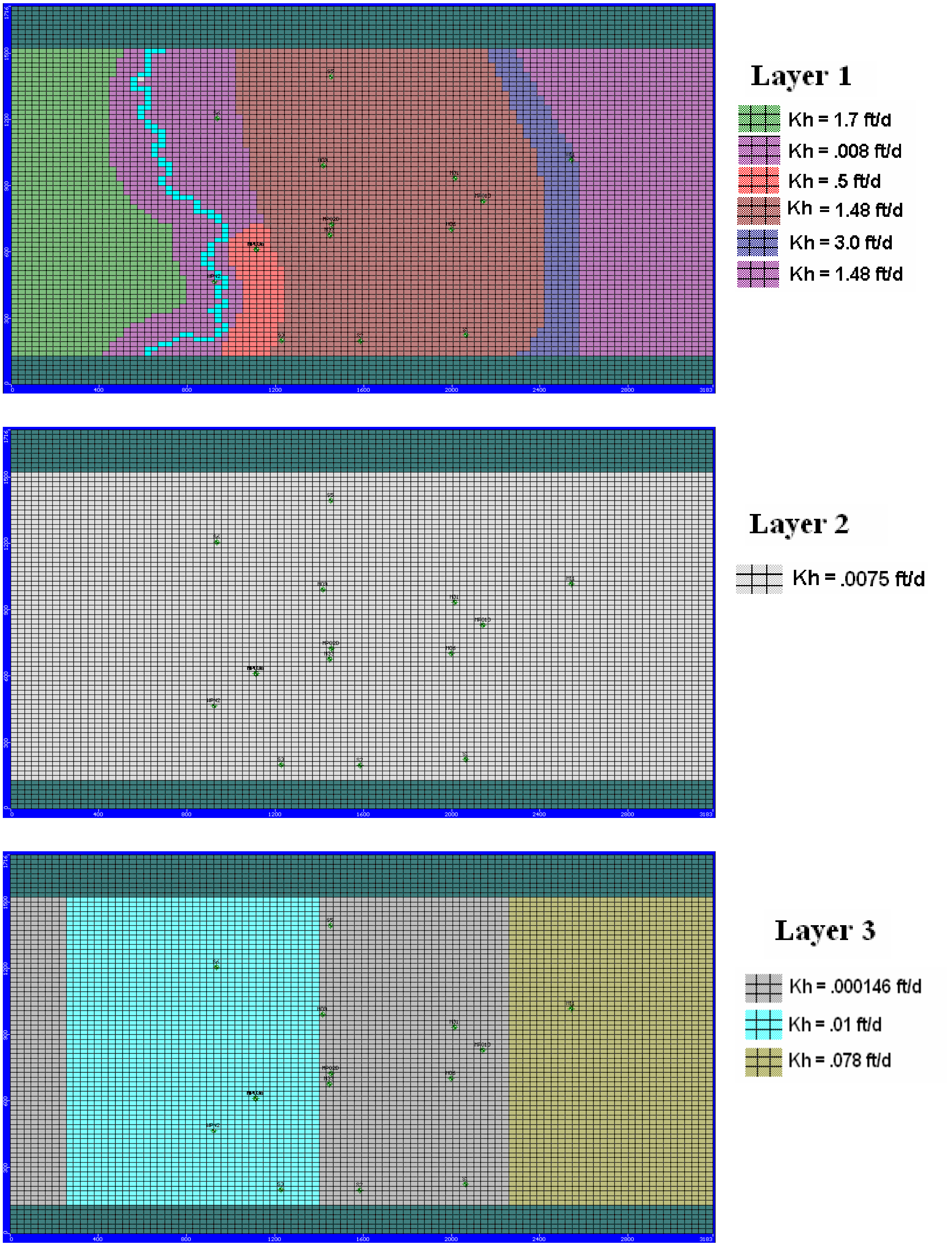


Figure 27. Modeled conductivity zones for layer 1, layer 2, and layer 3
Modflow calibrated model

The model contained three layers representing the three dominant lithologic units at the site. The first layer was designed to represent the upper coarse grained saturated sediments through which the majority of the contamination is believed to move. This layer contained six hydraulic conductivity zones. Water in this layer discharges primarily to the stream (Figure 27). Layer two is dominated by silts and was assigned a horizontal hydraulic conductivity of 0.0075 ft/day, layer three simulates the underlying low permeability sediments characterized by clays and ‘sensitive fines’. This layer was assigned a horizontal hydraulic conductivity of 1.46×10^{-5} ft/d to the west where it is dominated by fine grained sediments and 0.01 ft/d to the east where coarser silty sand/sand sediments dominate the unit.

The modeling effort was developed to represent steady state ground water conditions as well hydrographs varied on average by about 1-2 ft annually and ground water flow directions and gradients remained relatively constant. The modeling was based around head and flux data collect in June 2003. The model was then calibrated by the trial and error method with an absolute mean error of 0.136 ft using 13 wells. Head data from one well, WSPN-1 to the west of the creek, did not calibrate as well as other locations (residual of 4.1 ft). The values used for calibrating heads were collected by Loustaunau (2003) prior to the 2003 monitoring event. Vertical gradients were calibrated based on the June 2003 gradients recorded by HKM (2004) in the CMT wells.

Initial calibration identified the vertical hydraulic conductivity as one order of magnitude lower than that of the horizontal hydraulic conductivity. As calibration proceeded the averaged vertical hydraulic conductivities (lab values) were used for the three sediment types. When the calculated anisotropy ratios (10:1) were applied to the

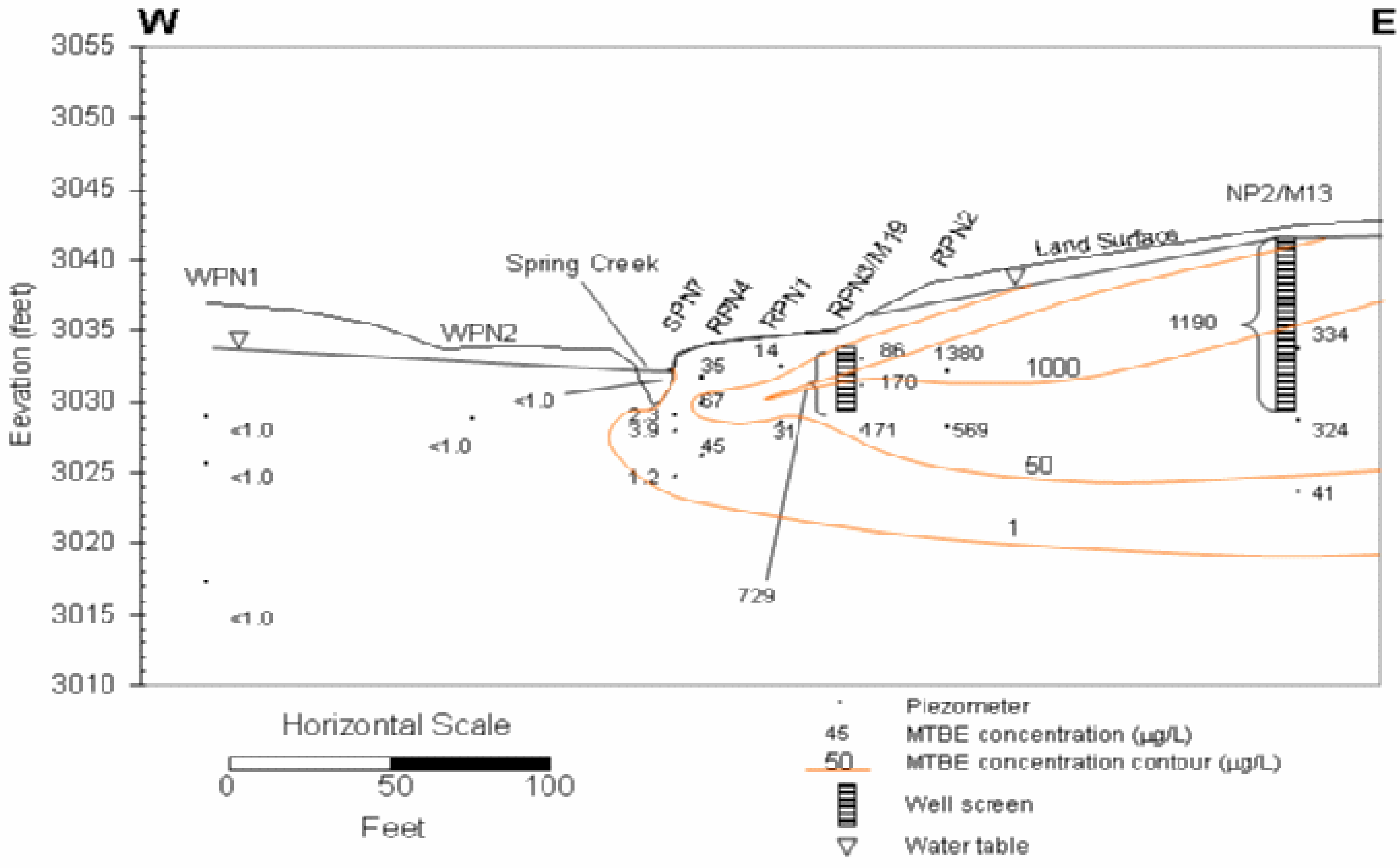


Figure 28. Groundwater gradients as shown by Loustaunau (2003).

modeled hydraulic conductivities, very little change was seen in the calibration of the water table elevation; however the vertical movement of water was slightly affected. The greatest distinction noticed was a lower residual error at well MP-03 (two head elevations were simulated reflecting the 10 ft and the 57 ft depth).

As mentioned previously, the ground water discharge through this aquifer and leakage to the river where also used as calibration targets. Generally, this modeled water budget was lowerthan the budget estimated from the field data.

Once the model was calibrated, particle tracking was applied to grossly evaluate ground water directions and velocities. Porosity values of 10-20% were used to represent fine grained glacial deposits and 35-50% for silt (Fetter 2001). The results of particle tracking showed the modeled ground water flow directions were similar to map directions; however, the velocity of particles significantly under predicted the site location of the center of mass of the MTBE plume. The velocity computed from the calibrated aquifer parameters showed particles moving 100 ft from the source in 10 years, a distance that does not correlate with the current plume position. The ground water velocity computed for the temperature analysis suggest the calibrated aquifer parameters are significantly under estimated, suggesting the heat plume migrated at a rate of 0.16 ft/d (assuming v=0.3ft/day)

In an attempt to examine the possibility that fracturing or some other mechanism affecting the site fine grained sediments would increase transport rates, the porosity was lowered incrementally to identify a value that more appropriately represented the observed center of mass movement over a ten year period. The effective porosity required to match the location of the 2004 center of plume mass in the upper high-permeability sediments (layer 1) was 0.0034. This would suggest either field and laboratory calculated hydraulic properties are higher than measured or estimated (up to 2 orders of magnitude) or a process allowing preferential rapid transport of contaminants is operating. One other possible explanation is that the source history is incorrect.

4.0 Discussion

4.1 Geologic Controls

While minor discrepancies between the identified SBT and the measured sediment grain size existed, the two generally compared very closely. Dominate lithologies of identifiable units were comparable in both interpretations. This indicated the CPT appropriately represented geologic conditions. An attempt was made to obtain a more complete core from deeper portions of the sediments; however, after repeated equipment malfunctions only one four-foot interval core was taken at a depth greater than 30 ft. The data from this core compared very well to the interpreted SBT. Hydrogeologic properties analyses were not preformed on these samples as the core was disturbed upon retrieval.

Comparison of historical well log data with SBT fence diagrams revealed several important aspects that were undetected in the original sampling and interpretations. Nearer the source zone just west of the fence line separating Highway 93 from the field, lenses of coarse sand are present which may enhance plume transport (Figure 9). In addition, below a silt and clay sequence a second sand and silt section is clearly present that may have similar properties to the overlying shallow water-bearing unit. Given the complex interfingering of sediments with high and low conductivity zones windows in the finer units may exist that would allow vertical movement of contaminated ground water under appropriate gradients.

The presence of fine and course sediments may indicate lacustrine deposits; however, the presence of sand and clay lenses may indicate a fluvial depositional environment formed the observed sediment. The lack of exposed outcroppings between the study site and the nearby Mission mountains makes it difficult to determine with any accuracy the nature of the depositional environment, although the presence of asymmetrical ripple marks in the core samples suggests shallow, possibly flowing water. The sediments may have been deposited by a post Lake Missoula tributary to the Lower Flathead River (Edwards, 2006, Hofmann, 2005).

If the contamination is indeed passing though the shallow clay underlying the near surface coarse grained unit, the second coarse grained unit may also have become impacted by the dissolved phase contamination possibly allowing contamination to enter deeper parts of the local ground water system. The east-west profile indicates a fairly uniform thickness in the upper coarse grained unit; however, the lower coarse grained unit is mapped as only present to the east. The unit appears to pinch out before reaching the center transect, although it may occur beneath the lower deposits of clays. If the clay is pinching out to the east then it is possible the lower coarser grained sediment package is present to the west.

The question of contamination within or below the lower clay unit has been highly debated as water samples from wells MP-01, MP-02, and MP-03 show impacted water to a depth of 72, 62, and 57 ft, respectively (HKM 2003, HKM 2004, HKM 2006). The three impacted wells are all finished at depths below the silt and sand unit. These three wells are all located along the plume axis and were previously used to quantify the depth of contamination. However, these three wells were installed using polyethylene casing that was shown by Loustanau (2003) to be permeable to hydrocarbons. The wells are designed to sample ground water at multiple depths; constructed of six radial septa running longitudinally through the casing. It has been suggested that hydrocarbon concentrations found in the deeper sampling ports in these wells are unreliable (Loustaunau 2003).

Given the low permeability of the lower sediments and the small vertical hydraulic gradients it seems unlikely that MTBE would be migrating to the depths indicated by water quality results. Jacobs (1999) indicates one of the greatest sources for deep MTBE contamination in zones of low hydraulic conductivity or beneath confined units is a man-made pathway. The permeability of the MP well casing material to hydrocarbons may have allowed MTBE from a shallow source to pass into the well causing water in the deep sampling ports resulting in a false positive test for MTBE. However, this issue remains unresolved.

4.2 Geologic Controls on Plume movement

Plume migration and movement is controlled by the predominant ground water east to west flow. Vertical migration appears to be controlled by the properties and spatial distribution of the upper and lower low clay units. Historical data collected by HKM since discovery of the plume has shown a predominantly shallow, narrow plume traveling at a rate seemingly faster than hydrogeologic conditions would allow. Wells installed outside of the plume area as part of this project and the intense probing of the plume region further support the previously interpreted position of the MTBE plume at the site. Initial monitoring of newly established wells showed high concentration of hydrocarbons including MTBE. Free product was sampled near the source area and a dissolve plume extended towards Spring Creek.

The results of CPT data and corresponding hydraulic conductivity testing indicate contaminate pathways may be greatly influenced by a complex site stratigraphy. The aquifer system is considerably more heterogeneous that was previously believed, and therefore the controls on water movement appear more complicated. Possibly inter-connected lenses of high hydraulic conductivity material may allow for the rapid migration of MTBE in some portions of the site.

Hydrocarbon contamination suggested by the MIP was greatest near the source, close to Highway 93. It is in this area that the higher conductivity sediments also exist in identifiable beds, occasionally as thick as several feet. The vertical conductivity of these sediments was measured at 68 ft/day and the horizontal conductivity 1190 ft/day.

The finer sediments found to be underlying the upper conductive zone showed an average vertical conductivity of 0.35 ft/day and a horizontal conductivity of 0.007 ft/day in the sandy silt unit. While it is improbable that the vertical conductivity exceeds the horizontal conductivity, this number was field measured in the area of interest and therefore describes the low conductivity sediments. The silt unit was not sampled and therefore no vertical conductivity data are available, however, the horizontal conductivity was estimated from field analysis to be about 0.69 ft/day. These values fall nearly within the expected range of 8.5-850 ft/d (Fetter, 2001).

The presence of hydrocarbons in the lower portion of the site sediments would suggest that either the finer sediments are discontinuous above the lower coarse grained unit or the clay sediments pinch out to the east nearer the source. Without further information regarding the stratigraphy to the east, it cannot be conclusively stated that the silt beds pinch out. For that reason it must be concluded that in this area the sediments do not confine the entire upper water bearing units, but instead form a unit that allows for flow of ground water from the upper unit into the lower units. Sediments farther west, described in the center and west transects, indicate a much greater clay content is present in this underlying unit. To the west a very clay rich unit defined by the CPT as 'sensitive fines' is found below the low conductivity unit where the second silty sand ground water unit exists to the east. The conductivity of this unit is significantly lower, described as 0.00017 ft/day. This unit is far more likely to act as a confining unit extending to the west.

Graphical analysis of historical ground water contaminant concentrations indicate total purgable hydrocarbon (TPH) concentrations were initially measured in the tens of thousands µg/L near the source until levels began decreasing in 2001. It was around this same time frame that concentrations began to spike at the tens of thousands µg/L in the center transect of the monitoring network (600 ft from the source area). Until this time, measurable concentrations at the center transect were in the thousands, suggesting the bulk of the dissolved contamination had not reach this point. TPH concentrations are indicative of the properties of a gasoline spill and have been used to track the migration of a plume (as MTBE concentrations are fewer in number). MTBE concentrations spiked on multiple occasions at the center transect beginning in 1996 with the last recorded spike occurring in 2004. On both occasions, MTBE levels exceeded 7,000μg/L. The finely bedded highly conductive units and longitudinal dilution are likely to be responsible for the lower levels of dissolved phase contamination preceding the arrival of higher MTBE center of mass concentrations. Graphs of MTBE, TPH, and BTEX levels over time are included in Appendix C.

The bulk of the contamination reached the center transect monitoring wells located 600 ft from the source in 2003. This indicates that the majority of the dissolved phase contamination, traveling with the ground water, required approximately nine years to travel 600 ft. At this rate, the plume is moving an average of 0.23 ft/day. This rate falls within the measured velocity of the upper aquifer, which has been calculated as between 0.99 ft/day and 0.004 ft/day. These values were calculated using the average horizontal hydraulic conductivity values measured in the field, gradient information obtained by HKM (2003), and the modeled porosity value of 34%. This rate is in the same range as the heat determined velocity (0.3 ft/d) and estimated hydraulic conductivity.

4.3 Plume Delineation

The MIP tool proved to be a much coarser tool for the identification of the presence of hydrocarbons than was expected. It provided minimal insight into the vertical extent of the plume. Locations within the east CPT/MIP transect indicated contamination at depths below 35 ft both above and below the low permeability sediments. If these interpretations are accurate, the heterogeneity of these sediments may provide pathways for contamination to reach multiple depths. MTBE may pass beneath low permeable lenses and enter more conductive silty sand/sand units. Contamination was found at shallower depths within the center transect which agrees with the historic data provided by HKM (2003, 2004, 2006).

The lateral extent of the plume was more clearly defined by the MIP. The lateral extent of the plume at the east and center transects suggests the plume may be slightly narrower than has been previously represented (HKM 2003, 2004, 2006). The west transect indicated contamination in two locations, CPT-25 and CPT-04. These points lie within the main axis of the plume; therefore contamination was expected to be higher than anywhere else along the west transect. It appears the bulk maximum contamination has not yet reached this area which may account for the absence of hydrocarbons within the MIP measurable range elsewhere along the west transect.

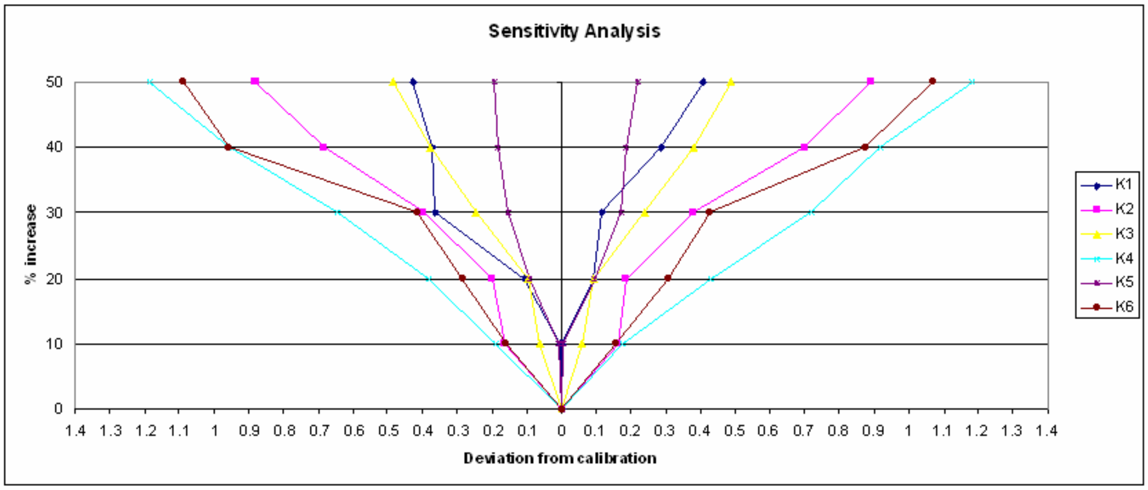
4.4 Modeled Contamination

Simulation of the flow at the Ronan MTBE site was calibrated to 14 wells and 15 head elevations (including one nested well). The head at the well location west of the creek, WSPN-1, was poorly calibrated suggesting the hydrogeologic framework in the vicinity of the creek is more complex than modeled. The simulated steady state ground water flow to the creek was similar to that presented by Loustaunau (2003).

The calibrated model supported water table elevations and gradients observed at the site (HKM 2004). Simulated upward gradients matched those evidenced at the CMT wells, and discharge into the river was similar to that found by Loustaunau (2003). Comparison to the calculated ground water budget, however, showed the modeled ground water flux to be lower than expected. The error in the estimated field determined values may account for part of the discrepancy.

<table>
<tr><th colspan="6">Q_{in}</th></tr>
<tr><td></td><td>10%</td><td>20%</td><td>30%</td><td>40%</td><td>50%</td></tr>
<tr><td>K_h +</td><td>611</td><td>667</td><td>723</td><td>778</td><td>834</td></tr>
<tr><td>K_h -</td><td>500</td><td>445</td><td>389</td><td>333</td><td>278</td></tr>
<tr><th colspan="6">Q_{out}</th></tr>
<tr><td></td><td>10%</td><td>20%</td><td>30%</td><td>40%</td><td>50%</td></tr>
<tr><td>K_h +</td><td>499</td><td>544</td><td>589</td><td>635</td><td>680</td></tr>
<tr><td>K_h -</td><td>408</td><td>363</td><td>317</td><td>272</td><td>227</td></tr>
</table>

Table 5. Error in discharge shown by the incremental increase and decrease of hydraulic conductivity by 10%.



Mean Absolute Error					
	- 50%	- 40%	- 30%	- 20%	- 10%
K1	1.5	1.5	1.5	1.2	1.1
K2	2.0	1.8	1.5	1.3	1.3
K3	1.6	1.5	1.4	1.2	1.2
K4	2.3	2.1	1.8	1.5	1.3
K5	1.3	1.3	1.3	1.2	1.1
K6	2.2	2.1	1.5	1.4	1.3

Table 6. Sensitivity analysis results for hydraulic conductivity. Hydraulic conductivities were incrementally increased and decreased by 10%, chart shows deviation from calibration and table indicates calibration results in absolute residual mean.

To determine a level of uncertainty in the modeled discharge estimated hydraulic conductivity, values were adjusted both positively and negatively by 10% up to a 50%. Uncertainty in the estimated hydraulic conductivity could account for ground water discharge ranging between 280ft^3/d and 830ft^3/d for ground water input. Ground water output could range between 230ft^3/d to 680ft^3/d depending on the uncertainty in the hydraulic conductivity (Table 5).

In order to determine the sensitivity of the calibration to model fitted hydraulic conductivity values, a sensitivity analysis was performed. Hydraulic conductivity zones were incrementally increased by 10% up to 50%, than decreased by 10% to 50%. The head calibration was fairly insensitive to variation in hydraulic conductivity (Table 6).

The computed model ground water velocity of the ground water, a component governed by the hydraulic conductivity, was called into question when particle tracking was performed using the calibrated model, resulting particle locations under predicted the observed center of mass of the MTBE plume. To investigate possible controls on the site ground water velocities, the hydraulic conductivities were increased to the maximum values reported for the site sediments. While the greater horizontal hydraulic conductivities resulted in an increase in ground water velocity, the absolute mean head error increased to as much as 10 ft. A further evaluation found that when the values were raised so that particles were located in about the correct position (based on the plume history) values were several orders of magnitude higher than horizontal hydraulic conductivities reported from field investigation. These values fell within the range of very coarse sand and gravel rather than silty sand or sand (Fetter 2001), materials not present at this site.

Particles were also placed in layer two, which simulated the low hydraulic conductivity silts. The upward gradients from this unit into the overlying higher permeability unit forced the particle track upward and into the overlying unit, suggesting that if the gasoline plume was sourced in this area would be transported upward into a portion of the aquifer containing the bulk of the contamination.

Although it is unlikely that MTBE reached a significant depth, particles were also placed in the third layer which modeled the silty sand/sand to the east and the clay and ‘sensitive fines’ dominated sediments to the west. Particles placed in this layer traveled within this unit west until the high conductivity sediments pinched out and became dominated by low permeability sediments. At this point they began to migrate upward to the overlying high permeability sediments at very slow rate (Figure 28).

The calibrated model appeared not to reproduce the ground water velocities necessary to explain the observed plume location. A new conceptual model was developed. Possibly the sediments are fractured and the rate of ground water flow is controlled by the fracture network. It has been well documented that fracture networks can create elevated ground water velocities (Helmke 2005, Ogili-Eger 2005, Davies 1991). Helmke (2005) reports effective porosities in a fractured till as low as 3.4%. For this reason the modeled porosity was adjusted as the second major control on ground water velocity in order to determine if a fracture network could be dominating ground water flow. Porosities were incrementally decreased within the first layer to attempt to match particle movement with observed plume positions. The porosity resulted in particles reaching the center transect after 3350 days was 0.0034. This porosity is extremely low for the sediments described, suggesting the possibility of fractures through which the contamination may be flowing. Unfortunately the more granular sediments are less likely to allow fractures to persist, thus, it is possible no fractures are present. Another possible explanation for the miss match of computed site ground water velocities and plume locations may be that the 1994 release (HKM 1996) is incorrect.

Future remediation efforts at this site tentatively include a second heating event conducted nearer to the source of the contamination where the highest concentrations of MTBE still exist. Should this occur, a comprehensive temperature monitoring network extending beneath Highway 93 and into the alfalfa field, monitored over a 2-3 year time span, would likely provide additional insight as to field based ground water velocity values.

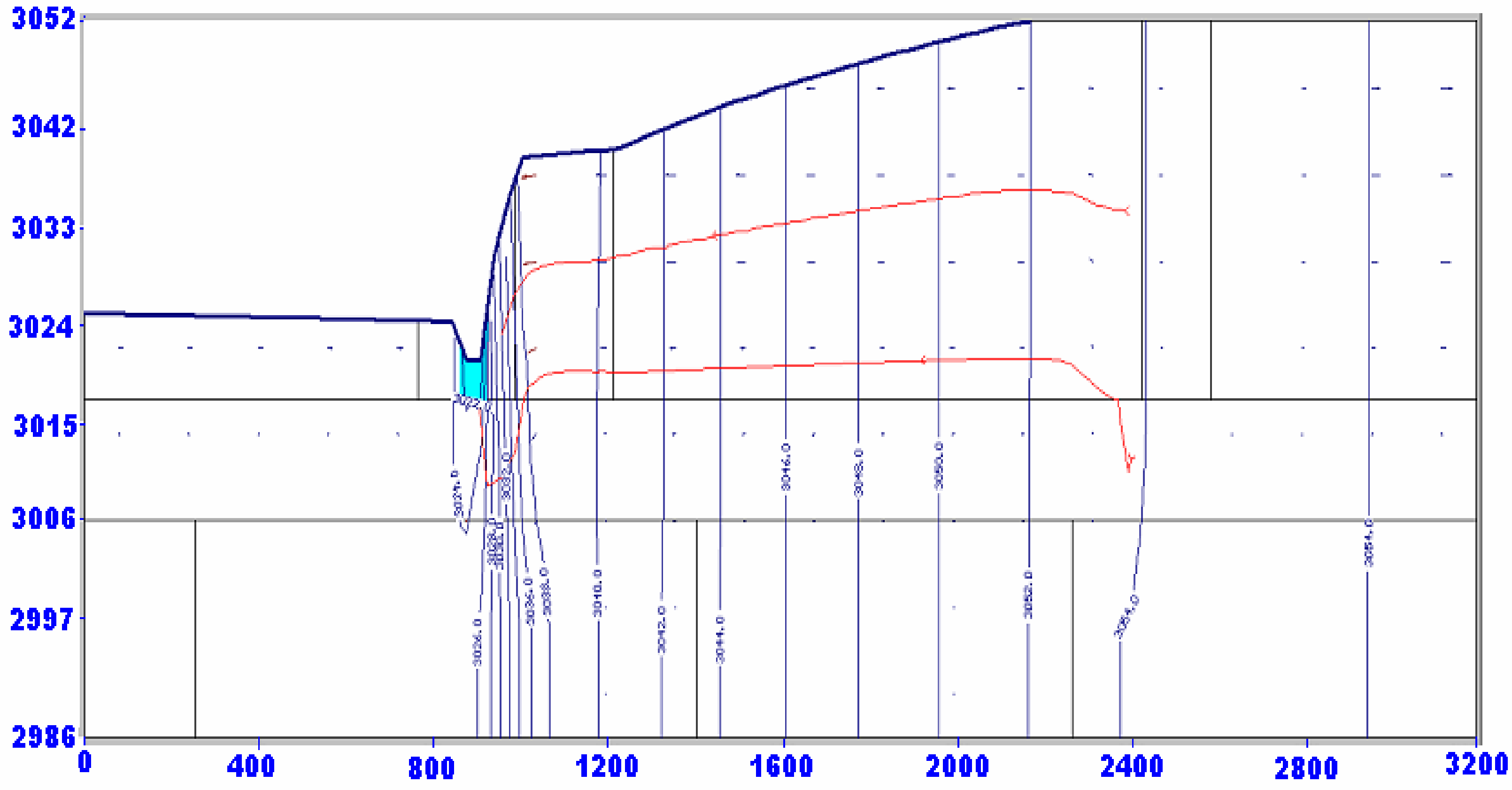


Figure 29. Cross section of plume axis showing particle movement through the upper two layers of sediment, modeled to represent the silty sand/sand sediments and the lower permeability silt unit. Particle tracks are shown in red. All units are in feet.

5.0 Conclusions

The lithology of the Ronan MTBE site is significantly more heterogeneous than previously believed, and the mapped plume movement is likely controlled by the site lithology. The CPT analysis provided a comprehensive analysis of the sediments to depths beyond the reach of traditional coring techniques. Comparisons of the CPT to shallow cored sediments indicated the CPT provided a reasonable analysis of the site lithology. The sediments found within the site are very similar to the regional sediments described as part of the glacial Lake Missoula depositional environment. The complex distribution of coarse and fine grained sediments may reflect a depositional environment more fluvially dominated than a lacustrine setting. Ground water flow outside of the contaminated zone shows a similar flow pattern governed by the regional hydraulics of the Mission Valley ground water flow system. Field and laboratory observed hydraulic conductivities closely matched the simulated ground water movement predicted by the temperature model.

Ground water flow was replicated in a 3-D steady state numerical model using field and laboratory hydraulic conductivity results. However, the modeled movement of the plume suggested ground water may be moving at a greater velocity than would be projected from average site conditions. This work suggests either sediment properties are significantly impacted by a highly conductive fracture network or the source history is poorly understood and MTBE releases occurred much earlier than believed. Although there is no evidence for fractured flow within this aquifer, the computed porosity needed to achieve observed plume locations was shown to be below the typical range for these sediments.

6.0 References:

Agency For Toxic Substances and Diseases Registry (ATSDR) 1996 http://www.atsdr.cdc.gov/toxprofiles/phs91.html

Anderson, M.P. 2005. Heat as a ground water tracer. Ground Water 43(6) p. 951-968

Anderson, M.P, Woessner, W.W. 1992. *Applied Ground water Modeling; simulation of flow and advective transport.* Academic Press, San Diego, California

Anthony, J.W., Henry, B.M., Wiedemeier T.H., Gordon, E.K., Bidgood, J.B. 1999. Methodology to evaluate natural attenuation of methyl tertiary-butyl ether. International In Situ and On-site Bioremediation Symposium. P121-133.

Bay, L. 2005. MTBE and Potential Production of TBA. USGS Toxic Substances Hydrology Program http://toxics.usgs.gov/sites/laurel_bay/MTBE_TBA.html

Bradley, P.M., Landmeyer, J.E., Chapelle, F.H. 1999. TBA Aerobic mineralization of MTBE and tert-butyl alcohol by stream-bed sediment midroorganisms. Environmental Science and Technology (33)11 p. 1877-1879

Bradley, P.M., Landmeyer, J.E., Chapelle, F.H. 2001. Widespread potential for microbial MTBE degradation in surface-water sediments. Environmental Science and Technology (35)4 p. 658-662

Bradley, P.M., Landmeyer, J.E., Chapelle, F.H. 2002. TBA Biodegradation in surface water sediments under aerobic and anaerobic conditions. Environmental Science and Technology (36)19 p. 4087-4090

Bradley, P.M., Landmeyer, J.E. 2006. Low-Temperature MTBE biodegradation in aquifer sediments with a history of low, seasonal ground water temperatures Ground water Monitoring and Remediation (26) 1 p. 101-105

Chen., K.F., Kao, C.M., Chen, T.Y., Weng, C.H., Tsai, C.T. 2006. Intrinsic bioremediation of MTBE-contaminated ground water at a petroleum-hydrocarbon spill site. Environmental Geology. (50) p. 439-445

Conant, B. 2000. Ground-water plume behavior near the ground-water/surface water interface of a river. Proceedings of the Ground-Water/Surface-water Interactions Workshop. U.S.EPA Office of Solid Waste and Emergency Response, Washington D.C. p23-30

Constantz, J., Tyler, S.W., Kwicklis, E. 2003. Temperature-profile methods for estimating percolation rates in arid environments. Vadose Zone Journal. 2 p. 12-24

Cozzarelli, L.M., Herman, J.S., Baedecker, M.J., Fischer, J.M. 1999. Geochemical heterogeneity of a gasoline-contaminated aquifer. Journal of Contaminant Hydrology. (40) p. 261-284

Davies, P.B., Hunter, R.L, Pickens, J.F. 1991. *Complexity in the validation of ground-water travel time in fractured flow and transport systems*. Stockholm, Sweden.

Deeb, R.A., Scow, K.M., Alvarez-Cohen, L. 2000. Aerobic MTBE biodegradation: an examination of past studies, current challenges and future research directions. Biodegradation 11 p. 171-186

Douglas, B.J, Olsen, R.S. 1999 Soil classification using electric cone penetrometer. Symposium on Cone Penetration Testing and Experience, Geotechnical Engineering Division, ASCE, St. Loius, p. 209-227

Edwards, J. 2006. Evidence for Glacial Outburst Floods along the Lower Flathead River: Results from Geologic Mapping, Geomorphologic Analysis and a Gravity Survey near Polson, Montana. M.S. Thesis, University of Montana.

Fetter, C. W. 2001. *Applied Hydrogeology*, Fourth Edition. Prentice Hall, Inc. Upper Saddle River, New Jersey.

Fiorenza, S., Rifai, H.S. 2003. Review of MTBE Biodegradation and Bioremediation. Bioremediation Journal (7)1 p. 1-35

Finneran, K.T., Lovley, D.R. 2001. Anaerobic Degradation of Methyl-tert-Butyl Ether (MTBE) and tert-Butyl Alcohol (TBA). Environmental Science and Technology (35)9 p. 1785-1790

Flathead Valley Visitor Information 2007 http://www.gonorthwest.com/Montana/northwest/Flathead/flathead_vis.htm

Geoprobe 2002. Geoprobe Pneumatic Slug Test Kit Standard Operating Procedure. Technical Bulletin No. 19344

Healy, R.W., and A.D. Ronan, 1996. Documentation of computer program VS2DH for simulation of energy transport in variably saturated porous media, U.S. Geological Survey Water Resour. Invest. Rep. 96-4230, 36pp.

Helmke, M.F., Simpkins, W.W., Horton, R. 2005. Simulating conservative tracers in a fractured till under realistic timescales. Ground Water 43(6)

Herrick, D. 2000. MTBE What is it? Why the concern? Water Well Journal. p. 33-35

HKM. 2003. 2003 Monitoring and Status Report for George's Conoco LUST Trust Site. Ronan, Montana. December

HKM. 2003. Site Maps and Well Logs. December.

HKM. 2004. 2004 Ground water and soil vapor extraction and air sparging system monitoring report George's Conoco – Ronan, Montana. December.

HKM. 2006. 2005 Monitoring Report George's Conoco Ronan, Montana. January.

Hofmann, M. 2005. Using sediments to infer the geologic history of northwestern Montana during and after the last glacial maximum, the record from Flathead Lake. Ph.D. Thesis, University of Montana.

Hong, M.S., Farmayan, W.F., Dortch I.J., Chiang, C.Y., McMillan, S.K., Schnoor, J.L. 2001. Phytoremediation of MTBE from a ground water plume. Environmental Science and Technology. (35)6 p. 1231-1239

Hurt, K.L. et al.1999. Anaerobic biodegradation of MTBE in a contaminated aquifer. Petroleum Hydrocarbons and MTBE p.103-108

Hvorslev, M.J. 1951. Time lag and soil permeability in ground water observations. U.S. Army Corps of Engineers Waterway Experimentation Station, Bulletin 36

Jacobs, J., Guertin, J., Herron, C. 2000. *MTBE: Effects on soil and ground water resources*. Lewis Publishers, Boca Raton, Florida.

Johnson, A.N., Boer, B.R. Woessner, W.W., Stanford, J.A., Poole, G.C., Thomas, S.A., O'Daniel, S.J. 2005. Evaluation of an inexpensive small diameter temperature logger for documenting ground water-river interactions. Ground Water Monitoring and Remediation 25(4) p. 68-74

Kern, E.A., Veeh, R.H., Langner, H.W., Macur, R.E., Cunningham, A.B. 2002. Characterization of methyl tert-butyl ether- degrading bacteria from a gasoline-contaminated aquifer. Bioremediation Journal (6)2 p. 113-124

Kolhatkar, R., Wilson, J., Dunlap, L.E. 2000. Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground water: Prevention, Detection, and Remediation Conference; special focus. p. 32-49

Land, L.A., Paull, C.K. 2001. Thermal gradients as a tool for estimating ground water advective rates in a coastal estuary: White Oak River, North Carolina, USA. Journal of Hydrology. 248 p. 198-215

Landmeyer, J.E., Chapelle, F.H., Herlong, H.H., Bradley, P.M. 2001 Methyl tert-butyl ether biodegradation by indigenous aquifer microorganisms under natural and artificial oxic conditions. Environmental Science and Technology. (35)6 p. 1118-1126

Leal-Bautista, R.M., Lensczewski, M.E. 2006. Sorption of methyl tert-butyl ether and benzene in fine-grained materials from northern Illinois and Chalco Basin, Mexico. The American Association of Petroleum Geologists. (13) 1 p. 31-41

Levish, D.R. 1997. Late Pleistocene sedimentation in glacial Lake Missoula and revised glacial history of the Flathead lobe of the Cordilleran ice sheet, Mission Valley, Montana. Ph.D. Thesis, University of Colorado.

Loustaunau, P.K., Woessner, W.W., Kuhn, J.A.2003. MTBE Fate near a Ground Water-Stream Interface. Proceedings 2003 Petroleum Hydrocarbons and Organic Chemicals in Ground Water, 20th Annual Conference, National Ground Water Association, Costa Mesa, CA.

Owili-Eger, A.S.C. 2005. Dynamic fractured flow simulation model. Mining Engineering 41(2) p.110-114.

Rath, V., Wolf, A., Bücker, H.M. 2006. Joint three-dimensional inversion of coupled ground water flow and heat transfer based on automatic differentiation: sensitivity calculation, verification, and synthetic examples. Geophysical Journal International. 167 p. 453-466

Robertson, P.K. 1989 Soil classification using the cone penetration test. Canadian Geotechnical Journal, 27(1) p. 151-158 (1989)

Robertson, P.K. et.al., 1986. Use of piezometer cone data. Proceedings, *In-Situ* '86, ASCE Specialty Conference, Blacksburg, VA, 1263-1280

Rong, Y., Tong, W. 2005. Tracking Methyl tert-Butyl Ether in ground water: four years Later. 2005 Environmental Forensics (6) p. 355-360

Rosell, M. et al. 2005. Fate of gasoline oxygenates in conventional and multilevel wells of a contaminated ground water table in Düsseldorf, Germany. Environmental Toxicology and Chemistry. (24)11 p. 2785-2795

Salanitro, J.P., Johnson, P.C., Spinnler, G.E., Maner, P.M., Wisniewski, H.L., Bruce, C. 2000. Environmental Science and Technology. (34)19 p. 4152-4162

Schirmer, M., Butler, B.J., Church, C.D., Barker, J.F., Nadarajah, N. 2003. Laboratory evidence of MTBE biodegradation in Borden aquifer material. Journal of Contaminant Hydrology. (60) p. 229-249

Schmidt, T.C. 2003. Analysis of Methyl-tert-Butyl Ether (MTBE) and tert-Butyl Alcohol (TBA) in ground and surface water. Trends in Analytical Chemistry (22)10 p. 776-784

Schmidt, T.C. 2004. Microbial degradation of methyl tert-butyl ether and ter-butyl alcohol in the subsurface. Journal of Contaminant Hydrology (70) p. 173-203

Smith, L.N. 2004. Late Pleistocene stratigraphy and implications for deglaciation and subglacial processes of the Flathead Lobe of the Cordilleran Ice Sheet, Flathead Valley, Montana, USA. Sedimentary Geology (165)3/4 p. 295-333

Sperazza, M., Moore, J.N., Hendrix, M.S. 2004. High-resolution particle size analysis of naturally occurring very fine-grained sediment through laser diffractometry. Journal of Sedimentary Research. (74)5 p. 736-743

Squillace, P.J., Zogorski, J.S, Wilber, W.G., Price, C.V. 1996. Preliminary assessment of the occurrence and possible sources of MTBE in ground water in the United States, 1993-1995. Environmental Science and Technology 30(5) p. 1721-1730

Stocking, A., McDonald, S., Woll, B., Kavanaugh, M. 1999. Evaluation of fate and transport of methyl tertiary butyl ether (MTBE) in gasoline following a small spill. Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground water: Prevention, Detection, and Remediation Conference. p. 348-353

Su, G.W., Jasperse, J., Seymour, D., Constantz, J. 2004. Estimation of hydraulic conductivity in an alluvial system using temperature. Ground Water (46)6 p. 890-901

Sweeney, R.E., Mayhew, J.D., Boust, R. 1999. Dispersion/Biodegradation monitoring – method to evaluate MTBE biodegradation. Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground water: Prevention, Detection, and Remediation Conference. p. 373-385

Williams, P. and Sheehan P. J. 2003 Health affects of TBA and MTBE Underground Tank Technology Update 17(4) p.2-6

Wilson, R.D., Mackay, D.M., Scow, K.M. 2002. In situ MTBE bioremediation supported by diffusive oxygen release. Environmental Science and Technology (36)2 p. 190-199

Appendix A
CPT analysis and SBT

Parameters for estimating soil behavior type (SBT):

The cone penetration test (CPT) identifies properties of the soil as the rod is driven into the sediment. The main components are qt, the corrected cone penetration resistance, fs, the sleeve friction stress, and u, the equilibrium pore pressure. These components are applied to calculate the SBT using the following equations:

$I_c = ((3.47 - \log Q_t)^2 + (\log F_r + 1.22)^2)^{0.5}$

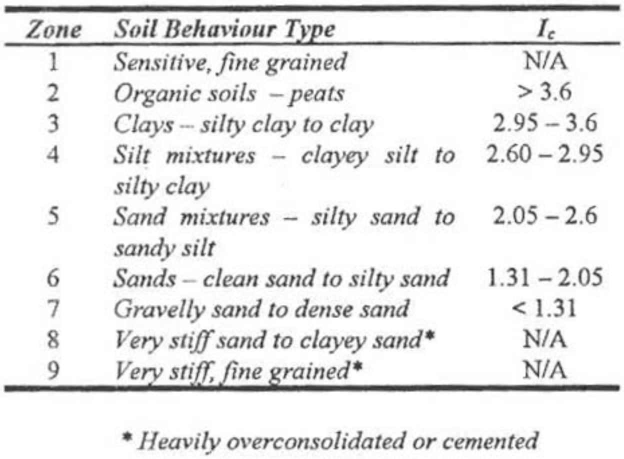
Where:

Q_t = the normalized cone penetration resistance, dimensionless
$= (q_t - \sigma_{vo})/\sigma'_{vo}$

F_r = the normalized friction ratio, in %
$= (f_s/(q_t - \sigma_{vo})) \times 100\%$

σ_{vo} is overburden stress
σ'_{vo} is effective overburden stress

The numeric value for I_c falls into one of nine zones, which determines the SBT. The figure below shows the values for I_c and the corresponding SBT.

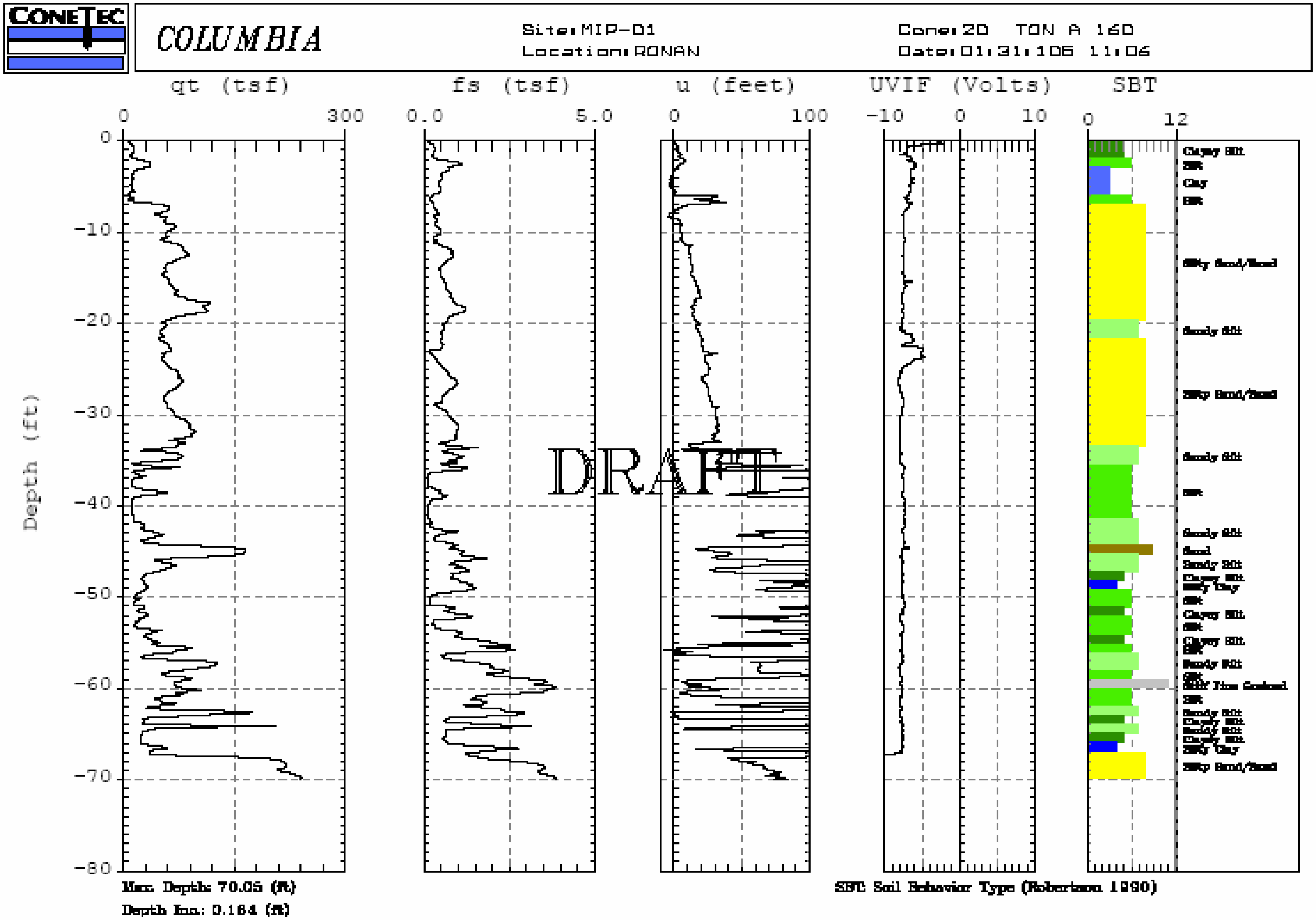


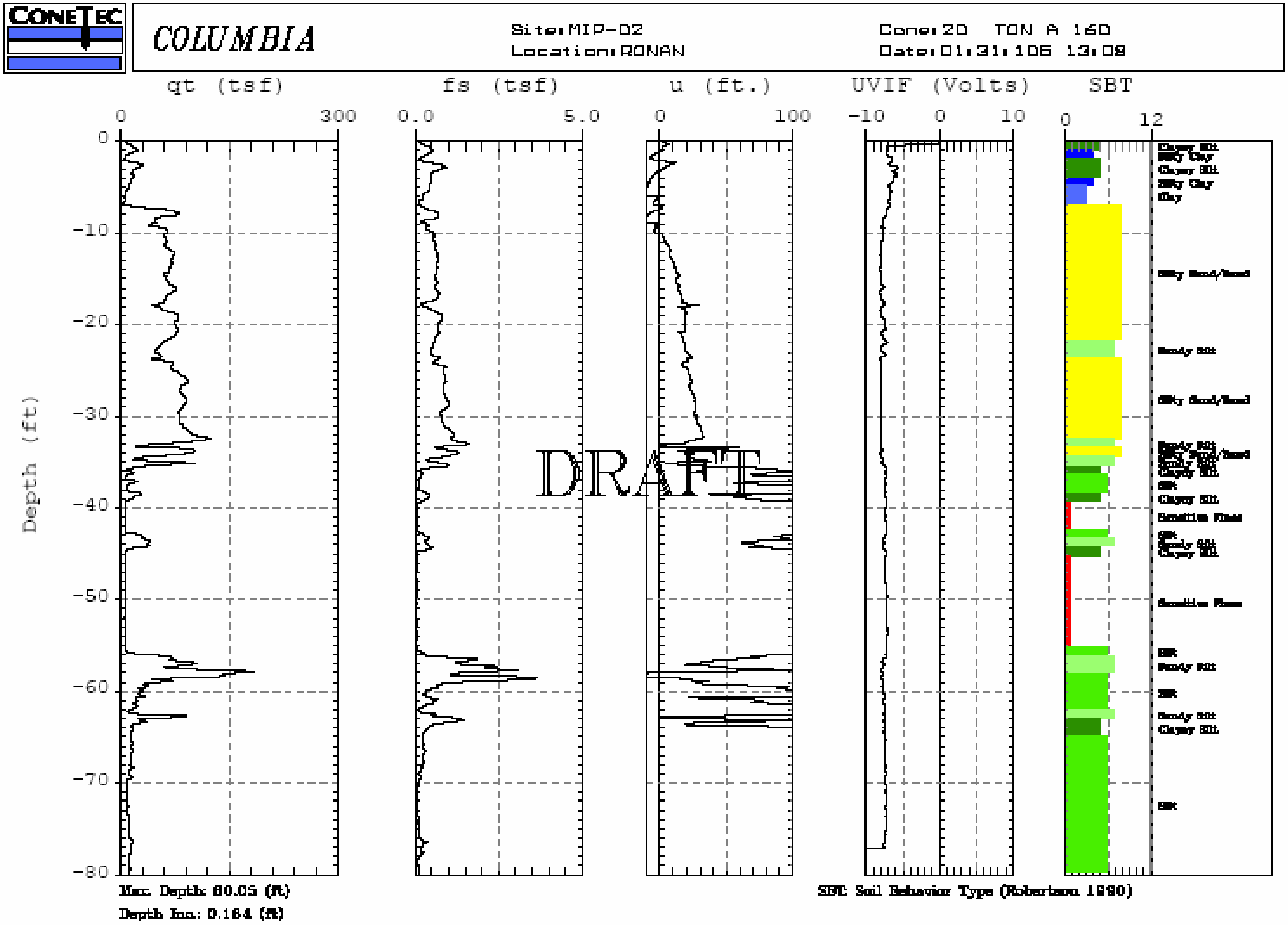
Zone	*Soil Behaviour Type*	I_c
1	*Sensitive, fine grained*	N/A
2	*Organic soils – peats*	> 3.6
3	*Clays – silty clay to clay*	2.95 – 3.6
4	*Silt mixtures – clayey silt to silty clay*	2.60 – 2.95
5	*Sand mixtures – silty sand to sandy silt*	2.05 – 2.6
6	*Sands – clean sand to silty sand*	1.31 – 2.05
7	*Gravelly sand to dense sand*	< 1.31
8	*Very stiff sand to clayey sand**	N/A
9	*Very stiff, fine grained**	N/A

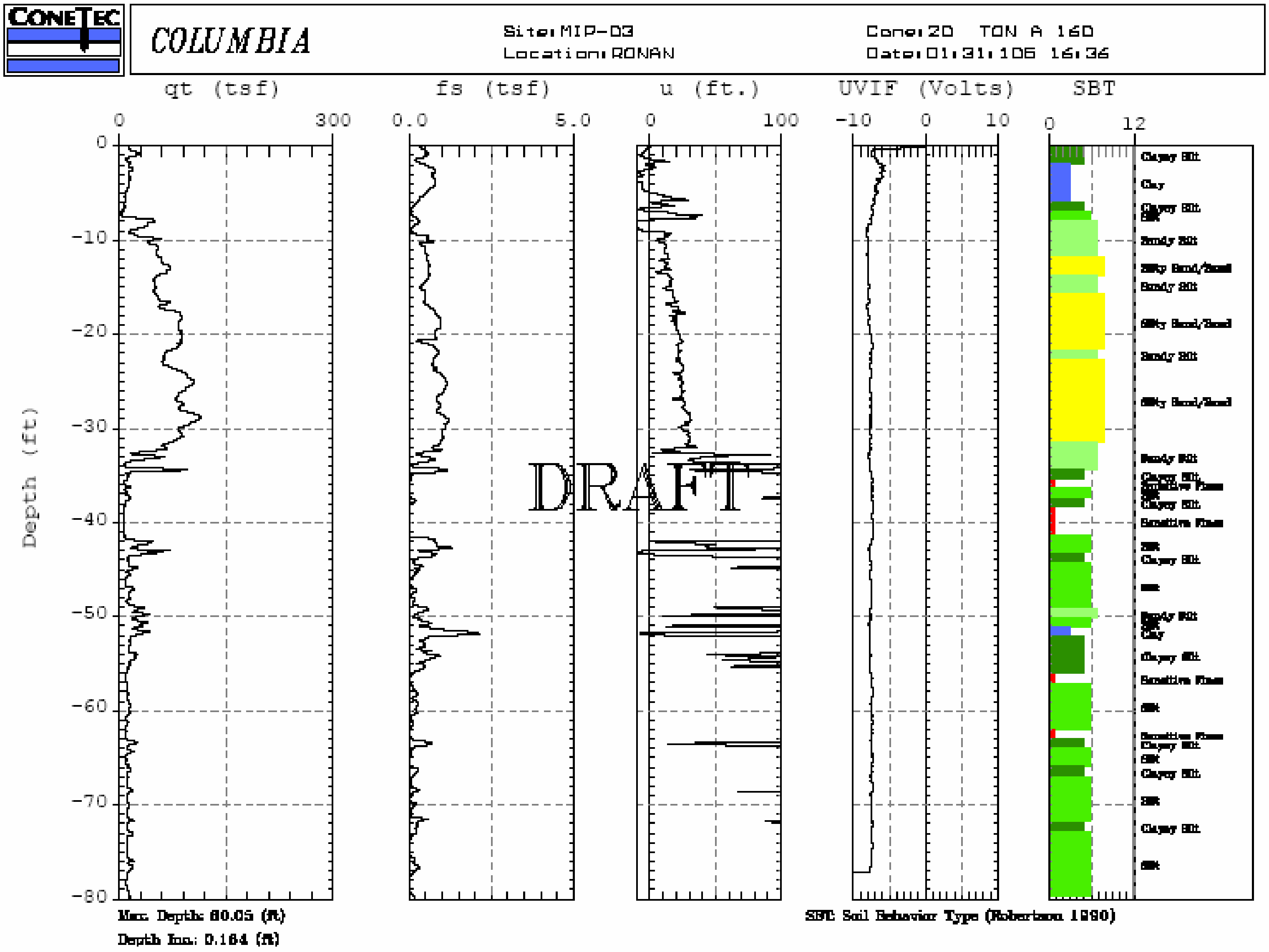
** Heavily overconsolidated or cemented*

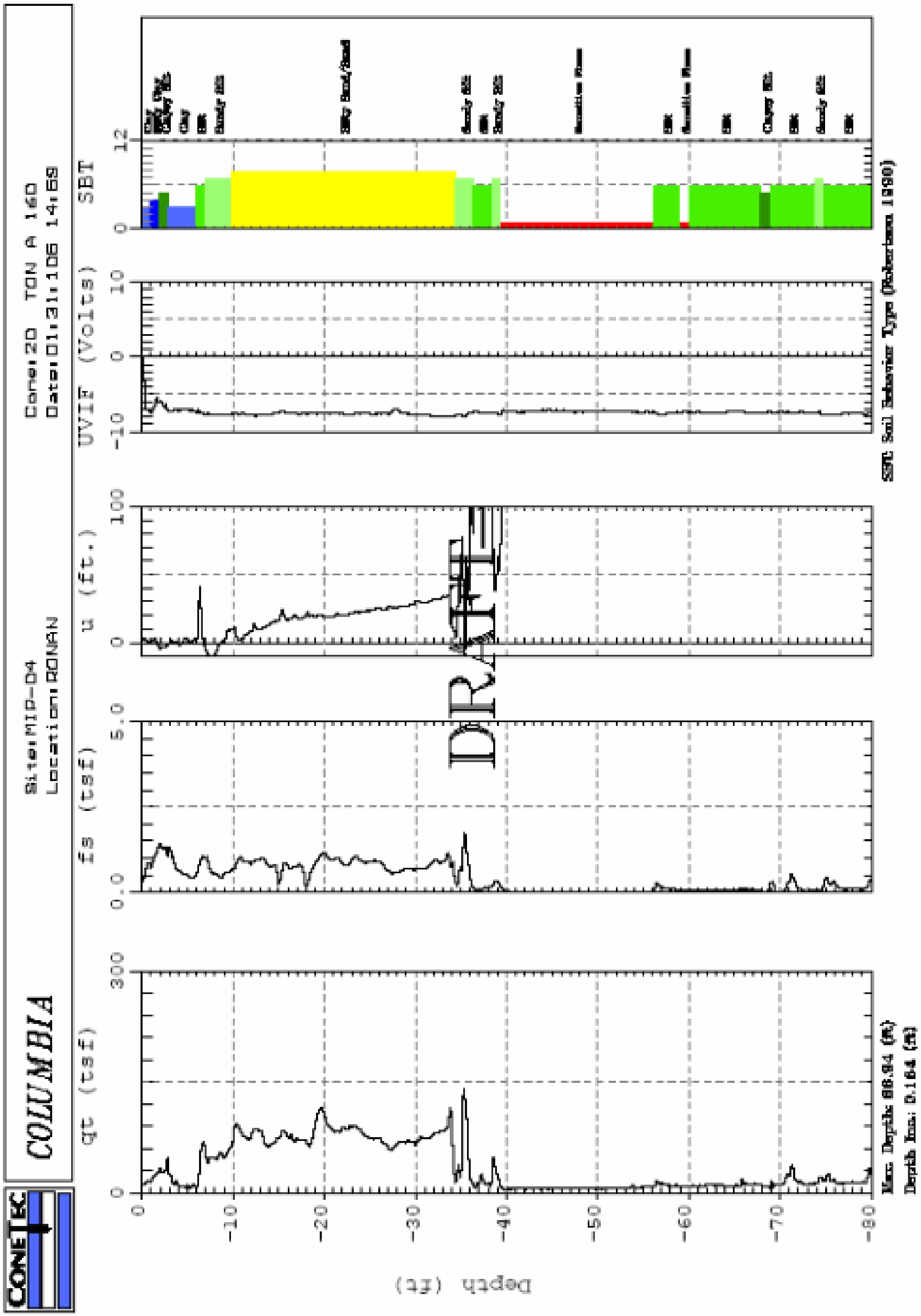
The above diagram and data was taken from *Cone Penetration Testing Geotechnical Applications Guide* (Robertson 1998).

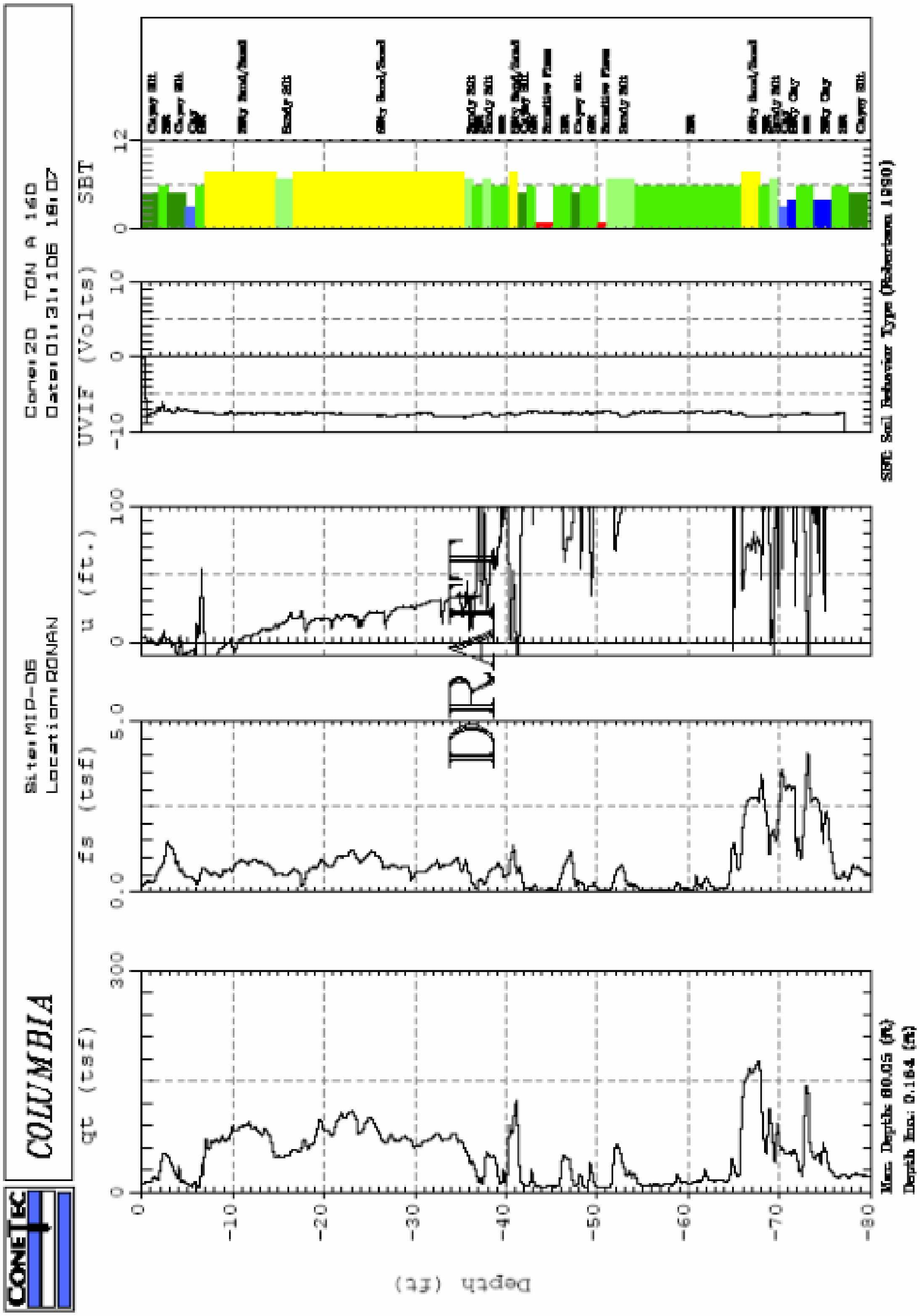
Site locations are shown in Figure 4.

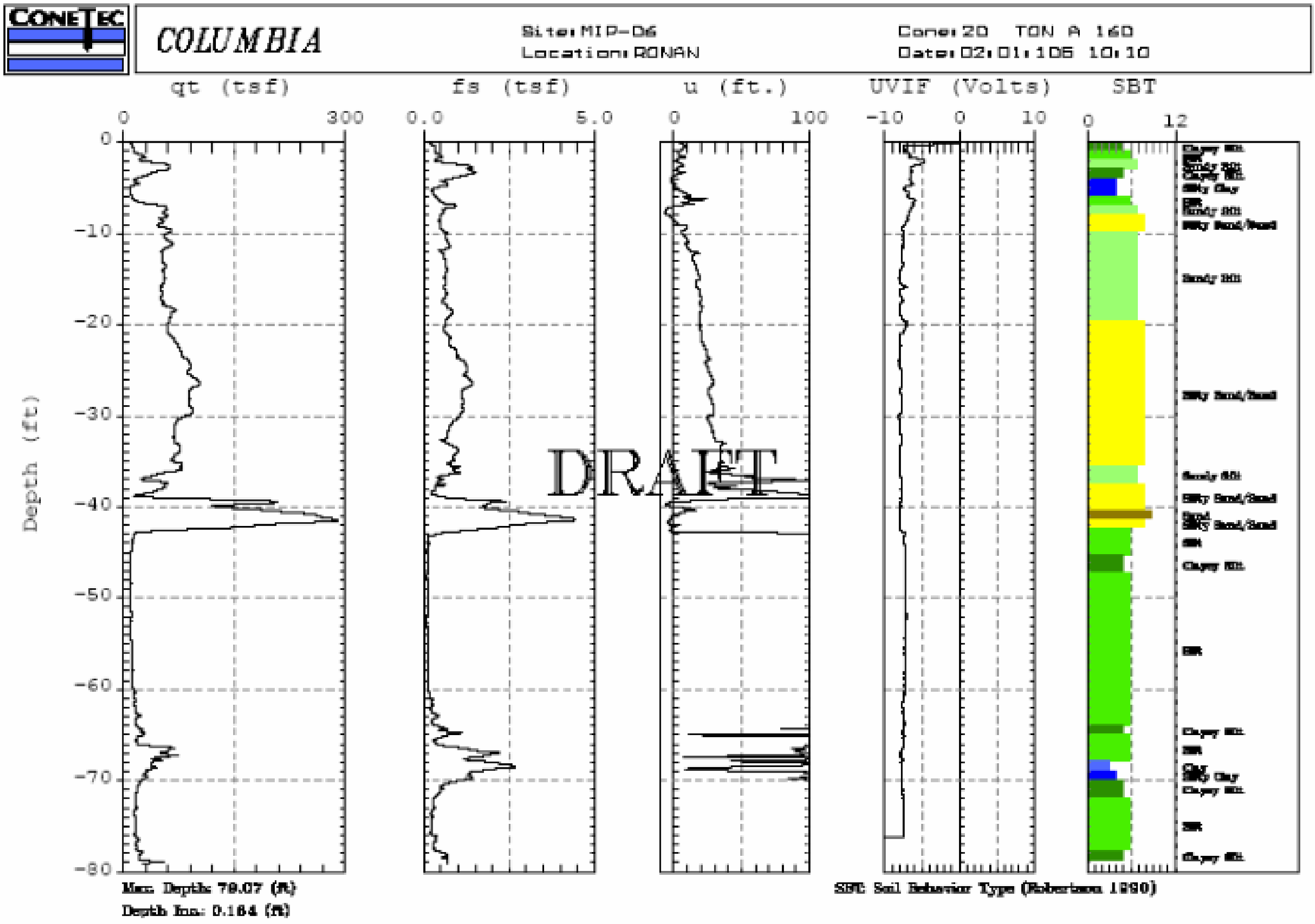

CONETEC
COLUMBIA
Site: MIP-01
Location: RONAN
Cone: 20 TON A 160
Date: 01:31:106 11:06
qt (tsf)
fs (tsf)
u (feet)
UVIF (Volts)
SBT
0
300
0.0
5.0
0
100
-10
0
10
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silt
Clay
Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Sand
Sandy Silt
Clayey Silt
Silty Clay
Silt
Clayey Silt
Silt
Clayey Silt
Silt
Sandy Silt
Silt
Stiff Fine Grained
Silt
Sandy Silt
Clayey Silt
Sandy Silt
Clayey Silt
Silty Clay
Silty Sand/Sand
Max. Depth: 70.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)


CONETEC
COLUMBIA
Site:MIP-02
Location:RONAN
Cone:2D TON A 16D
Date:01:31:106 13:08
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silty Clay
Clayey Silt
Silty Clay
Clay
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Silt
Clayey Silt
Sensitive Fines
Silt
Sandy Silt
Clayey Silt
Sensitive Fines
Silt
Sandy Silt
Silt
Sandy Silt
Clayey Silt
Silt
Max. Depth: 80.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

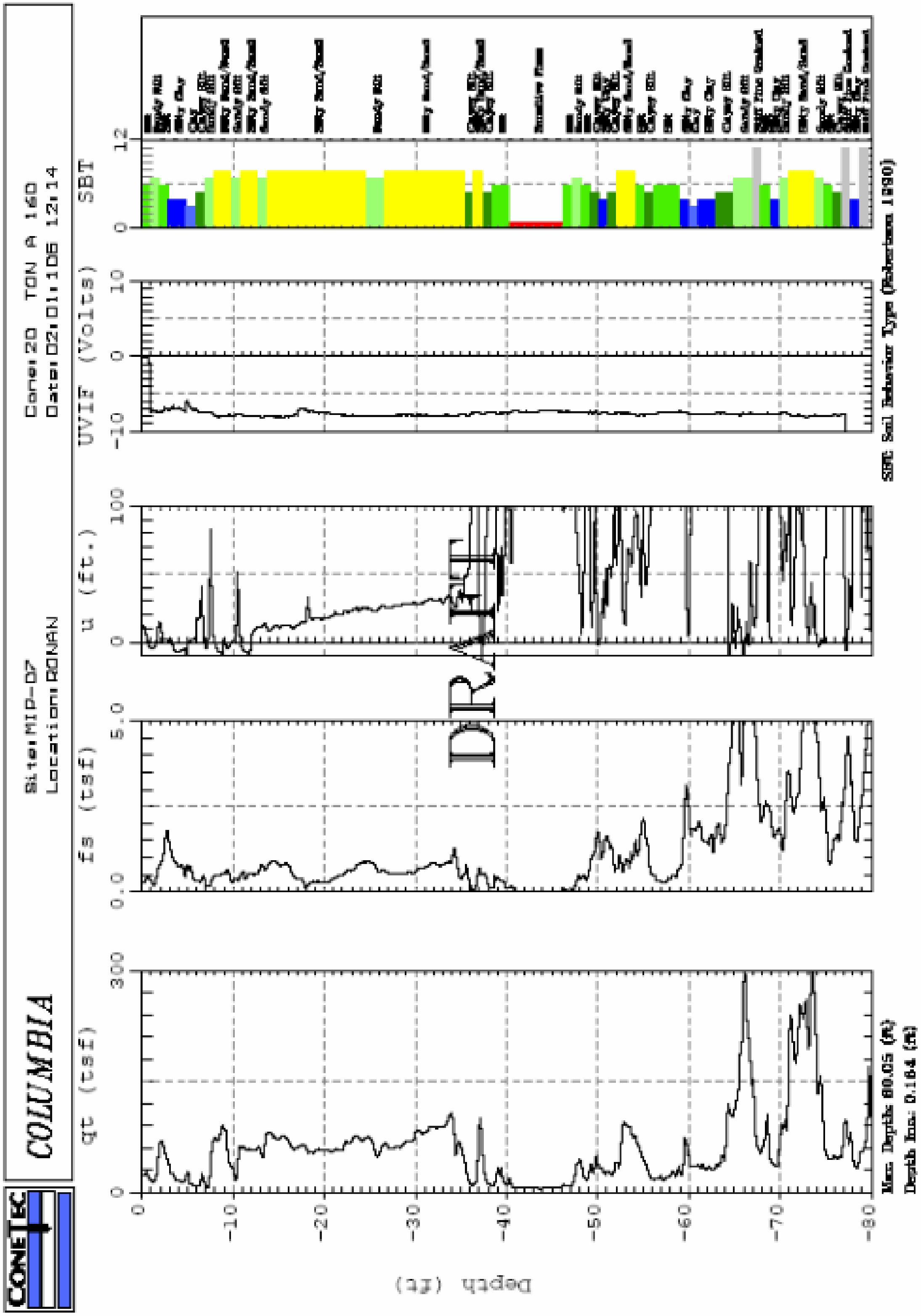

CONETEC
COLUMBIA
Site: MIP-03
Location: RONAN
Cone: 2D TON A 160
Date: 01:31:106 16:36
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Clay
Clayey Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Sensitive Fines
Silt
Clayey Silt
Sensitive Fines
Silt
Clayey Silt
Silt
Sandy Silt
Silt
Clay
Clayey Silt
Sensitive Fines
Silt
Sensitive Fines
Clayey Silt
Silt
Clayey Silt
Silt
Clayey Silt
Silt
Max. Depth: 80.05 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

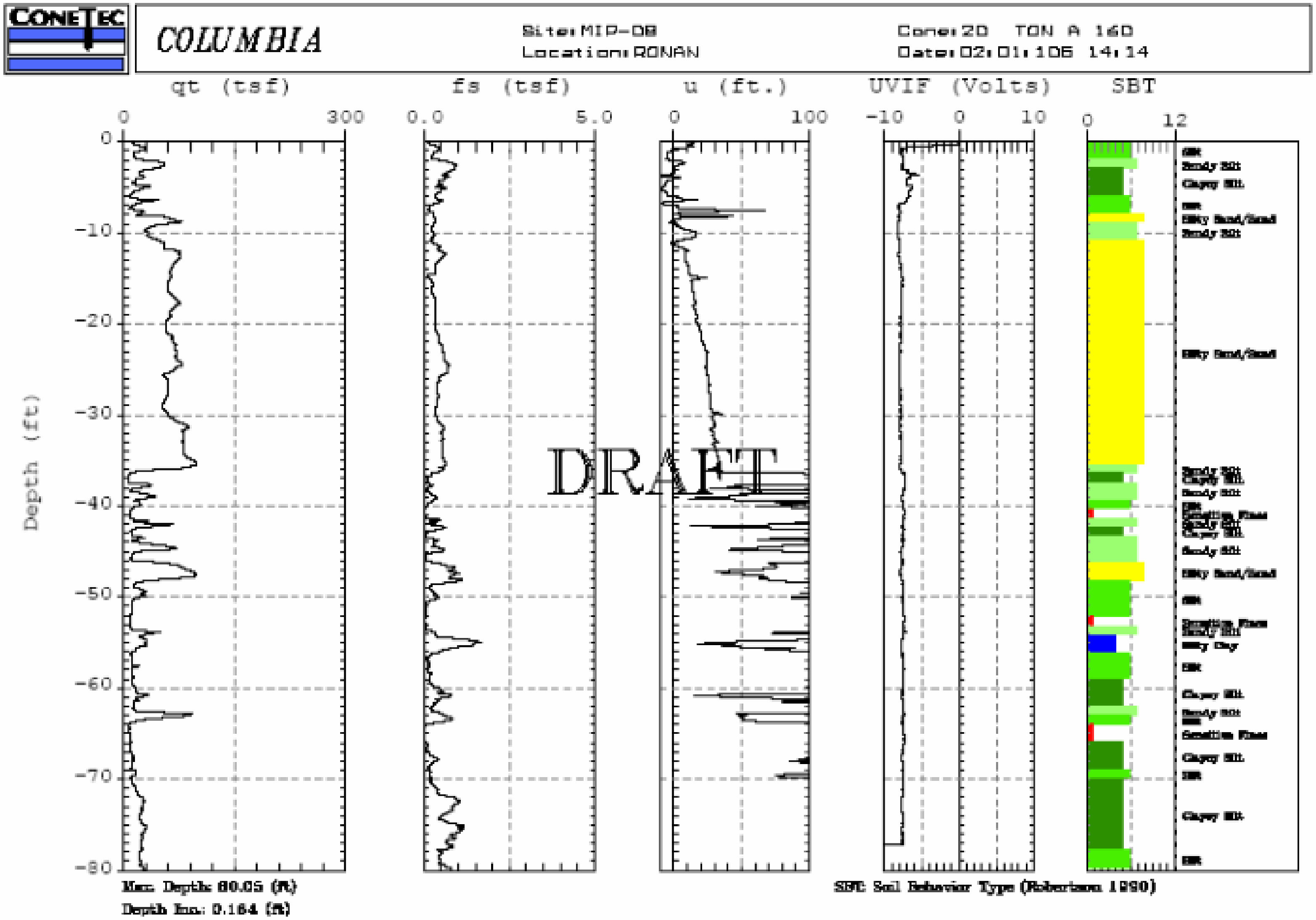

ConeTec
COLUMBIA
Site:MIP-04
Location:RONAN
Cone:20 TON A 160
Date:01:31:106 14:59
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clay
Silty Clay
Clayey Silt
Clay
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Sensitive Fines
Silt
Sensitive Fines
Silt
Clayey Silt
Silt
Sandy Silt
Silt
Max. Depth: 80.84 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)


ConeTec
COLUMBIA
Site:MIP-06
Location:RONAN
Cone:20 TON A 160
Date:01:31:106 10:07
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
300
5.0
100
10
12
Max Depth: 80.05 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Clayey Silt
Sandy Silt
Silty Sand/Sand
Silty Clay
Sensitive Fines
Silt
Clay
DRAFT



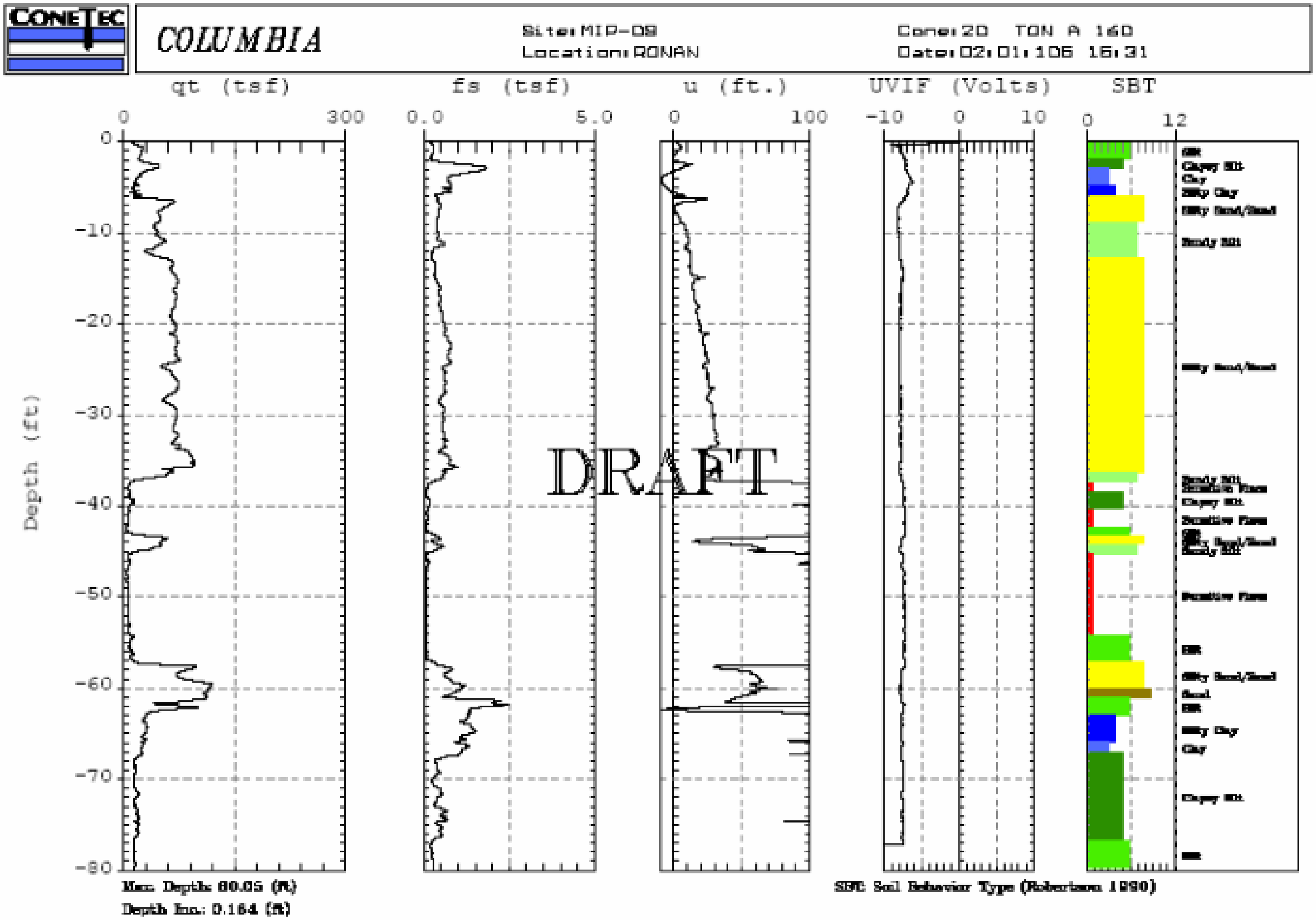
CONETEC
COLUMBIA
Site: MIP-D6
Location: RONAN
Cone: 20 TON A 160
Date: 02:01:106 10:10
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silt
Sandy Silt
Clayey Silt
Silty Clay
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Silt
Clayey Silt
Silt
Clayey Silt
Silt
Clay
Silty Clay
Clayey Silt
Silt
Clayey Silt
Max. Depth: 79.07 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

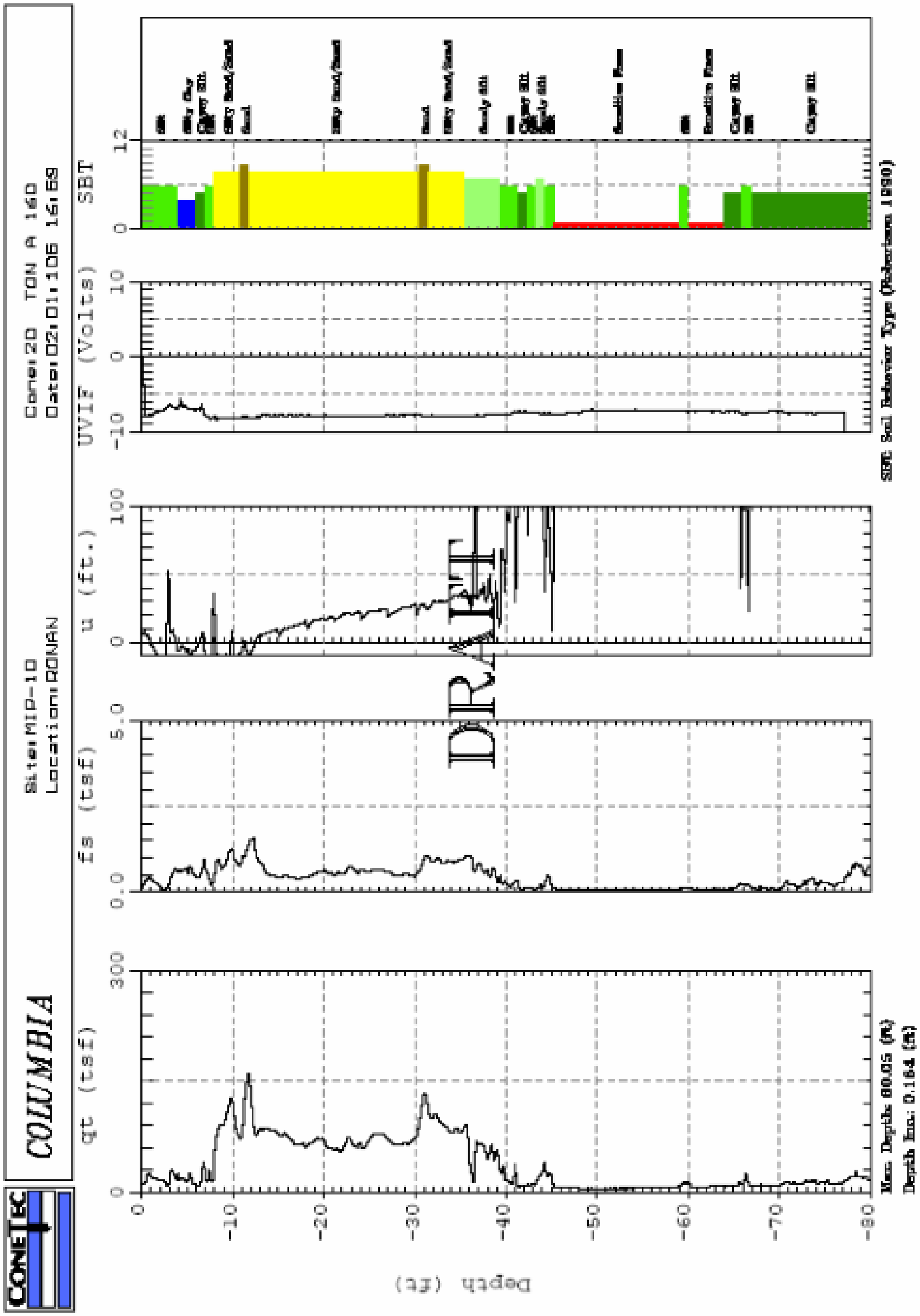

CONETEC
COLUMBIA
Site: MIP-07
Location: RONAN
Cone: 20 TON A 160
Date: 02:01:106 12:14
Depth (ft)
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
0
-10
-20
-30
-40
-50
-60
-70
-80
0
300
0.0
5.0
0
100
-10
0
10
0
12
Max. Depth: 80.05 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)



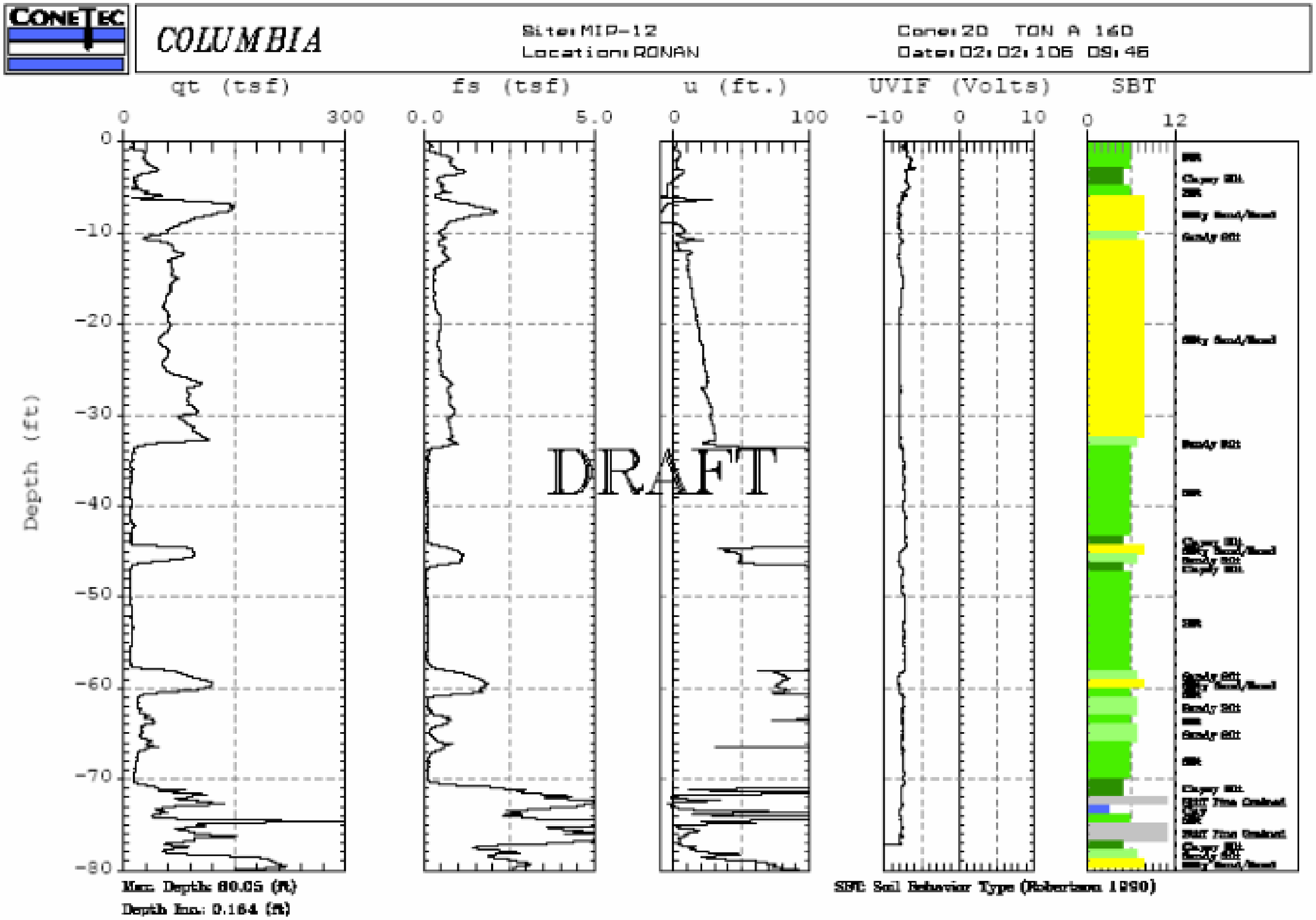
Max. Depth: 80.05 (ft)
Depth Inc.: 0.164 (ft)

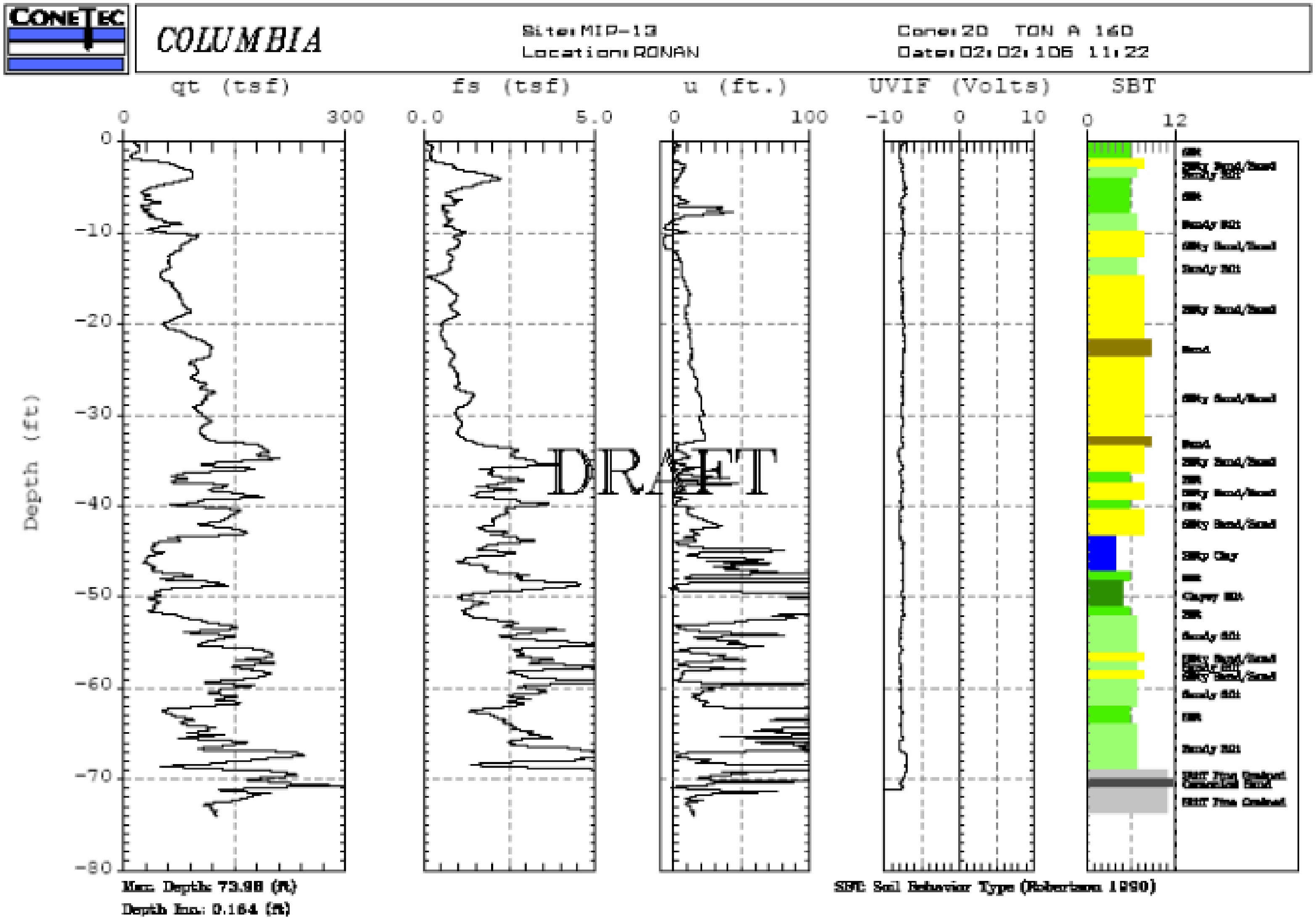
SBT: Soil Behavior Type (Robertson 1990)

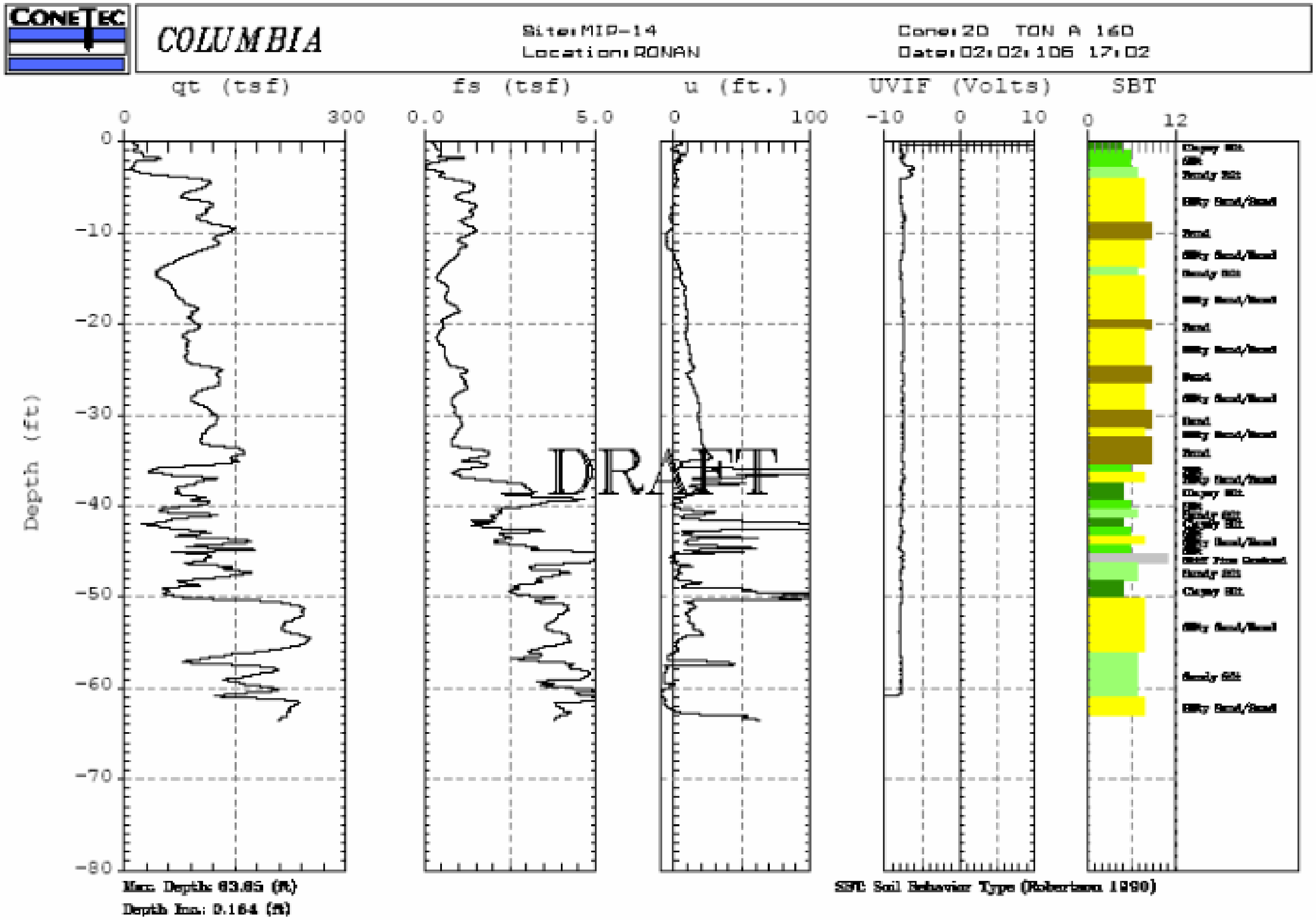

ConeTec
COLUMBIA
Site:MIP-09
Location:RONAN
Cone:20 TON A 160
Date:02:01:106 16:31
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
0
300
0.0
5.0
0
100
-10
0
10
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Clay
Silty Clay
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Sensitive Fines
Clayey Silt
Sensitive Fines
Silty Sand/Sand
Sandy Silt
Sensitive Fines
Silty Sand/Sand
Sand
Silty Clay
Clay
Clayey Silt
Max. Depth: 80.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

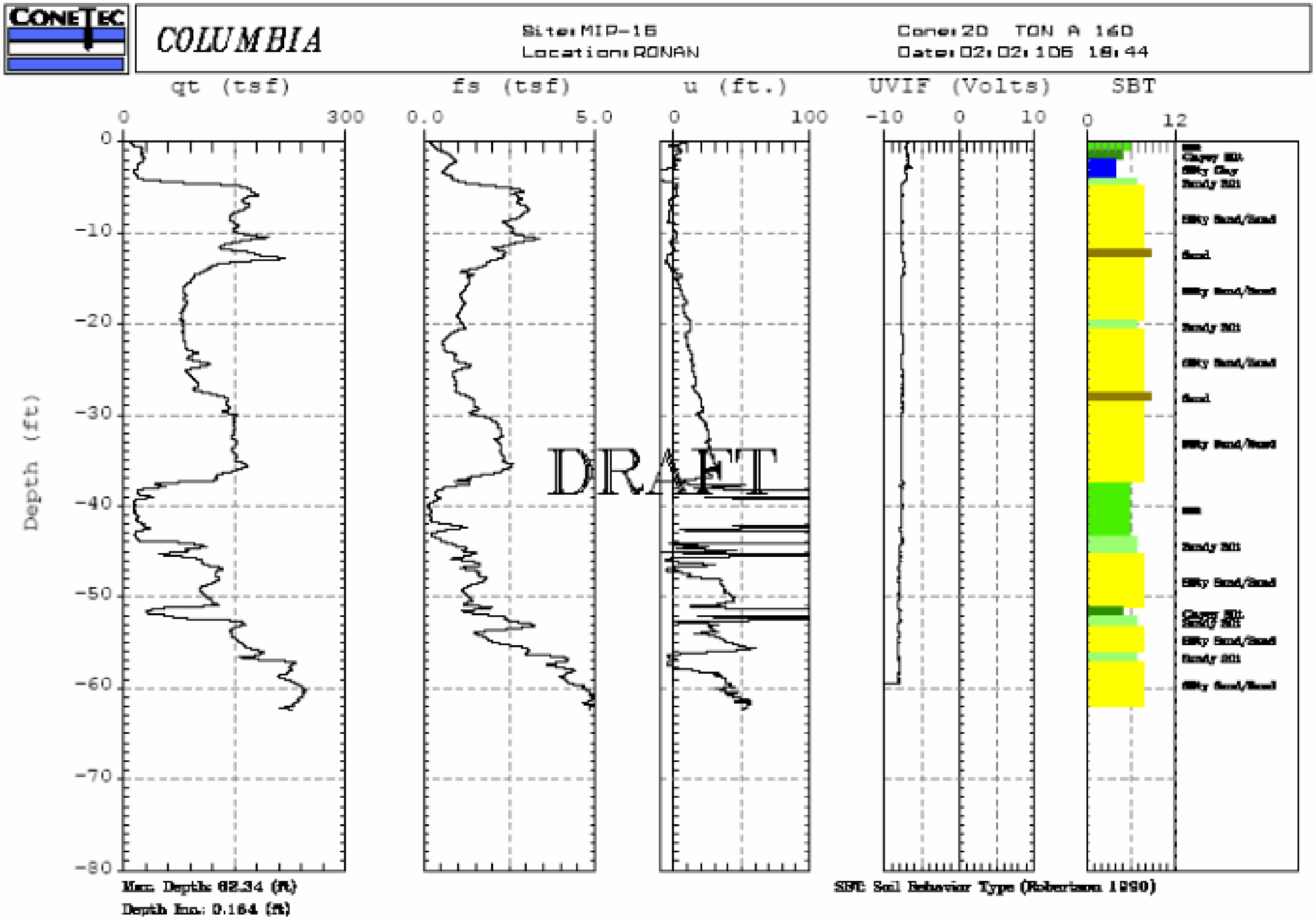


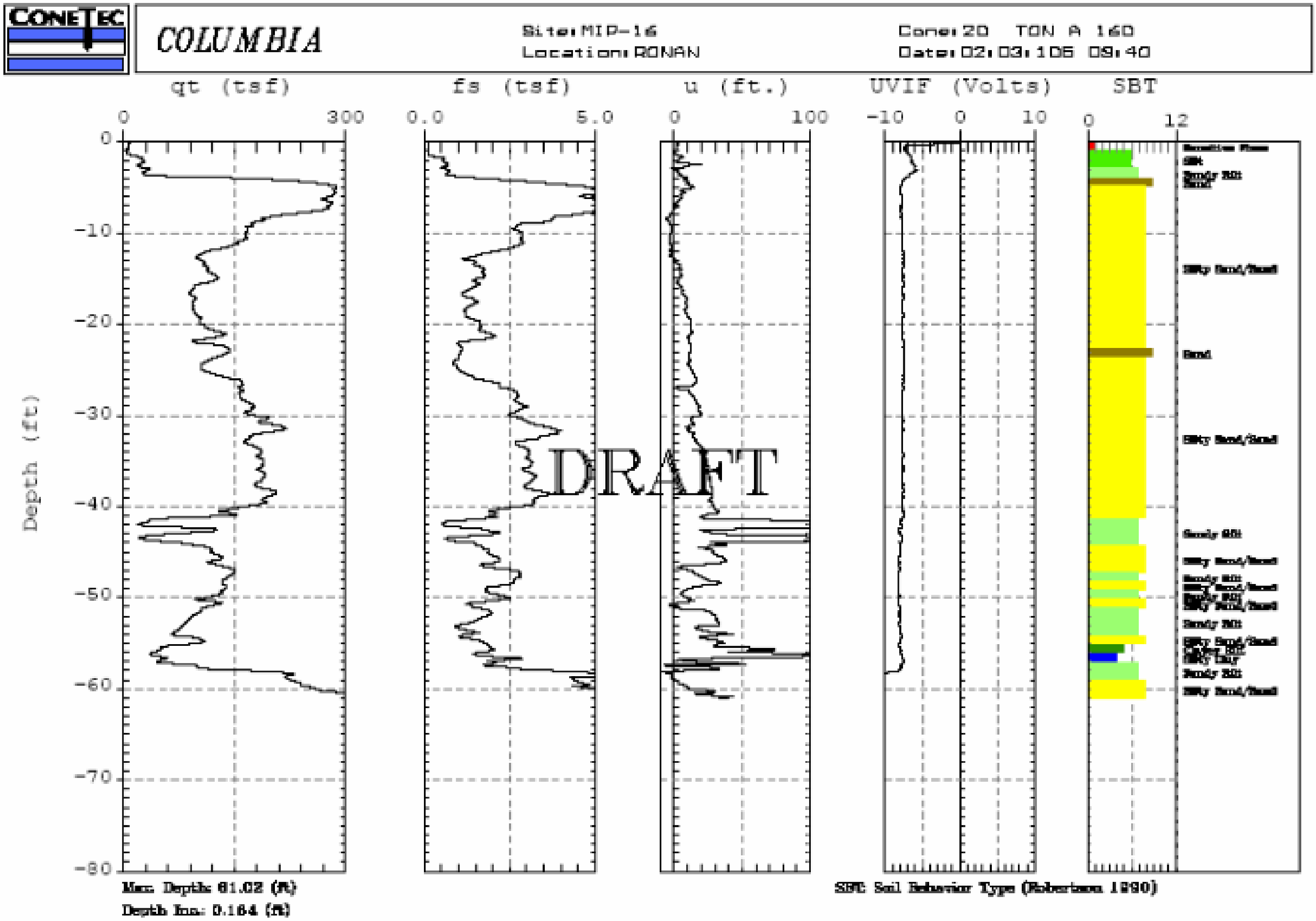
CONETEC
COLUMBIA
Site:MIP-10
Location:RONAN
Cone:20 TON A 160
Date:02:01:106 16:59
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
Depth (ft)
DRAFT
Max. Depth: 80.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Silty Clay
Clayey Silt
Silty Sand/Sand
Sand
Sandy Silt
Sensitive Fines

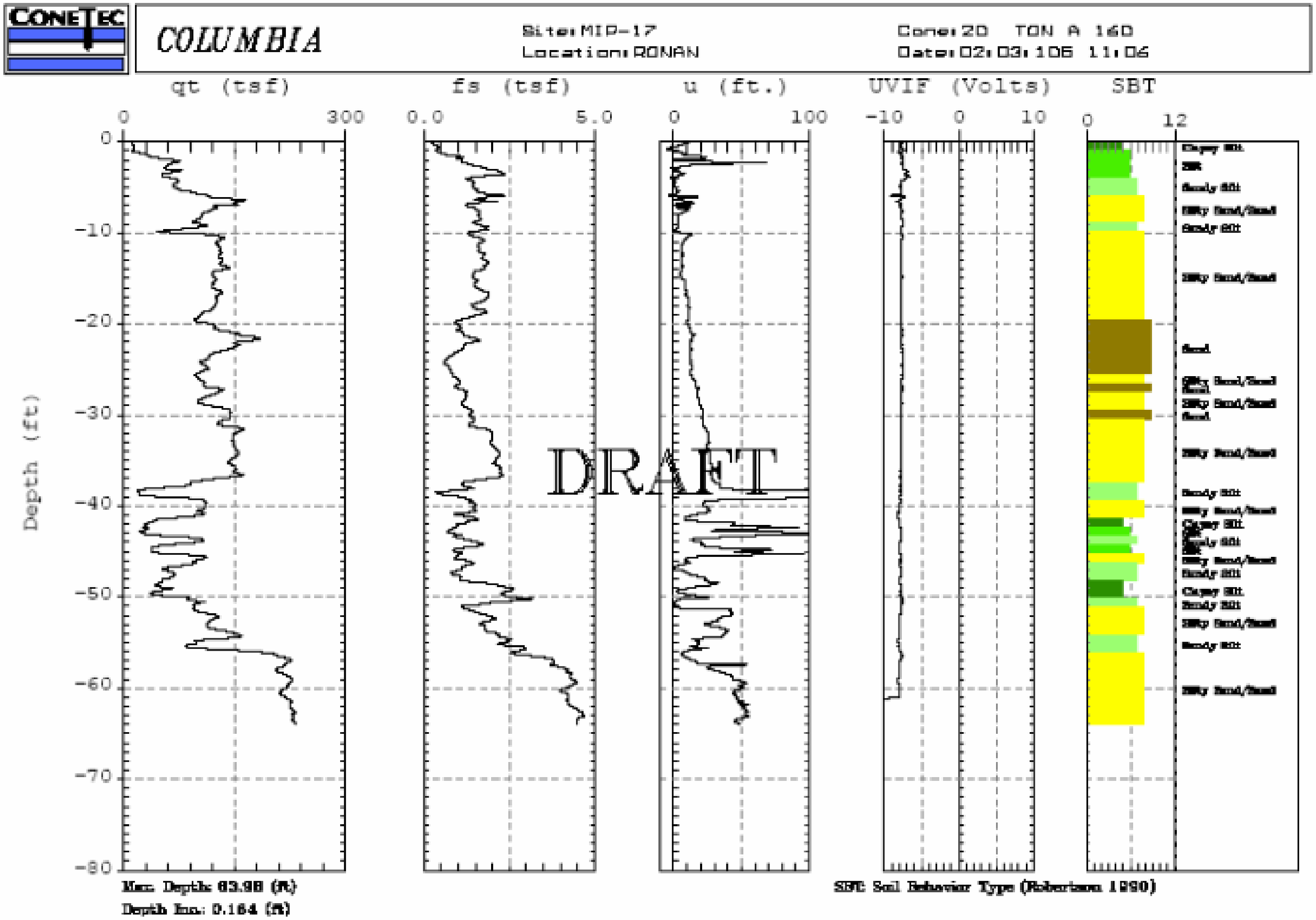

CONETEC
COLUMBIA
Site:MIP-12
Location:RONAN
Cone:2D TON A 16D
Date:02:02:106 09:46
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Silt
Clayey Silt
Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Clayey Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Silt
Sandy Silt
Silty Sand/Sand
Silt
Sandy Silt
Silt
Sandy Silt
Silt
Clayey Silt
Stiff Fine Grained
Clay
Silt
Stiff Fine Grained
Clayey Silt
Sandy Silt
Silty Sand/Sand
Max. Depth: 80.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

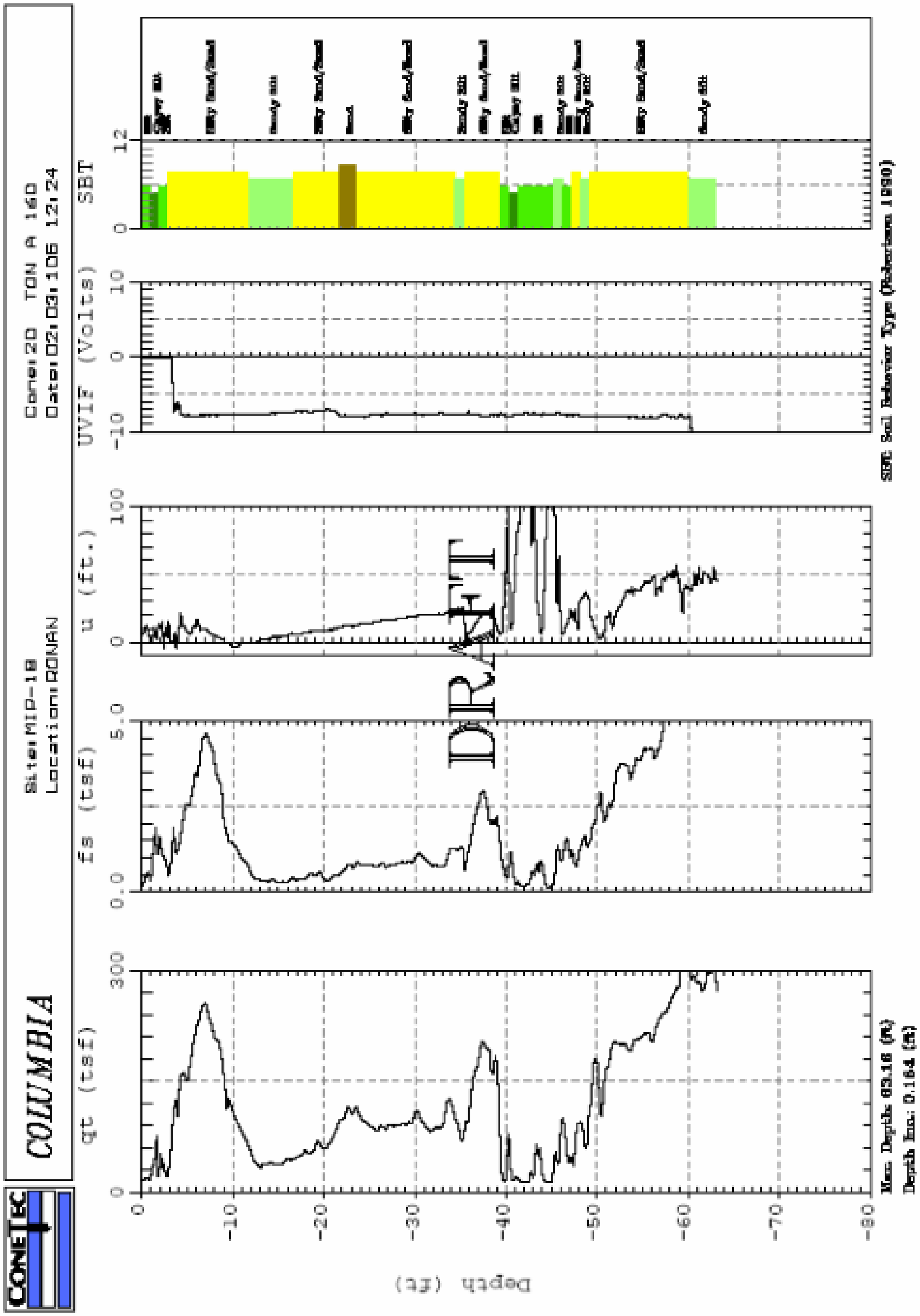

ConeTec
COLUMBIA
Site: MIP-13
Location: RONAN
Cone: 2D TON A 160
Date: 02:02:106 11:22
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Silt
Silty Sand/Sand
Silt
Silty Sand/Sand
Silty Clay
Silt
Clayey Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Max. Depth: 73.98 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
DRAFT

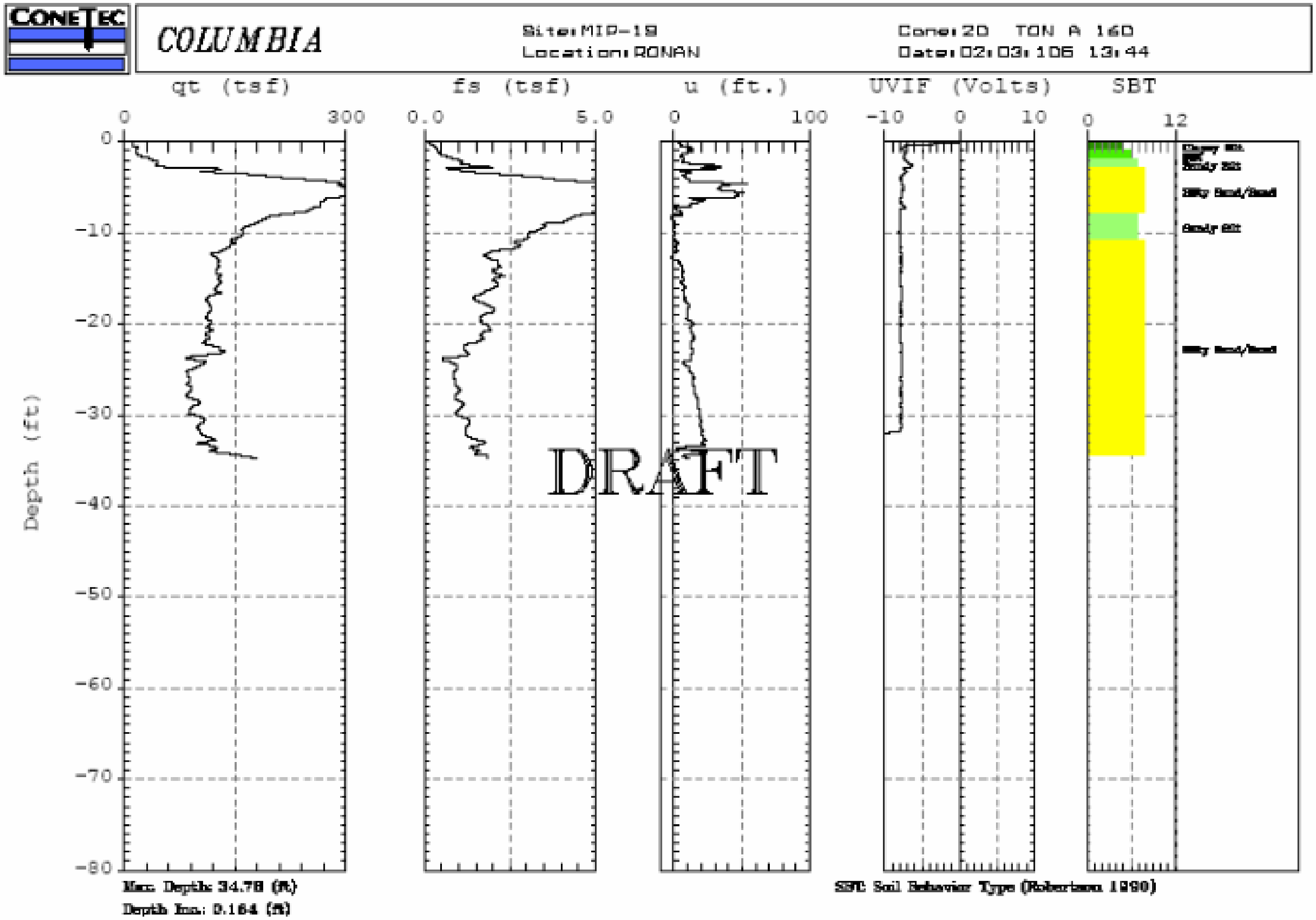

CONETEC
COLUMBIA
Site:MIP-14
Location:RONAN
Cone:2D TON A 16D
Date:02:02:106 17:02
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
0
300
0.0
5.0
0
100
-10
0
10
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silt
Sandy Silt
Silty Sand/Sand
Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Clayey Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Max. Depth: 63.65 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

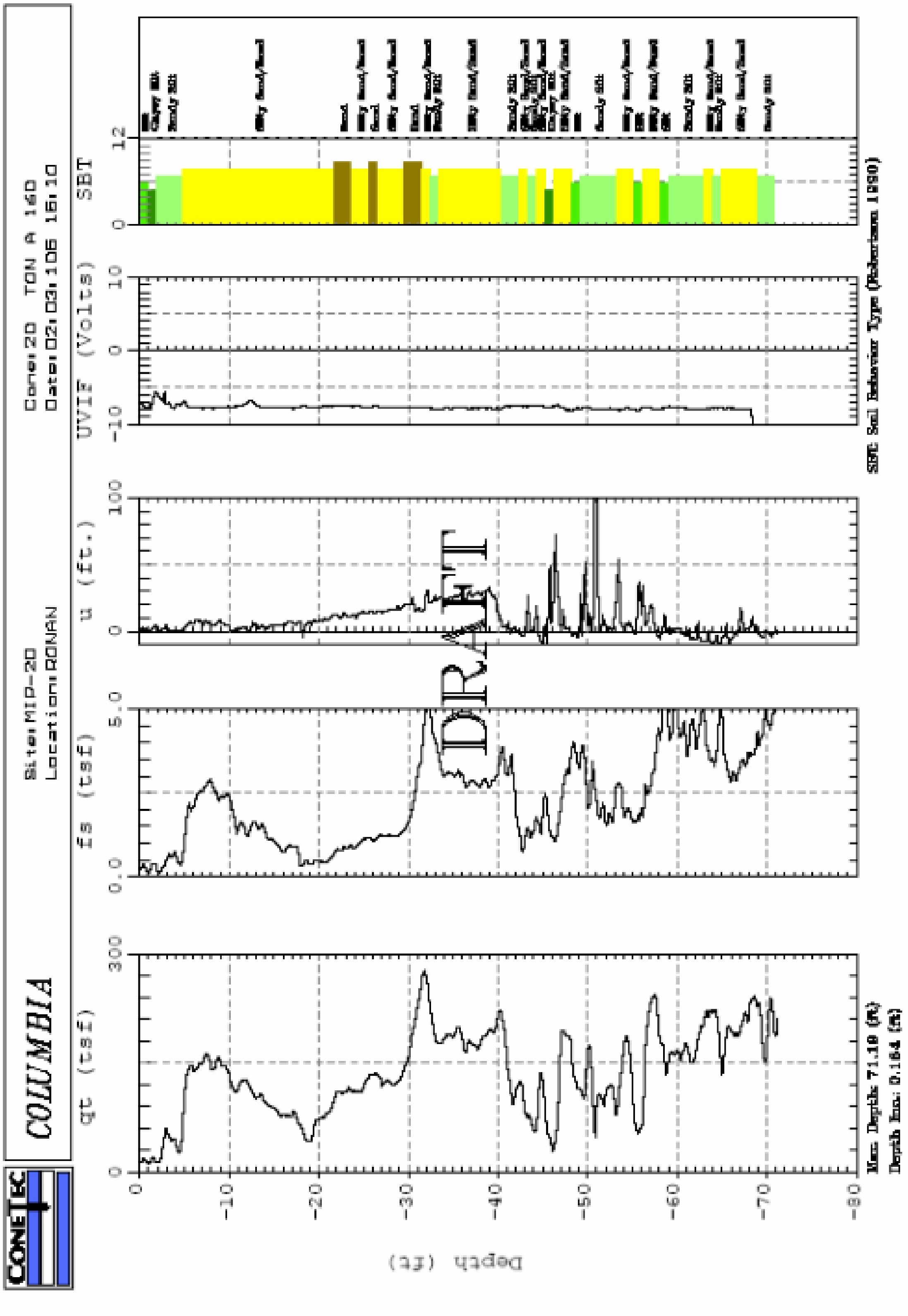

ConeTec
COLUMBIA
Site: MIP-16
Location: RONAN
Cone: 20 TON A 160
Date: 02:02:106 18:44
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
DRAFT
Clayey Silt
Silty Clay
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Clayey Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Max. Depth: 62.34 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

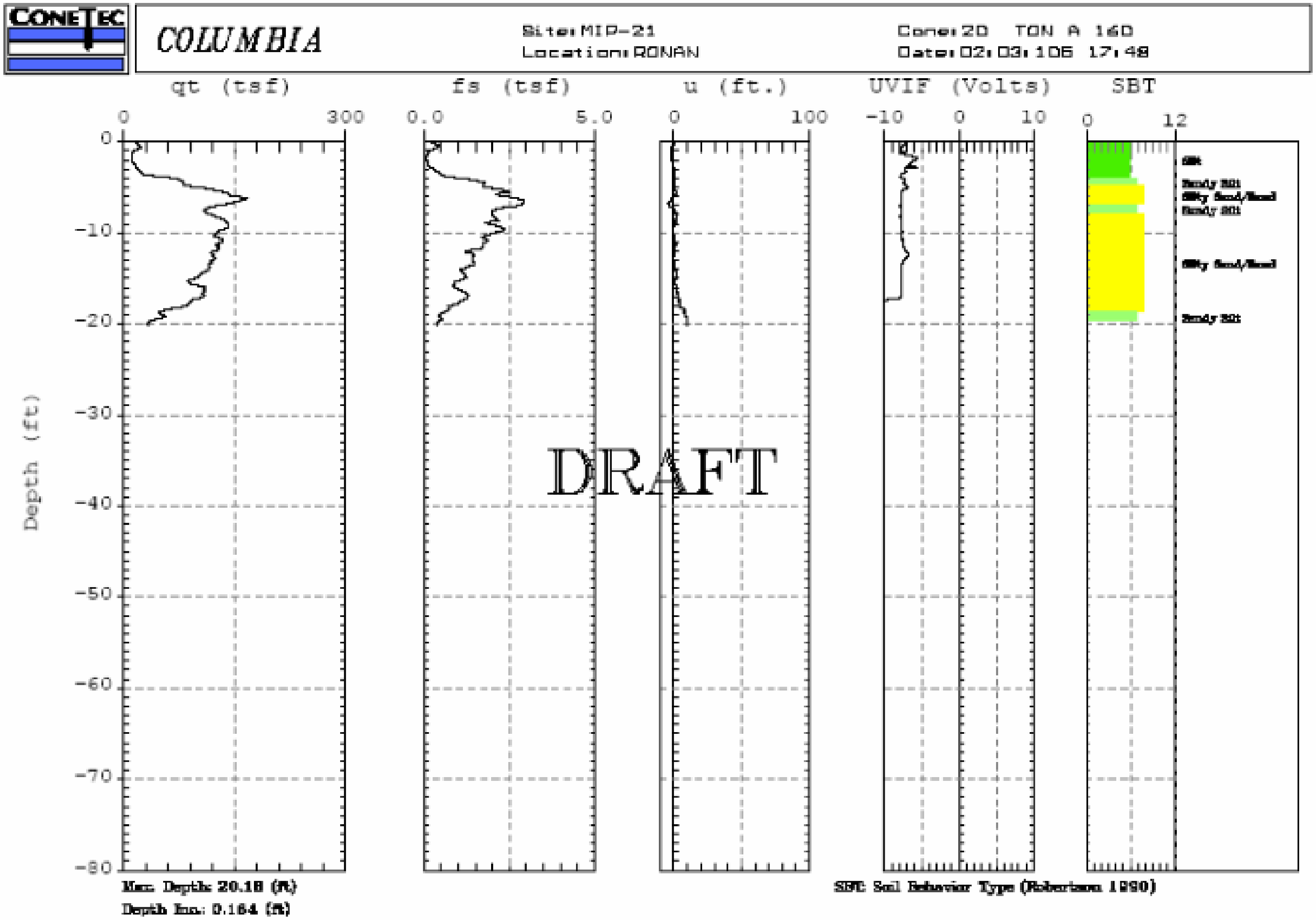

CONETEC
COLUMBIA
Site: MIP-16
Location: RONAN
Cone: 20 TON A 160
Date: 02:03:106 09:40
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Sensitive Fines
Silt
Sandy Silt
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Clayey Silt
Silty Clay
Sandy Silt
Silty Sand/Sand
Max. Depth: 61.02 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

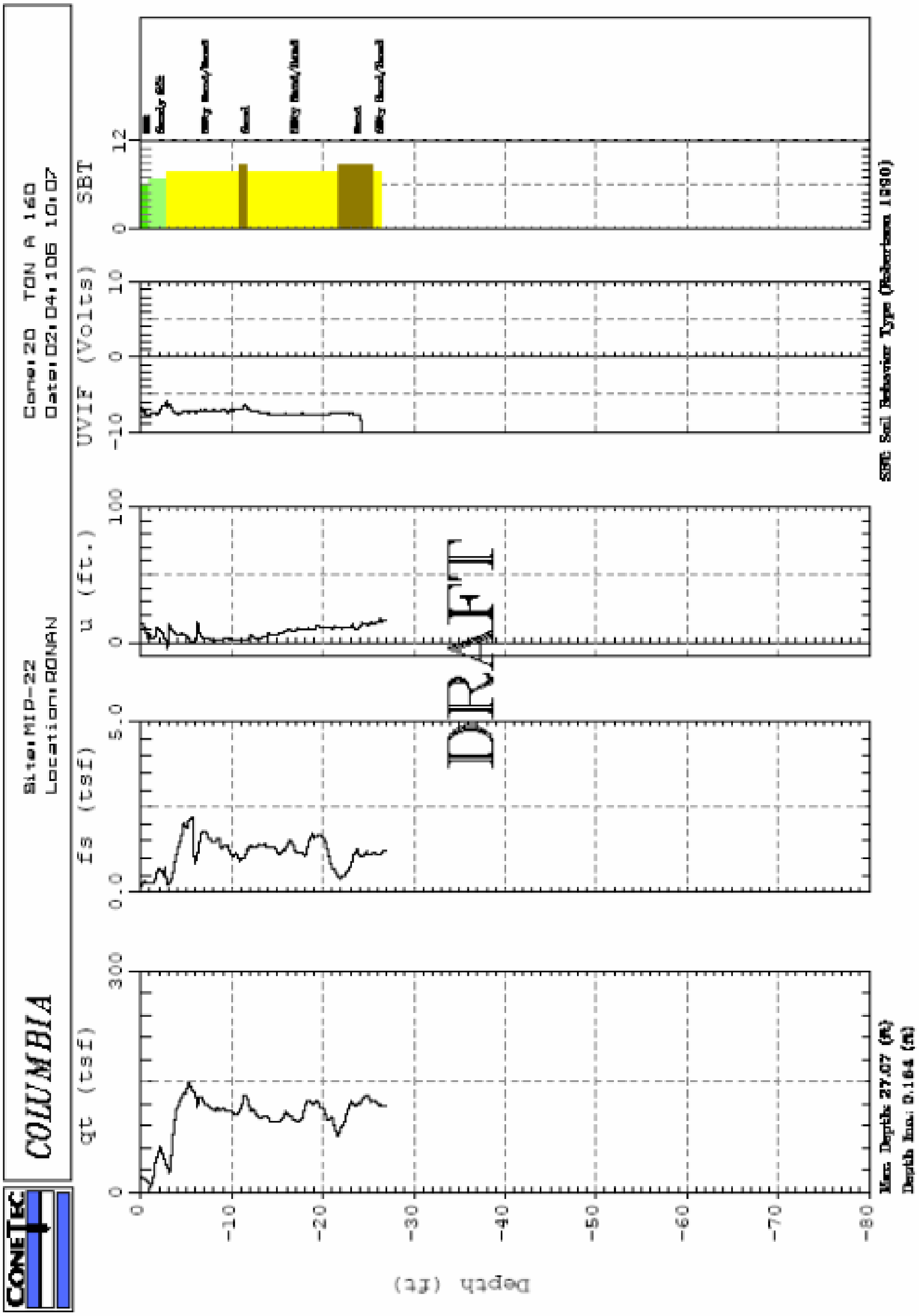

CONETEC
COLUMBIA
Site:MIP-17
Location:RONAN
Cone:20 TON A 16D
Date:02:03:106 11:06
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
0
300
0.0
5.0
0
100
-10
0
10
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Clayey Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Max. Depth: 63.98 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

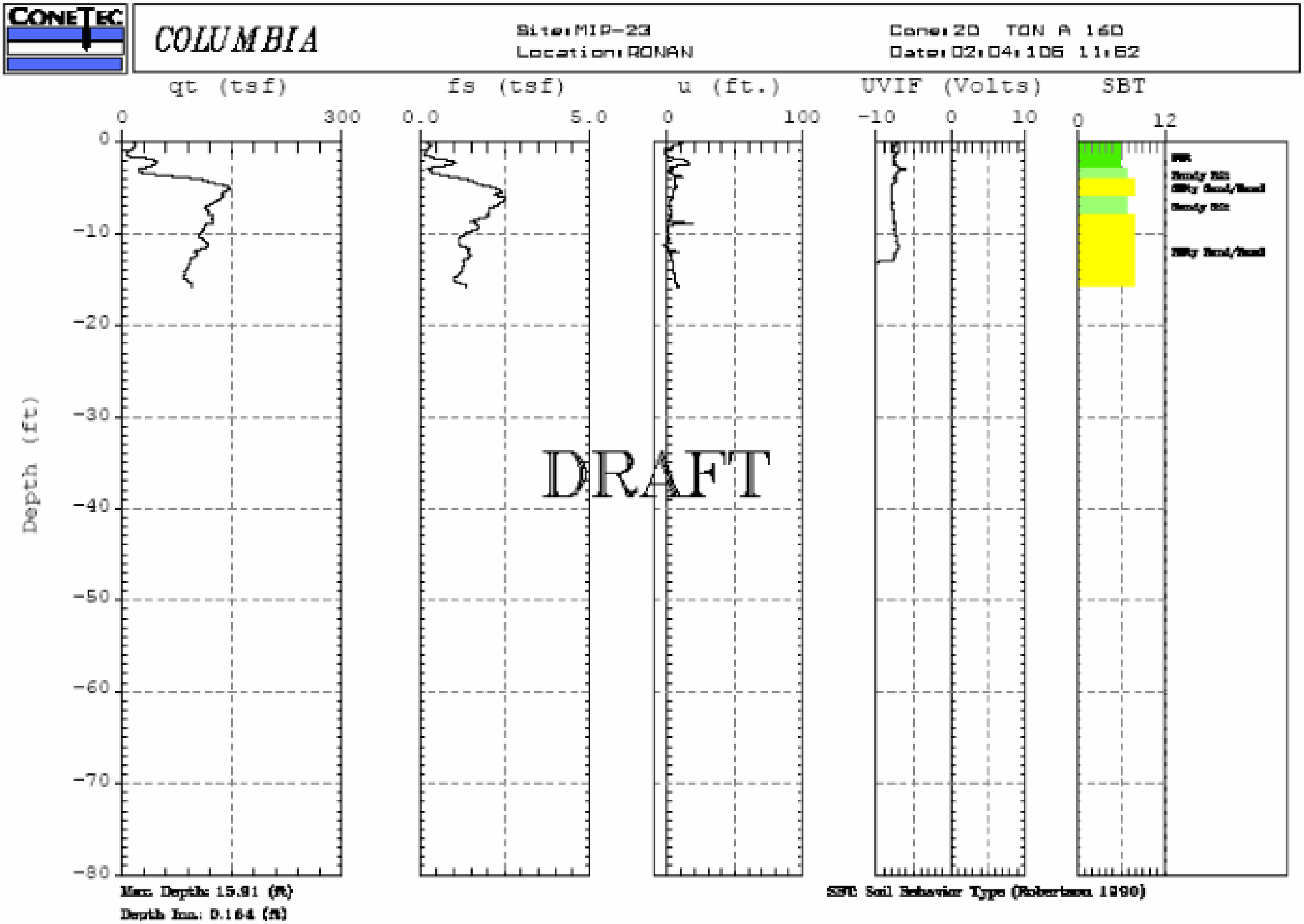

ConeTec
COLUMBIA
Site: MIP-18
Location: RONAN
Cone: 20 TON A 160
Date: 02:03:106 12:24
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Silty Sand/Sand
Sandy Silt
Sand
Clayey Silt
Max. Depth: 63.16 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
DRAFT

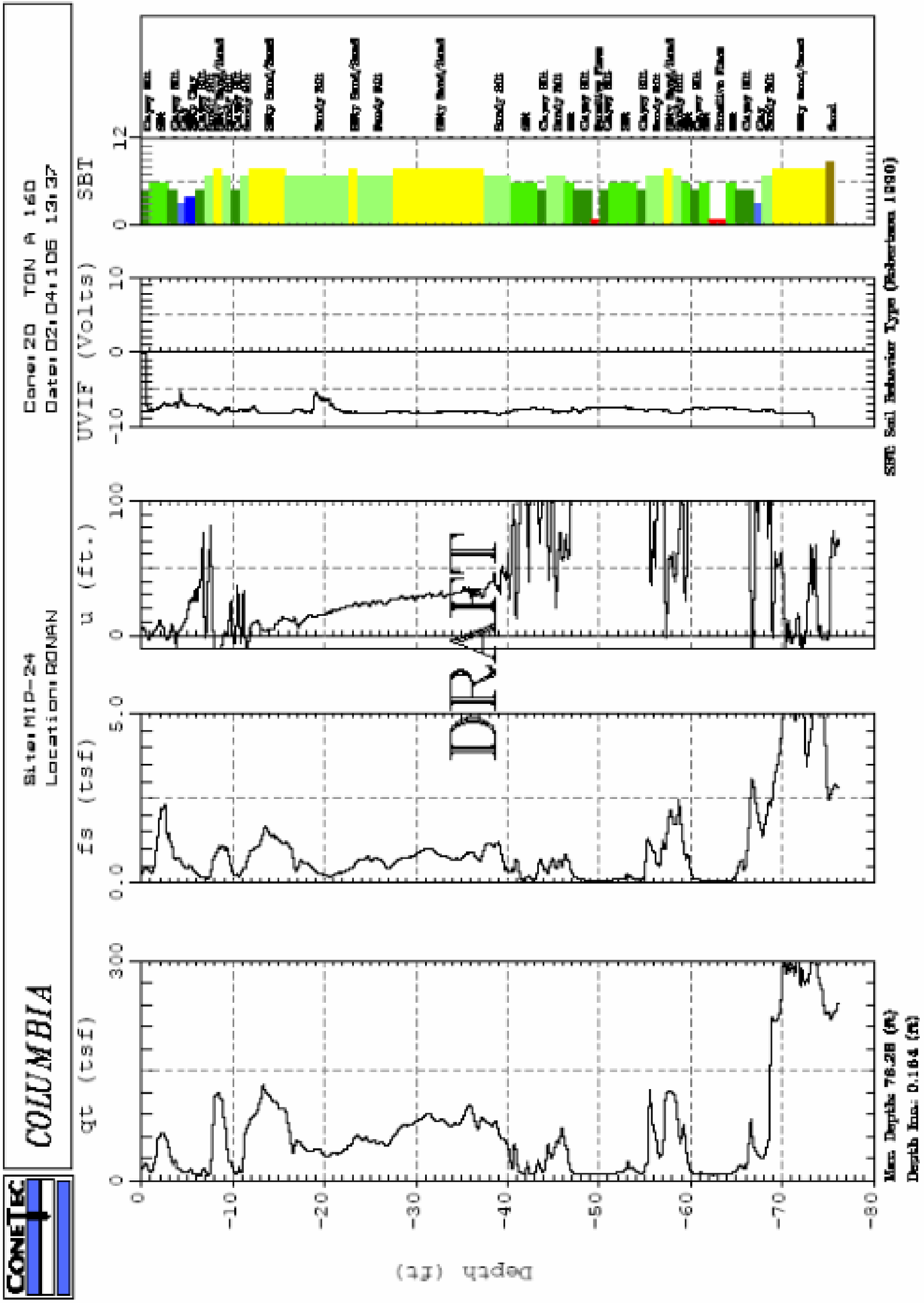

CONETEC
COLUMBIA
Site:MIP-19
Location:RONAN
Cone:2D TON A 16D
Date:02:03:106 13:44
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
DRAFT
Max. Depth: 34.78 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

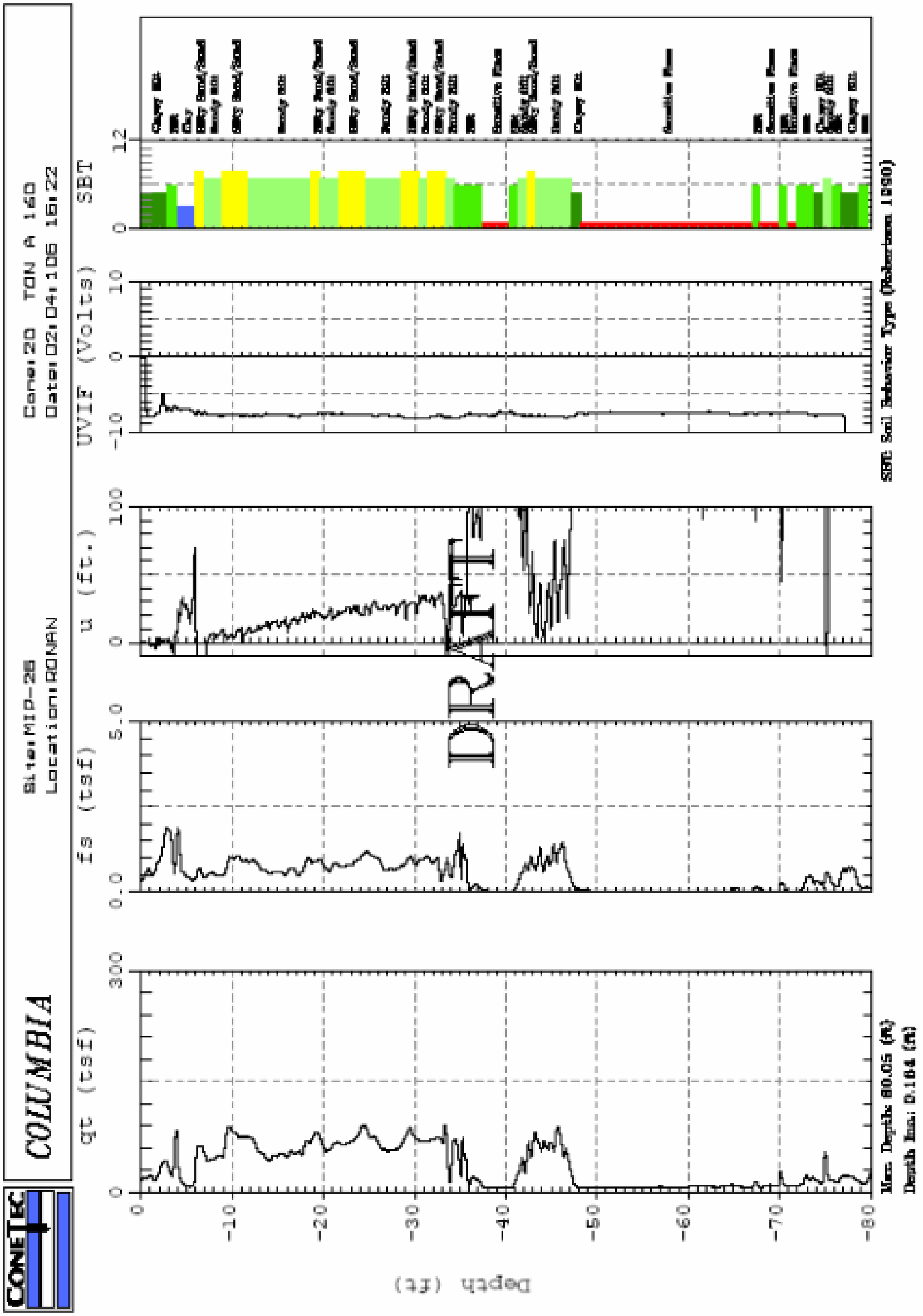

CONETEC
COLUMBIA
Site:MIP-20
Location:RONAN
Cone:20 TON A 160
Date:02:03:106 16:10
qt (tsf)
fs (tsf)
u (ft.)
UVIF (Volts)
SBT
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
300
0.0
5.0
100
10
-10
12
Max. Depth: 71.10 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)


ConeTec
COLUMBIA
Site:MIP-21
Location:RONAN
Cone:2D TON A 16D
Date:02:03:106 17:48
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Max. Depth: 20.18 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

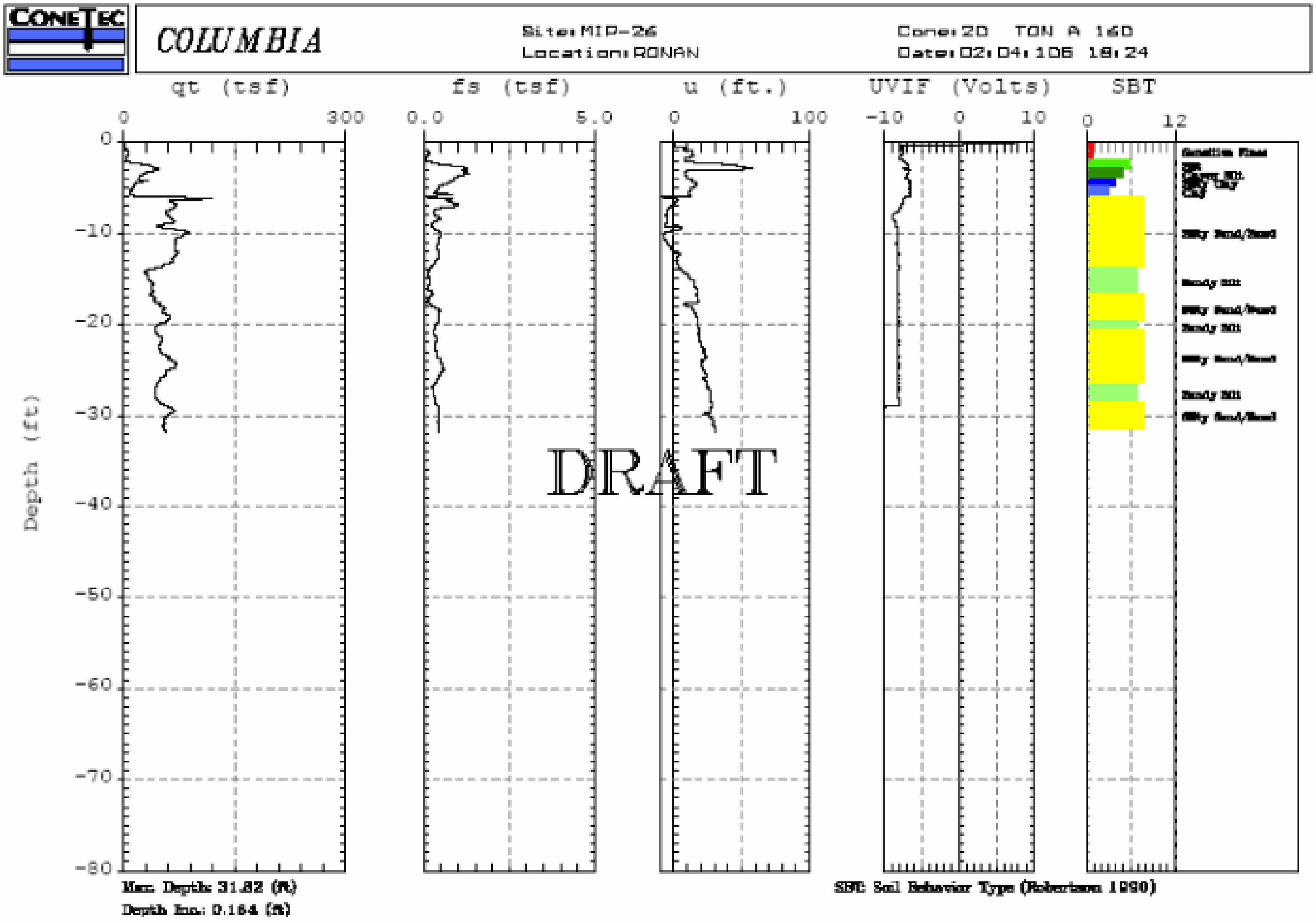

ConeTec
COLUMBIA
Site: MIP-22
Location: RONAN
Cone: 20 TON A 160
Date: 02:04:106 10:07
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Silt
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Max. Depth: 27.07 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

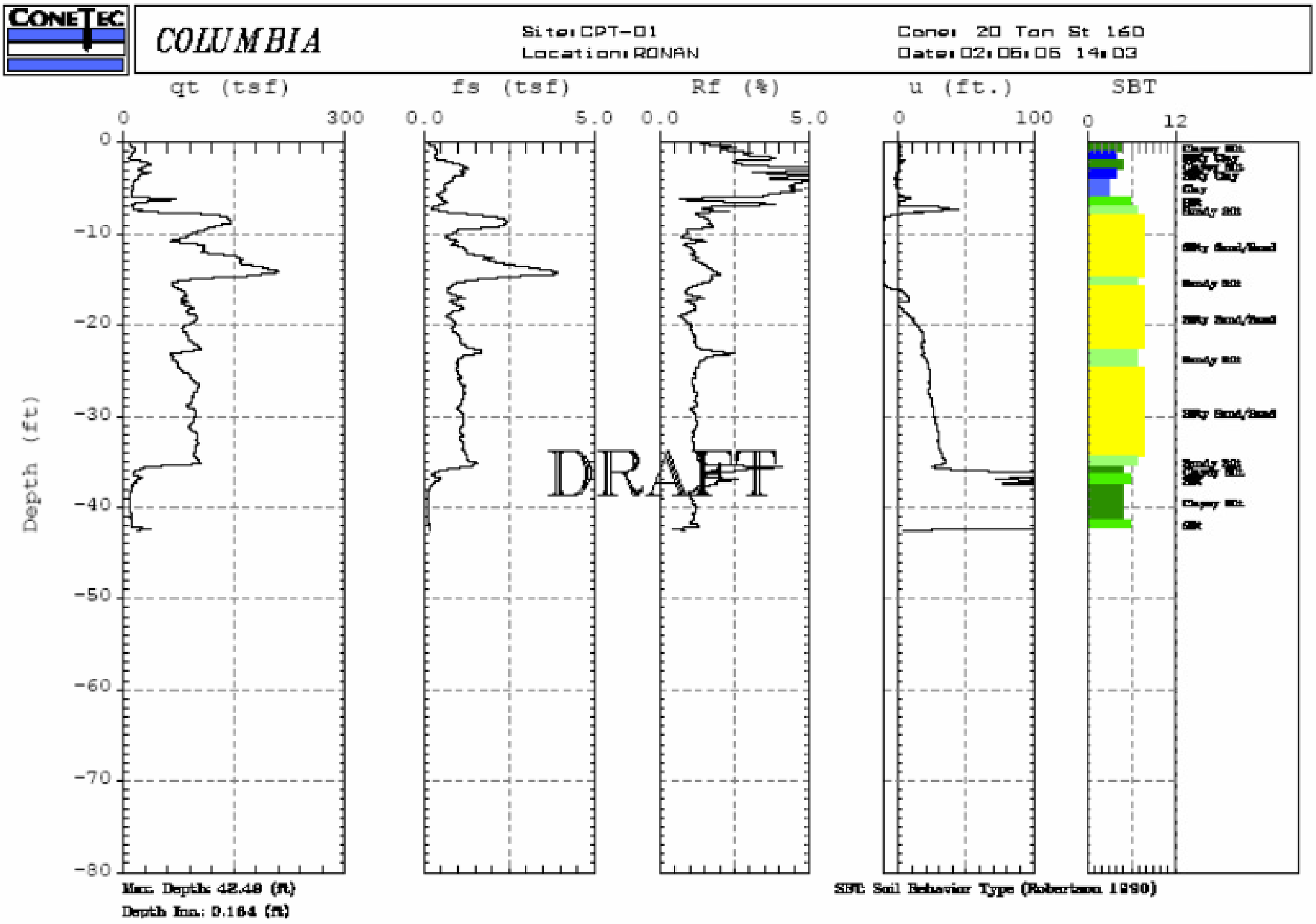

ConeTec
COLUMBIA
Site:MIP-23
Location:RONAN
Cone:20 TON A 160
Date:02:04:106 11:62
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
DRAFT
Max. Depth: 15.91 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

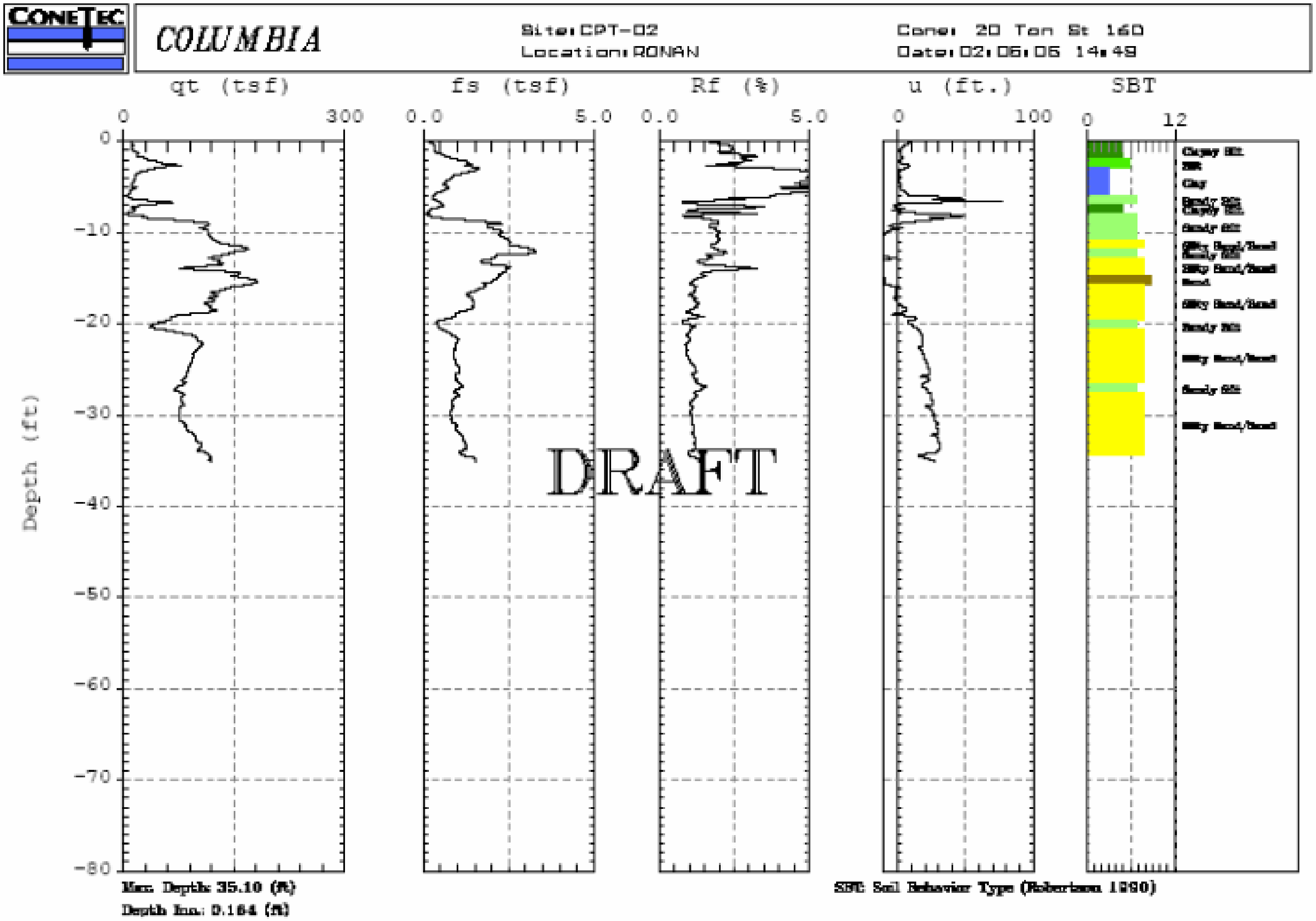

ConeTec
COLUMBIA
Site:MIP-24
Location:RONAN
Cone:2D TON A 160
Date:02:04:106 13:37
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Max. Depth: 76.28 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
DRAFT

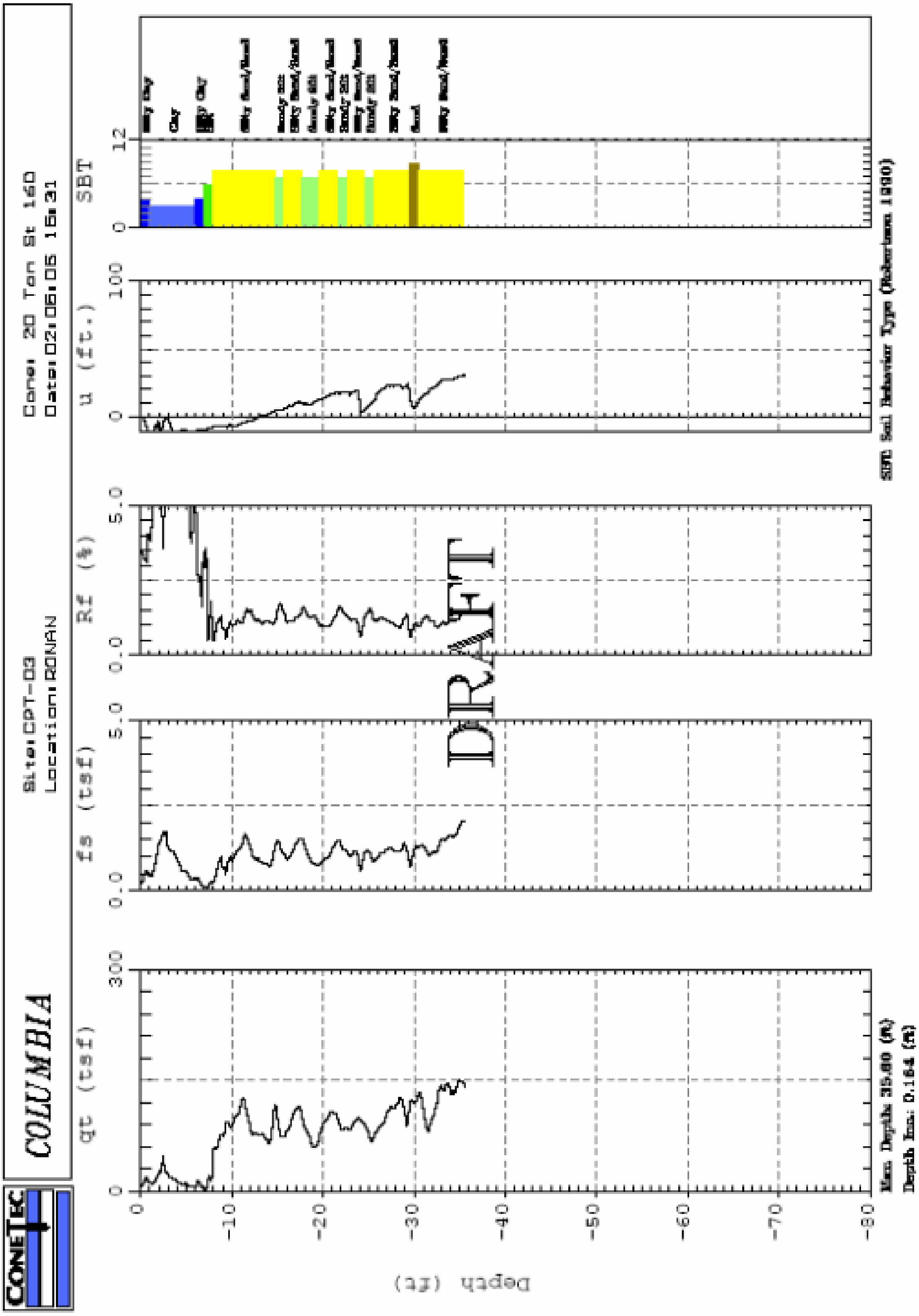


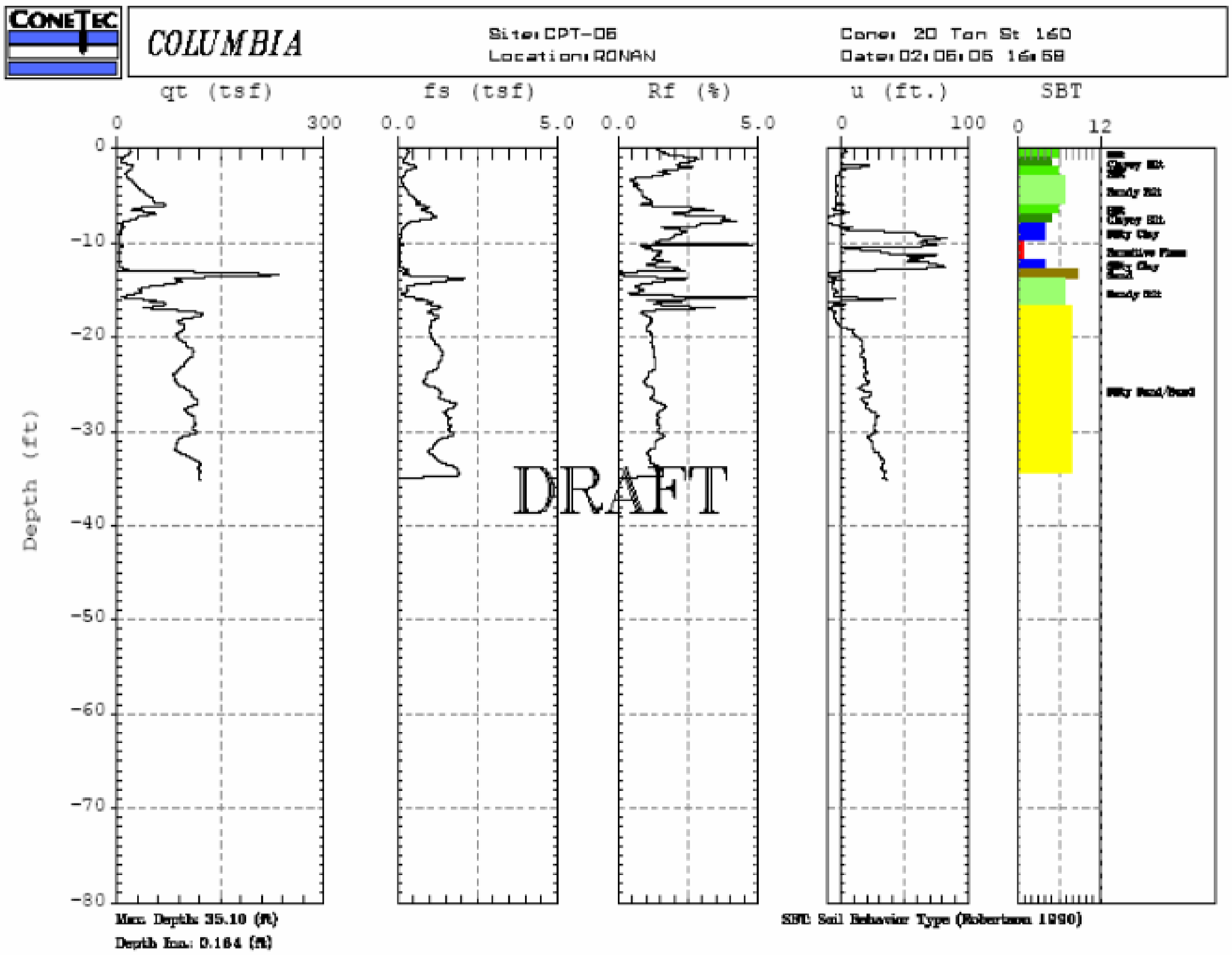
CONETEC
COLUMBIA
Site:MIP-28
Location:ROMAN
Cone:20 TON A 160
Date:02:04:106 16:22
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Max. Depth: 80.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
DRAFT

CONETEC
COLUMBIA
Site:MIP-26
Location:RONAN
Cone:20 TON A 160
Date:02:04:106 18:24
qt (tsf)
0
300
fs (tsf)
0.0
5.0
u (ft.)
0
100
UVIF (Volts)
-10
0
10
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Sensitive Fines
Clayey Silt
Silty Clay
Clay
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Max. Depth: 31.82 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)


CONETEC
COLUMBIA
Site:CPT-01
Location:RONAN
Cone: 20 Ton St 160
Date:02:06:06 14:03
qt (tsf)
fs (tsf)
Rf (%)
u (ft.)
SBT
0
300
0.0
5.0
0.0
5.0
0
100
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silty Clay
Clayey Silt
Silty Clay
Clay
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Silt
Clayey Silt
Silt
Max. Depth: 42.49 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

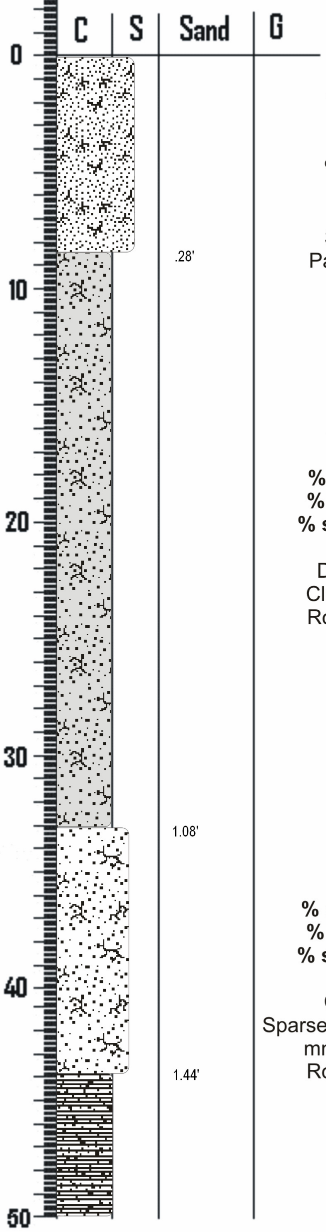

ConeTec
COLUMBIA
Site:CPT-02
Location:RONAN
Cone: 20 Ton St 160
Date:02:06:06 14:49
qt (tsf)
0
300
fs (tsf)
0.0
5.0
Rf (%)
0.0
5.0
u (ft.)
0
100
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Silt
Clay
Sandy Silt
Clayey Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Max. Depth: 35.10 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)


CONETEC
COLUMBIA
Site:CPT-03
Location:RONAN
Cone: 20 Ton St 16D
Date:02:06:06 16:31
qt (tsf)
0
300
fs (tsf)
0.0
5.0
Rf (%)
0.0
5.0
u (ft.)
0
100
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Max. Depth: 35.60 (ft)
Depth Inc: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)


CONETEC
COLUMBIA
Site:CPT-06
Location:RONAN
Cone: 20 Ton St 160
Date:02:06:05 16:58
qt (tsf)
0
300
fs (tsf)
0.0
5.0
Rf (%)
0.0
5.0
u (ft.)
0
100
SBT
0
12
Depth (ft)
0
-10
-20
-30
-40
-50
-60
-70
-80
Clayey Silt
Sandy Silt
Clayey Silt
Silty Clay
Sensitive Fines
Clay
Sandy Silt
Silty Sand/Sand
DRAFT
Max. Depth: 35.10 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

Appendix B
Described Geoprobe Cores

MIP 18



A
0-8.5cm
10YR 5/2
% clay =
% silt =
% sand =

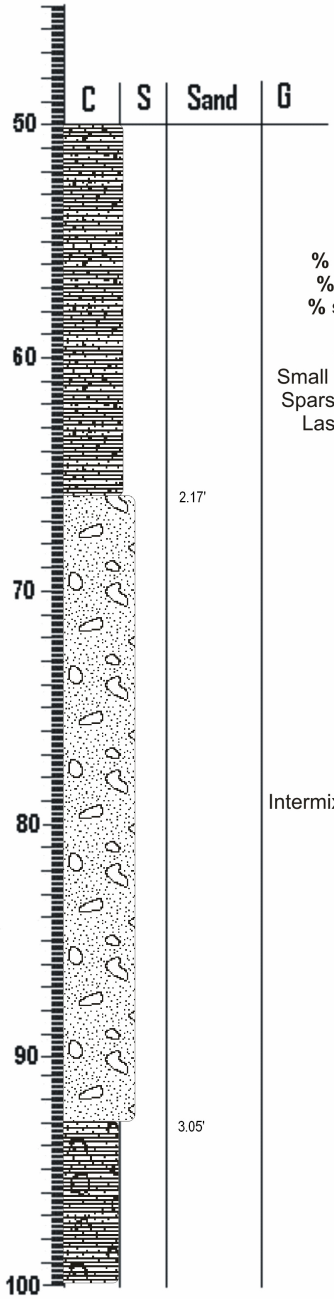
Topsoil
Silty loam
Packed roots

B
8.5-33cm
10YR 2/2
% clay = 8.11
% silt = 66.01
% sand = 25.89

Dark topsoil
Clay rich loam
Roots present

C
33-44cm
10YR 8/4
% clay = 27.14
% silt = 60.27
% sand = 12.59

Clayey silt
Sparse angular cobbles
mm-2cm scale
Roots present



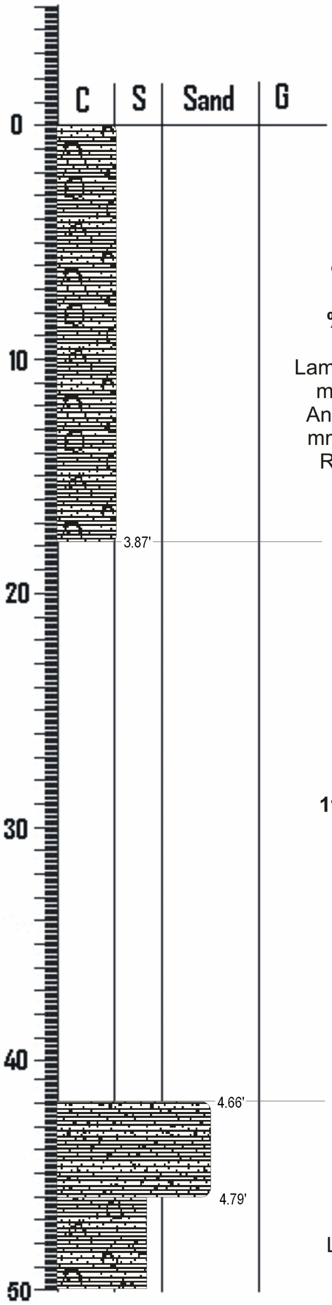
D
44-66cm
5YR 5/4
% clay = 31.96
% silt = 56.16
% sand = 11.88

Clayey silt
Small gravel mm scale
Sparse cobbles ~2cm
Last root @49cm

E
66-93cm
10YR 7/2
% clay = 19.63
% silt = 67.19
% sand = 13.19

Silt and gravel
Intermixed gravel mm-1cm scale

MIP 18



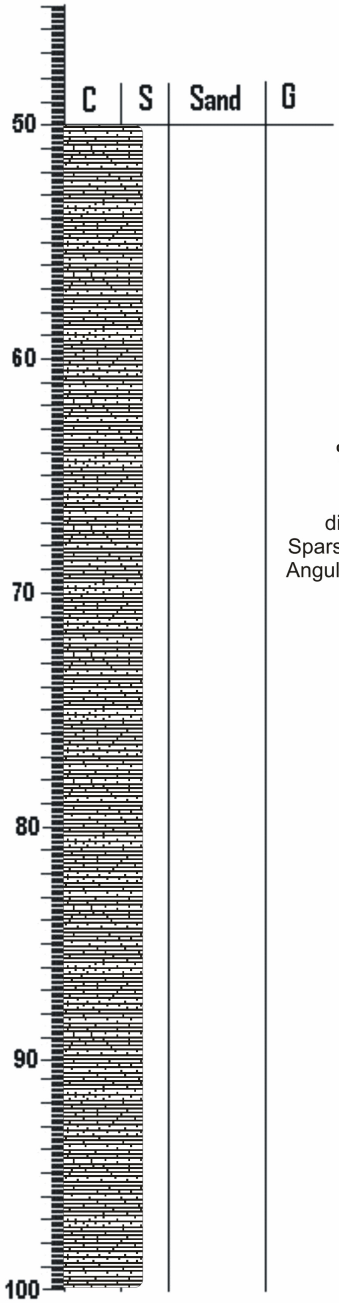
F
93-118cm
5YR 5/4
% clay = 33.47
% silt = 52.31
% sand = 14.22

Laminated silt and clay
mm scale bedding
Angular small gravel
mm-cm scale gravel
Rounded cobbles

118-142cm

G
142-146cm
10YR 4/2
% clay =
% silt =
% sand =

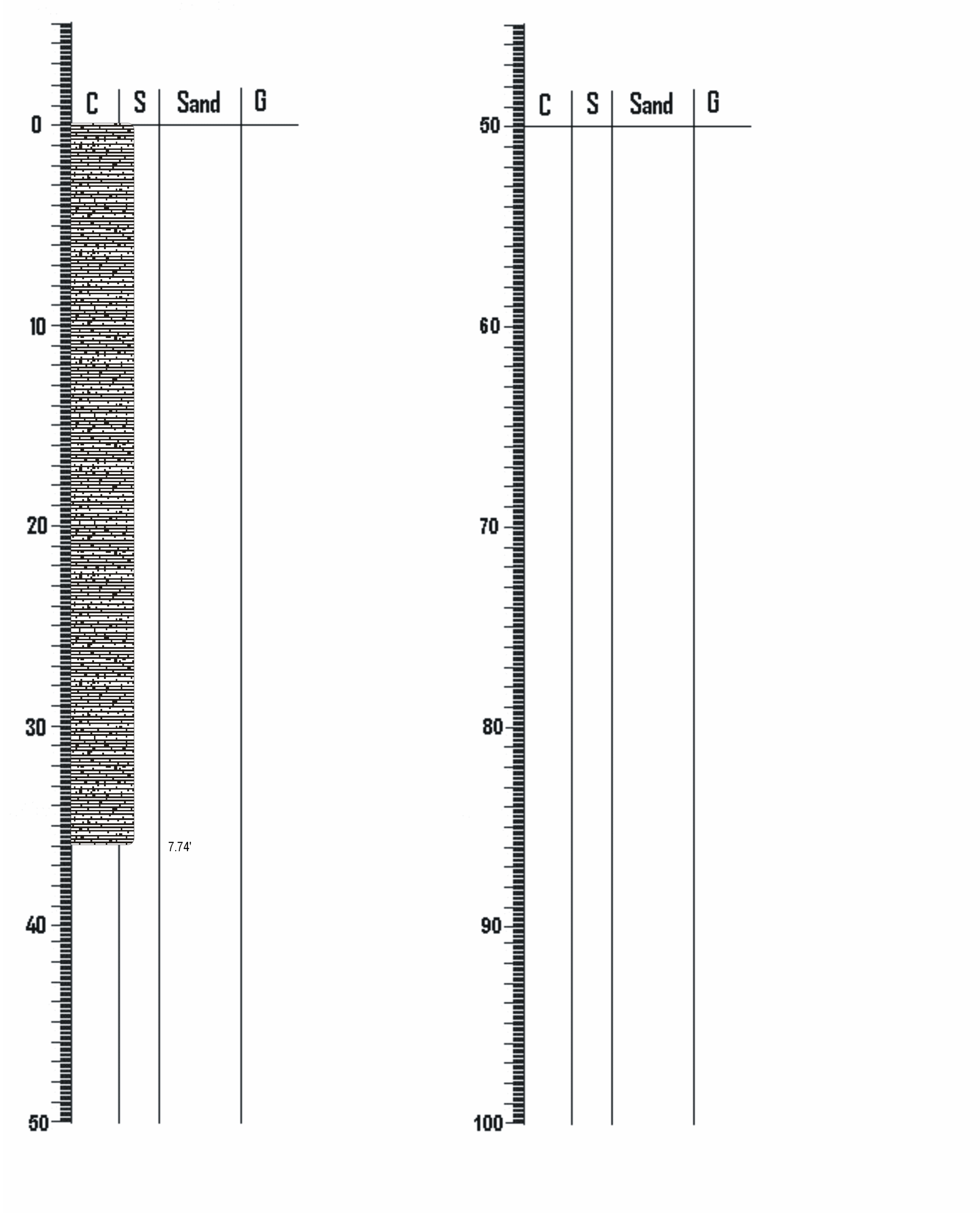
Laminated sand



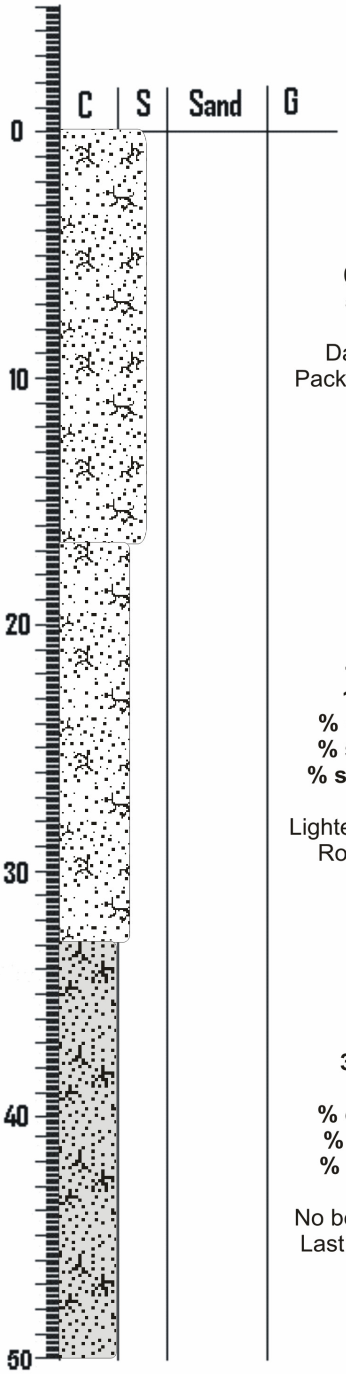
H
146-236cm
10YR 8/2
% clay = 2.82
% silt = 63.35
% sand = 33.82

Laminated silt
distorted by coring
Sparse gravel at top 20cm
Angular cobbles up to 3cm

MIP 18



MIP 28



A
0-17 cm
5YR 4/2

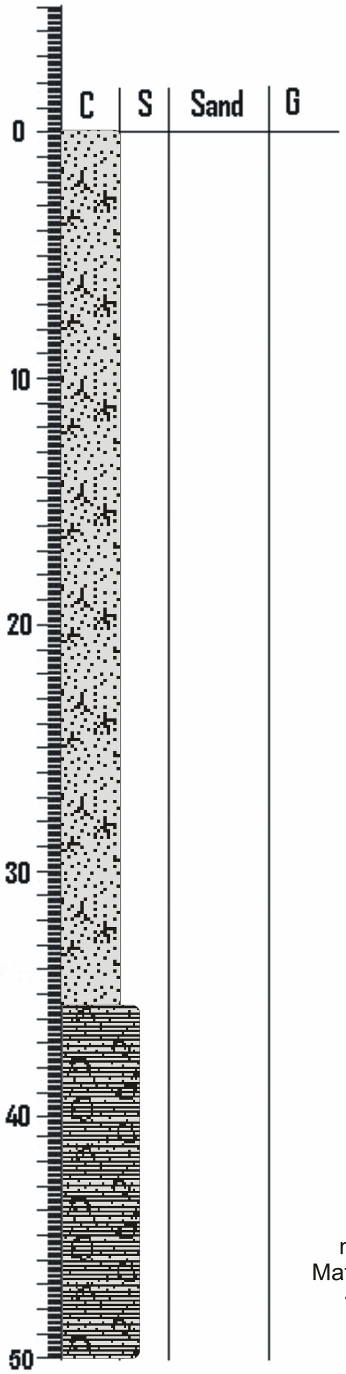
Dark topsoil
Packed with roots
Fe rich

B
17-33cm
10YR 5/2
% clay = 7.61
% silt = 74.13
% sand = 18.26

Lighter color topsoil
Roots present

C
33-85.5cm
10YR 7/2
% clay = 37.17
% silt = 55.59
% sand = 7.24

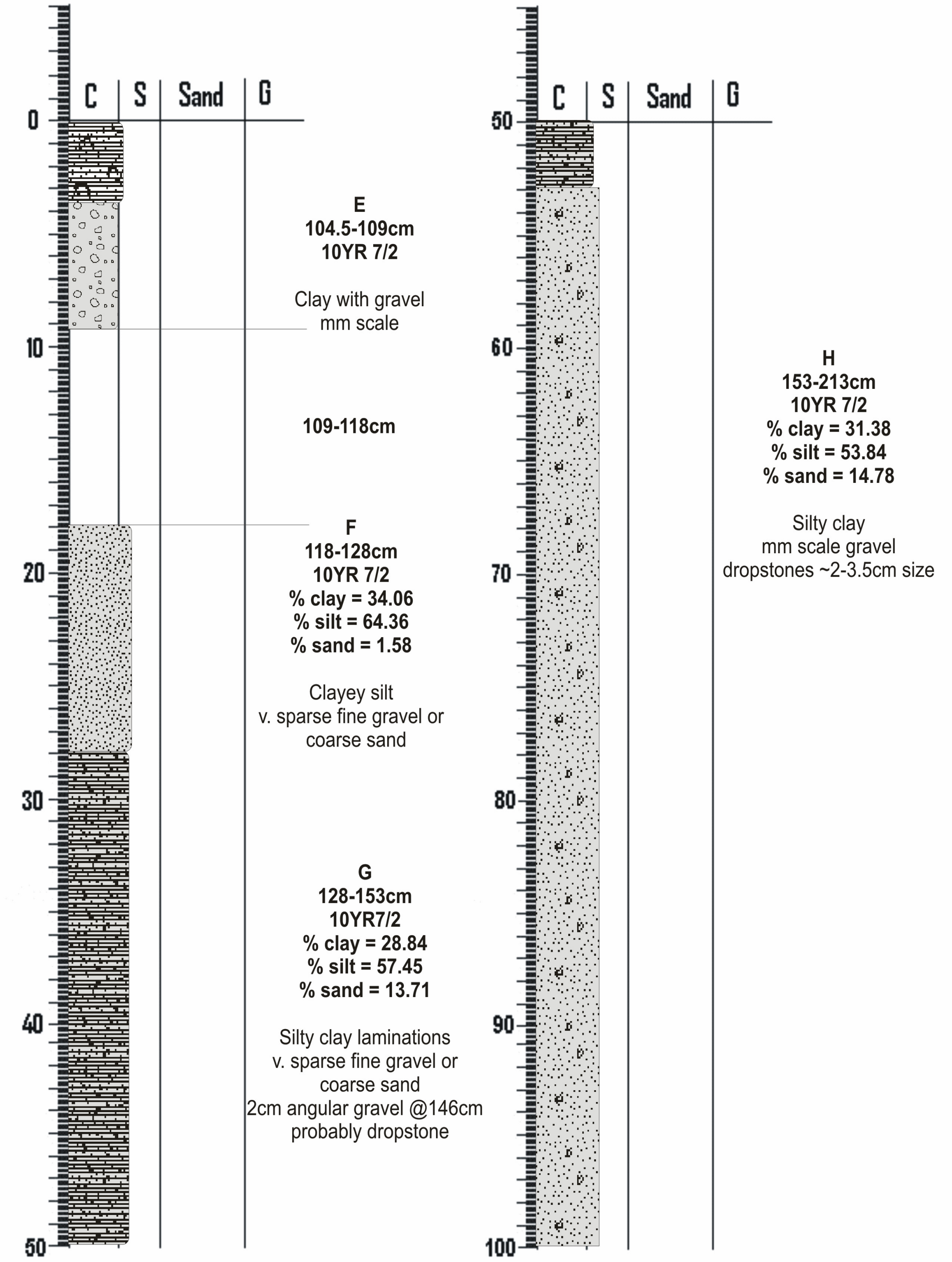
No bedding present
Last roots at 83cm
Clay rich



D
85.5-104.5cm
10YR 7/2
% clay = 33.24
% silt = 54.82
% sand = 11.94

mm scale bedding
Matrix supported gravel
<1cm, not sparse

MIP 28



E
104.5-109cm
10YR 7/2

Clay with gravel
mm scale

109-118cm

F
118-128cm
10YR 7/2
% clay = 34.06
% silt = 64.36
% sand = 1.58

Clayey silt
v. sparse fine gravel or
coarse sand

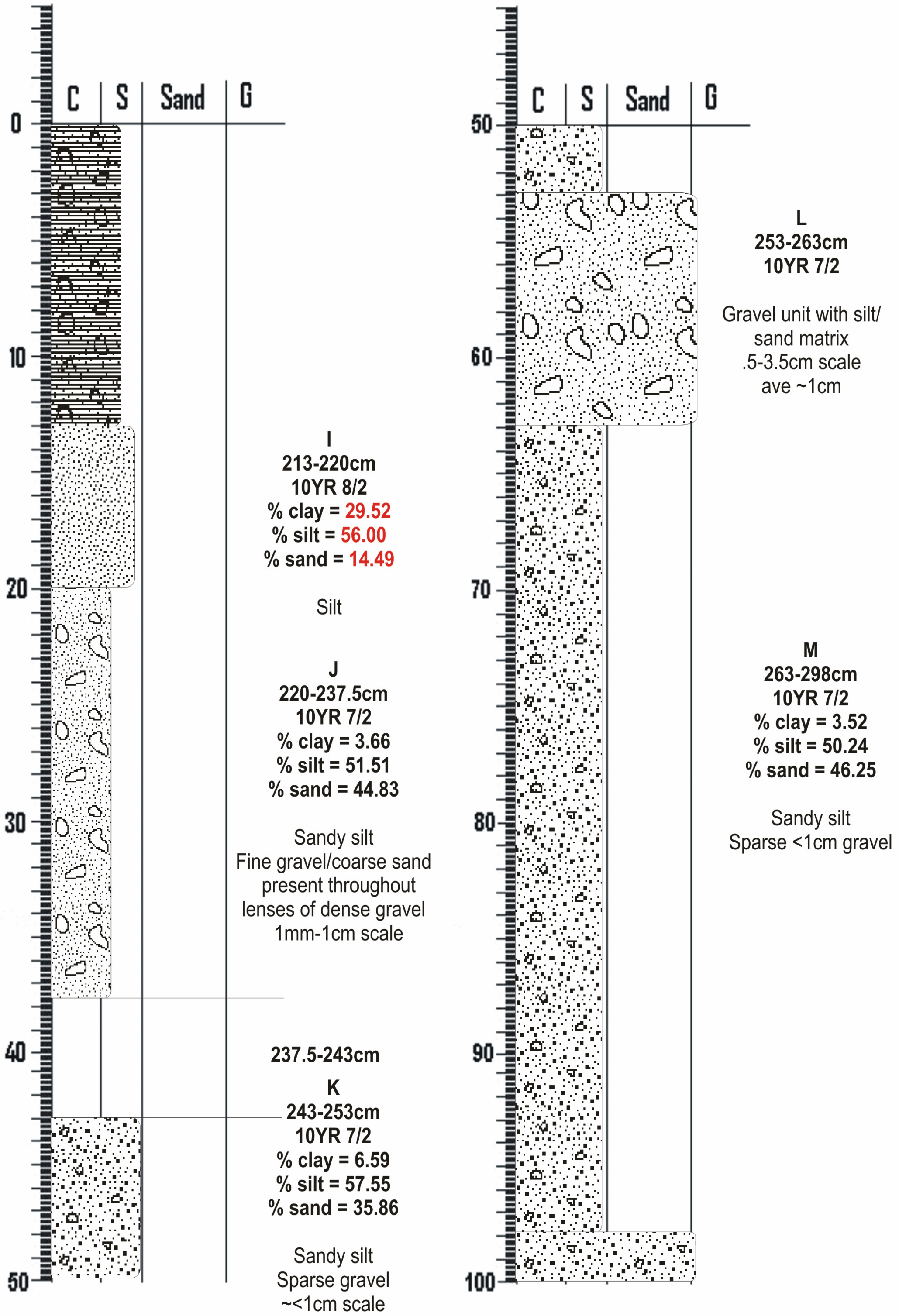
G
128-153cm
10YR7/2
% clay = 28.84
% silt = 57.45
% sand = 13.71

Silty clay laminations
v. sparse fine gravel or
coarse sand
2cm angular gravel @146cm
probably dropstone

H
153-213cm
10YR 7/2
% clay = 31.38
% silt = 53.84
% sand = 14.78

Silty clay
mm scale gravel
dropstones ~2-3.5cm size

MIP 28



I
213-220cm
10YR 8/2
% clay = 29.52
% silt = 56.00
% sand = 14.49

Silt

J
220-237.5cm
10YR 7/2
% clay = 3.66
% silt = 51.51
% sand = 44.83

Sandy silt
Fine gravel/coarse sand
present throughout
lenses of dense gravel
1mm-1cm scale

237.5-243cm

K
243-253cm
10YR 7/2
% clay = 6.59
% silt = 57.55
% sand = 35.86

Sandy silt
Sparse gravel
~<1cm scale

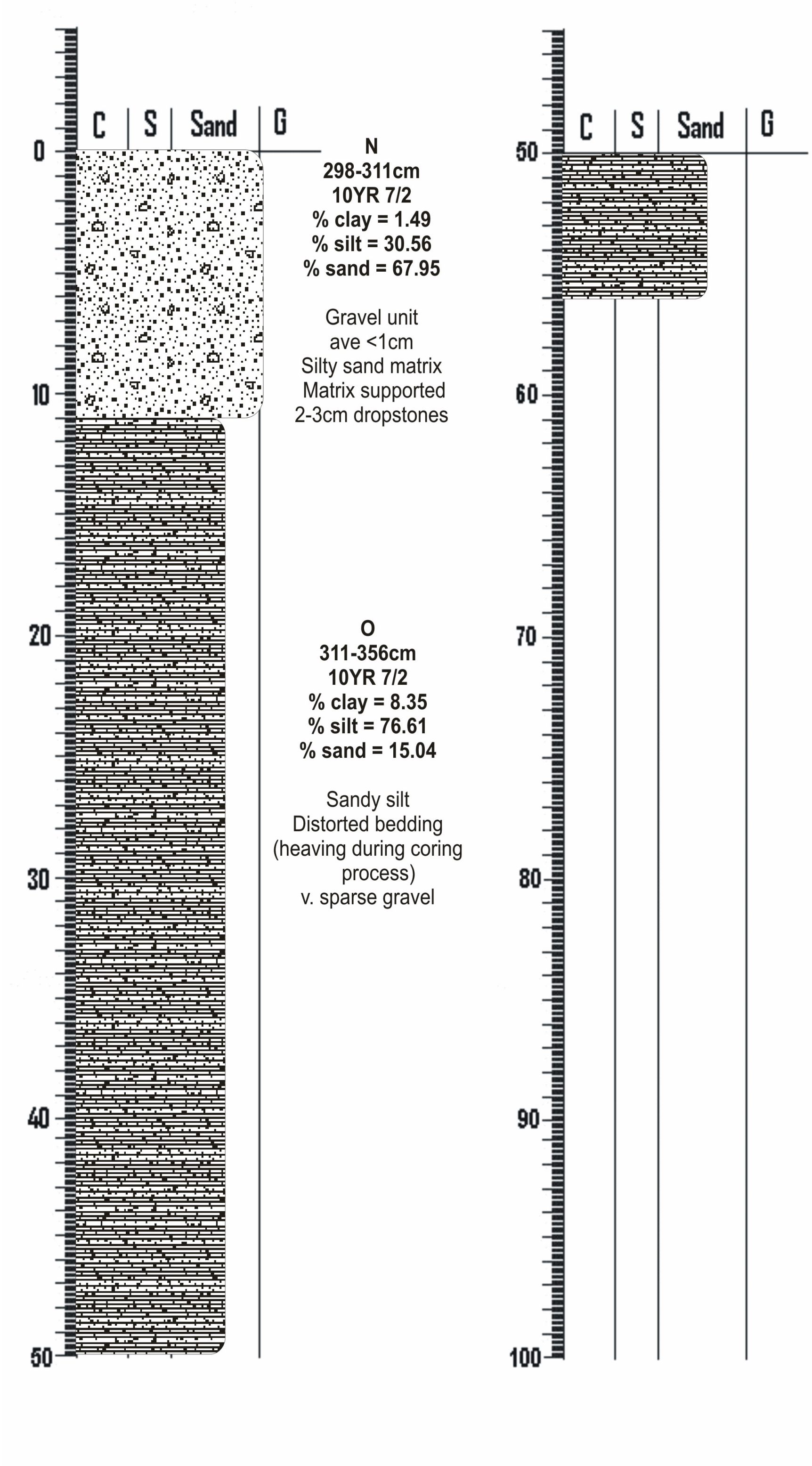
L
253-263cm
10YR 7/2

Gravel unit with silt/
sand matrix
.5-3.5cm scale
ave ~1cm

M
263-298cm
10YR 7/2
% clay = 3.52
% silt = 50.24
% sand = 46.25

Sandy silt
Sparse <1cm gravel

MIP 28



N
298-311cm
10YR 7/2
% clay = 1.49
% silt = 30.56
% sand = 67.95

Gravel unit
ave <1cm
Silty sand matrix
Matrix supported
2-3cm dropstones

O
311-356cm
10YR 7/2
% clay = 8.35
% silt = 76.61
% sand = 15.04

Sandy silt
Distorted bedding
(heaving during coring
process)
v. sparse gravel

Appendix C

Sampling Data
Historic Water Levels
BTEX Components and MTBE over Time
TPH, BTEX, and MTBE over Time
BTEX, MTBE, and DO over Time

Sampling Data

Data was compiled from HKM 2003, 2005, 2006 and Loustaunau 2003.

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M2	12/11/2002	3051.1	20	4281	9070	2.71	1640	1710	131	800
	3/25/2003	3051.85								
	6/18/2003	3051.23	19	4670	8760	2.61	1860	1890	147	773
	7/7/2004	3051.12	98	6952	14300	2.08	2560	2890	232	1270
	6/16/2005		20	1544	2820		655	570	50	269

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M3	3/25/1996			7385	11900		2930	3040	125	1290
	8/22/1996		343	8934	14800		3680	3830	104	1320
	12/3/1996		32	1825	3250		973	582	16	254
	2/25/1997		111	6008	10500		3160	1890	55	903
	5/13/1997		159	7618	13500	1.23	3020	3070	118	1410
	9/17/1997	3053.3	26	2653	5250	1.58	1220	950	21	462
	12/18/1997	3052.64	20	1266	3100	2	630	402	26	208
	3/10/1998	3053.06	20	1448	4740	4.61	787	395	21	245
	6/9/1998	3053.22	109	4643	9650	1.91	1730	1800	103	1010
	9/17/1998	3052.65	430	16756	35700	1.57	6690	6040	256	3770
	11/17/1998	3052.06	2	1003	2480	2.62	556	251	16	180
	3/11/1999	3052.69	200	2851	7680	1	1190	904	58	699
	6/20/1999	3051.62	20	544	2170		422	55	5	62
	9/27/1999	3051.24	10	1062	2560	1.4	426	420	29	187
	12/6/1999	3051.19	1	150	364	1.2	61	43	7.1	38.9
	3/15/2000	3052.29	10	558	2110	1.92	328	131	25	74
	6/20/2000	3051.57	1	332.5	2020	0.4	222	51	5.5	54
	9/15/2000	3051.82	1.3	31.1	134		29	0.75	0.5	0.85
	11/9/2000	3051.72	2	100	236	1.2	54	16	5	25
	4/2/2001	3052.88	1	106.6	533	1.95	52	19	6.6	29
	7/10/2001	3052.47	2	50.9	309	3.42	42	3.8	0.5	4.6
	9/26/2001	3051.65	1	33.05	63	1.35	18	8.2	0.95	5.9
	3/6/2002	3050.96	1	4.4	20	2.89	2.9	0.5	0.5	0.5
	5/21/2002	3051.45	1	11.44	55	3.09	10	0.44	0.5	0.5
	12/11/2002	3050.9								
	3/24/2003	3051.6								
	6/17/2003	3051.05								
	7/7/2004	3050.78	1	2.22	20	7.28	0.5	0.72	0.5	0.5
	6/16/2005		1	31.1	269		2.3	7.7	4.1	17

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M4	3/25/1996			10987			4420	4110	259	2198
	5/30/1996		11	601.5	1850		350	171	5.5	75
	8/22/1996		268	15963	29700		6170	6850	373	2570
	12/3/1996		932	29345	46600		10800	13100	665	4780
	2/25/1997		220	11127	21600	0.6	4600	4290	247	1990
	5/13/1997		406	14024	26100	0.96	5530	5620	414	2460
	9/16/1997	3052.67	864	23010	42000	1.01	9210	9360	620	3820
	12/18/1997	3052.12	2160	33531	54000	1.45	12400	14000	921	6210
	3/10/1998	3052.71	1810	45280	91700	4.61	17200	19400	1080	7600
	6/9/1998	3052.67	1230	22840	40600	0.81	9370	9150	590	3730
	9/17/1998	3052.1	886	17289	31700	1.18	7160	6800	489	2840
	11/17/1998	3051.54	1740	30366	54400	2.41	12600	12100	836	4830
	3/11/1999	3052.36	1640	27662	47800	1.8	12200	10100	792	4570
	6/15/1999	3051.05	1820	26950	59300		10900	10400	1020	4630
	9/27/1999	3050.58	2530	28620	58400	1.2	12100	9770	1110	5640
	12/6/1999	3050.74	2620	33670	53600	0.66	13500	12400	1130	6640
	3/15/2000	3052	2470	20632	44800	1	9320	6940	722	3650
	6/20/2000	3051.04	1920	20404	44600	0.6	10800	5470	654	3480
	9/15/2000	3051.23	2090	19080	54400	1.2	7880	4910	1040	5250
	11/9/2000	3051.28	2690	22994	45700	0.9	11200	6100	944	4750
	4/3/2001	3052.8	1420	7582	19000	2.54	5170	635	297	1480
	7/10/2001	3051.95	685	79.7	627	8.32	26	28	2.7	23
	9/26/2001	3051.01	528	266.5	1130	4.6	99	101	7.5	59
	3/6/2002	3050.59	548	4.1	519	5.92	0.5	0.5	0.5	2.6
	5/22/2002	3051.59	501	78.5	688	12.18	32	32	0.5	14
	12/11/2002	3050.41	428	10.84	536	8.83	0.92	0.92	6.9	2.1
	3/24/2003	3051.31								
	6/17/2003	3050.49	267	7.15	235	10.09	0.5	0.5	5.4	0.75
	7/8/2004	3049.3	42	3.9	57	9.28	0.5	0.5	2.4	0.5
	6/15/2005		62	3.83	48		1.9	0.5	0.93	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M6	3/25/1996			2.5	20		0.5	0.5	0.5	1
	5/30/1996		2	2.5	20		0.5	0.5	0.5	1
	8/22/1996		2	2.5	20		0.5	0.5	0.5	1
	12/3/1996		2	3.3	20		0.5	0.5	0.5	1.8
	2/25/1997		2	2.5	20	6.06	0.5	0.5	0.5	1
	5/13/1997		2	2.5	20	5.14	0.5	0.5	0.5	1
	9/17/1997	3052.41	2	2.5	20	5.53	0.5	0.5	0.5	1
	12/18/1997	3051.78	2	2.5	20	5.35	0.5	0.5	0.5	1
	3/10/1998	3052.31	2	2.5	20	7.2	0.5	0.5	0.5	1
	6/9/1998	3051.45	2	2.5	20	5.4	0.5	0.5	0.5	1
	9/17/1998	3051.92	2	2.5	20	5.06	0.5	0.5	0.5	1
	11/17/1998	3051.22	2	2.5	20	6.58	0.5	0.5	0.5	1
	3/11/1999	3052.13								
	6/15/1999	3050.29	2	2.5	20	6.8	0.5	0.5	0.5	1
	9/27/1999	3050.29								
	12/6/1999	3050.39	1	2	20	5.4	0.5	0.5	0.5	0.5
	3/14/2000	3051.71								
	6/20/2000	3050.69	1	16.51	31	5.2	3.2	7.7	0.61	5
	9/15/2000	3050.99								
	11/9/2000	3050.98	1	11.69	20	7.8	5.7	3.5	0.59	1.9
	4/2/2001	3052.52								
	7/9/2001	3051.72	1	2	20	5.7	0.5	0.5	0.5	0.5
	3/6/2002	3050.21	1	2	20	5.44	0.5	0.5	0.5	0.5
	5/22/2002	3050.84	1	17	39	7.15	14	1.3	0.5	1.2
	12/10/2002	3050.04								
	3/24/2003	3050.97								
	6/17/2003	3050.13								
	7/7/2004	3049.72	102	2.7	55	6.44	0.5	0.5	0.5	1.2
	6/15/2005		21	2	20		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M9	3/25/1996			1.72	20		0.5	0.5	0.5	0.22
	5/30/1996		2	2.5	20		0.5	0.5	0.5	1
	8/22/1996		2	2.5	20		0.5	0.5	0.5	1
	12/3/1996		2	2.5	20		0.5	0.5	0.5	1
	2/25/1997		2	2.5	20	4.87	0.5	0.5	0.5	1
	5/13/1997		2	2.5	20	5.26	0.5	0.5	0.5	1
	9/17/1997	3048.8	2	2.5	20	2.28	0.5	0.5	0.5	1
	12/18/1997	3048.67	2	2.5	20	3.03	0.5	0.5	0.5	1
	3/10/1998	3052.62	2	2.5	20	3.28	0.5	0.5	0.5	1
	6/9/1998	3049.11	2	2.5	20	3.45	0.5	0.5	0.5	1
	9/17/1998	3048.69	2	2.5	20	3.64	0.5	0.5	0.5	1
	11/17/1998	3048.2	2	2.5	20	3.61	0.5	0.5	0.5	1
	3/11/1999	3049.54								
	6/15/1999	3047.25	2	2.5	20	0.45	0.5	0.5	0.5	1
	9/27/1999	3046.9								
	12/6/1999	3047.32	1	2	20	1.48	0.5	0.5	0.5	0.5
	3/14/2000	3049.47								
	6/20/2000	3047.43	1	2	20	1.13	0.5	0.5	0.5	0.5
	11/9/2000	3048.12	1	2	20	1.29	0.5	0.5	0.5	0.5
	4/2/2001	3050.58								
	7/10/2001	3048.71	1	2	20	2.74	0.5	0.5	0.5	0.5
	9/25/2001	3047.14								
	3/6/2002	3047.44	1	2	20	2.51	0.5	0.5	0.5	0.5
	5/22/2002	3047.73	1	2	20	3.27	0.5	0.5	0.5	0.5
	12/11/2002	3047.18								
	3/24/2003	3048.51								
	6/17/2003	3046.66								
	7/8/2004	3046.84	1	2	20	4.37	0.5	0.5	0.5	0.5
	6/15/2005		1	2	20		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M10	3/25/1996			99.2	299		86	6.5	0.5	6.2
	5/30/1996		1460	482.5	1570		443	29	0.5	10
	8/22/1996		7340	2204.5	7790		2170	23	0.5	11
	12/3/1996		2900	1551.3	3880		1410	79	9.3	53
	2/25/1997		190	21.35	112	4.07	19	0.85	0.5	1
	5/13/1997		2800	1202.4	3820	3.12	1080	78	1.4	43
	9/17/1997	3048.54	4720	3521	7980	1.85	3010	264	13	234
	12/18/1997	3048.54	4570	3359	8270	2.47	2790	354	10	205
	3/10/1998	3049.61	6210	4399	11900	3.46	3680	435	18	266
	6/9/1998	3049.11	3410	1934	5830	2.84	1740	121	10	63
	9/17/1998	3048.61	1660	729.2	3090	2.24	656	35	1.2	37
	11/17/1998	3048.09	4650	3434	9760	2.84	3110	184	17	123
	3/11/1999	3049.5	120	44.458	129	0.48	42	0.958	0.5	1
	6/15/1999	3047.25	3580	1979	5770	0.43	1780	74	14	111
	9/27/1999	3046.84	1380	5305.8	10900	0.37	4550	438	8.8	309
	12/6/1999		804	333.8	874	0.28	328	2.9	0.5	2.4
	3/15/2000	3049.56	291	301.1	886	3.28	280	15	0.5	5.6
	6/20/2000	3047.39	3220	2775	8190	0.72	1480	819	56	420
	9/15/2000	3047.65	1510	1717	5920	0.36	1440	202	8	67
	11/9/2000	3047.95	2090	1832.9	3910	0.66	1630	121	4.9	77
	4/3/2001	3050.76	461	297.6	949	1.65	264	18	0.6	15
	7/10/2001	3048.17	3370	7236	15300	0.81	6060	745	44	387
	9/26/2001	3047.12	3630	11483	22000	0.56	9020	1170	213	1080
	3/6/2002	3047.44	3290	5646	15300	0.38	5240	262	27	117
	5/22/2002	3047.59	5580	8116	23900	0.53	6810	675	170	461
	12/11/2002	3047.16	2400	6774	14400	0.64	5510	612	184	468
	3/25/2003	3048.51	1480	2933	7050	0.41	2740	109	22	62
	6/18/2003	3046.67	4380	7776	19500	3.02	7220	276	83	197
	7/8/2004	3046.81	4060	8603	19800	2.41	8060	290	127	126
	6/14/2005		1870	3189	7930		3110	43	9	27

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M11	3/25/1996			1.69	20		0.5	0.5	0.5	0.19
	8/22/1996		2	2.5	20		0.5	0.5	0.5	1
	5/12/1997		2	2.5	20	5.16	0.5	0.5	0.5	1
	9/16/1997	3054.2	2	2.5	20		0.5	0.5	0.5	1
	12/18/1997	3053.61	2	2.5	20	4.96	0.5	0.5	0.5	1
	3/10/1998	3053.82	2	2.5	20	4.7	0.5	0.5	0.5	1
	6/9/1998	3053.91	2	2.5	20	4.99	0.5	0.5	0.5	1
	9/17/1998	3053.44	1	4	20	43.68	1	1	1	1
	11/17/1998	3052.9	2	2.5	20	4.78	0.5	0.5	0.5	1
	3/11/1999	3053.32								
	6/15/1999	3053.32	2	2.5	20	3.6	0.5	0.5	0.5	1
	9/27/1999	3052.11								
	12/6/1999	3052.07	1	2	20	5.6	0.5	0.5	0.5	0.5
	3/14/2000	3052.88								
	6/19/2000	3052.32	1	2	20	4.2	0.5	0.5	0.5	0.5
	11/8/2000	3052.51	1	2	20	5.5	0.5	0.5	0.5	0.5
	4/2/2001	3053.39								
	7/9/2001	3053.28	1.5	2	20	4.5	0.5	0.5	0.5	0.5
	9/25/2001	3052.51								
	3/26/2002	3052.21	1	2	20	6.88	0.5	0.5	0.5	0.5
	5/21/2002	3052.17	1	2	20	7.9	0.5	0.5	0.5	0.5
	12/10/2002	3051.75								
	6/17/2003	3051.89								
	7/7/2004	3051.82								

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M12	3/25/1996			55970	94400		25100	21000	1300	8570
	5/30/1996		19800	57274	101000		25700	22000	854	8720
	12/3/1996		15800	56660	94100		22900	23000	1440	9320
	2/25/1997		11100	59420	87900	0.57	26600	23600	1180	8040
	9/17/1997	3052.07	8860	63600	99300	1.93	28500	25200	1430	8470
	12/18/1997	3051.56	9540	53720	98500	1.46	22800	21100	1580	8240
	3/10/1998	3052.11	8600	66350	120000	3.68	28600	26500	1610	9640
	6/9/1998	3051.26	8060	58720	94000	2.46	23900	24600	1340	8880
	9/17/1998	3051.62	6480	50030	84700	1.91	19100	19800	1540	9590
	11/17/1998	3050.98	4950	41810	68900	2.88	16400	16800	1220	7390
	3/11/1999	3051.96	3500	26850	40700	1.4	10900	9530	880	5540
	6/20/1999		2060	12504	21900		7270	1820	604	2810
	9/27/1999	3050.02	2260	10198	21400	3	5850	2490	400	1458
	12/6/1999	3050.16	1940	17834	27600	1.67	11900	3950	564	1420
	3/15/2000	3051.6	3910	17704	31700	1.2	11500	4340	434	1430
	6/20/2000	3050.46	3870	17349	33900	0.4	11100	4380	409	1460
	9/15/2000	3050.72	5940	20486	60400	0.5	9870	6410	806	3400
	11/9/2000	3050.73	5470	24274	40000	1	15900	6010	584	1780
	4/3/2001	3052.4	2840	10923	21900		7100	2500	73	1250
	7/10/2001	3051.43	4840	21123	45900	3.49	11000	7180	493	2450
	9/26/2001	3050.39	5590	27952	48400	2.2	14000	10400	592	2960
	3/6/2002	3050.04	4110	17789	32600	3.1	9160	5560	359	2710
	5/22/2002	3050.58	6310	15036	31300	2.76	8100	4660	336	1940
	12/11/2002	3049.91	5770	27653	58300	1.38	12000	9290	983	5380
	3/25/2003	3050.86	7170	19879	44200	0.89	9580	5740	719	3840
	6/17/2003	3049.82	8190	15268	32800	2.14	8450	3790	348	2680
	7/8/2004	3049.79	6670	312	4580	2.69	250	14	15	33
	6/15/2005		2310	8.57	1890		4.1	1.2	0.77	2.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M13	12/3/1996		221	2.5	100		0.5	0.5	0.5	1
	2/25/1997		271	18	122	3.2	16	0.5	0.5	1
	5/12/1997		197	26	177	3.6	24	0.5	0.5	1
	9/16/1997	3039.07	97	10	68	2.56	8	0.5	0.5	1
	12/18/1997	3039.23	204	47	201	3.64	45	0.5	0.5	1
	3/10/1998	3039.93	193	23	133	4.86	21	0.5	0.5	1
	6/9/1998	3039.42	103	3	66	3.57	1	0.5	0.5	1
	9/17/1998	3039.41	34	4	25	2.45	1	1	1	1
	11/17/1998	3039.22	57	8	51	2.85	6	0.5	0.5	1
	3/11/1999	3039.22								
	6/15/1999	3038.94	72	11	58	0.65	9	0.5	0.5	1
	9/27/1999	3038.23								
	12/6/1999	3038.64	274	48.5	223	1.42	47	0.5	0.5	0.5
	3/14/2000	3040.15								
	6/19/2000	3038.83	1810	287.5	1790	0.86	286	0.5	0.5	0.5
	9/15/2000	3039.28								
	11/9/2000	3039.77	1950	31.5	1120	1.59	30	0.5	0.5	0.5
	4/3/2001	3040.96	1940	501	2850	0.55	498	2	0.5	0.5
	7/10/2001	3039.04	2090	772	3240	3.41	769	2	0.5	0.5
	9/25/2001	3038.79	1520	459.5	1930	0.41	458	0.5	0.5	0.5
	3/5/2002	3039.3	931	122.5	992	0.46	121	0.5	0.5	0.5
	5/21/2002	3039.3	1300	16.5	951	3.88	15	0.5	0.5	0.5
	12/10/2002	3039.01	1330	5.7	967	1.6	4.2	0.5	0.5	0.5
	3/24/2003	3039.86								
	6/17/2003	3038.55	1970	225.5	2010	0.44	224	0.5	0.5	0.5
	7/7/2004	3038.49	1430	10.9	1250	3.1	9.4	0.5	0.5	0.5
	6/13/2005		1060	2	741		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M14	5/12/1997		6.9	2.5	20	4.51	0.5	0.5	0.5	1
	9/16/1997	3035.64	153	2.5	76	1.9	0.5	0.5	0.5	1
	12/18/1997	3035.88	30	2.5	22	4.32	0.5	0.5	0.5	1
	3/10/1998	3036.43	6.8	2.5	20	4.51	0.5	0.5	0.5	1
	6/9/1998	3034.31	4.4	2.5	20	2.17	0.5	0.5	0.5	1
	9/17/1998	3035.92	9.5	2.5	20	3.2	0.5	0.5	0.5	1
	11/17/1998	3036.05	15	2.5	20	5.15	0.5	0.5	0.5	1
	3/11/1999	3035.94								
	6/15/1999	3035.14	4	2.5	20	0.45	0.5	0.5	0.5	1
	9/27/1999	3035.43								
	12/6/1999	3035.85	292	2	191	0.38	0.5	0.5	0.5	0.5
	3/14/2000	3036.32								
	6/19/2000	3035.44	178	3.6	133	0.77	2.1	0.5	0.5	0.5
	9/15/2000	3035.8	208	6.3	189	0.35	4.8	0.5	0.5	0.5
	11/9/2000	3036.11	194	2	126	0.94	0.5	0.5	0.5	0.5
	4/3/2001	3036.52	63	2	55	1.9	0.5	0.5	0.5	0.5
	7/10/2001	3035.27	151	41.5	160	4.26	40	0.5	0.5	0.5
	9/25/2001	3035.62	229	66.5	288	0.39	65	0.5	0.5	0.5
	3/5/2002	3036.51	74	2	59	0.61	0.5	0.5	0.5	0.5
	5/21/2002	3036.5	29	2	22	0.62	0.5	0.5	0.5	0.5
	12/10/2002	3035.92	290	2	194	0.55	0.5	0.5	0.5	0.5
	3/24/2003	3036.27								
	6/17/2003	3034.3	33	2	28	0.28	0.5	0.5	0.5	0.5
	7/7/2004	3035.46	124	7	126	5.75	5.5	0.5	0.5	0.5
	6/13/2005		57	2	45		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M16	5/13/1997		2	2.5	20	4.23	0.5	0.5	0.5	1
	9/17/1997	3052.64	2	2.5	20	4.53	0.5	0.5	0.5	1
	12/18/1997	3051.86	2	2.5	20	2.45	0.5	0.5	0.5	1
	3/10/1998	3052.59	2	2.5	20	6.91	0.5	0.5	0.5	1
	6/9/1998	3052.62	2	2.5	20	3.8	0.5	0.5	0.5	1
	9/17/1998	3052.86	2	2.5	20	3.23	0.5	0.5	0.5	1
	11/17/1998	3051.33	2	2.5	20	4.66	0.5	0.5	0.5	1
	6/15/1999	3050.8	2	2.5	20	3.64	0.5	0.5	0.5	1
	12/6/1999	3050.55	1	2	20	4.26	0.5	0.5	0.5	0.5
	3/14/2000	3051.34								
	6/20/2000	3050.85	1	2	20	4.87	0.5	0.5	0.5	0.5
	9/15/2000	3050.96								
	11/9/2000	3051.08	1	2	20	1.2	0.5	0.5	0.5	0.5
	4/3/2001	3052.94	1	2	20	4.27	0.5	0.5	0.5	0.5
	7/9/2001	3051.65	1	2	20	7.19	0.5	0.5	0.5	0.5
	3/6/2002	3050.35	1	2	20	4.61	0.5	0.5	0.5	0.5
	5/22/2002	3052.02	1	2	20	3.03	0.5	0.5	0.5	0.5
	12/11/2002	3050.19	1	2	20	4.05	0.5	0.5	0.5	0.5
	3/24/2003	3051.18								
	6/18/2003	3050.26	1	2	20	7.96	0.5	0.5	0.5	0.5
	7/8/2004	3049.81	1	2	20	6.88	0.5	0.5	0.5	0.5
	6/15/2005		1	2	20		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M17	5/13/1997		33	2.5	24	1.99	0.5	0.5	0.5	1
	9/17/1997	3048.49	63	2.5	42	1.92	0.5	0.5	0.5	1
	12/18/1997	3048.56	86	2.5	62	2.35	0.5	0.5	0.5	1
	3/10/1998	3049.83	80	2.5	47	5.41	0.5	0.5	0.5	1
	6/9/1998	3049.13	80	17	64	2.2	15	0.5	0.5	1
	9/17/1998	3048.56	156	5.6	86	1.9	3.6	0.5	0.5	1
	11/17/1998	3048.12	210	7.5	165	2.3	5.5	0.5	0.5	1
	3/11/1999	3049.5	123	2.5	61	0.49	0.5	0.5	0.5	1
	6/15/1999	3047.09	268	140.29	406	0.44	138	0.79	0.5	1
	9/27/1999	3046.7	562	422.8	1490	0.31	418	2.6	1.2	1
	12/6/1999	3047.19	625	615.09	1680	0.66	611	2.2	0.69	1.2
	3/14/2000	3049.55	738	895.7	2420	1.58	888	4.6	1.1	2
	6/20/2000	3047.21	799	1328.82	3230	0.75	1320	6.9	0.62	1.3
	9/15/2000	3047.41	1430	1569.5	5620	0.47	1550	8.5	5.2	5.8
	11/9/2000	3047.78	4270	5511.7	1140	0.76	5410	75	3.7	23
	4/3/2001	3050.78	4470	4081.5	11700	0.42	3980	72	0.5	29
	7/10/2001	3048.7	5410	4955.2	12400	0.55	4840	81	5.2	29
	9/26/2001	3046.99	8630	7344.5	19200	0.47	7200	100	0.5	44
	3/6/2002	3047.35	6940	5396.5	18100	0.62	5260	96	0.5	40
	5/22/2002	3047.42	6510	5563.5	16700	0.49	5440	90	3.5	30
	12/11/2002	3047.06	12000	11545	35700	0.82	11100	298	6	141
	3/24/2003	3048.42								
	6/18/2003	3046.71	10700	12193	35900	1.91	11700	265	27	201
	7/8/2004	3046.72	8330	1408	27700	2.09	1080	237	4	87
	6/14/2005		4110	4765.9	13000		4680	59	3.9	23

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M18	9/17/1998	3051.63	739	18719	35300	2.7	3010	8660	799	6250
	11/17/1998	3051.12	1190	14844	28200	2.39	2550	6360	894	5040
	3/11/1999	3052.05	1990	9680	23000	0.8	3840	1320	1020	3500
	6/21/1999	3050.65	2190	10862	23100		5870	1630	832	2530
	9/27/1999	3050.2								
	3/15/2000	3051.68	3540	9218	20200	1.4	6960	1510	231	517
	6/20/2000	3050.63	4310	10259	24000	0.5	9150	429	256	424
	9/15/2000	3050.87	5520	7515	23700		6860	141	175	339
	11/9/2000	3050.84	7190	12170	23500	1.7	11200	526	111	333
	4/3/2001	3052.26	4870	9568	22400		6010	2130	138	1290
	7/10/2001	3051.53	2350	6286	16100	3.52	4580	957	199	550
	5/22/2002	3050.75								
	3/24/2003	3050.97								
	6/15/2005		297	2.6	214		1.1	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M19	9/17/1998	3035	159	2.5	80	3.59	0.5	0.5	0.5	1
	11/17/1998	3034.95	278	2.51	213	3.84	0.51	0.5	0.5	1
	3/11/1999	3035.25	101	2.7	48	0.7	0.7	0.5	0.5	1
	6/15/1999	3033.97	139	3.9	101	0.46	1.9	0.5	0.5	1
	9/27/1999	3034.09	148	3	122	0.24	1	0.5	0.5	1
	12/6/1999	3034.81	887	2	559	0.53	0.5	0.5	0.5	0.5
	1/31/2000		1200	4			1	1	1	1
	3/14/2000	3035.64	841	2.8	657	1.15	1.3	0.5	0.5	0.5
	6/19/2000	3035.54	384	8.6	331	0.74	7.1	0.5	0.5	0.5
	9/15/2000	3035.61	247	8.2	230	0.36	6.7	0.5	0.5	0.5
	11/8/2000	3035.7	401	2.8	262	0.83	1.3	0.5	0.5	0.5
	4/3/2001	3035.71	516	11.1	416	1.85	9.6	0.5	0.5	0.5
	7/10/2001	3033.83	547	4.3	348	2.68	2.8	0.5	0.5	0.5
	9/25/2001	3035.31	418	2	350	0.44	0.5	0.5	0.5	0.5
	3/5/2002	3035.58	628	2	509	0.5	0.5	0.5	0.5	0.5
	5/21/2002	3035.66	651	15.5	517	0.64	14	0.5	0.5	0.5
	12/10/2002	3035.58	732	2	486	0.54	0.5	0.5	0.5	0.5
	3/25/2003	3035.54	854	2.8	513	0.38	1.3	0.5	0.5	0.5
	6/17/2003	3035.04	994	2.41	868	0.27	0.91	0.5	0.5	0.5
	7/7/2004	3035.51	1220	2	1120	3	0.5	0.5	0.5	0.5
	6/13/2005		2390	5.2	1620		3.7	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M20	9/17/1998	3036.29	2.7	2.5	20	3.35	0.5	0.5	0.5	1
	11/17/1998	3036.26	2.5	2.5	20	3.62	0.5	0.5	0.5	1
	3/11/1999	3036.57								
	6/15/1999	3035.73	11	2.5	20		0.5	0.5	0.5	1
	9/27/1999	3035.72								
	12/6/1999	3036.16	9.2	2	20	2.85	0.5	0.5	0.5	0.5
	3/14/2000	3036.99								
	6/19/2000	3036.26	12	2	20	0.81	0.5	0.5	0.5	0.5
	9/15/2000	3036.56	15	2	21	0.42	0.5	0.5	0.5	0.5
	11/8/2000	3036.82	17	2	20	4.26	0.5	0.5	0.5	0.5
	4/3/2001	3037.41	29	2	25	0.47	0.5	0.5	0.5	0.5
	7/10/2001	3036.04	37	2.18	26		0.68	0.5	0.5	0.5
	9/25/2001	3035.95	45	2	48	2.29	0.5	0.5	0.5	0.5
	3/5/2002	3036.67	87	2	68	0.79	0.5	0.5	0.5	0.5
	5/21/2002	3036.82	69	1.91	51	0.56	0.5	0.5	0.41	0.5
	12/10/2002	3036.47	52	2	37	0.78	0.5	0.5	0.5	0.5
	3/24/2003	3036.89								
	6/17/2003	3035.94	91	2.05	72	1.36	0.5	0.5	0.55	0.5
	7/7/2004	3035.72	88	2	84	5.8	0.5	0.5	0.5	0.5
	6/13/2005		111	2	80		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M30	7/10/2001	3048.47	1100	3557.2	9740	0.32	3530	11	1.2	15
	9/26/2001	3047.31	1270	3225.74	6590	0.43	3200	13	0.74	12
	3/6/2002	3047.67	833	1828.2	4750	0.57	1820	1.6	0.5	6.1
	5/22/2002	3048	844	4445.8	13200	0.45	4370	37	3.8	35
	12/11/2002	3047.36	1150	7924	16400	0.43	7700	167	4	53
	3/25/2003	3048.78	1140	7232	13400	0.43	7040	110	17	65
	6/18/2003	3046.91	940	5111.5	15500	1.33	4960	109	0.5	42
	7/8/2004	3046.99	1230	4548.8	12100	1.34	4500	29	4.8	15
	6/14/2005		797	3330.23	9310		3310	8.4	0.83	11

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M31	7/9/2001	3052.08	1	2	20	4.24	0.5	0.5	0.5	0.5
	9/25/2001	3051.09								
	3/6/2002	3050.7	1	2	20	2.34	0.5	0.5	0.5	0.5
	5/22/2002	3052.9	1	30.63	48	5.6	14	10	0.83	5.8
	12/11/2002	3050.54	1	10.3	19	3.35	3.9	3.7	0.5	2.2
	3/24/2003	3051.78								
	6/17/2003	3050.91	1	2	20	6.08	0.5	0.5	0.5	0.5
	7/8/2004	3050.34	1	2	20	2.79	0.5	0.5	0.5	0.5
	6/15/2005		1	2	20		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M32	7/10/2001	3036.98	1	2	20	4.5	0.5	0.5	0.5	0.5
	9/25/2001	3036.95								
	3/5/2002	3037.34	1	2	20	1.36	0.5	0.5	0.5	0.5
	5/21/2002	3037.29	1	2	20	1.27	0.5	0.5	0.5	0.5
	12/10/2002	3037.07								
	3/24/2003	3037.68								
	6/17/2003	3036.66								
	7/7/2004	3036.52	1	2	20	0.66	0.5	0.5	0.5	0.5
	6/13/2005		1	2	20		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
M33	12/11/2002	3047.39	1	2	20	6.56	0.5	0.5	0.5	0.5
	3/24/2003	3048.91								
	6/18/2003	3047.06	1	2	20	4.71	0.5	0.5	0.5	0.5
	7/8/2004	3047.26	1	2	20	4.14	0.5	0.5	0.5	0.5
	6/14/2005		1	2	20		0.5	0.5	0.5	0.5

Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
MP01 25'	9/26/2001	3050.69	32	59.2	528	1.61	32	19	1.1	7.1
	3/26/2002	3050.27	22	164.2	264	2.3	83	66	2.2	13
	5/22/2002	3051.05	13	121.5	254	4.69	65	46	1.4	9.1
	12/11/2002	3050.12	5.8	121.4	171	1.71	51	46	3.4	21
	6/18/2003	3050.12	3.9	123.8	239	1.9	48	44	4.8	27
	7/8/2004	3046.95	459	3264	7160	0.66	2900	175	26	163
	6/14/2005		1	18.3	40		9.2	1.3	1.8	6
MP01 35'	7/24/2001	3051.5								
	9/26/2001	3050.7	8.9	25.24	96	1.52	11	8.4	0.54	5.3
	3/26/2002	3050.28	115	252.7	646	1.95	100	125	3.7	24
	5/22/2002	3051.05	24	197.7	353	3.31	130	55	1.7	11
	12/11/2002	3050.07	10	145	228	1.02	69	54	3	19
	3/24/2003	3051.12								
	6/18/2003	3050.1	23	234	445	0.48	109	78	7	40
	7/9/2004	3049.63	2	23.3	49		9.3	4.6	1	8.4
	6/14/2005		1	4.83	20		2	0.53	0.5	1.8
MP01 53'	7/24/2001	3051.46								
	9/26/2001	3050.59	118	159.4	4820	1.42	86	51	2.4	20
	3/26/2002	3050.18	199	490.5	8870	1.75	274	167	5.5	44
	5/22/2002	3050.92	385	3177	20400	3.35	1600	1220	44	313
	12/11/2002	3050	105	524.5	22500	0.72	294	166	7.5	57
	3/24/2003	3051.04								
	6/18/2003	3050.02	59	198.4	5400	0.31	110	56	4.4	28
	7/9/2004	3049.6	23	17.69	7390		9.4	2.7	0.69	4.9
	6/14/2005		6.8	16.74	9630		11	1.7	0.64	3.4
MP01 64'	7/24/2001	3051.15								
	9/26/2001	3050.58	322	188.7	23200	2.3	95	67	2.7	24
	3/26/2002	3050.2	898	2110	20000	2.71	1200	738	18	154
	5/22/2002	3050.79	738	3441	28800	3.34	1760	1320	41	320
	12/11/2002	3050.05	274	999	39200	0.65	615	297	11	76
	3/24/2003	3051.02								
	6/18/2003	3050.08	259	744	33300	0.35	445	215	11	73
	7/7/2004	3049.61	18	24.49	12200		16	4	0.79	3.7
	6/14/2005		14	24.04	15500		15	3.2	0.94	4.9

MP01 72'	7/24/2001	3051.65								
	9/26/2001	3050.63	431	534.8	1510	3.88	256	205	7.8	66
	3/26/2002	3050.2	562	2013	3020	2.77	1180	653	26	154
	5/22/2002	3050.83	1040	8146	12500		3110	3640	166	1230
	12/11/2002	3050.06	649	6453	12000	1.3	4160	1630	103	560
	3/24/2003	3051.02								
	6/18/2003	3050.03	293	699	2480	0.55	478	166	7	48
	7/7/2004	3049.66	50	27.11	2320		15	5	0.81	6.3
	6/14/2005		36	50.7	622		33	6.5	1.5	9.7

MP02 37'	7/10/2001	3048.53	18	18.52	1960	1.66	17	0.52	0.5	0.5
	9/25/2001	3047.28								
	3/6/2002	3047.69	4.3	30.57	417	3.15	29	0.57	0.5	0.5
	5/22/2002	3048.03	1.9	91.81	304	2.39	90	0.81	0.5	0.5
	12/11/2002	3047.35	2.3	42.44	68	0.65	41	0.44	0.5	0.5
	3/24/2003	3048.76								
	6/18/2003	3046.85	1	62.68	121	0.63	61	0.68	0.5	0.5
	7/7/2004	3046.96								
	6/14/2005		1	35.5	54		34	0.5	0.5	0.5

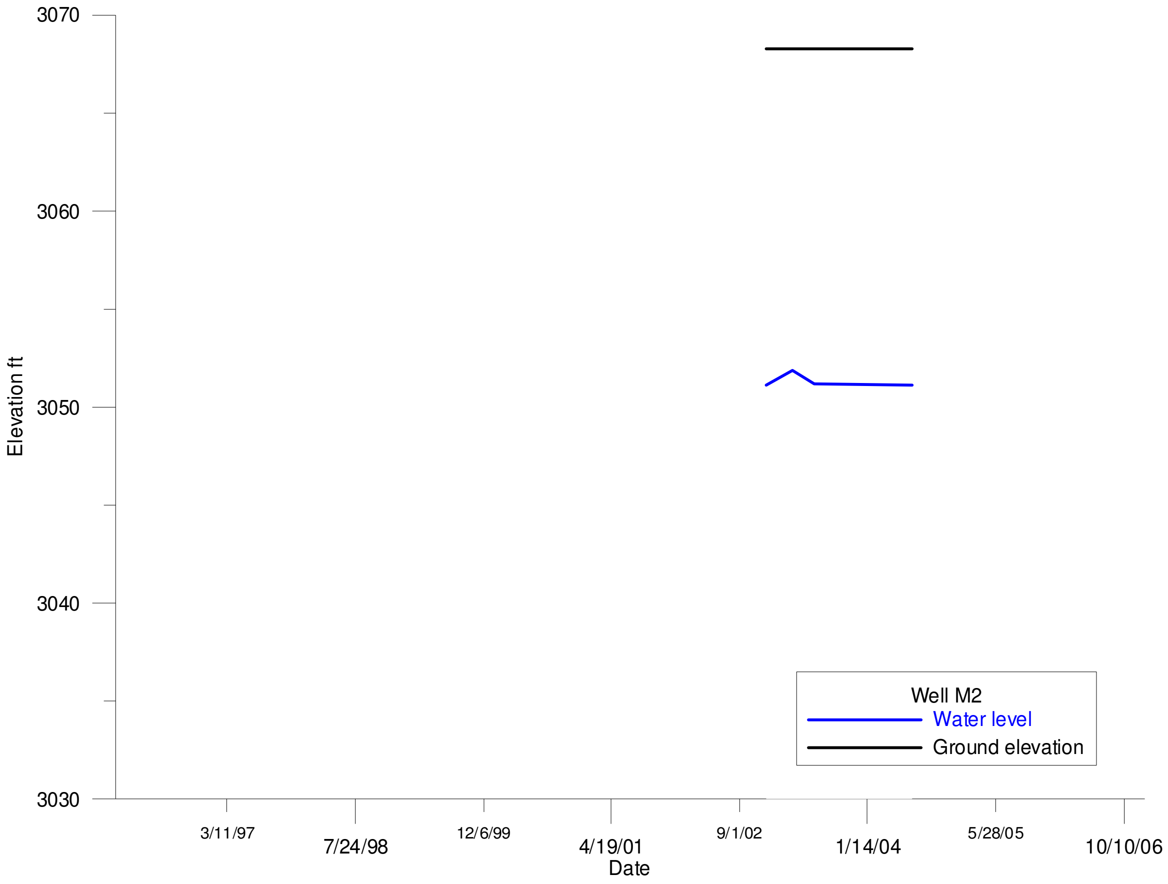
MP02 50'	7/10/2001	3048.22	72	21.77	3890	2.06	20	0.55	0.5	0.72
	9/25/2001	3047.6								
	3/6/2002	3047.88	248	192.7	9810	2.82	178	4.7	5	5
	5/22/2002	3048.1	32	302.59	23300	2.49	299	2.7	0.5	0.39
	12/11/2002	3047.57	19	254.1	12600	1.51	250	3.1	0.5	0.5
	3/24/2003	3048.93								
	6/18/2003	3047.21	16	234.3	11800	0.57	232	1.3	0.5	0.5
	7/7/2004	3047.18								
	6/14/2005		16	99.95	1030		98	0.98	0.5	0.47

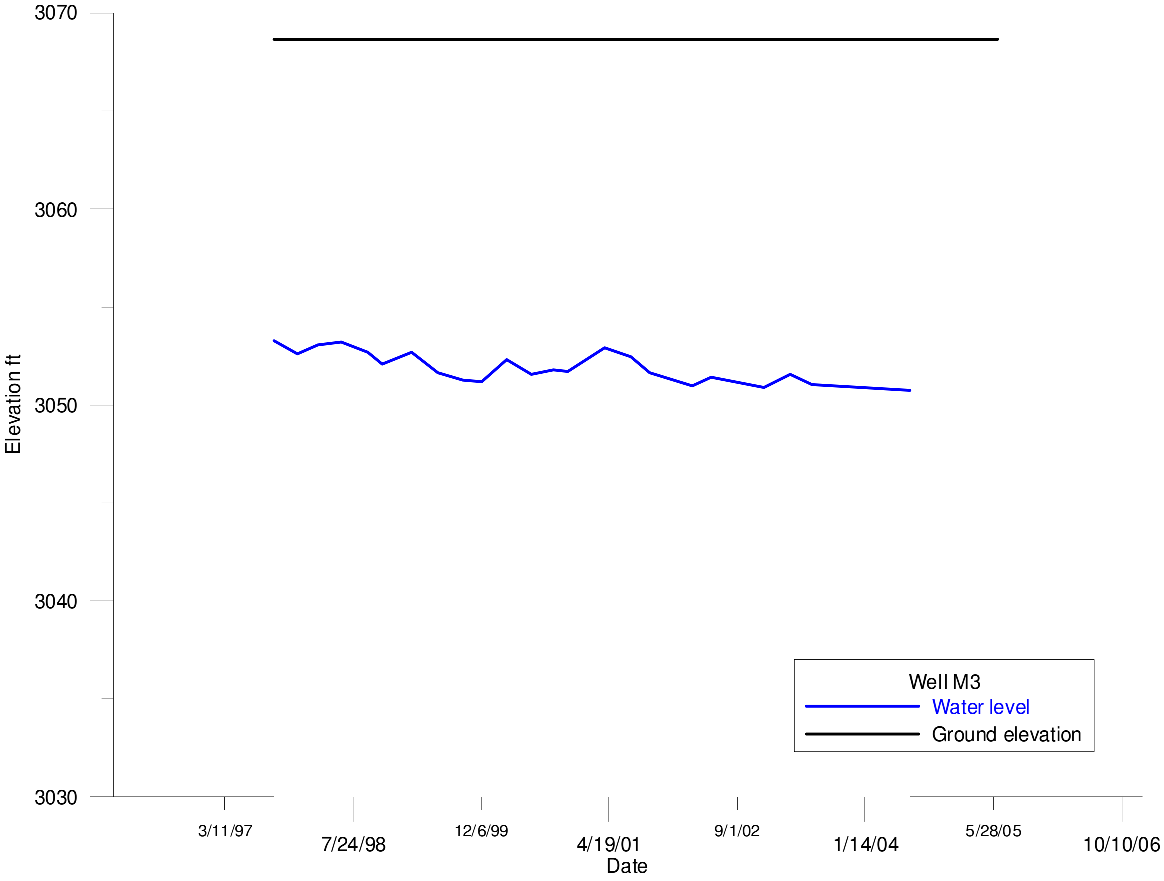
MP02 62'	7/10/2001	3048.63	32	18.58	2010	4.71	17	0.58	0.5	0.5
	9/25/2001	3048.56								
	3/6/2002	3048.4	39	174.3	1150	2.15	170	3.3	0.5	0.5
	5/22/2002	3048.68	10	354.6	18500	2.29	351	2.6	0.5	0.5
	12/11/2002	3048.11	10	52.1	3720	1.51	50	1.1	0.5	0.5
	3/24/2003	3049.4								
	6/18/2003	3047.9	16	301.1	2310	0.4	298	2.1	0.5	0.5
	7/7/2004	3047.82								
	6/14/2005		1.6	32.75	54		31	0.75	0.5	0.5

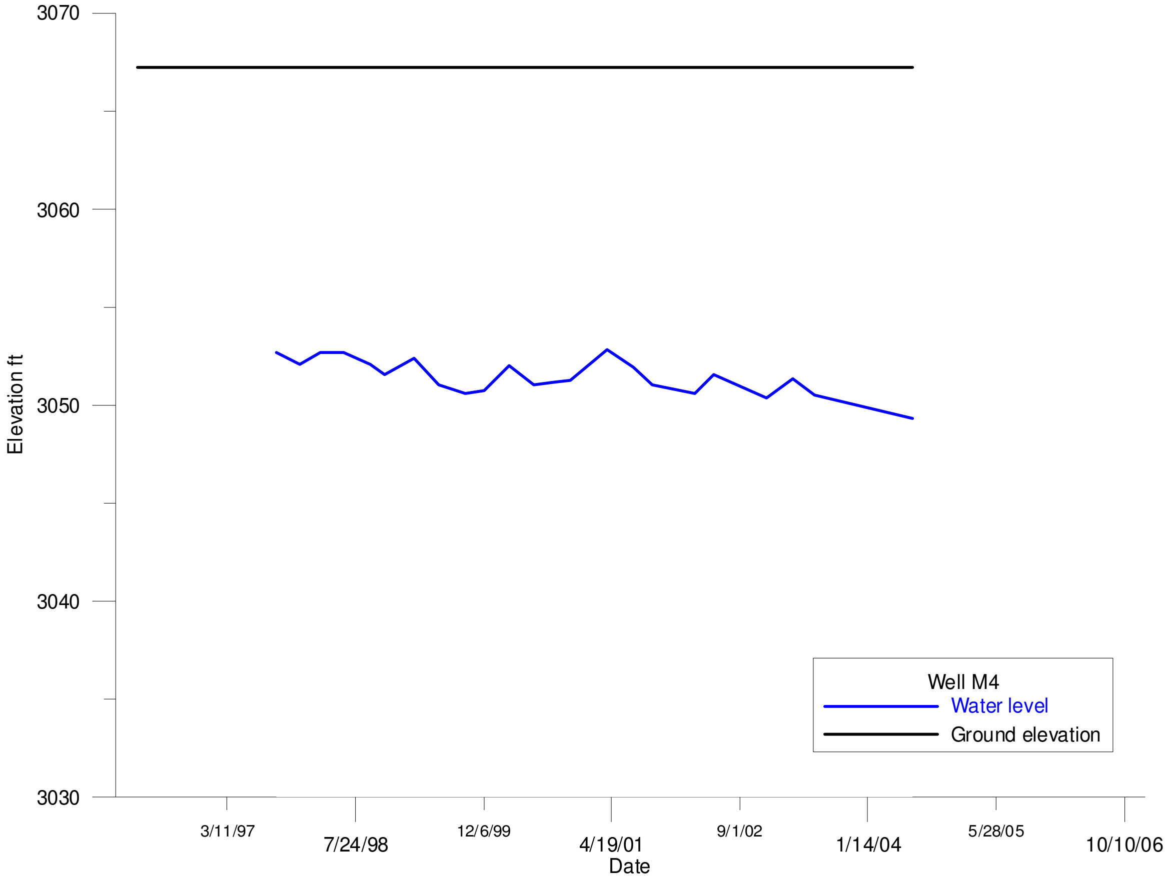
Well	Date	WL	MTBE	BTEX	TPH	DO	B	T	E	X
MP03 10'	7/24/2001	3039.54								
	9/25/2001	3038.99	1080	296.54	3790	4.78	294	1.5	0.5	0.54
	3/5/2002	3039.54	1840	562	2000		560	1	0.5	0.5
	5/21/2002	3039.49	1950	547.94	2800		546	0.94	0.5	0.5
	12/10/2002	3039.22	2110	85.5	1480	1.81	84	0.5	0.5	0.5
	3/24/2003	3040.11								
	6/17/2003	3038.72	2770	47.42	2410	1.75	46	0.42	0.5	0.5
	6/2/2004		2420	60	1700		30	10	10	10
	7/7/2004	3038.69								
	6/13/2005		2020	18.46	1380		17	0.46	0.5	0.5
MP03 22'	7/24/2001	3039.47								
	9/25/2001	3038.95	249	40.56	2930	1.99	39	0.56	0.5	0.5
	3/5/2002	3039.48	1160	310.5	2820		309	0.5	0.5	0.5
	5/21/2002	3039.45	1200	269.95	3270		268	0.95	0.5	0.5
	12/10/2002	3039.21	4140	1436.4	5730	0.53	1410	19	1	6.4
	3/24/2003	3040.06								
	6/17/2003	3038.68	5650	917.24	4150	1.54	910	5.9	0.5	0.84
	6/7/2004		9790	1890	9810		1810	30	25	25
	7/7/2004	3038.62								
	4/6/2005		7780	1340.39	7290		1310	25	0.49	4.9
	6/13/2005		7390	1577.4	8050		1550	23	0.5	3.9
MP03 32'	7/24/2001	3039.47								
	9/25/2001	3038.92	3.5	4.1	57	2.93	2.6	0.5	0.5	0.5
	3/5/2002	3039.46	2.5	6.2	20	1.01	4.7	0.5	0.5	0.5
	5/21/2002	3039.41	7.1	23.5	634		22	0.5	0.5	0.5
	12/10/2002	3039.14	6.2	6.9	20	1.9	5.4	0.5	0.5	0.5
	3/24/2003	3040.03								
	6/17/2003	3038.64	51	74.78	144	1.12	73	0.78	0.5	0.5
	6/7/2004		10	91	222		76	5	5	5
	7/7/2004	3038.58								
	4/6/2005		2.3	9.2	17		7.7	0.5	0.5	0.5
	6/13/2005		1.6	8.7	20		7.2	0.5	0.5	0.5
MP03 57'	7/24/2001	3039.49								
	9/25/2001	3039.14	167	14.5	209	4.77	13	0.5	0.5	0.5
	3/5/2002	3039.48	157	19.19	168	2.05	14	4.1	0.5	0.59
	5/21/2002	3039.52	189	22.5	208		21	0.5	0.5	0.5
	12/10/2002	3039.09	2290	153.52	1750	3.24	152	0.52	0.5	0.5
	3/24/2003	3039.79								
	6/17/2003	3039.2	104	307	367	0.55	305	1	0.5	0.5
	7/7/2004	3038.62								
	4/6/2005		89	36.27	118		34	1.2	0.5	0.57
	6/13/2005		231	120.4	343		118	1.4	0.5	0.5

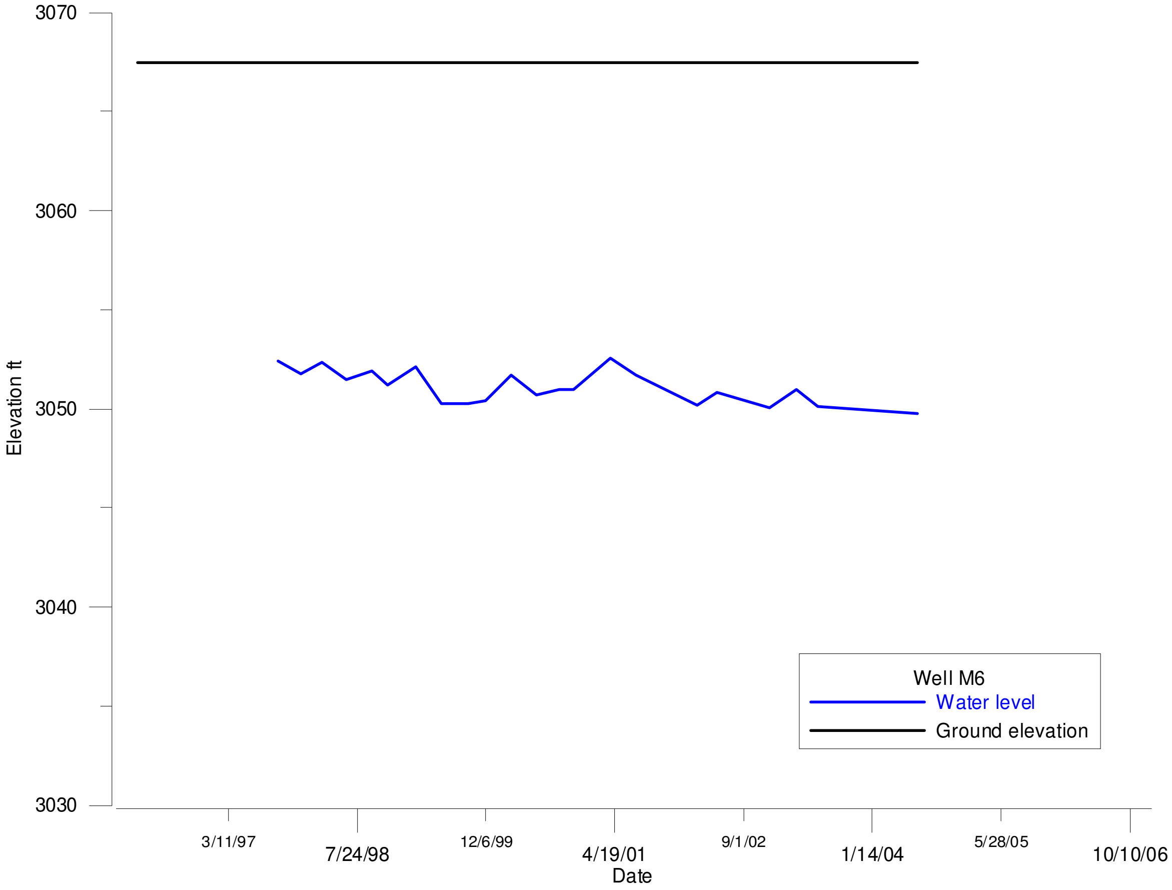
Historic Water Levels

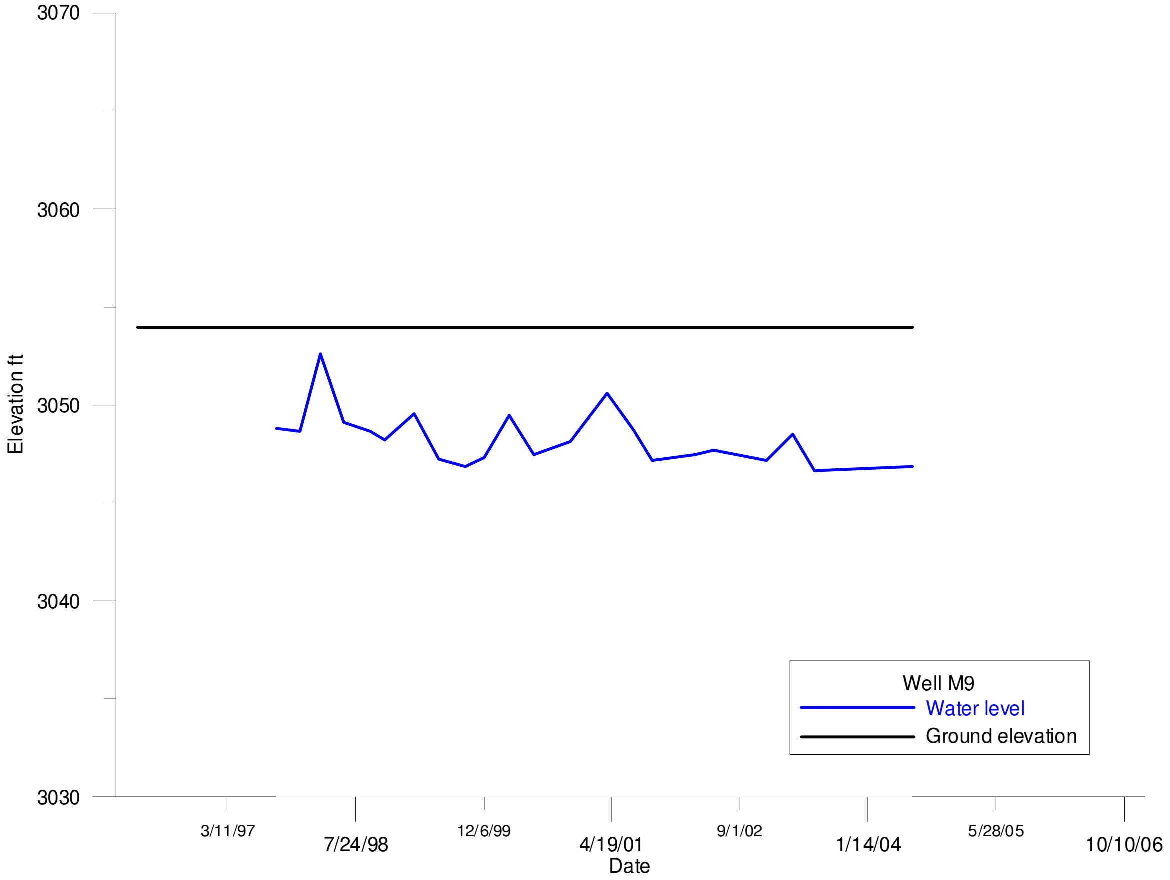
Data was compiled from HKM 2003, 2005, 2006 and Loustaunau 2003. Graphical analysis represents sampling data presented in this appendix.

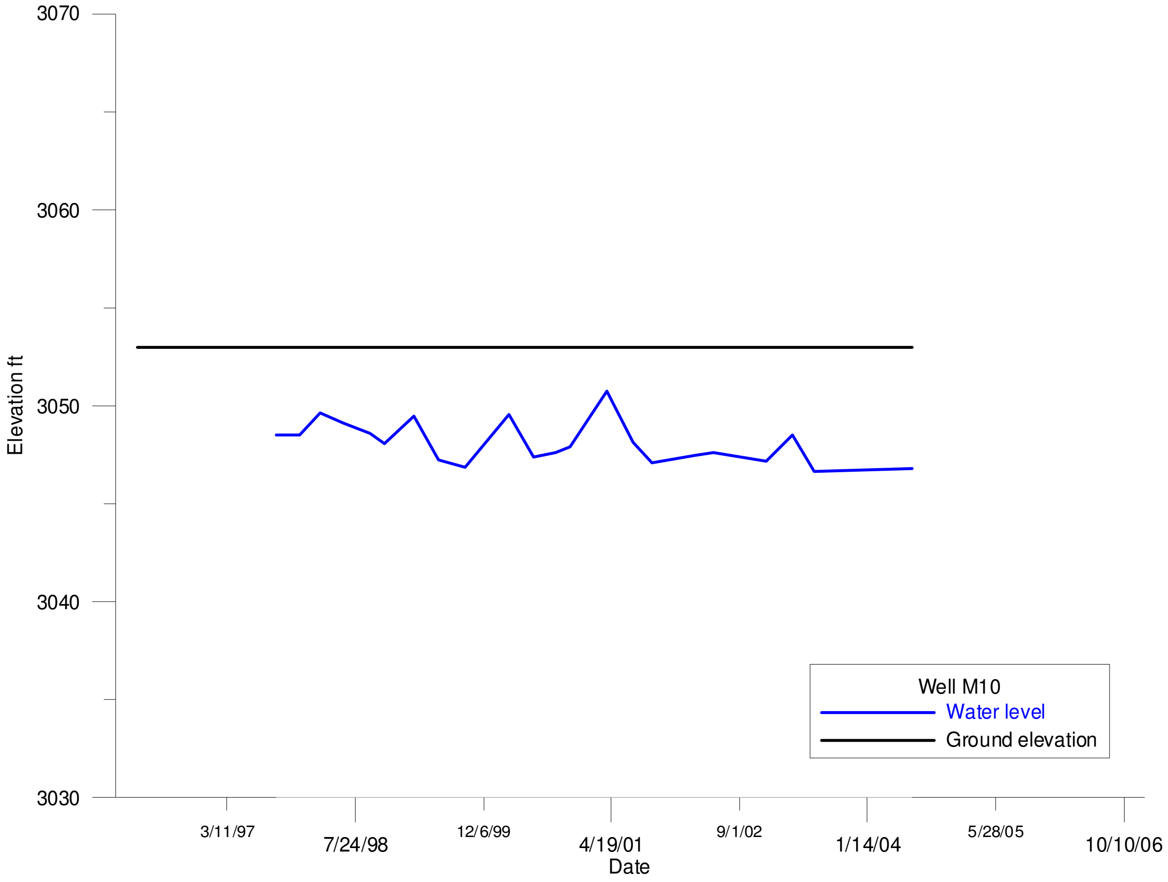

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M2
Water level
Ground elevation

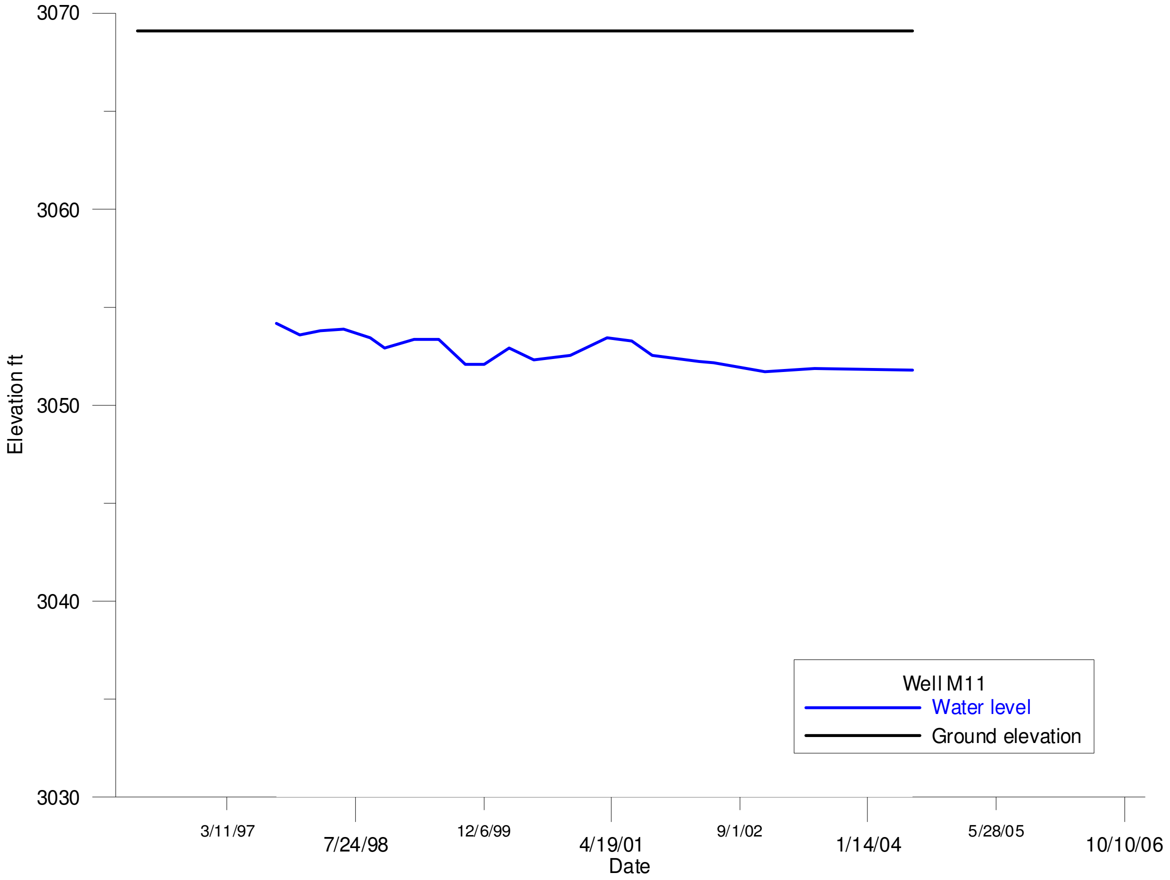

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M3
Water level
Ground elevation

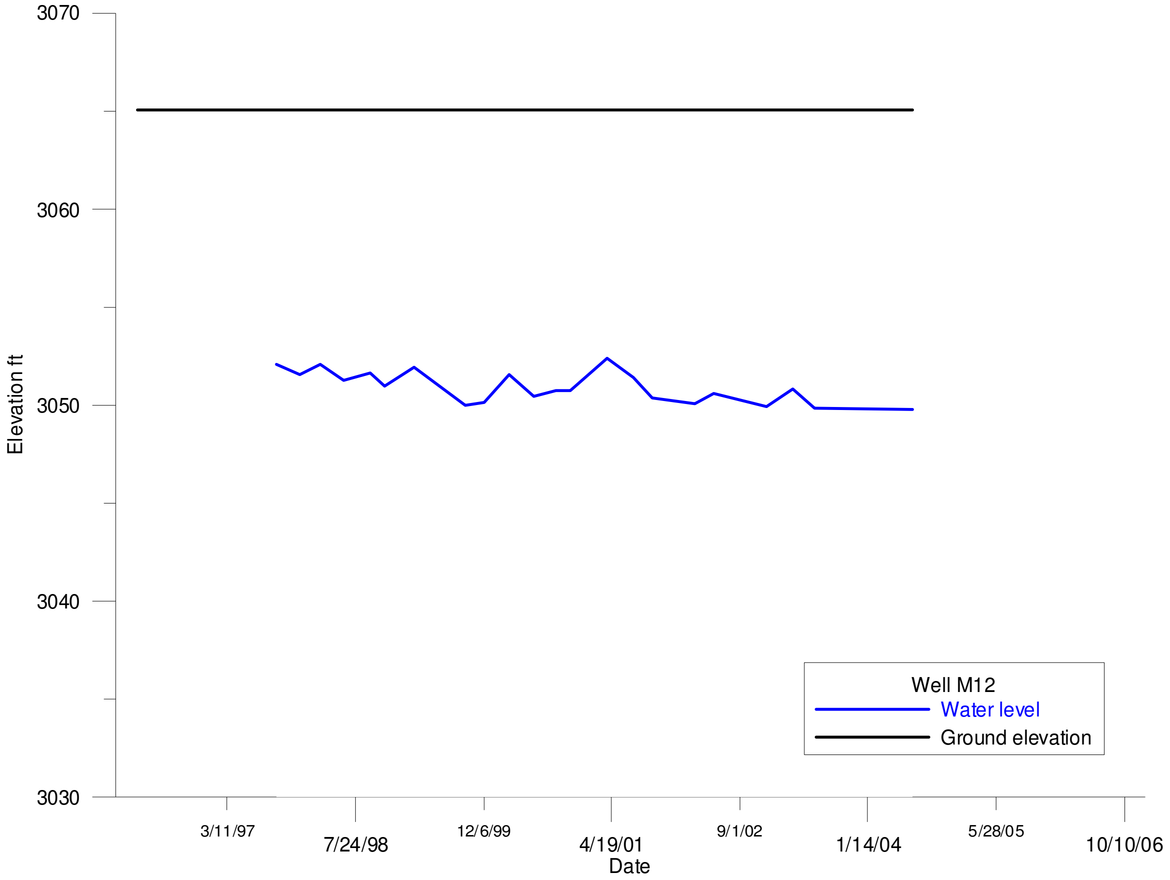

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M4
Water level
Ground elevation

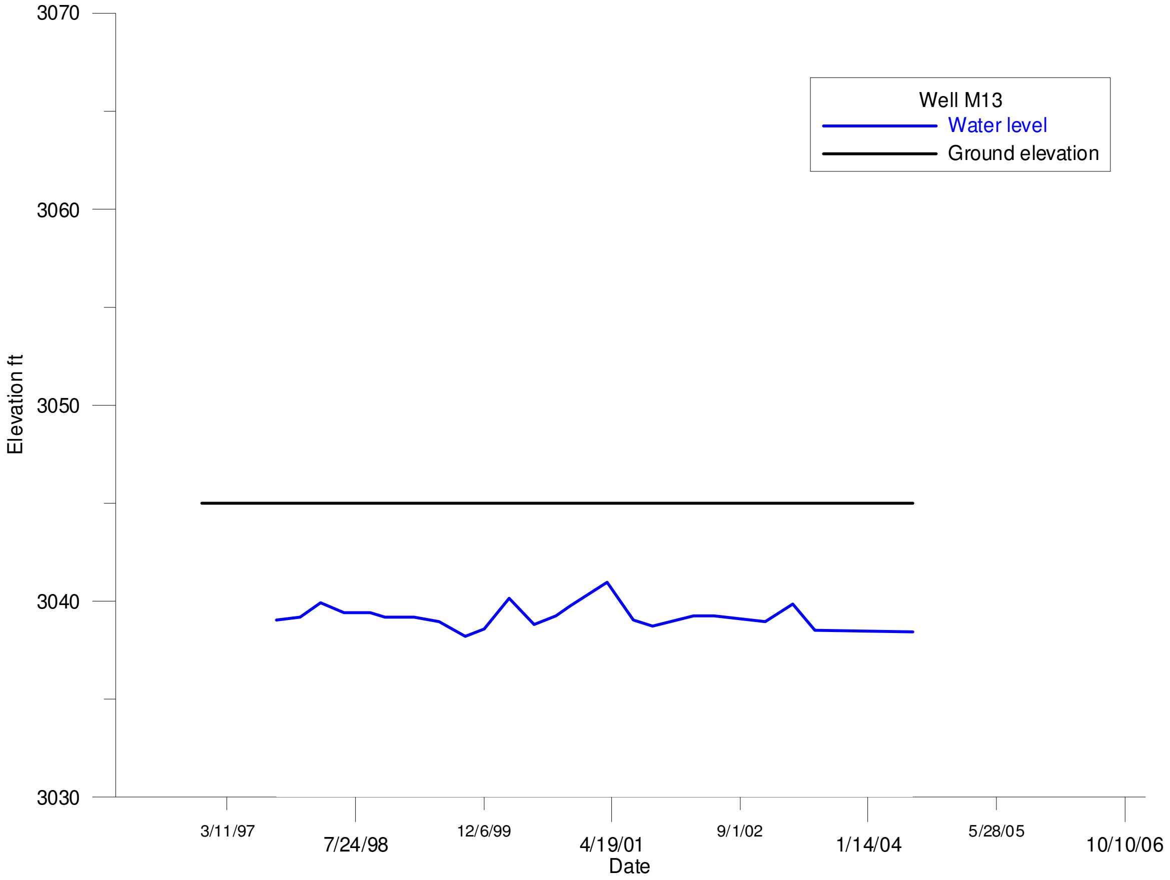

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M6
Water level
Ground elevation


3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M9
Water level
Ground elevation

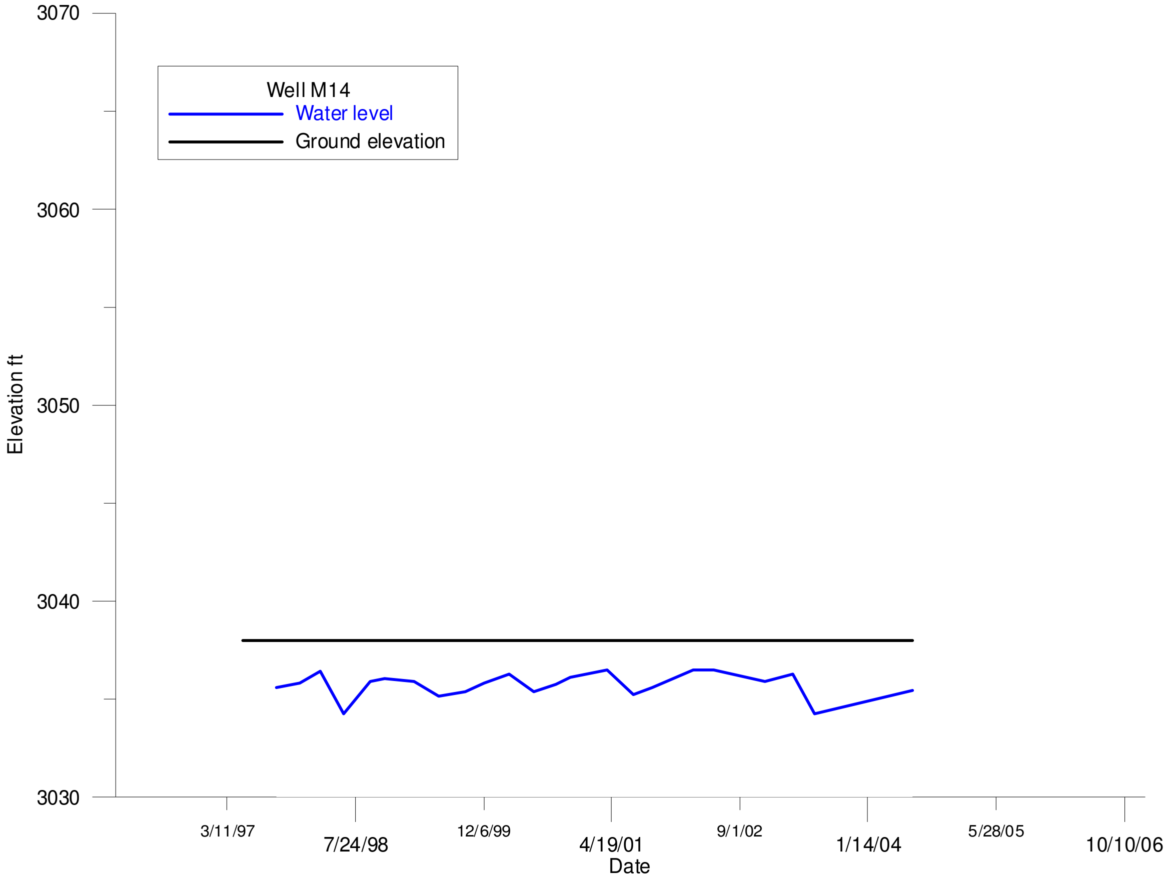

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M10
Water level
Ground elevation

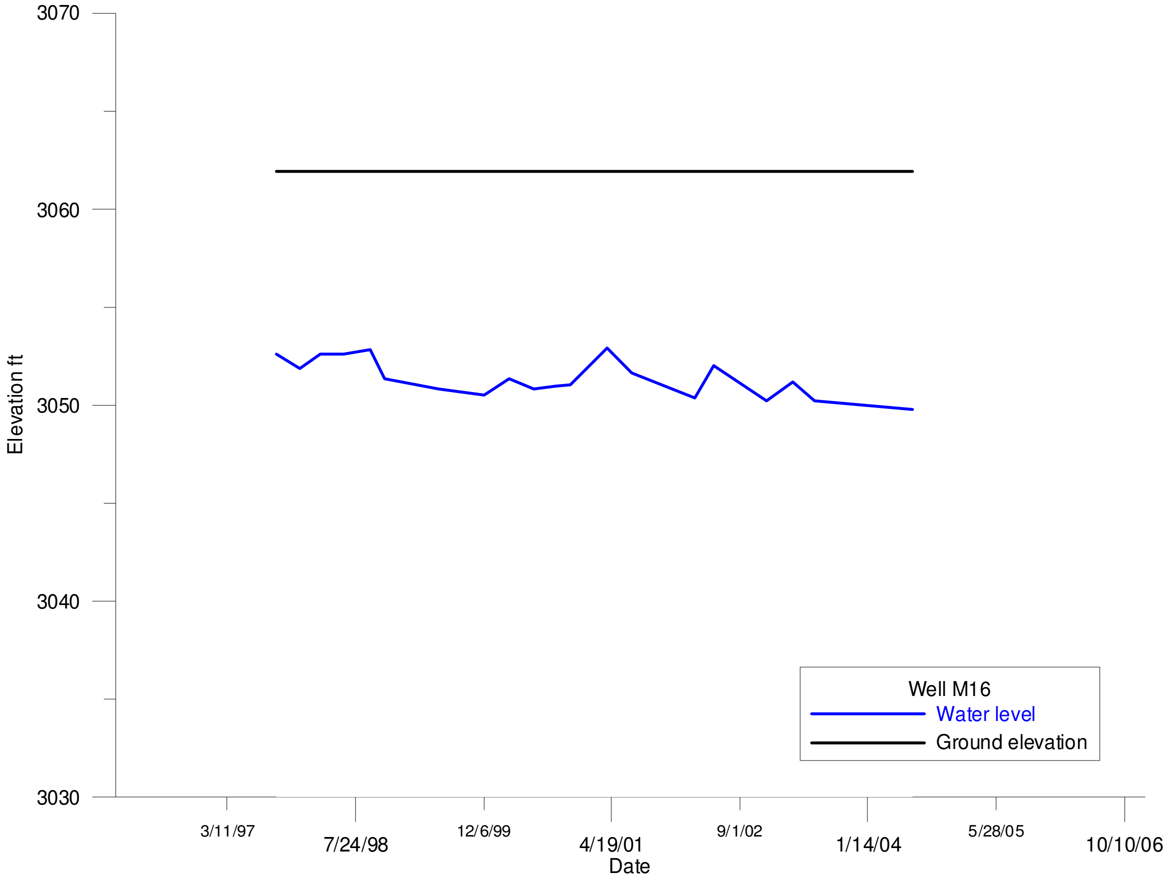

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M11
Water level
Ground elevation

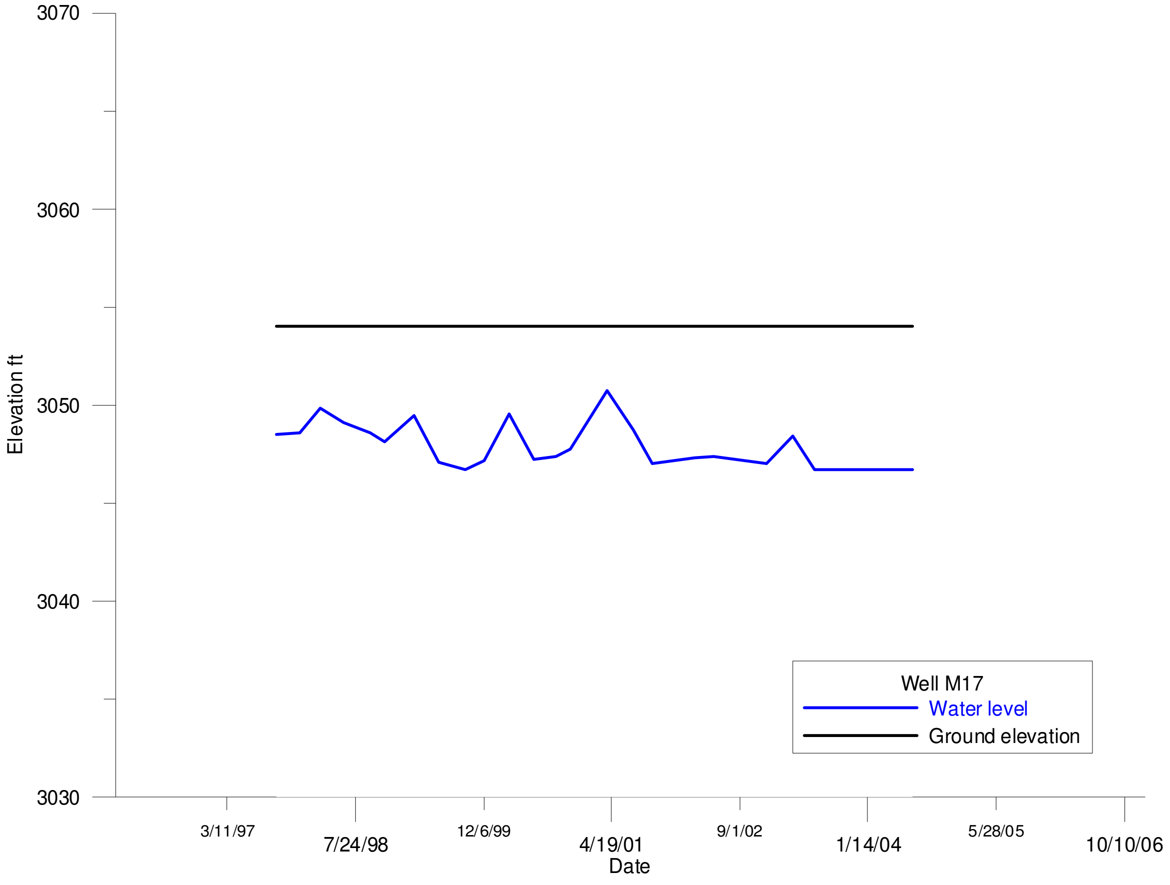

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M12
Water level
Ground elevation



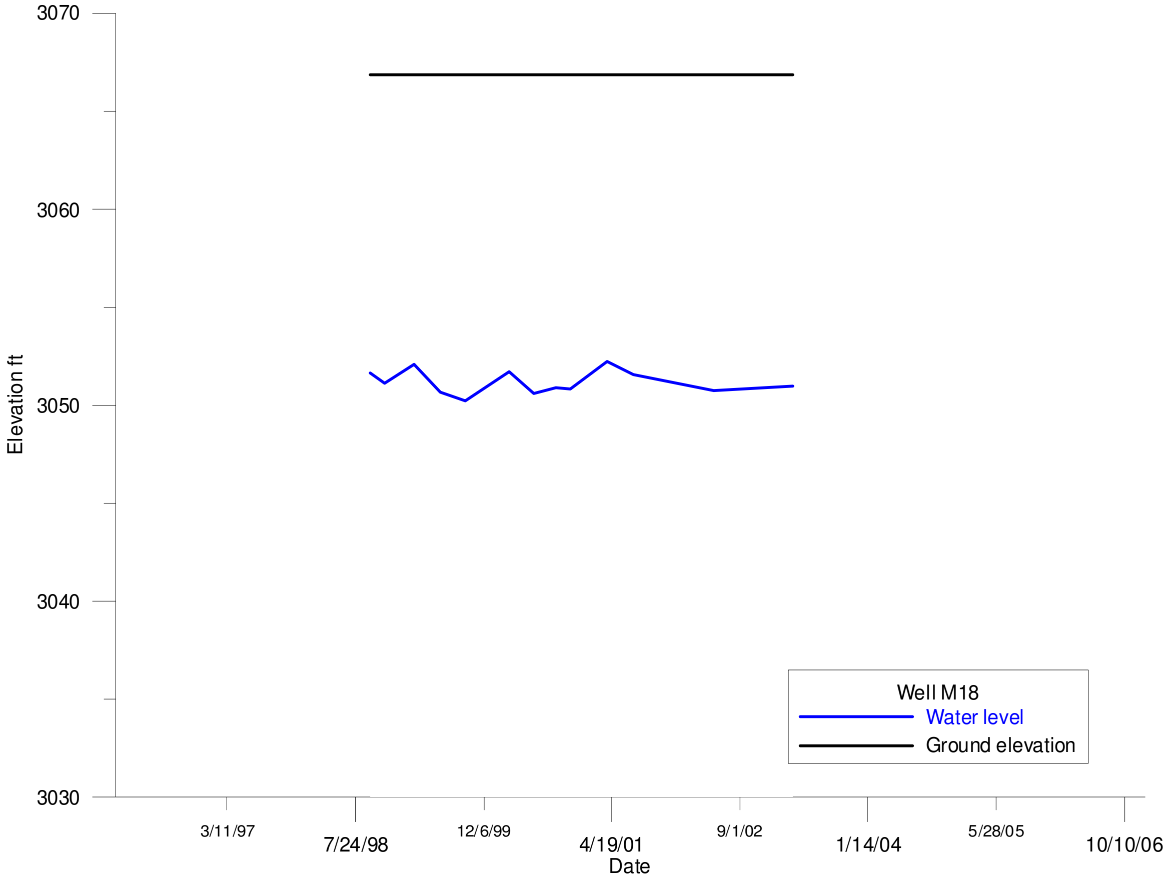
3070
3060
3050
3040
3030
Elevation ft
Well M13
Water level
Ground elevation
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date

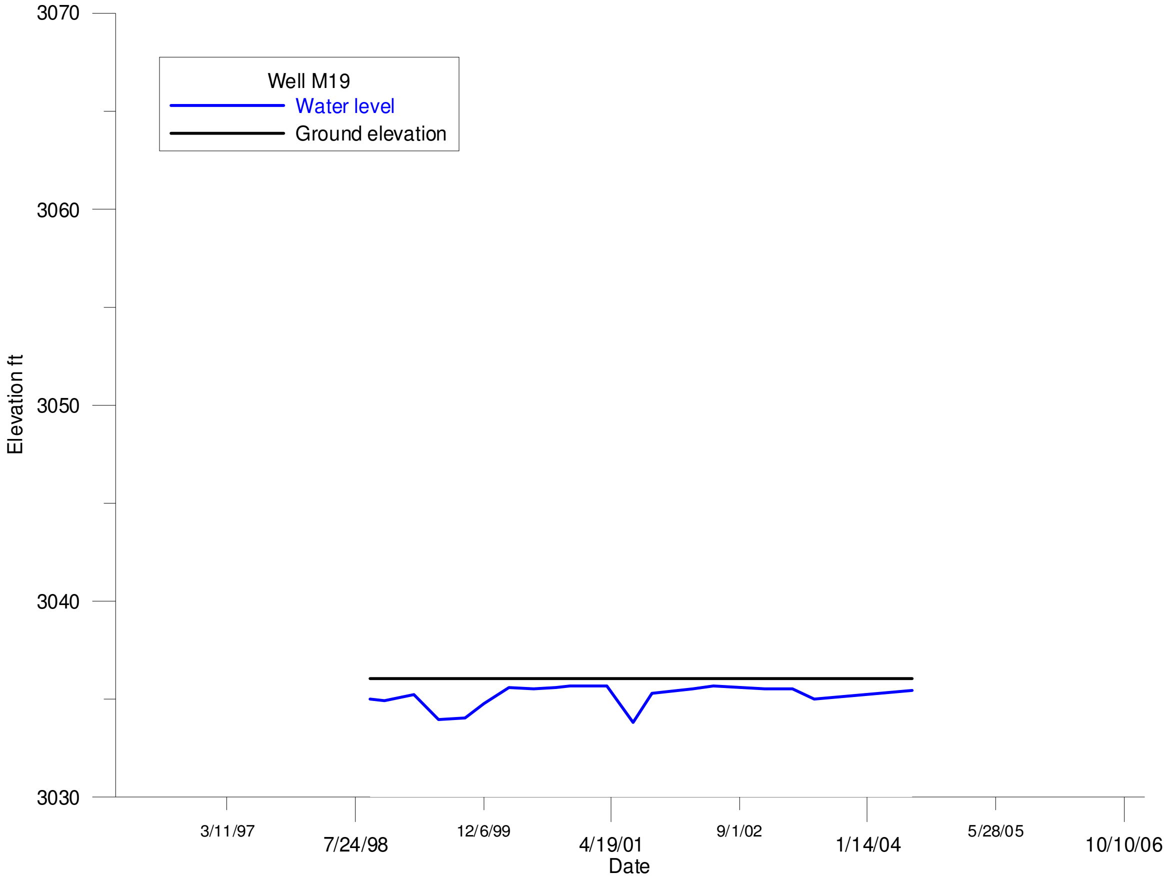

Well M14
Water level
Ground elevation
Elevation ft
3070
3060
3050
3040
3030
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date

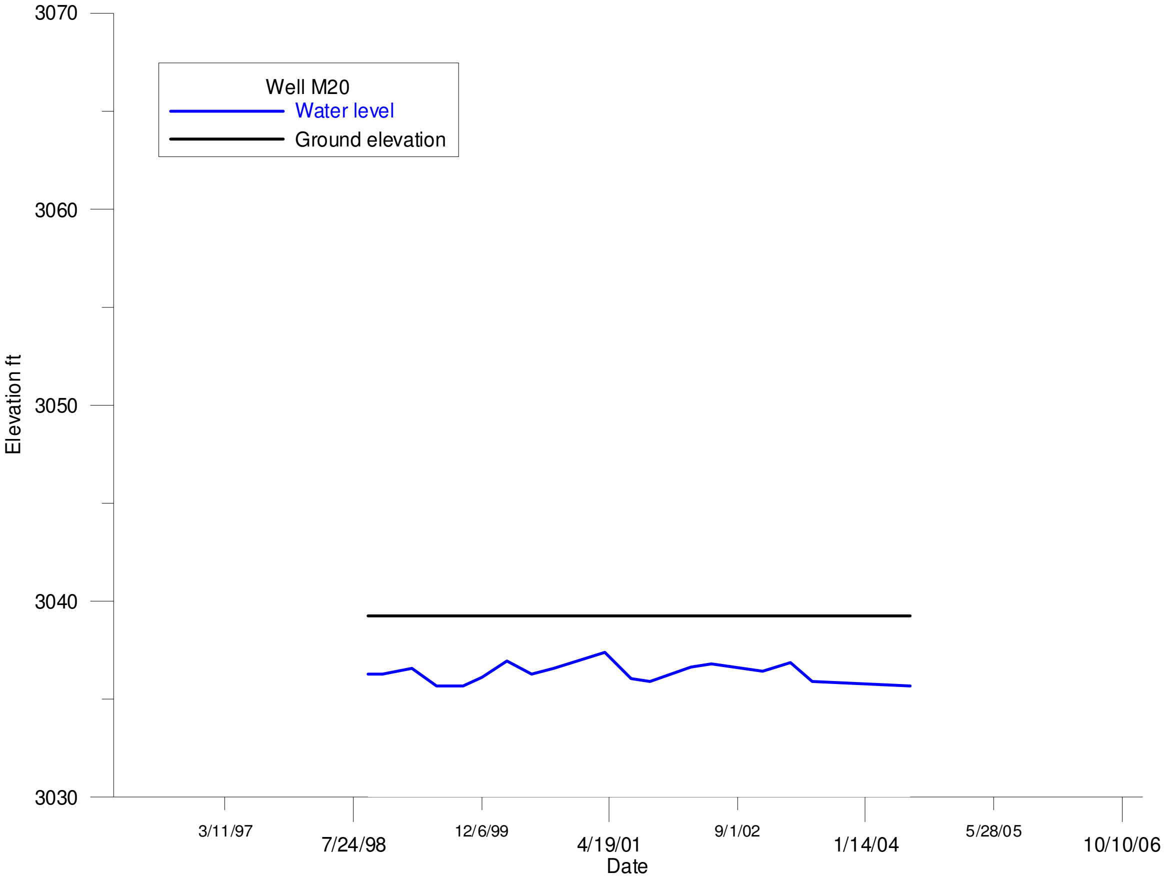

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M16
Water level
Ground elevation

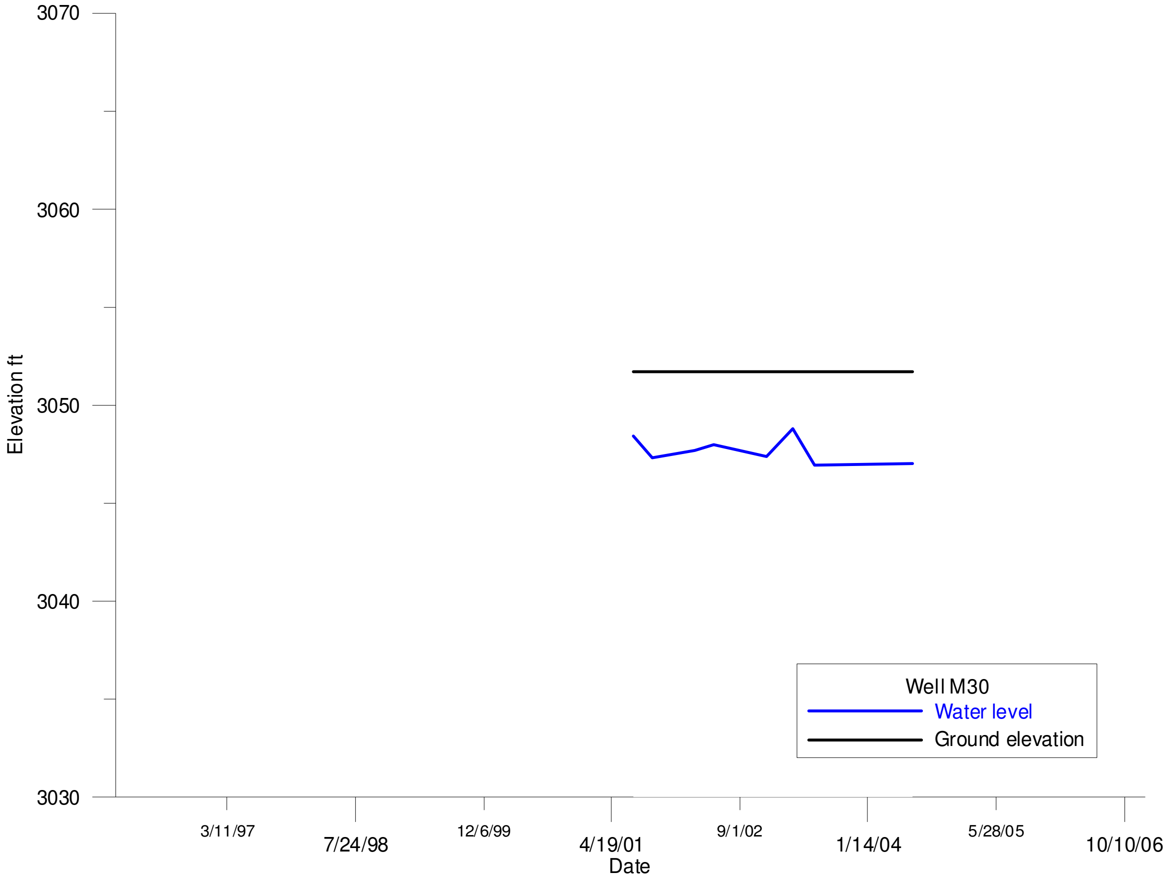


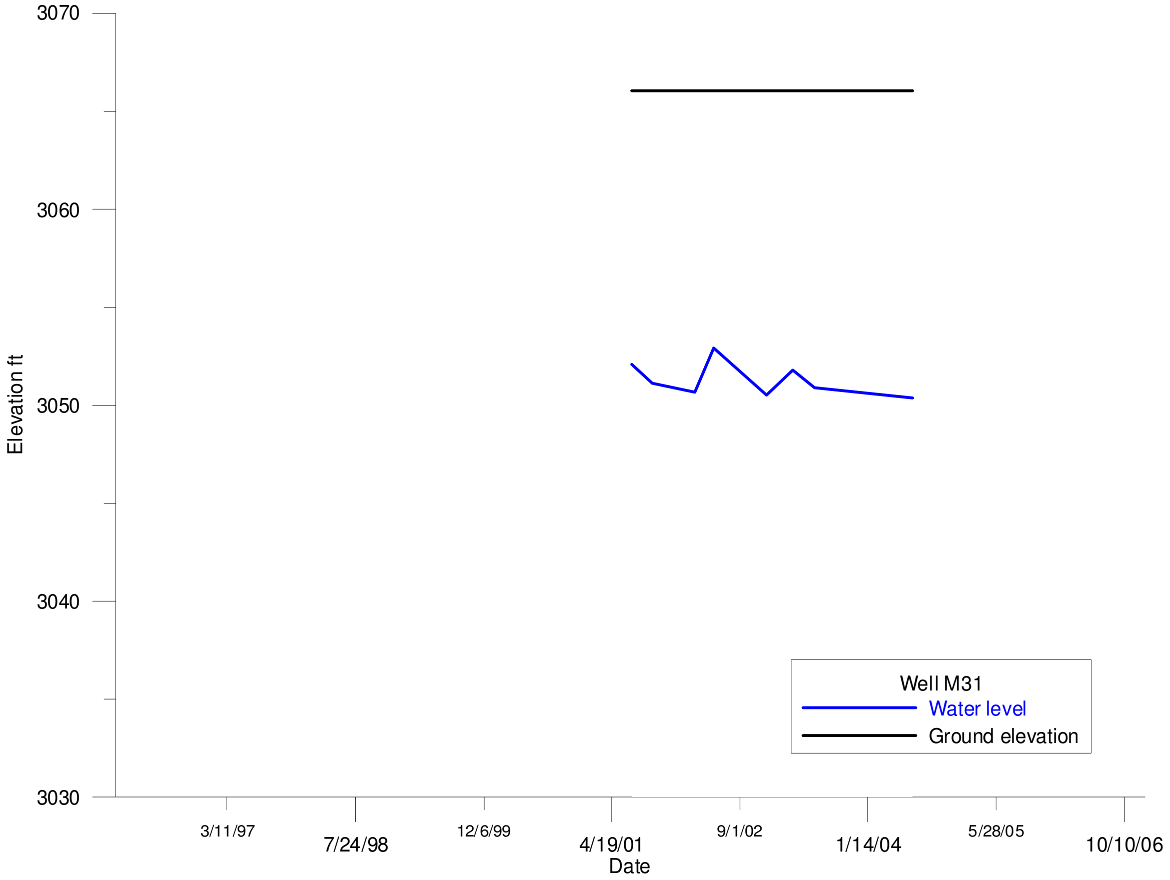
3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M17
Water level
Ground elevation

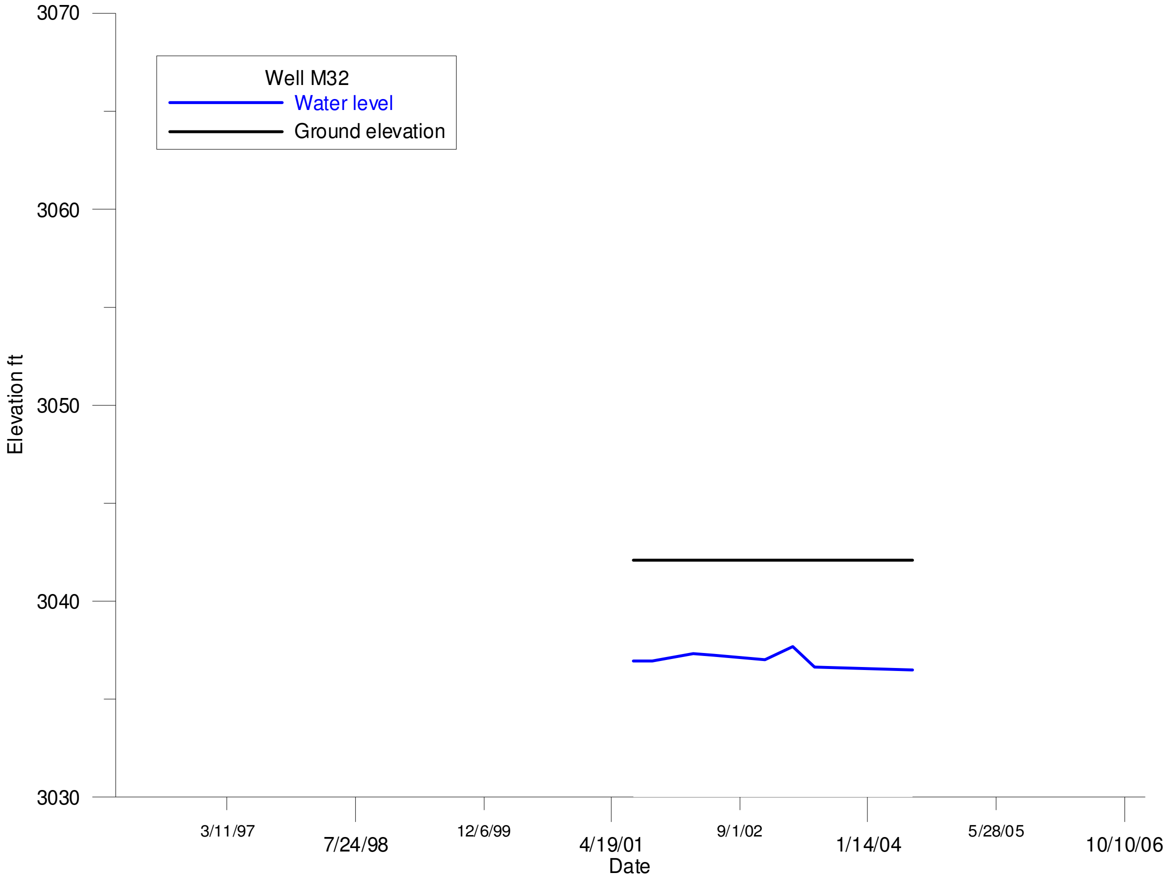

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M18
Water level
Ground elevation


Well M19
Water level
Ground elevation
Elevation ft
3070
3060
3050
3040
3030
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date

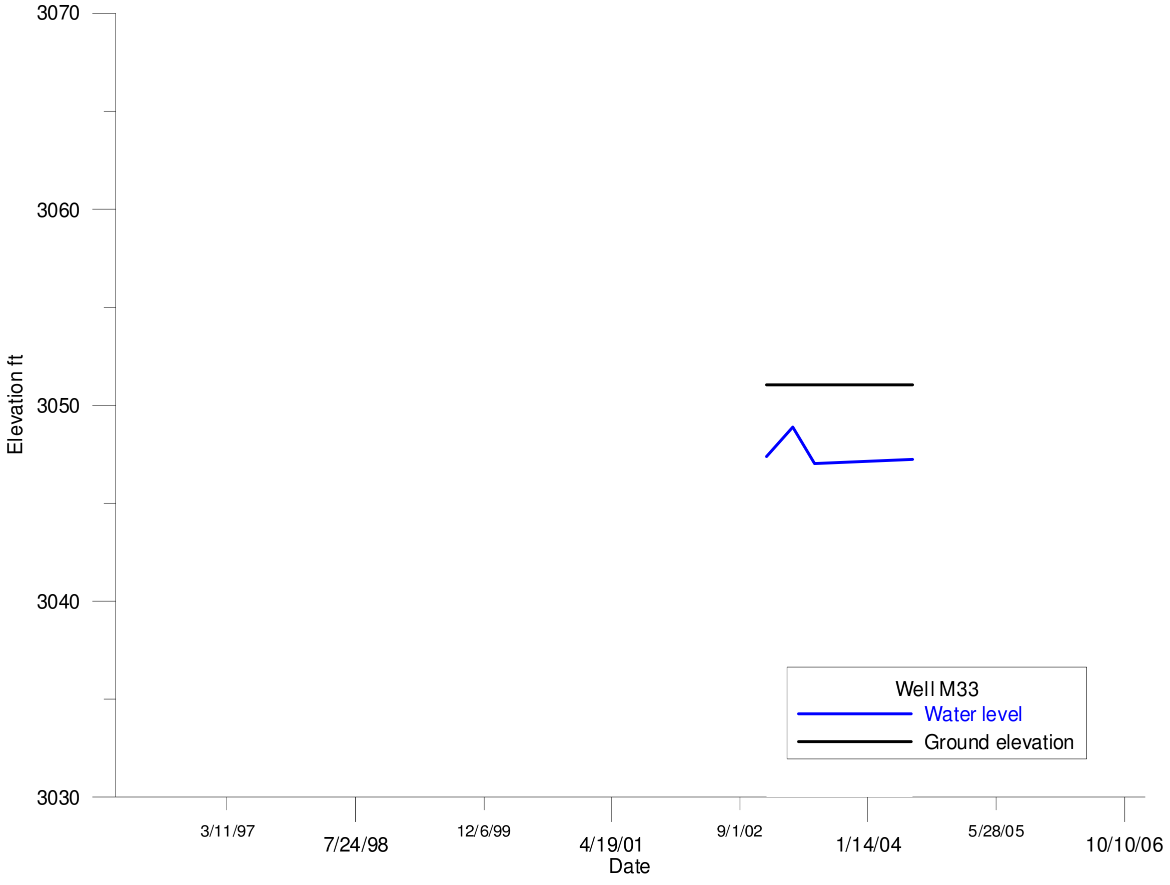

Well M20
Water level
Ground elevation
3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date

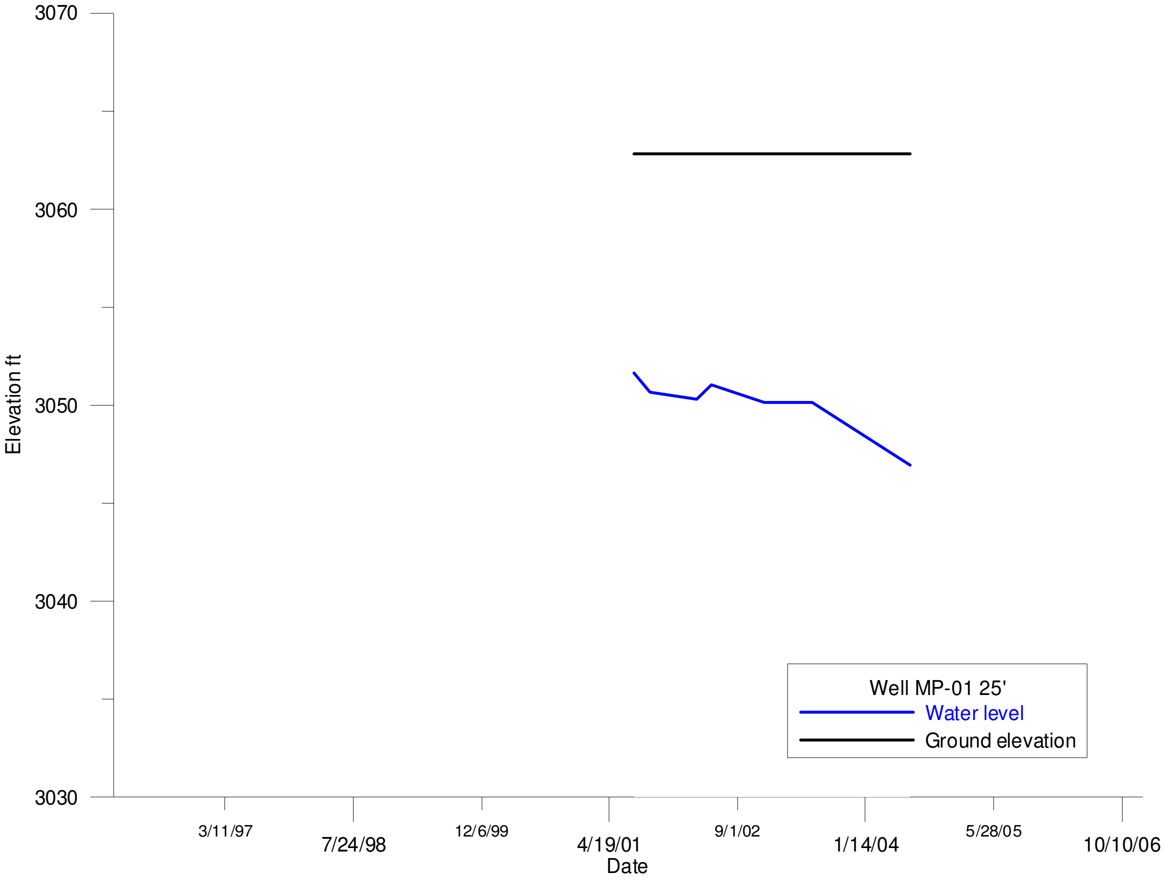

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M30
Water level
Ground elevation


3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M31
Water level
Ground elevation

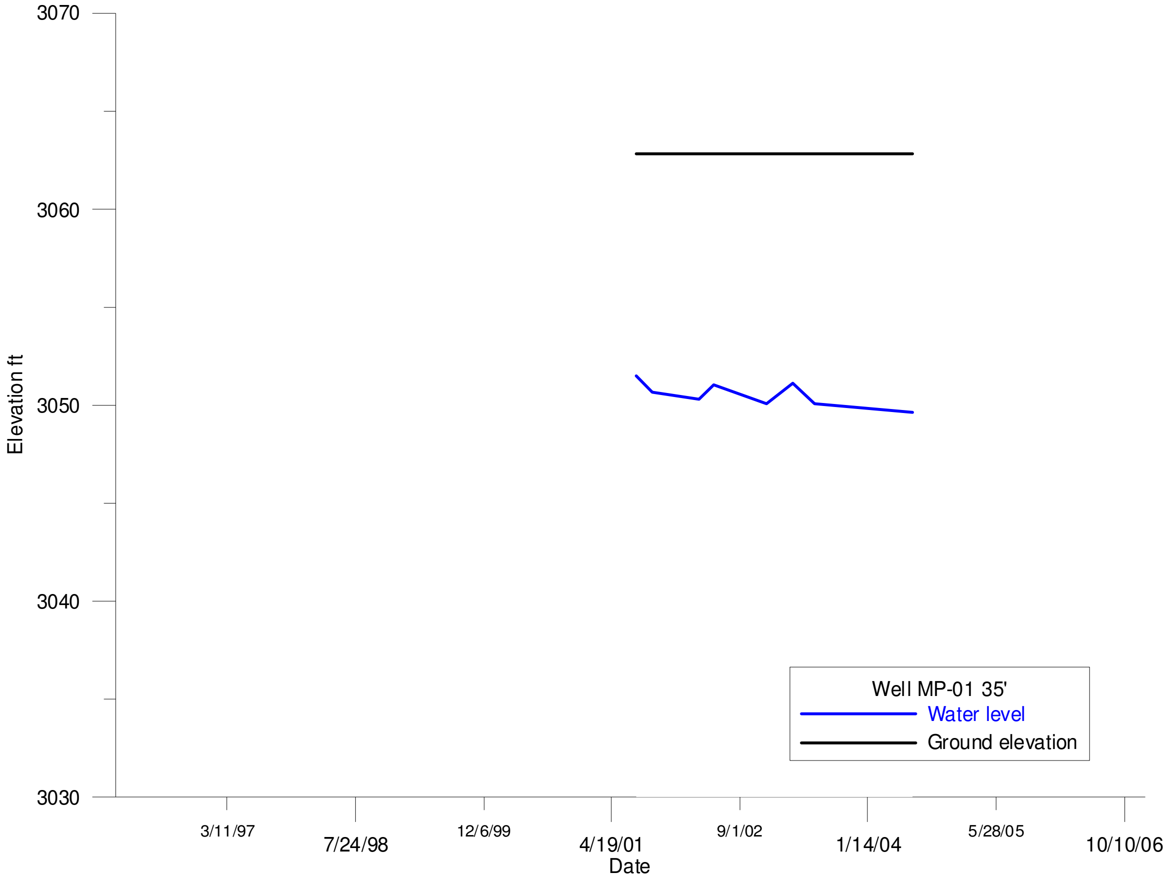


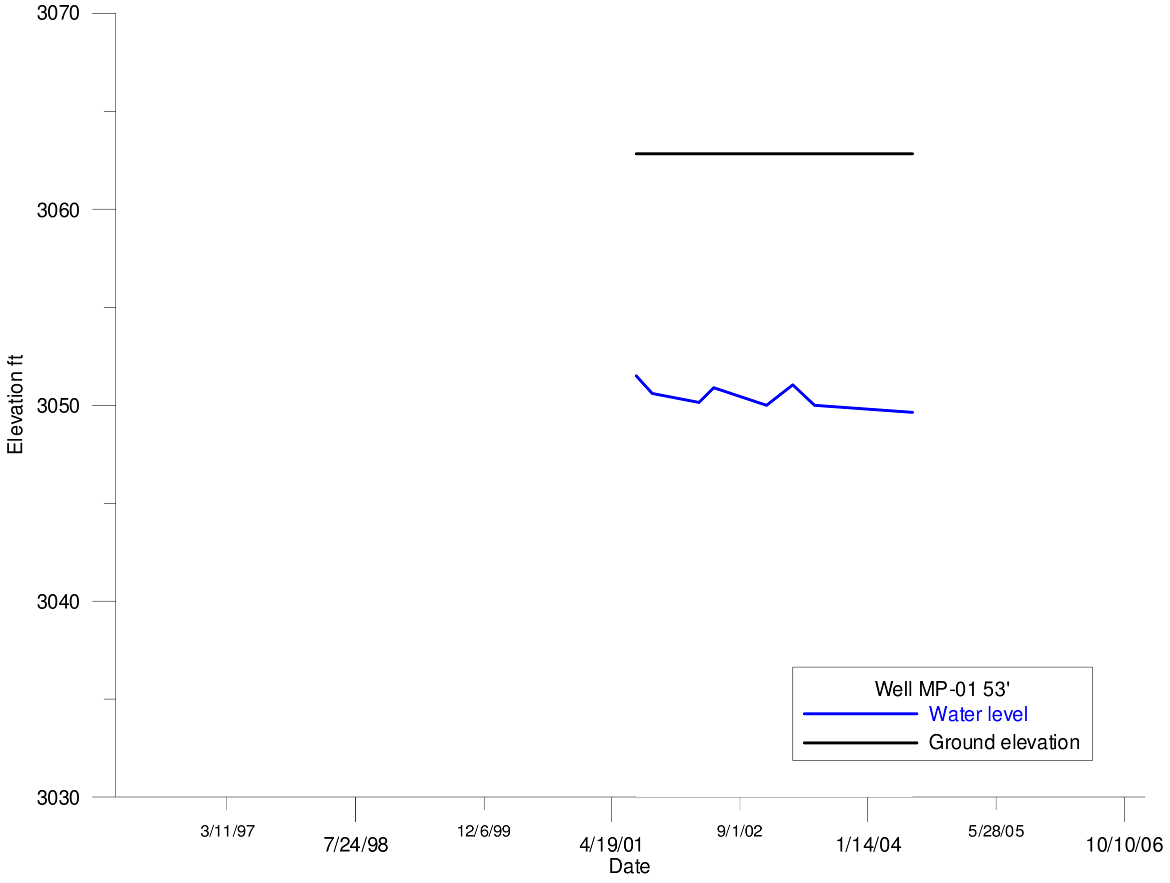
Well M32
Water level
Ground elevation
Elevation ft
3070
3060
3050
3040
3030
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date

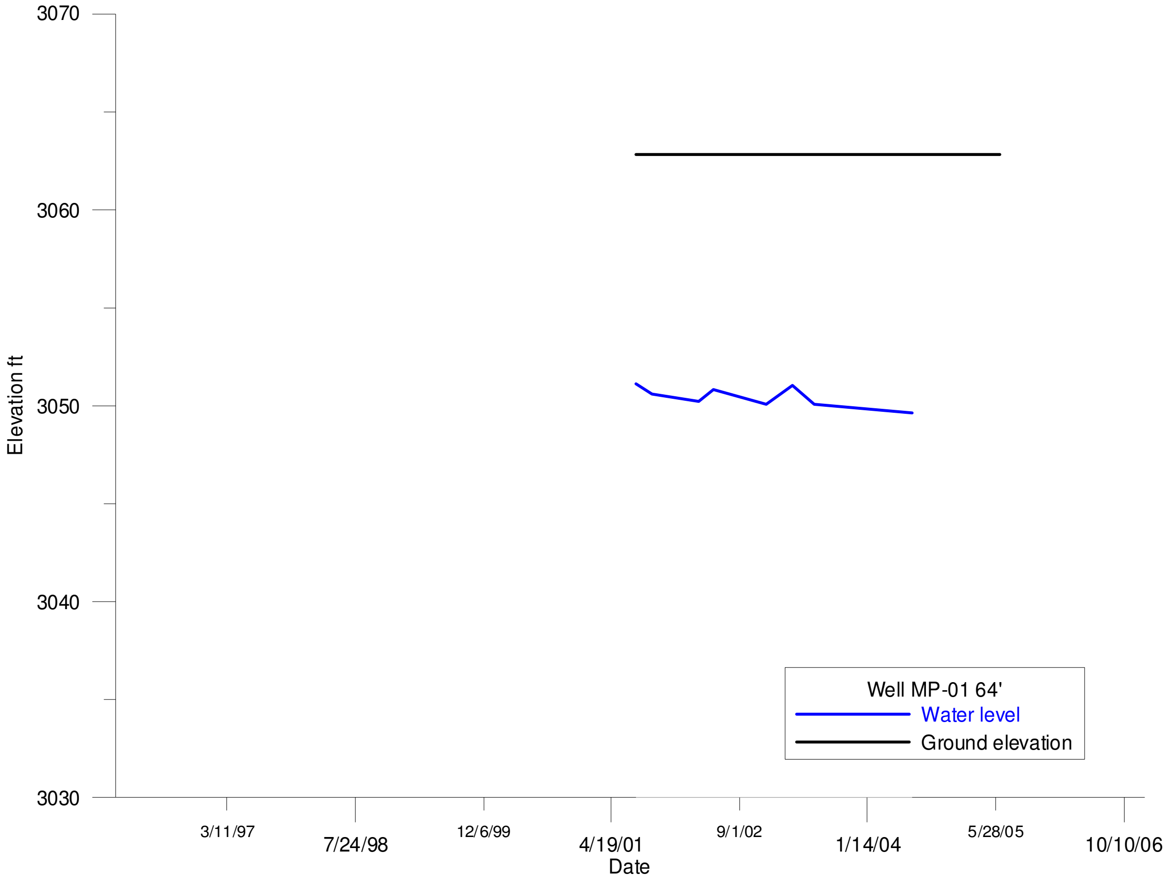

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well M33
Water level
Ground elevation

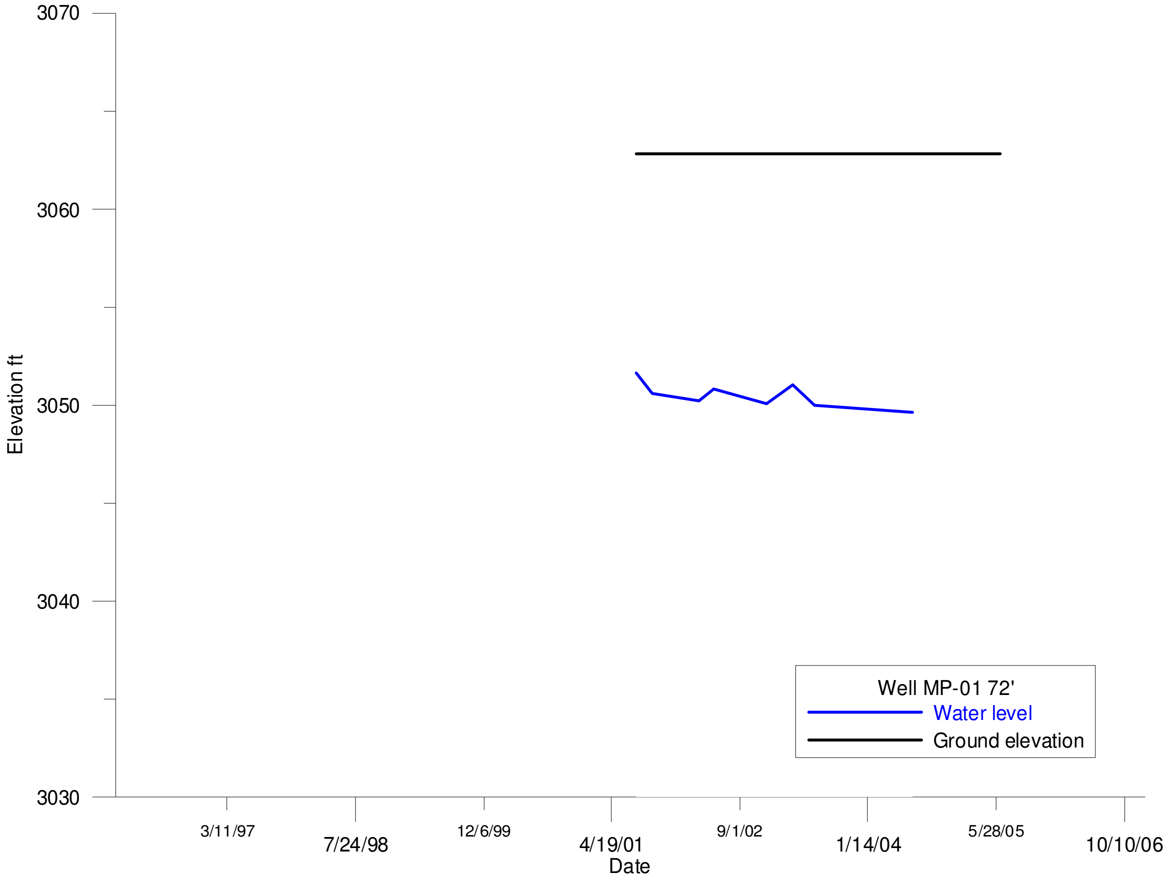


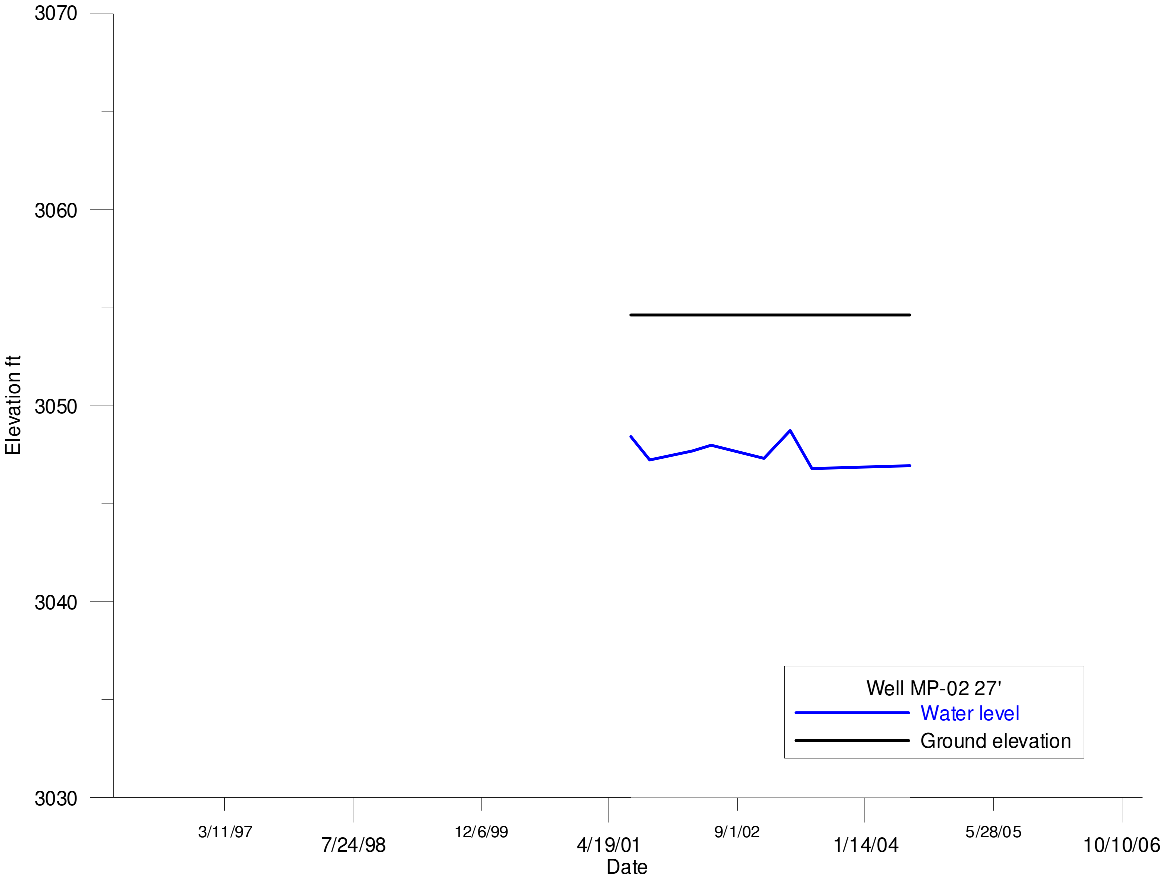
3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-01 25'
Water level
Ground elevation

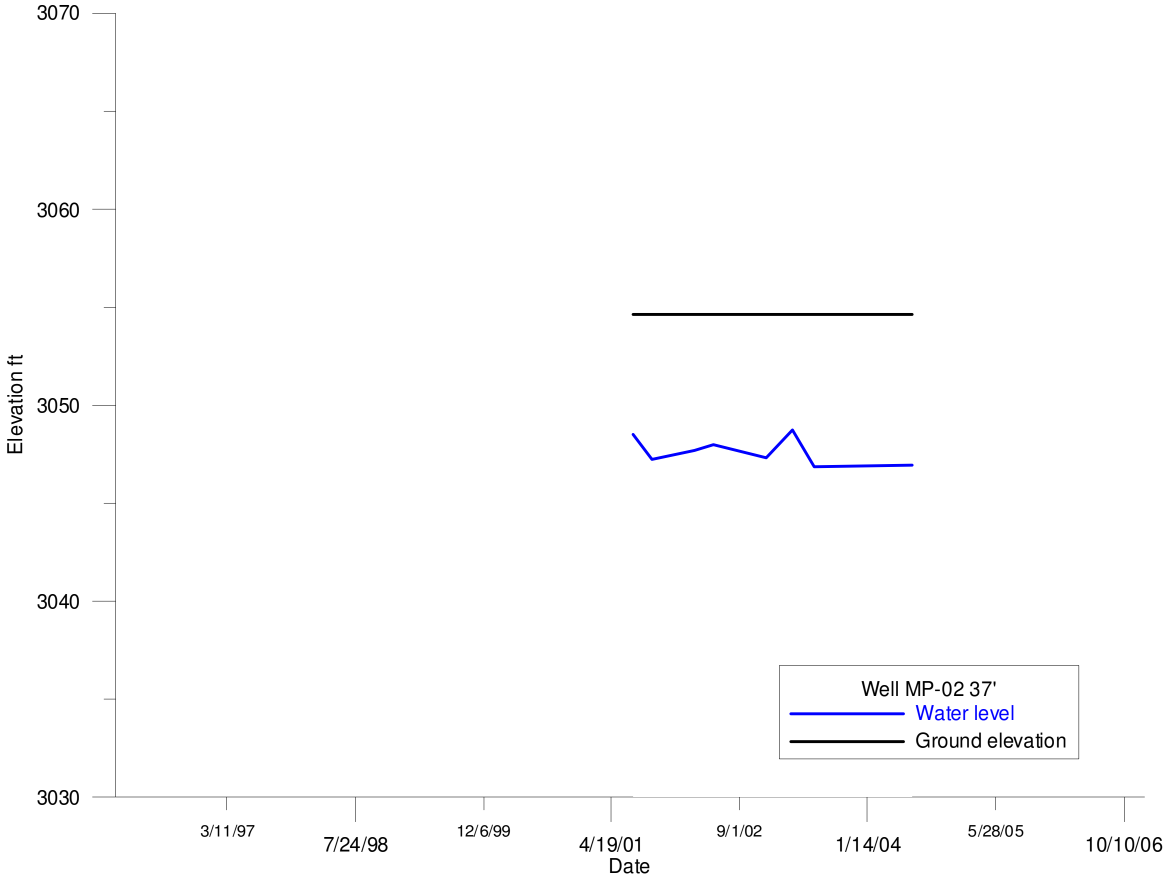

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-01 35'
Water level
Ground elevation

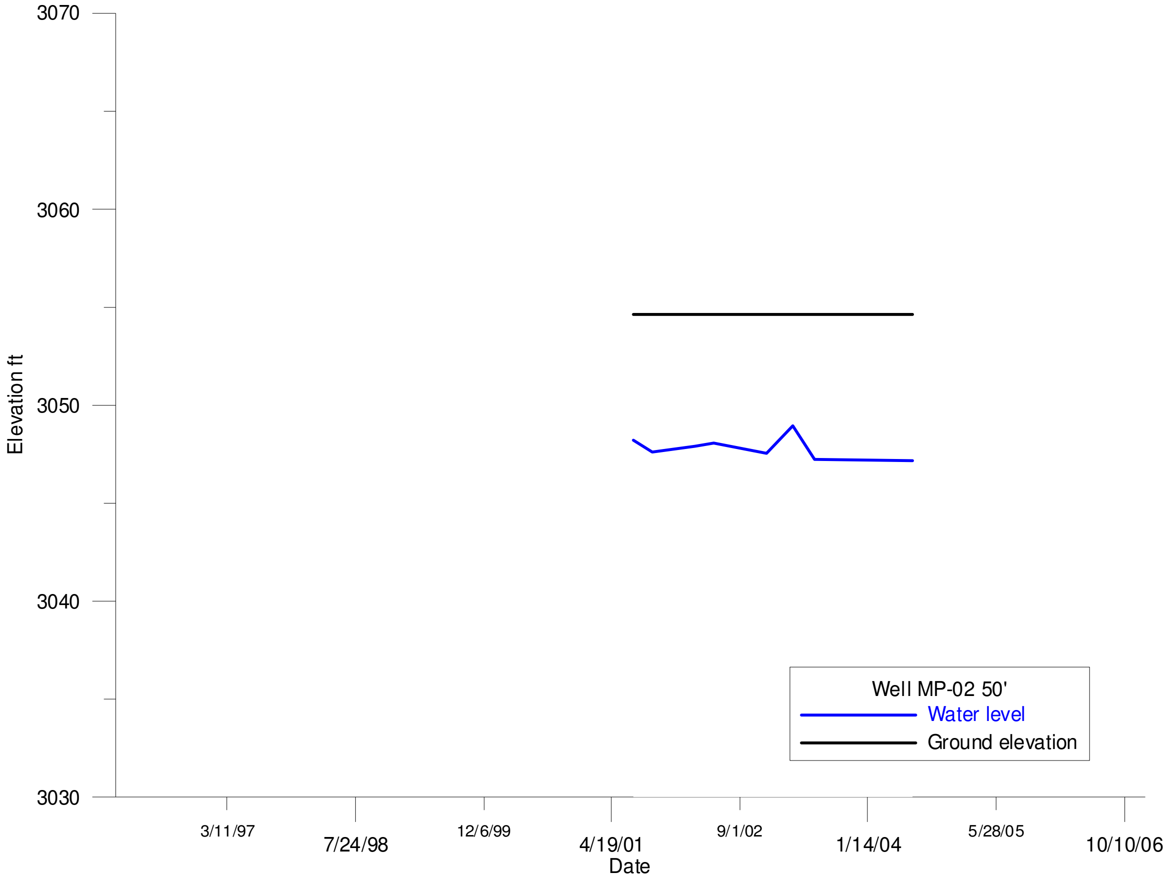

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-01 53'
Water level
Ground elevation

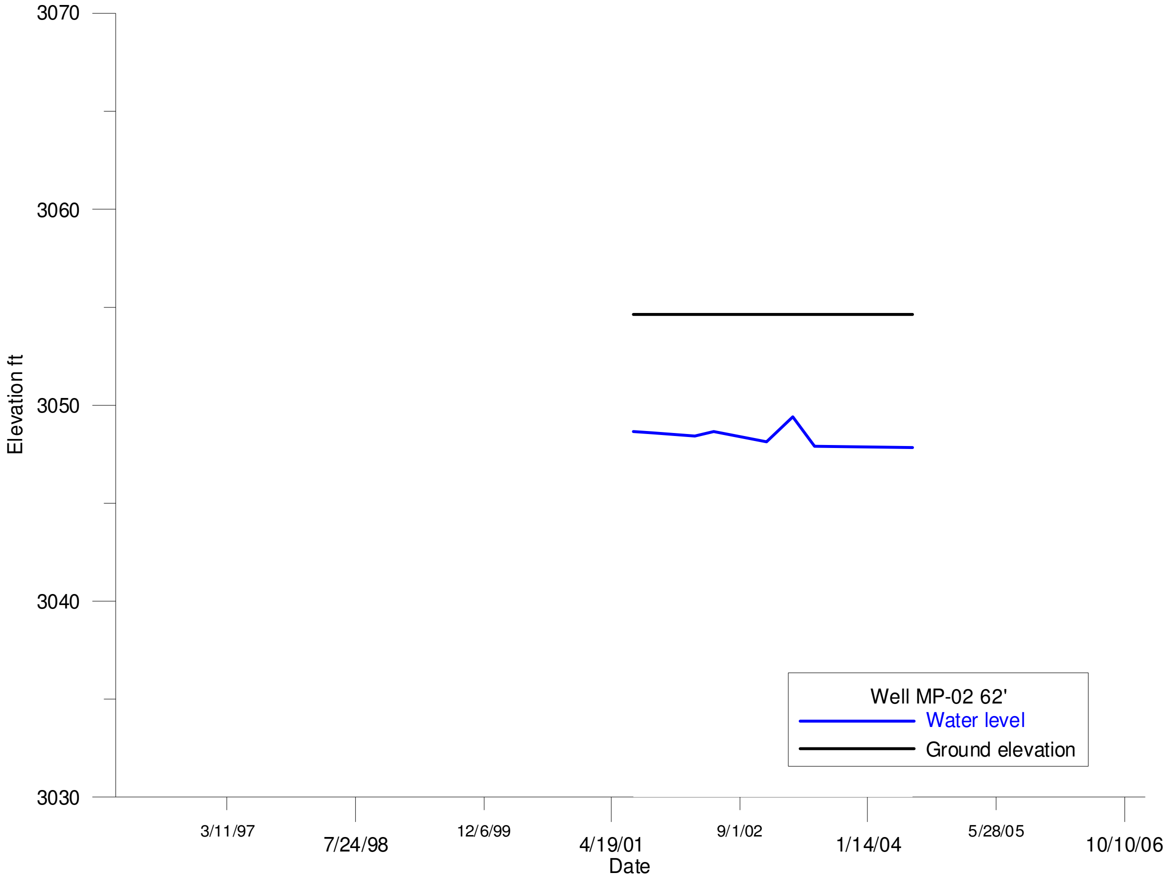

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-01 64'
Water level
Ground elevation

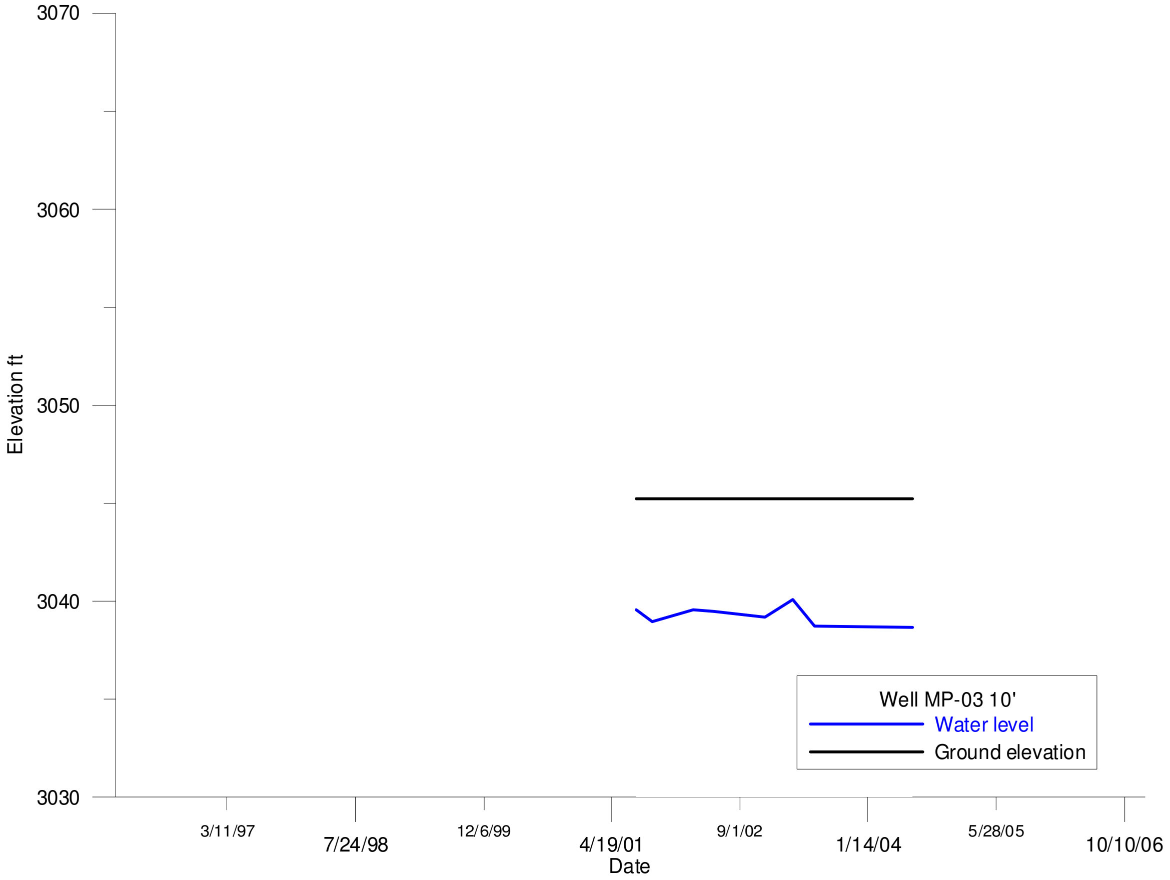

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-01 72'
Water level
Ground elevation

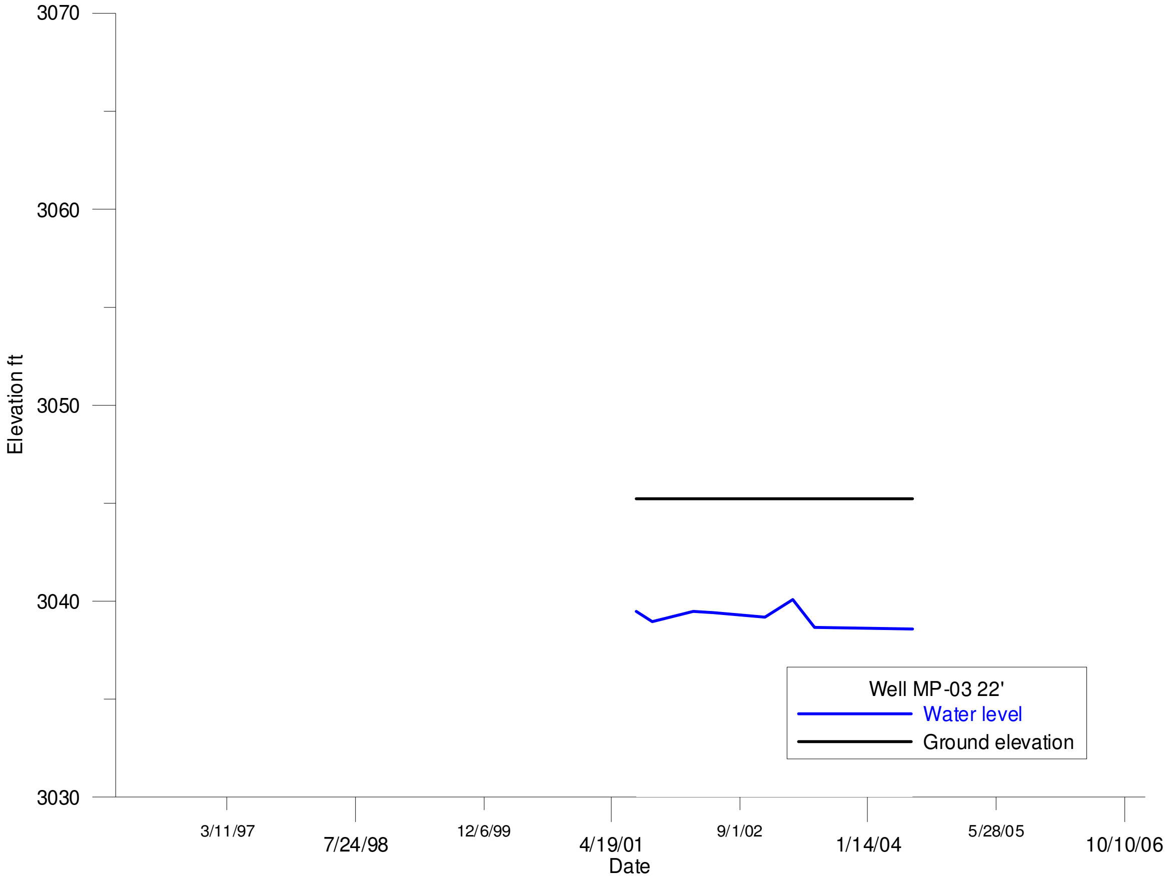

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-02 27'
Water level
Ground elevation

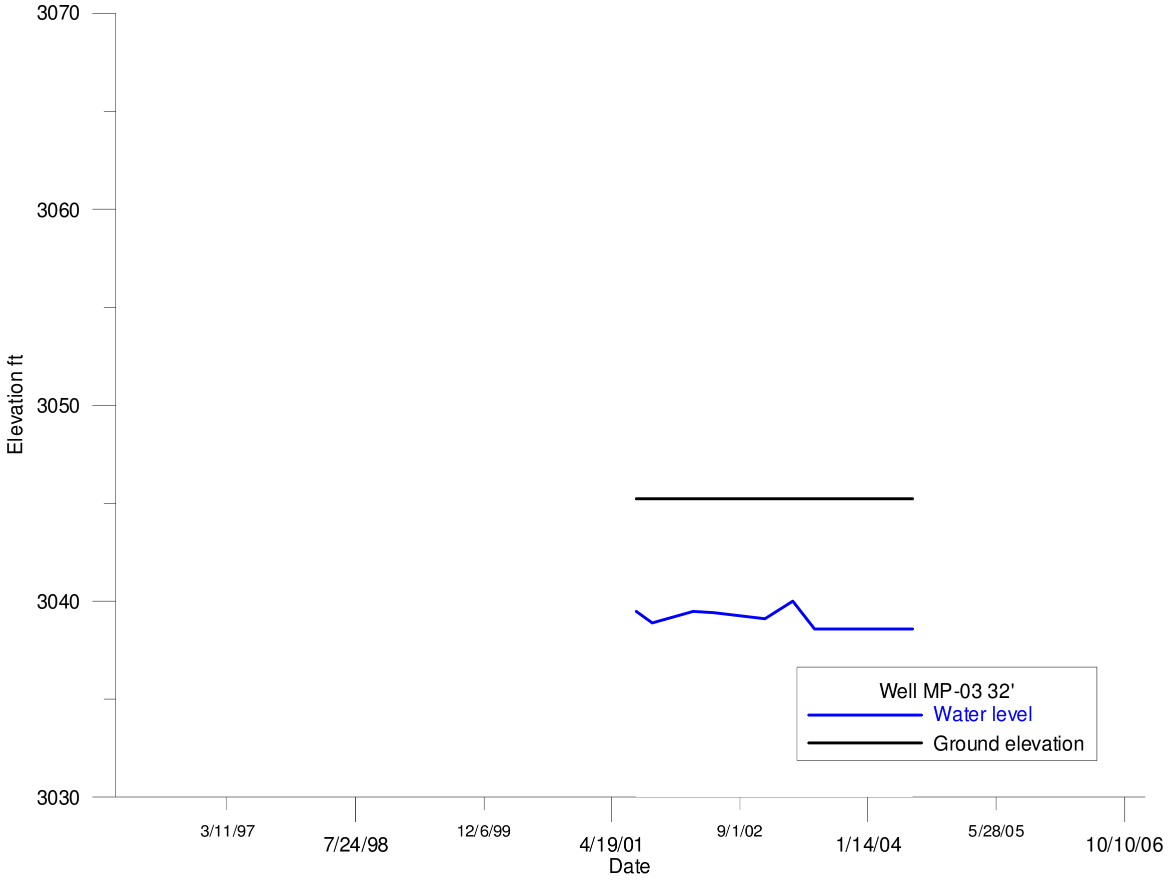

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-02 37'
Water level
Ground elevation

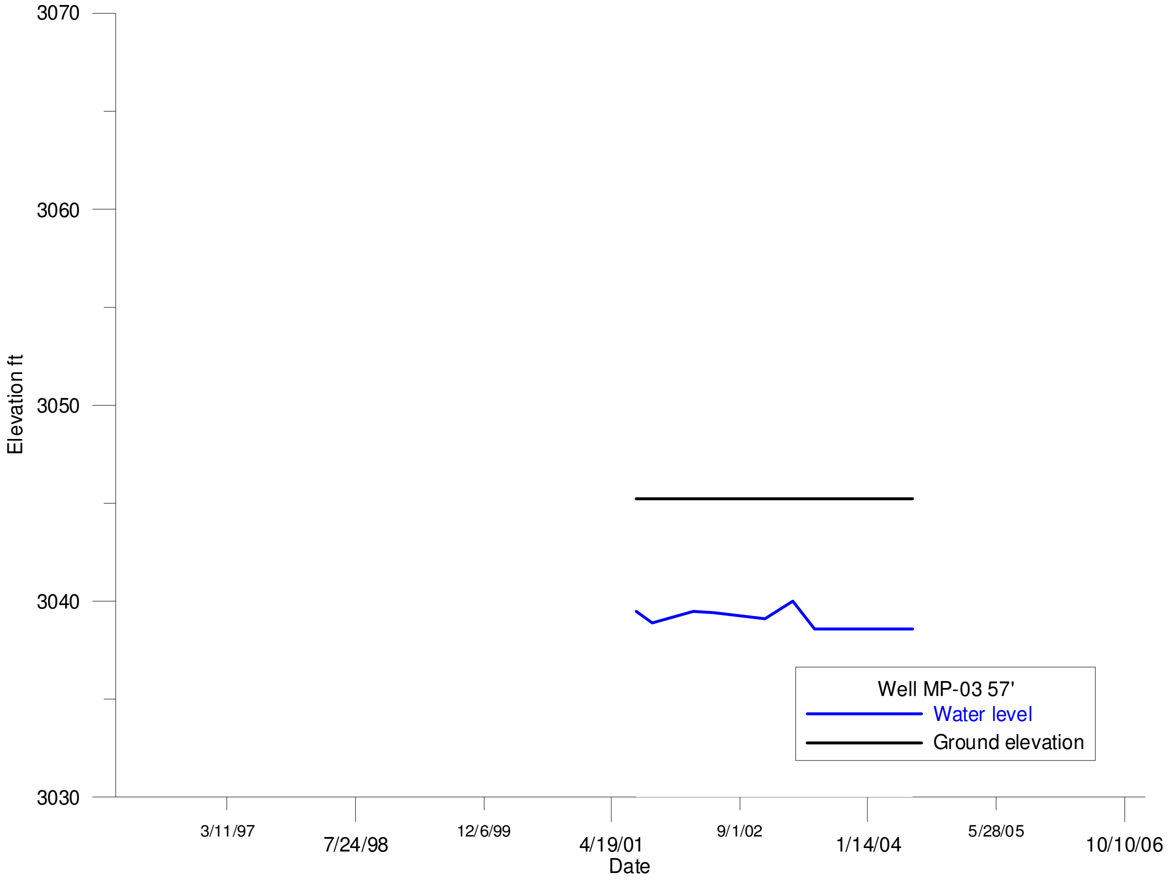

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-02 50'
Water level
Ground elevation


3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-02 62'
Water level
Ground elevation


3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-03 10'
Water level
Ground elevation

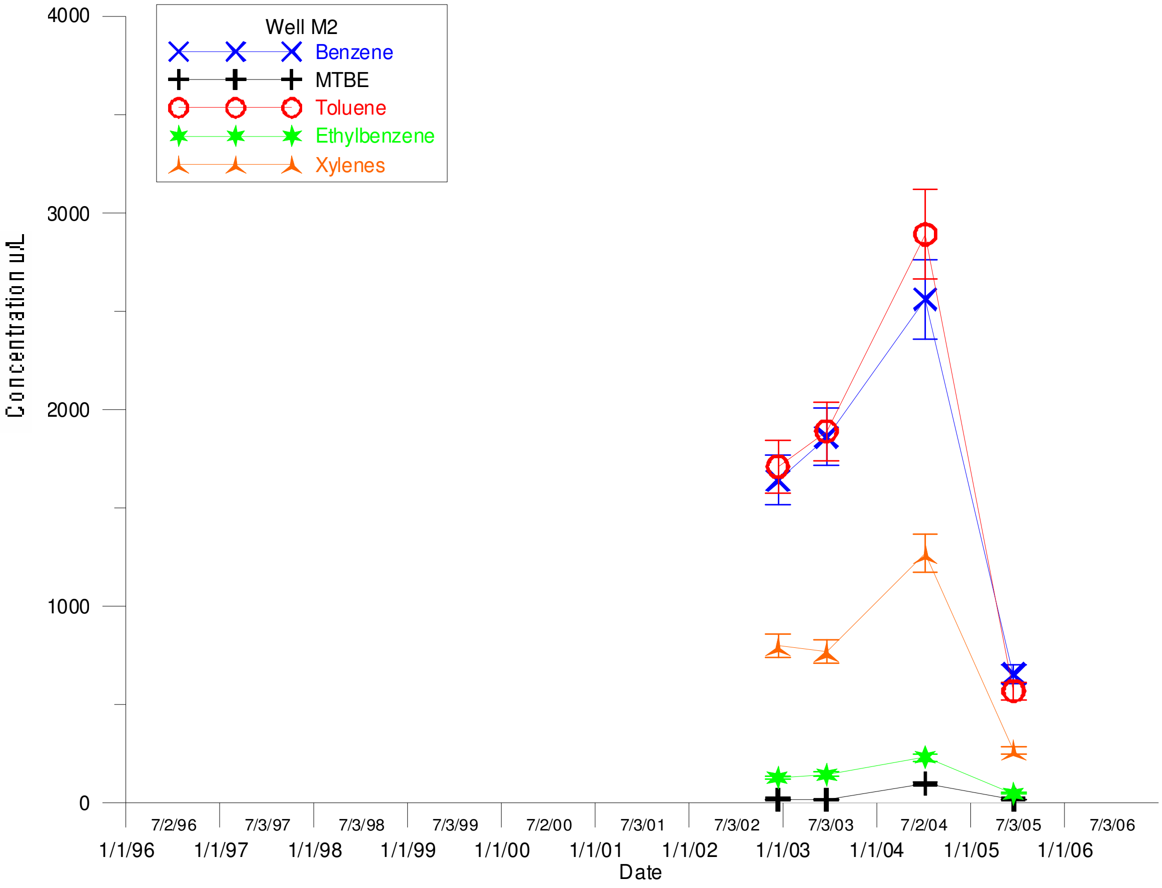

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-03 22'
Water level
Ground elevation

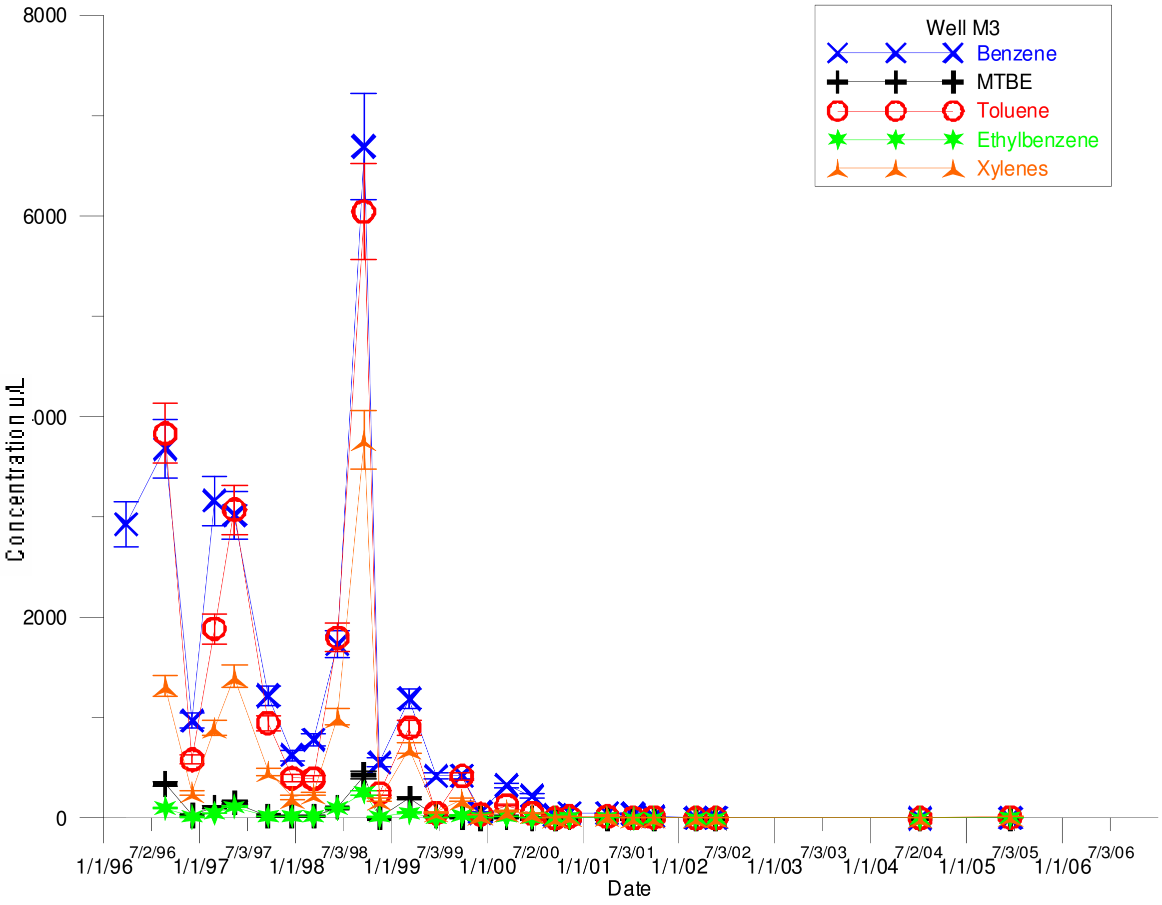

Elevation ft
3070
3060
3050
3040
3030
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-03 32'
Water level
Ground elevation

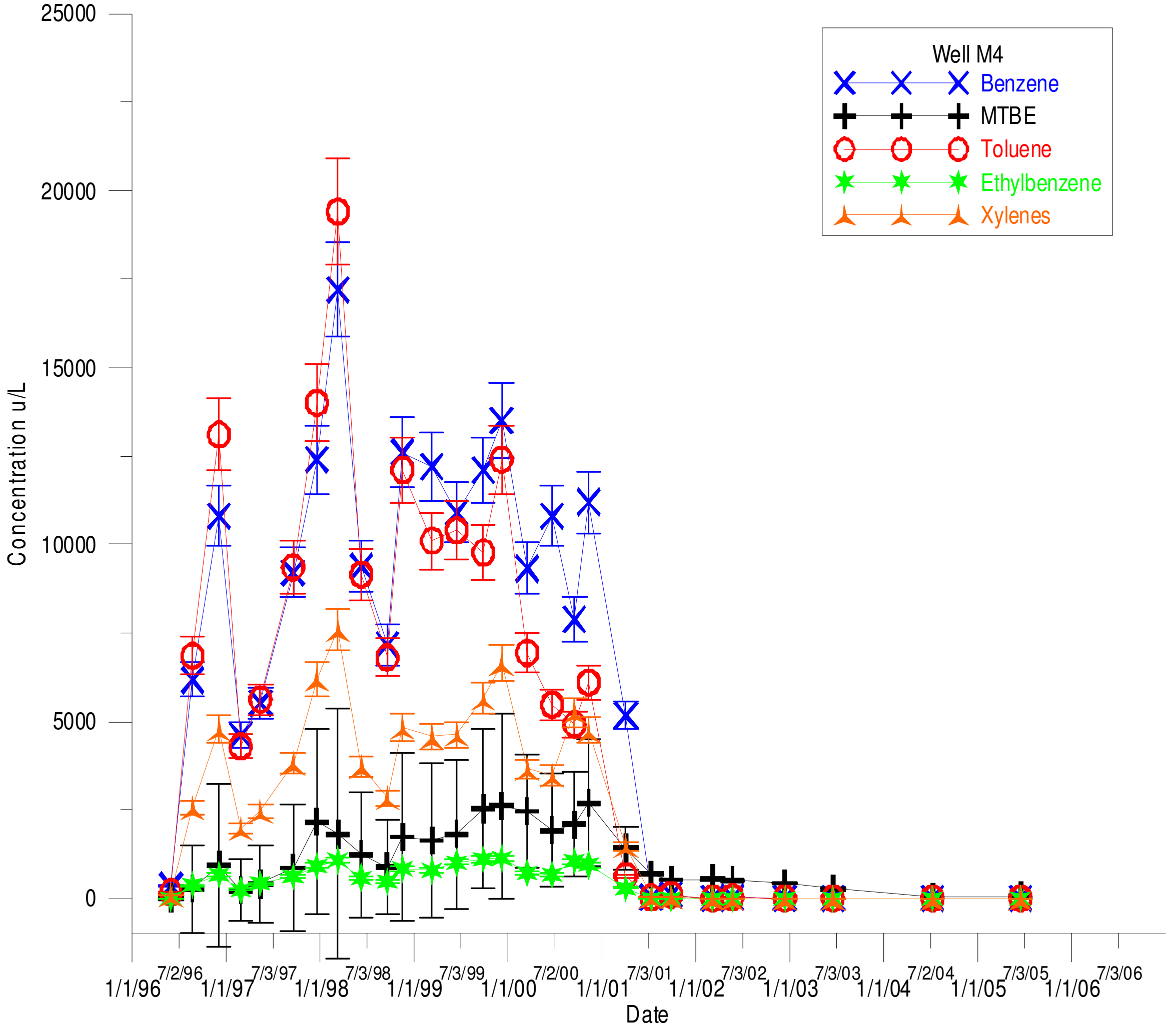

3070
3060
3050
3040
3030
Elevation ft
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
1/14/04
5/28/05
10/10/06
Date
Well MP-03 57'
Water level
Ground elevation

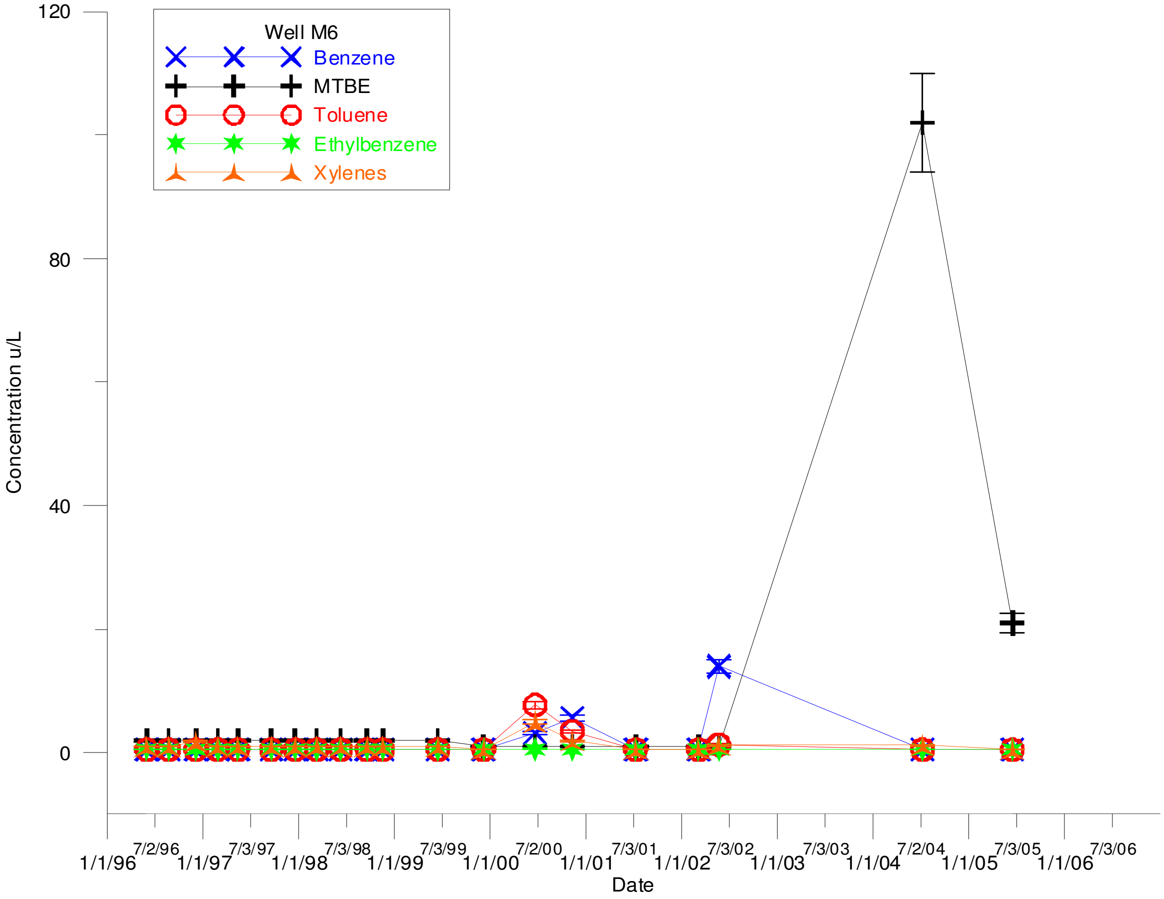
BTEX Components and MTBE over Time

Data was compiled from HKM 2003, 2005, 2006 and Loustaunau 2003. Graphical analysis represents sampling data presented in this appendix. Error bars reflect uncertainty in field and laboratory analysis.

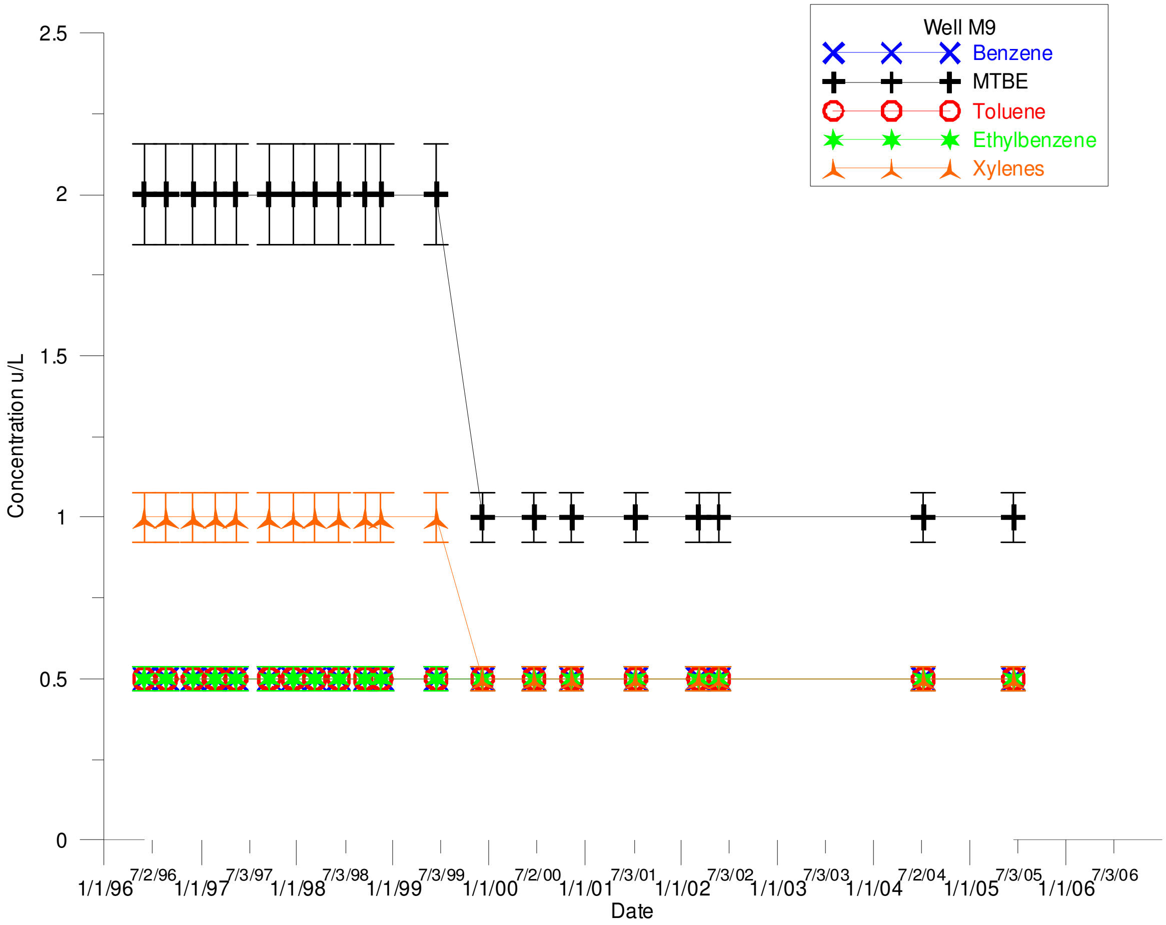

Well M2
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
4000
3000
2000
1000
0
7/2/96
7/3/97
7/3/98
7/3/99
7/2/00
7/3/01
7/3/02
7/3/03
7/2/04
7/3/05
7/3/06
1/1/96
1/1/97
1/1/98
1/1/99
1/1/00
1/1/01
1/1/02
1/1/03
1/1/04
1/1/05
1/1/06
Date

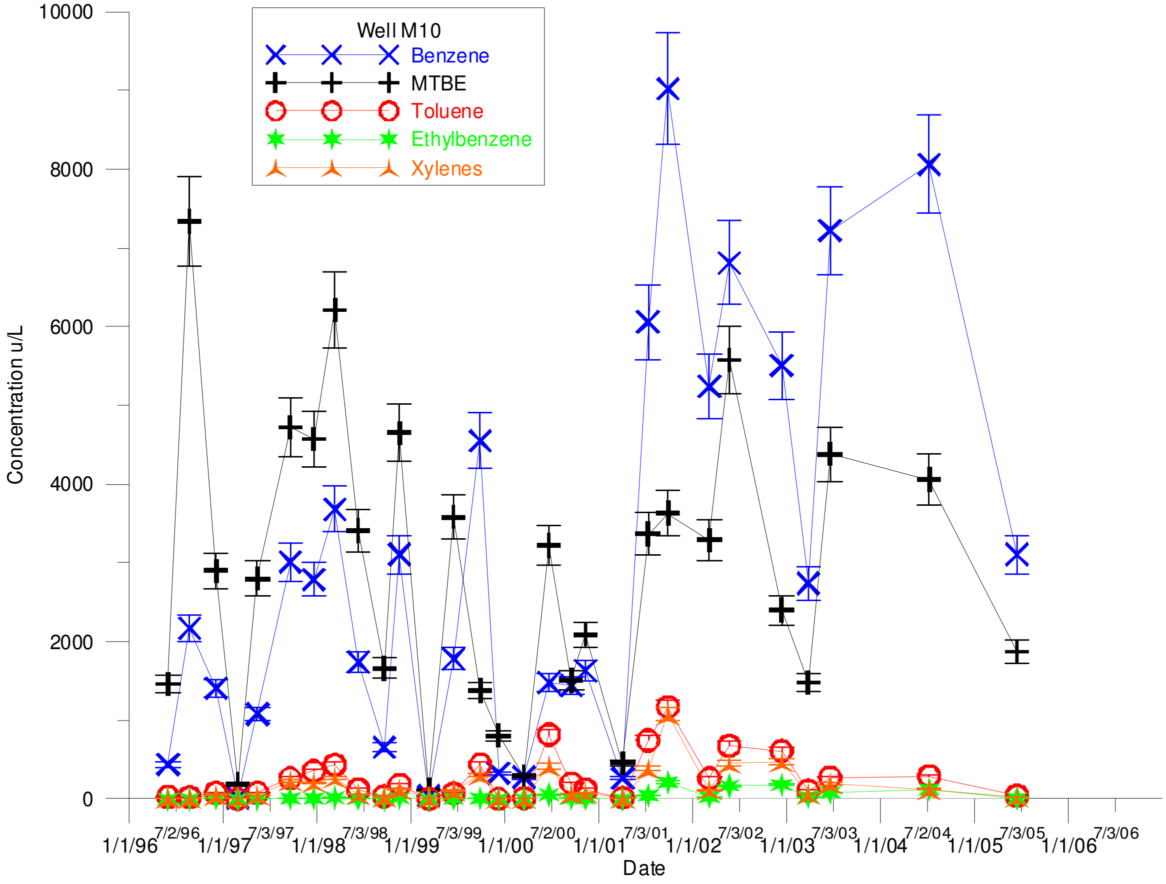

Well M3
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
8000
6000
.000
2000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

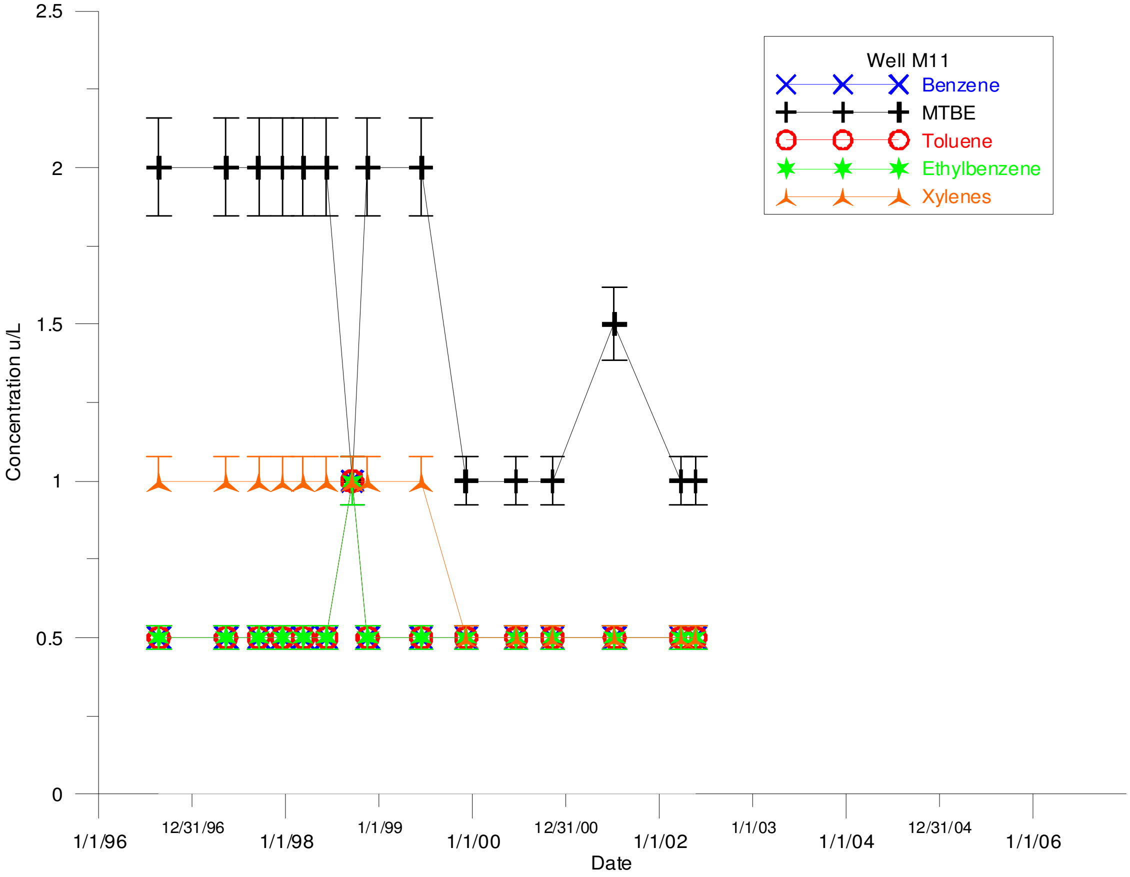

Well M4
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
25000
20000
15000
10000
5000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date



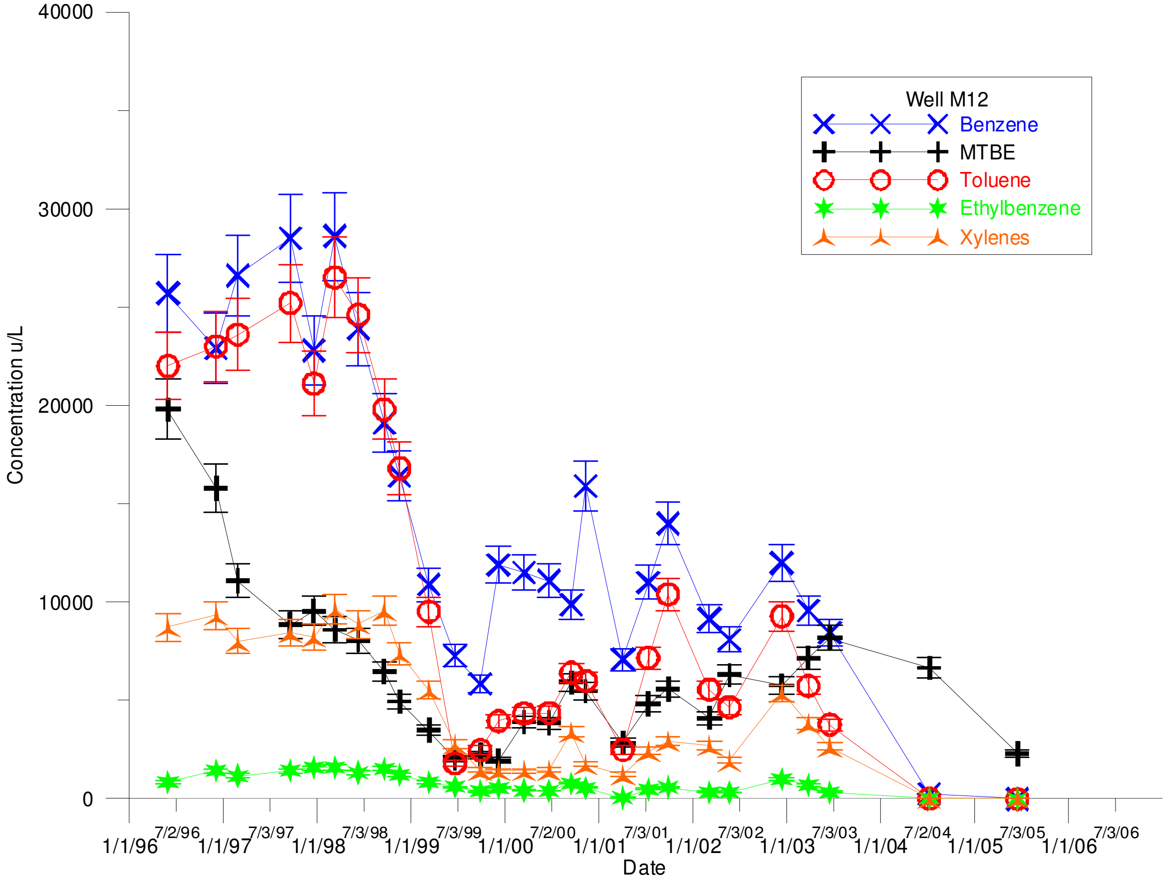
Well M6
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
120
80
40
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well M9
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

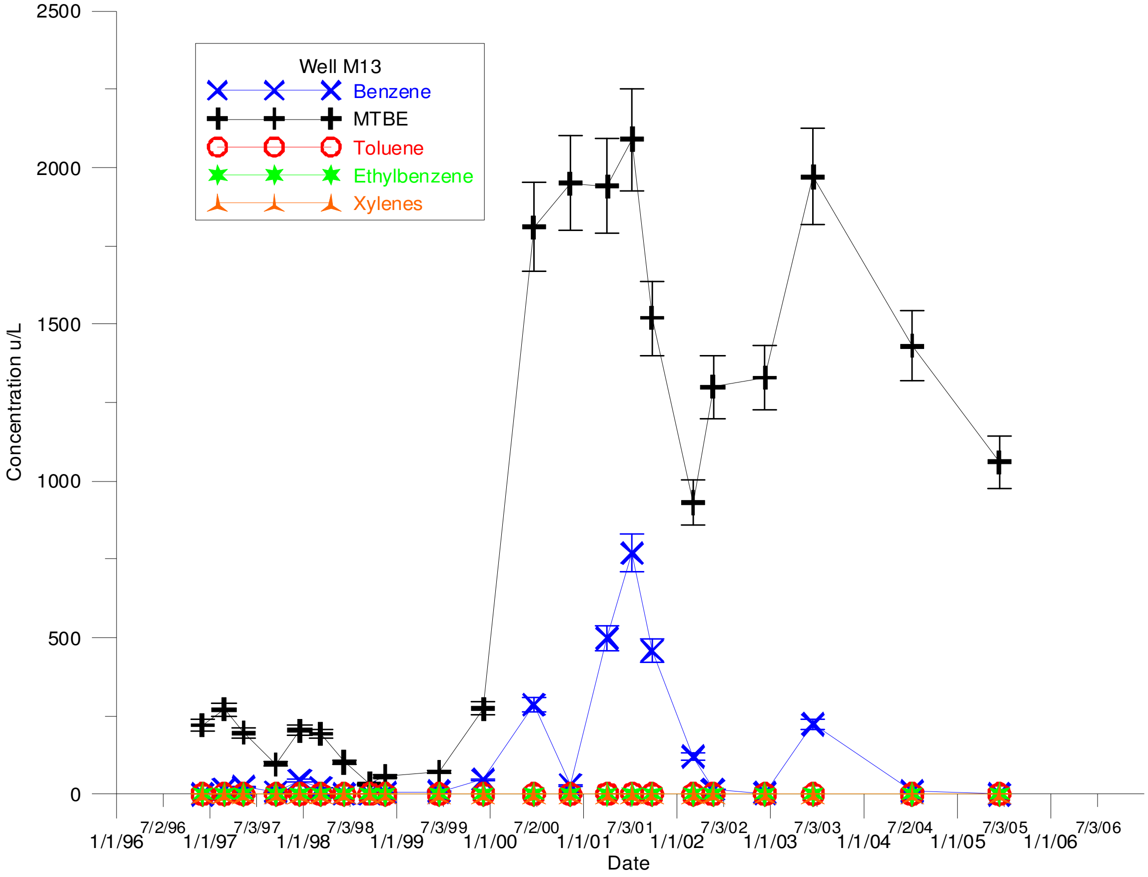

Well M10
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
10000
8000
6000
4000
2000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

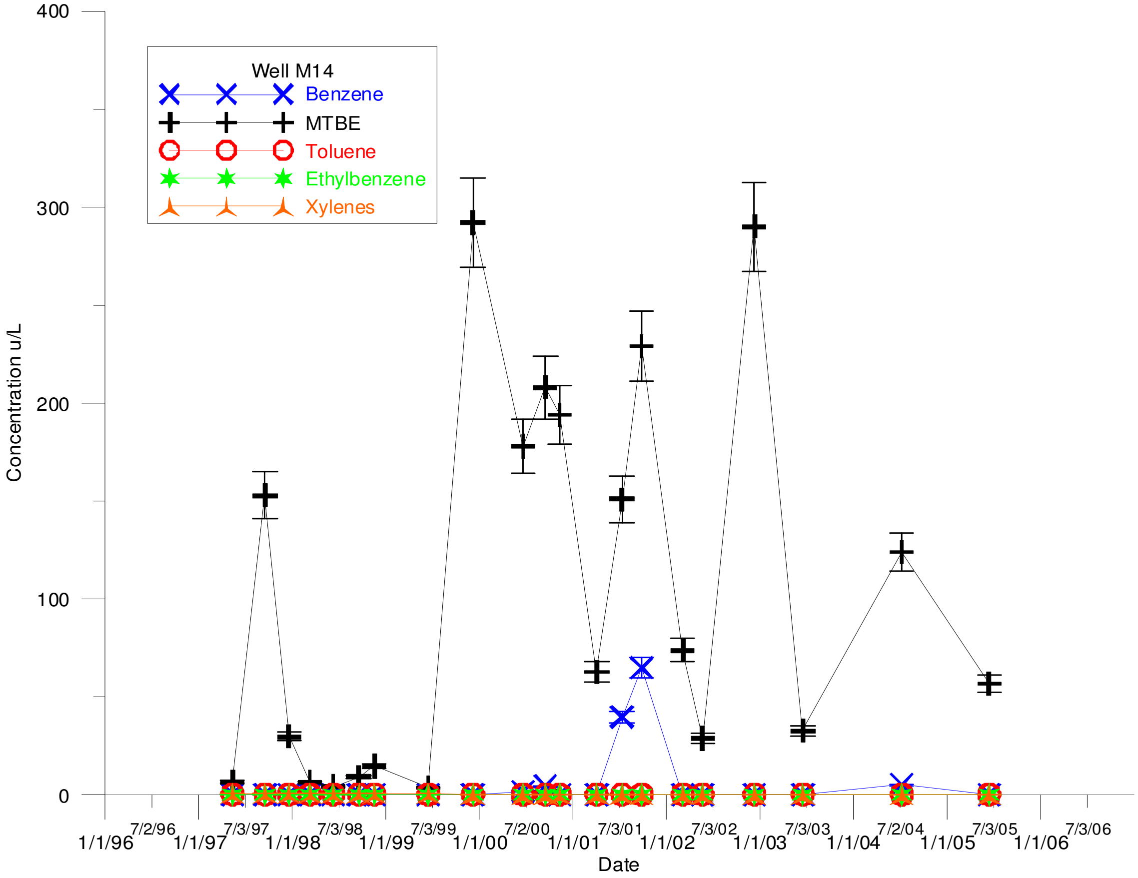


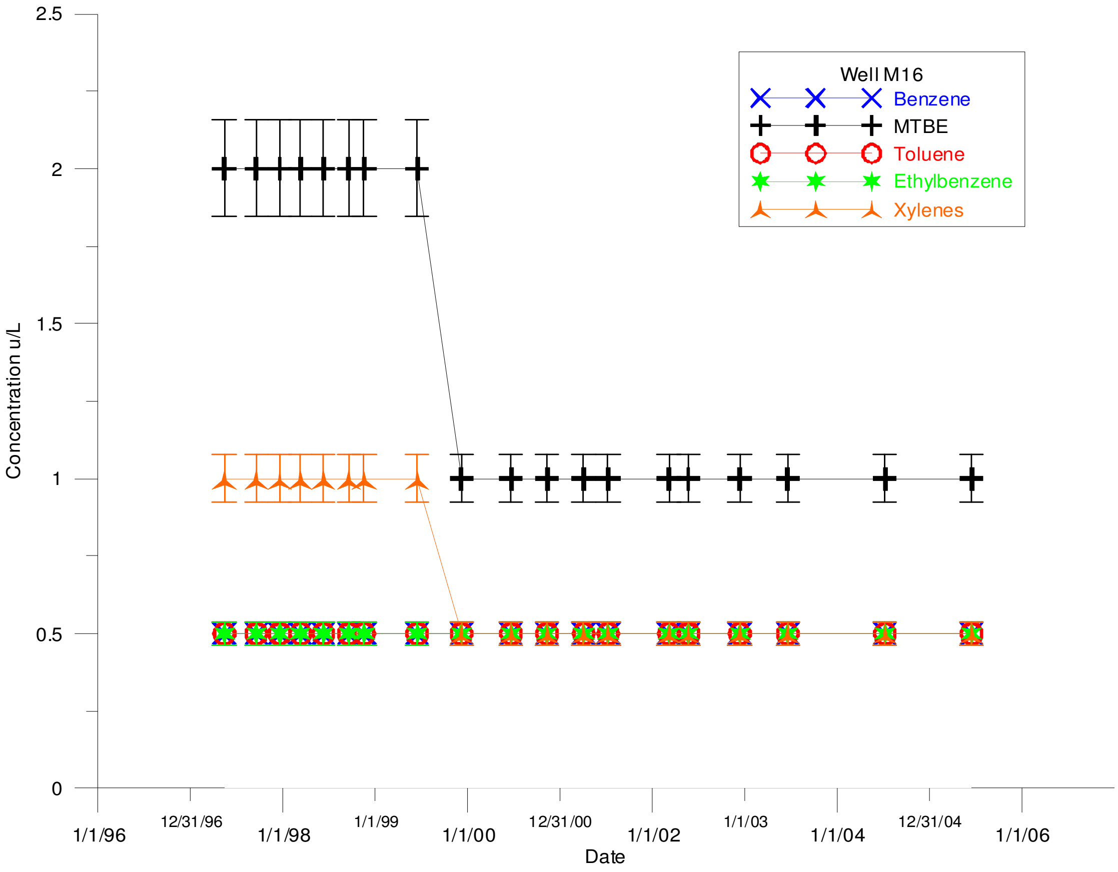
Well M11
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
2.5
2
1.5
1
0.5
0
1/1/96
12/31/96
1/1/98
1/1/99
1/1/00
12/31/00
1/1/02
1/1/03
1/1/04
12/31/04
1/1/06
Date

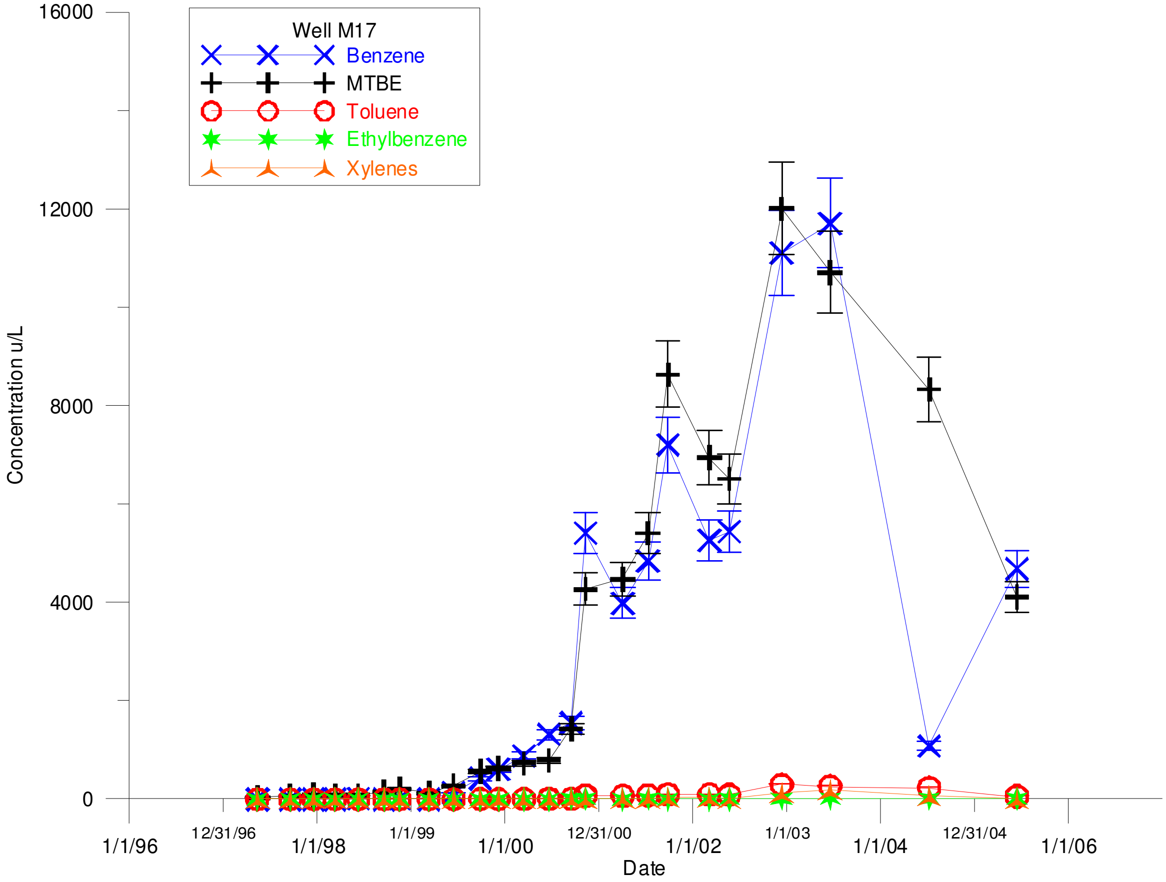


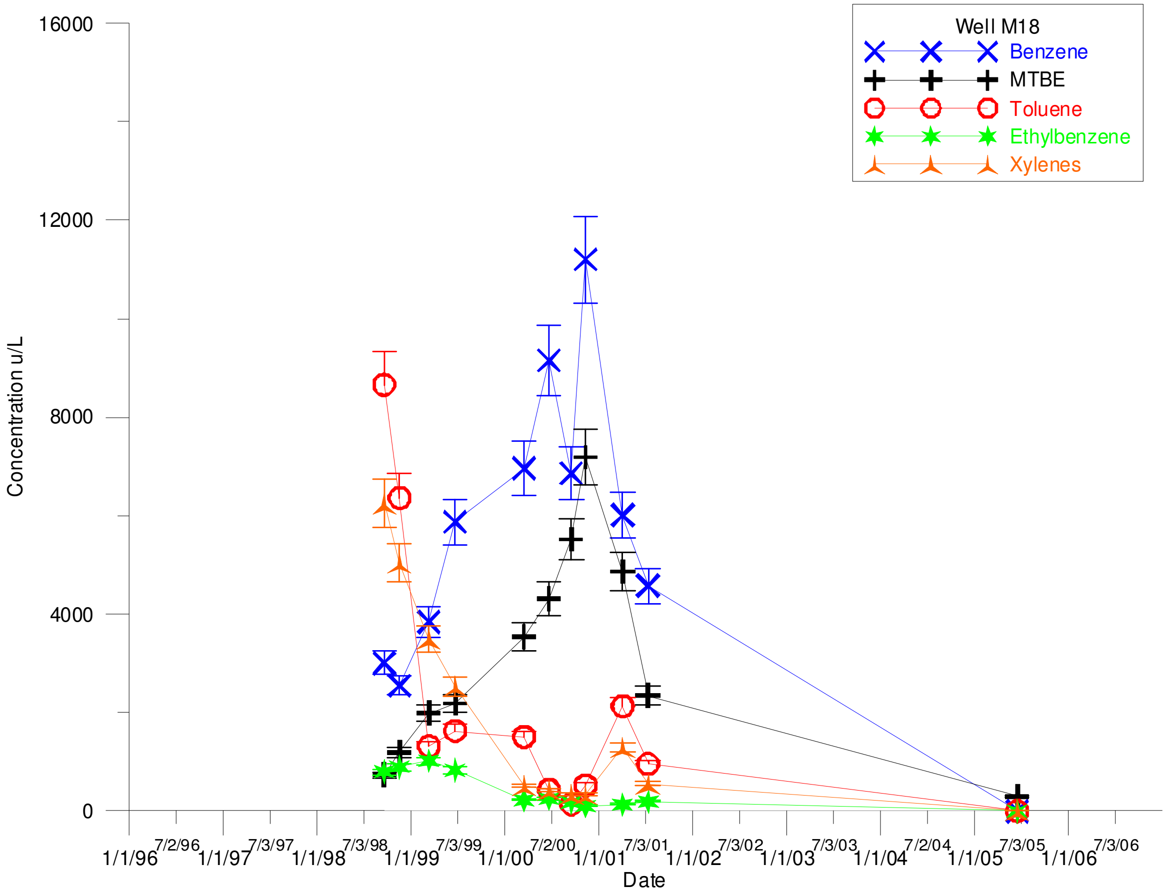
40000
30000
20000
10000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date
Well M12
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes


Well M13
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
2500
2000
1500
1000
500
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

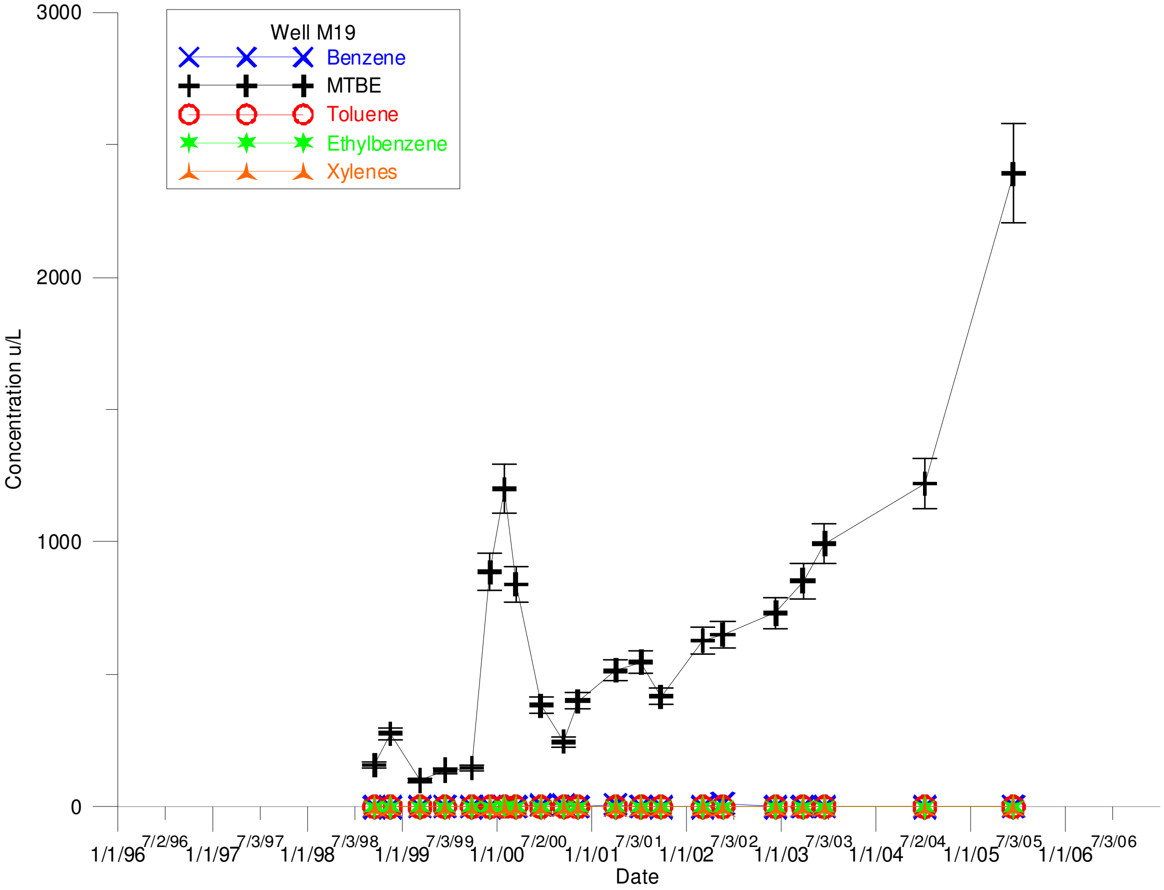

400
300
200
100
0
Concentration u/L
Well M14
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

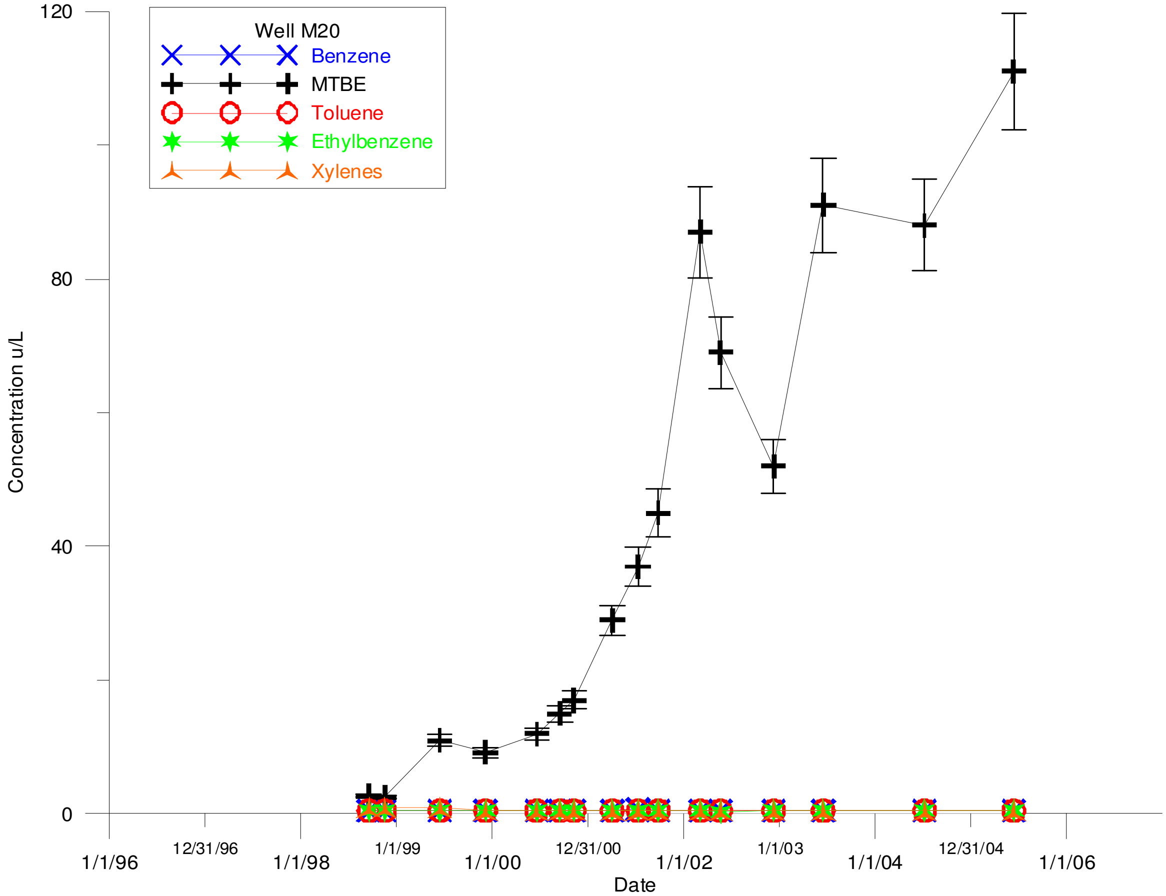

2.5
2
1.5
1
0.5
0
Concentration u/L
Well M16
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
1/1/96
12/31/96
1/1/98
1/1/99
1/1/00
12/31/00
1/1/02
1/1/03
1/1/04
12/31/04
1/1/06
Date


Well M17
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
16000
12000
8000
4000
0
Date
1/1/96
12/31/96
1/1/98
1/1/99
1/1/00
12/31/00
1/1/02
1/1/03
1/1/04
12/31/04
1/1/06

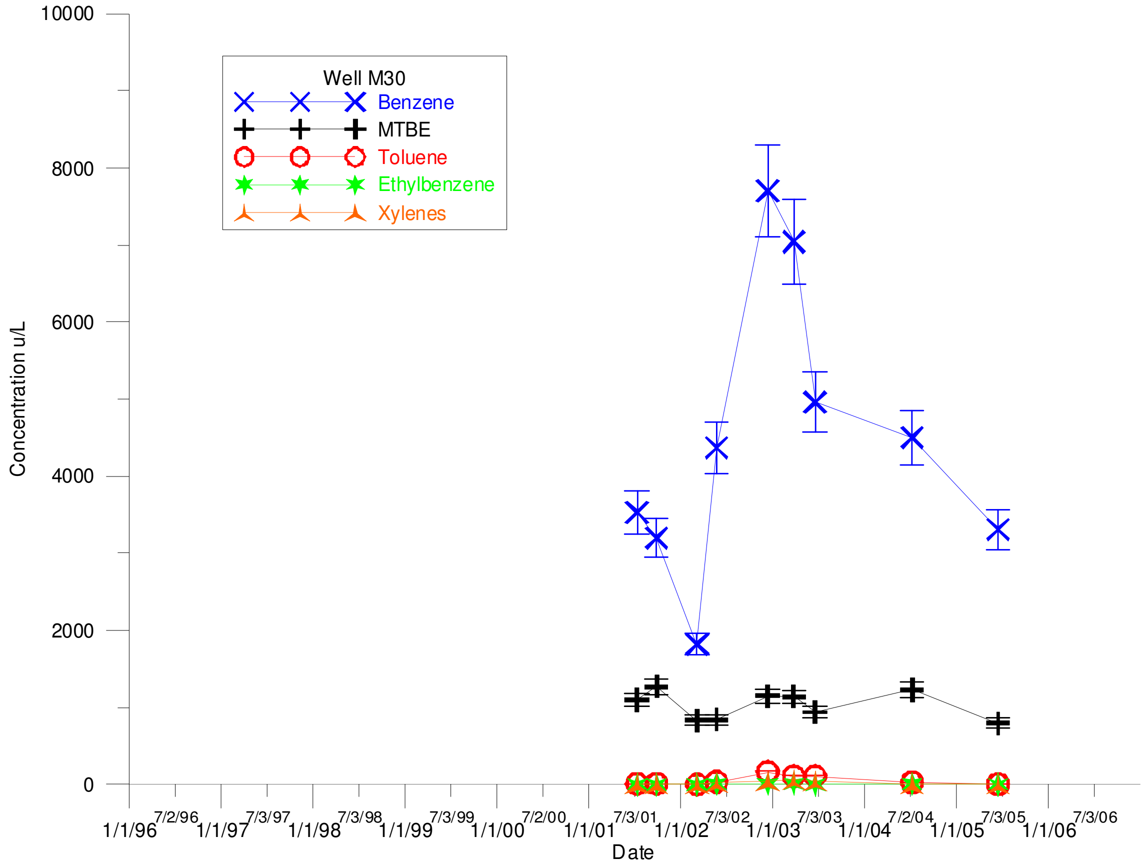


Well M18
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
16000
12000
8000
4000
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

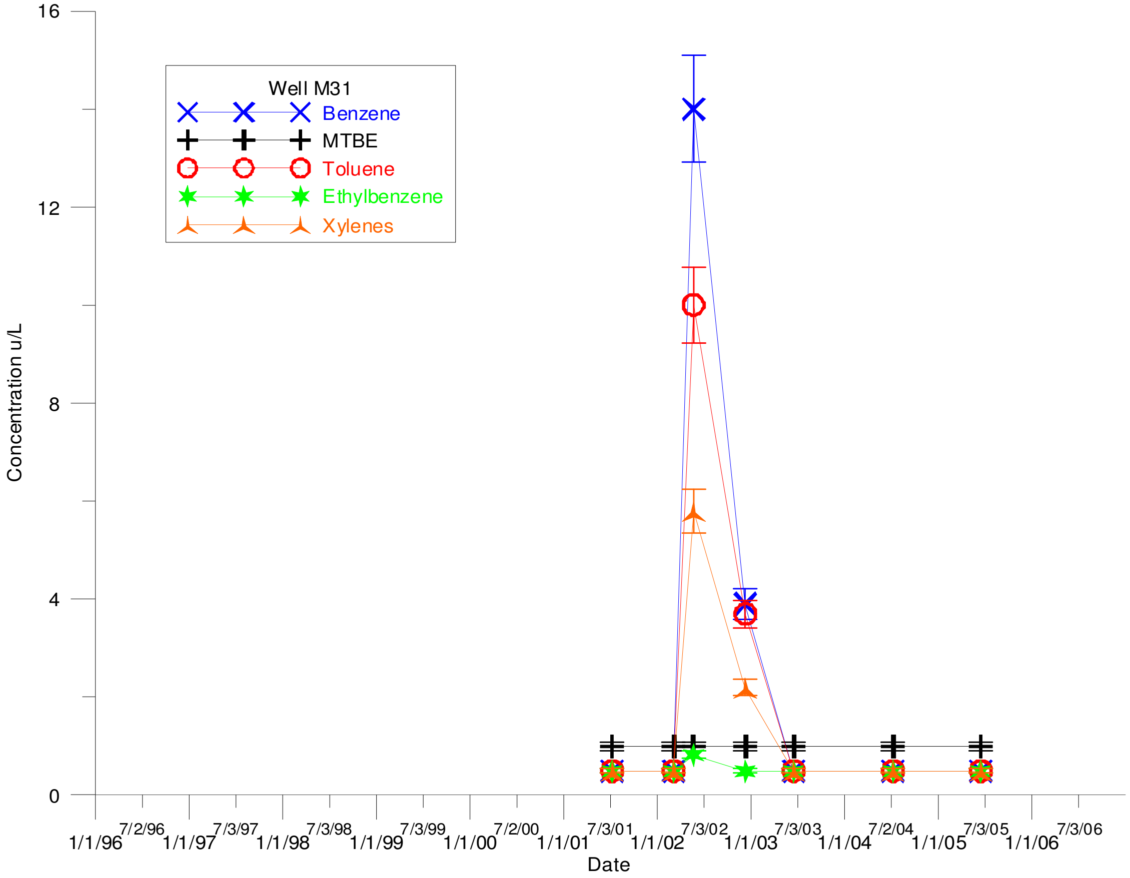

Well M19
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
3000
2000
1000
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

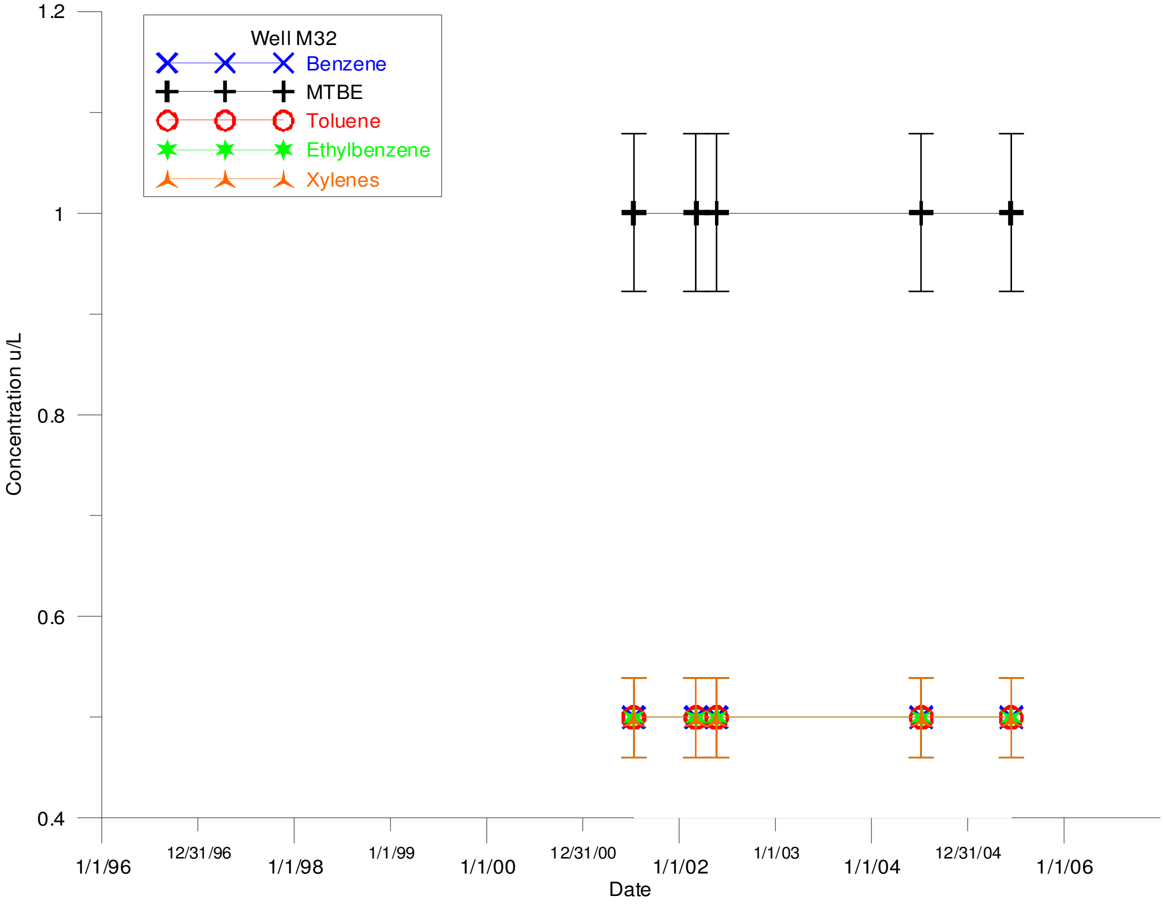


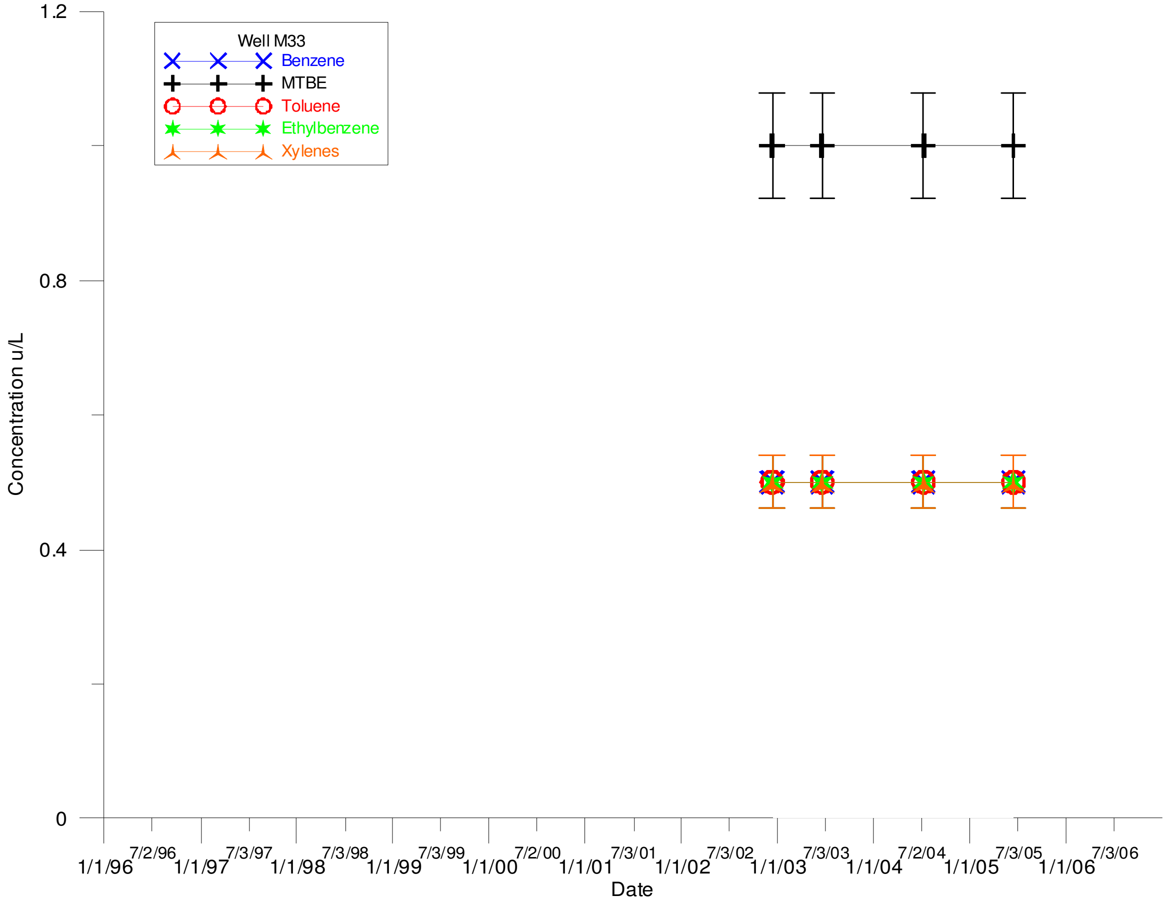
Well M20
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
120
80
40
0
Concentration u/L
1/1/96
12/31/96
1/1/98
1/1/99
1/1/00
12/31/00
1/1/02
1/1/03
1/1/04
12/31/04
1/1/06
Date

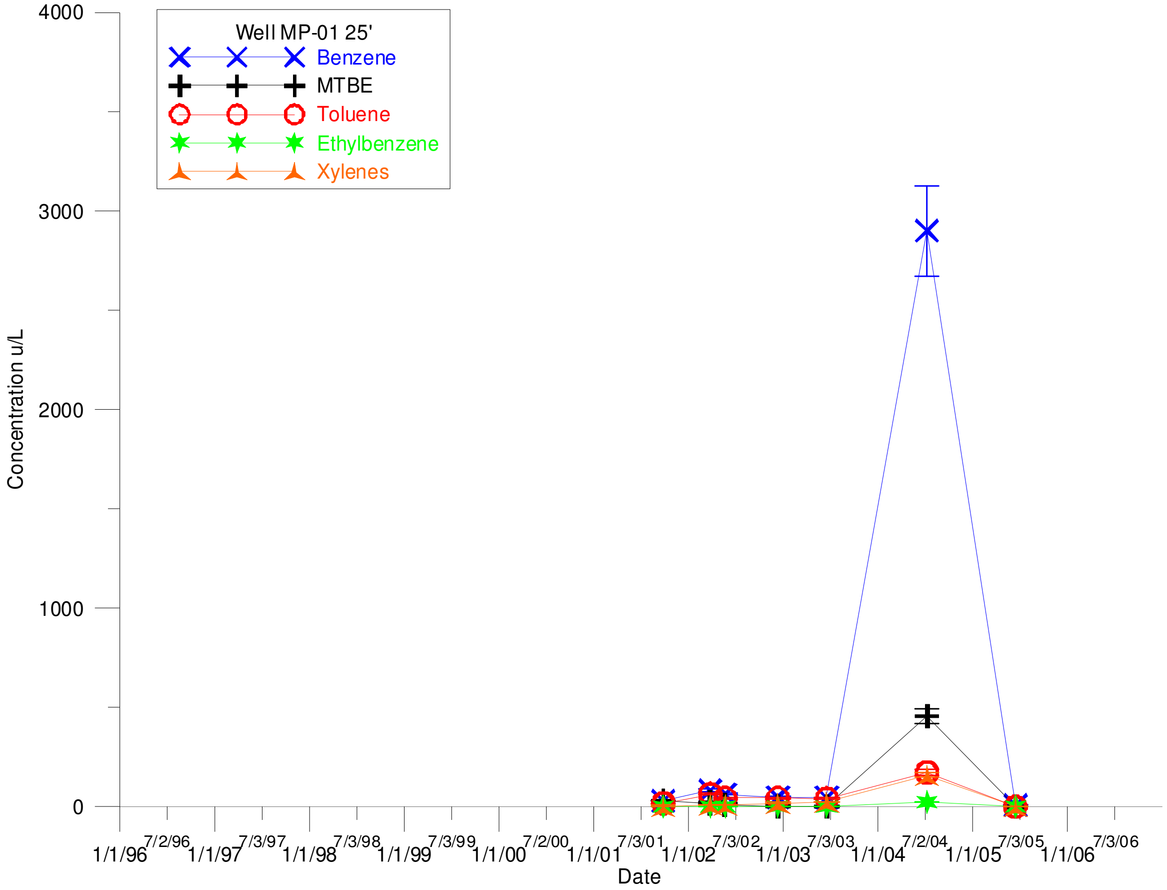


Well M30
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
10000
8000
6000
4000
2000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

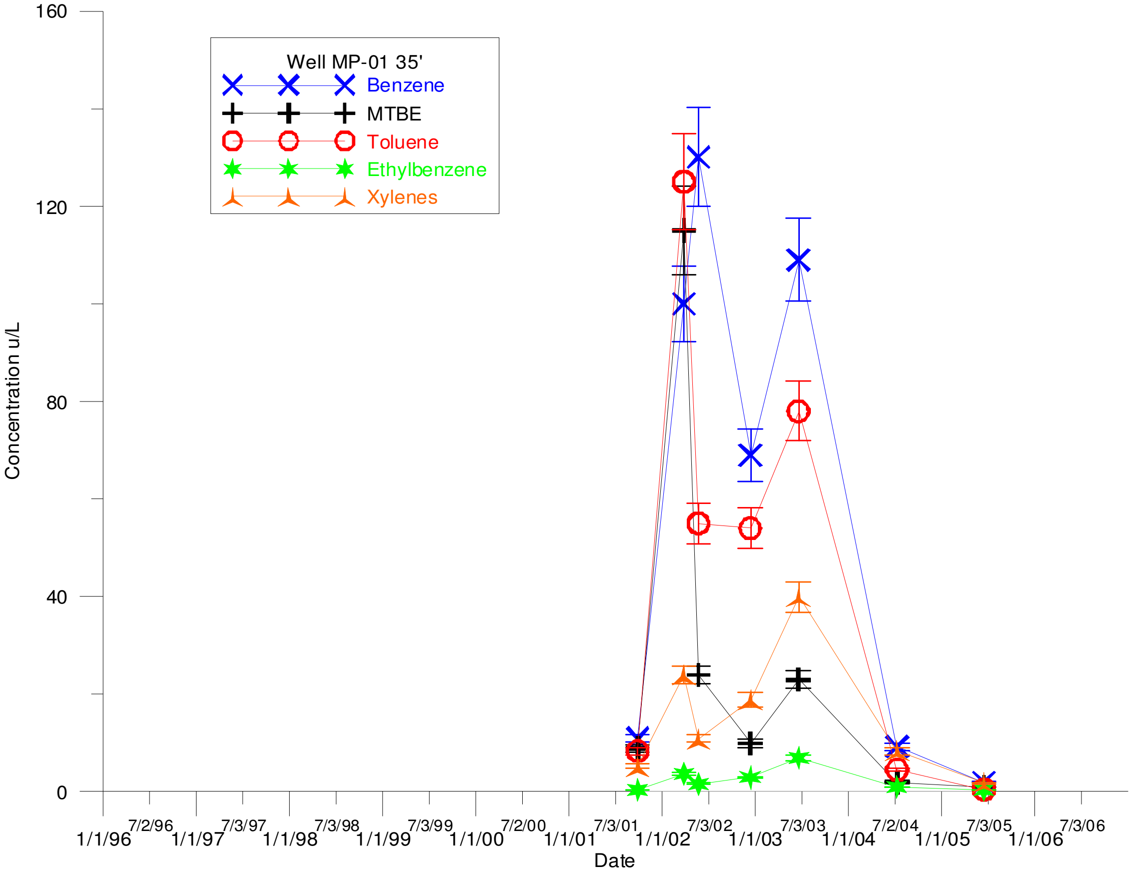

Well M31
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
16
12
8
4
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

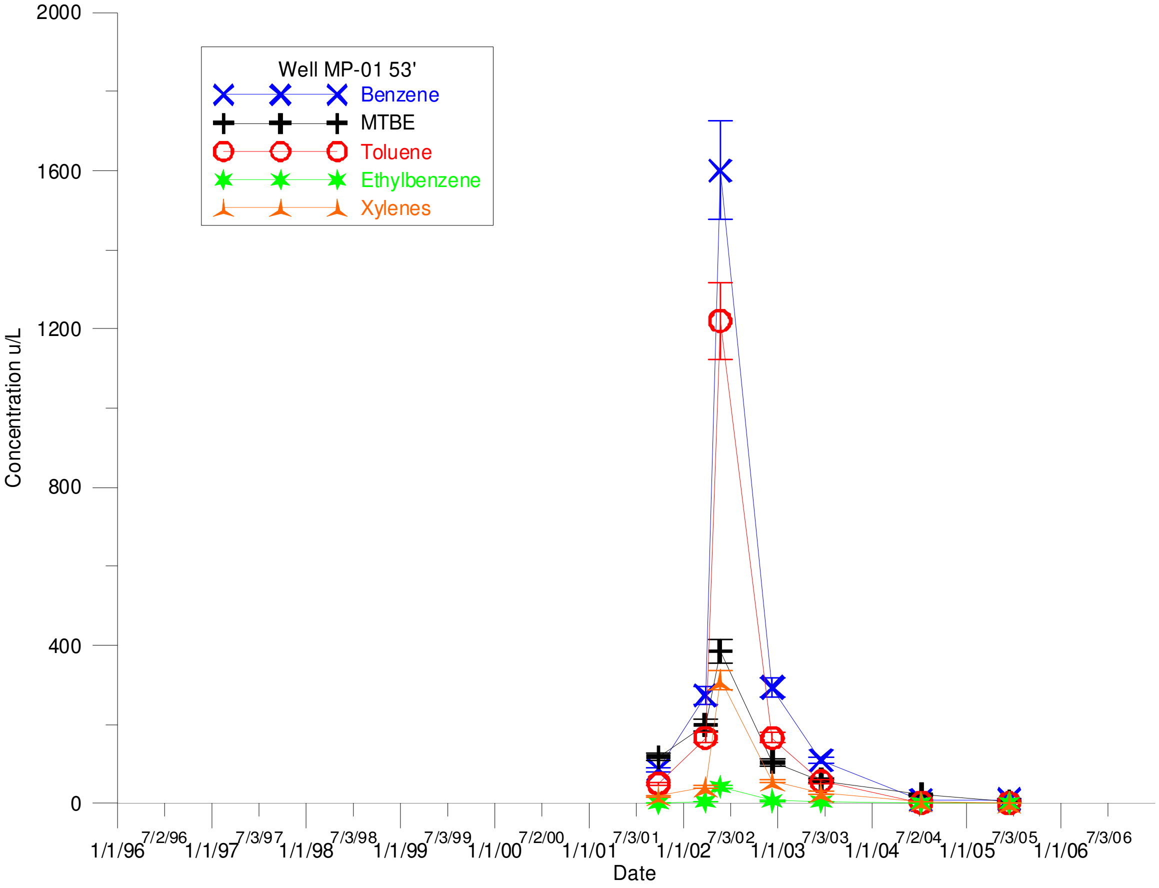

Well M32
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
1.2
1
0.8
0.6
0.4
1/1/96
12/31/96
1/1/98
1/1/99
1/1/00
12/31/00
1/1/02
1/1/03
1/1/04
12/31/04
1/1/06
Date

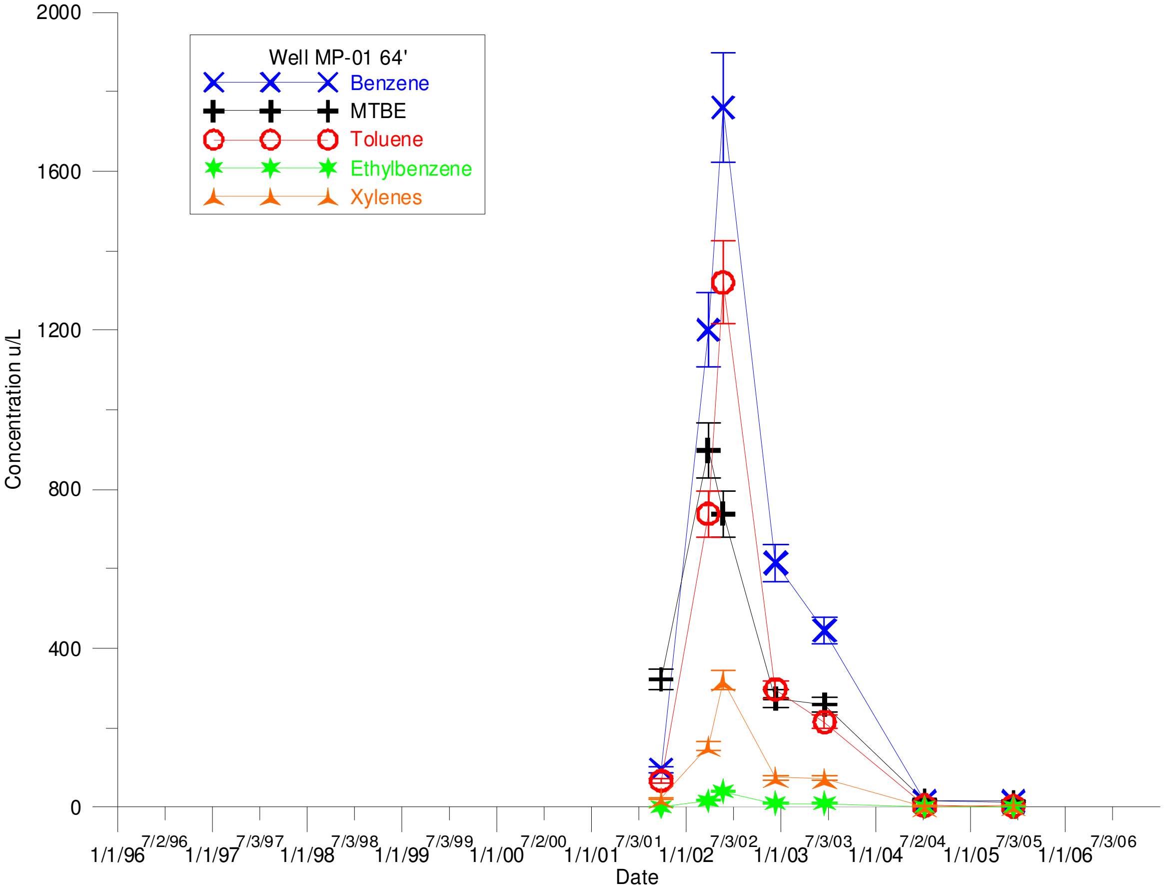

Well M33
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
1.2
0.8
0.4
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

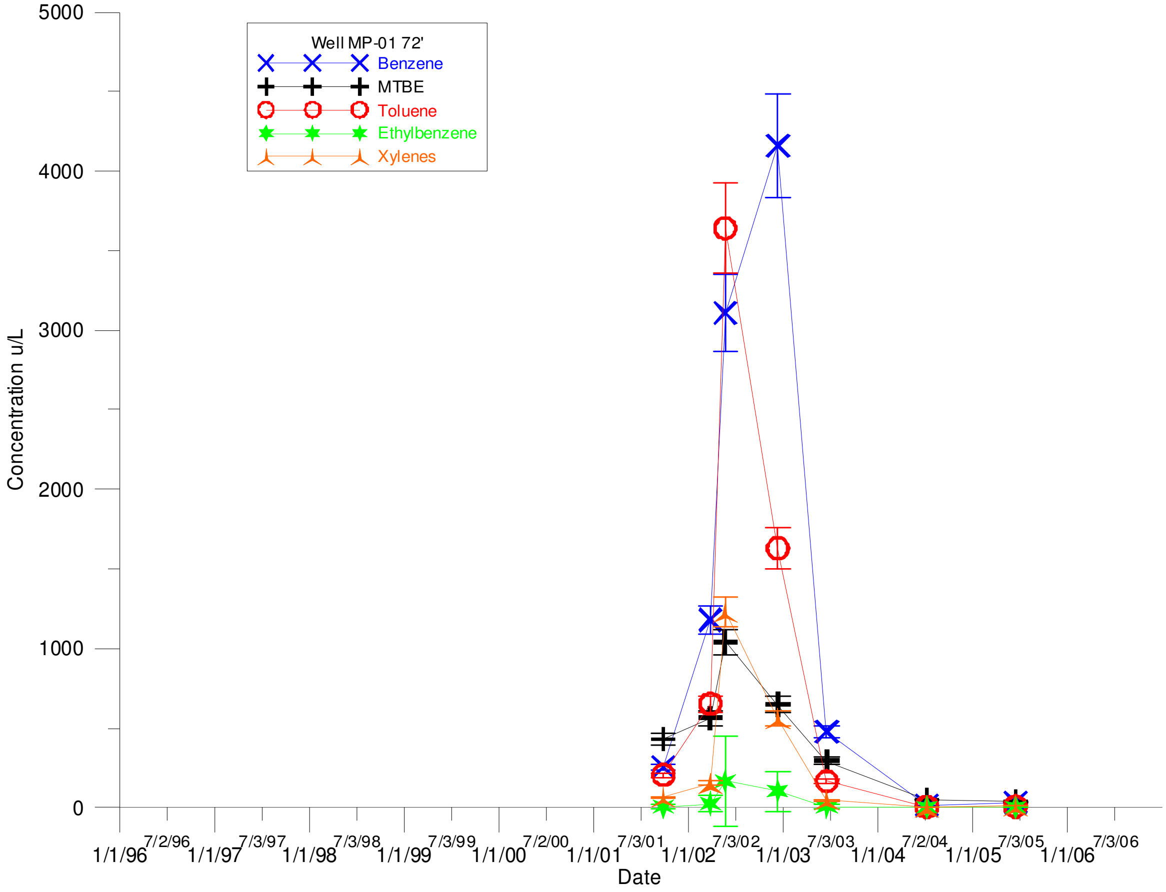


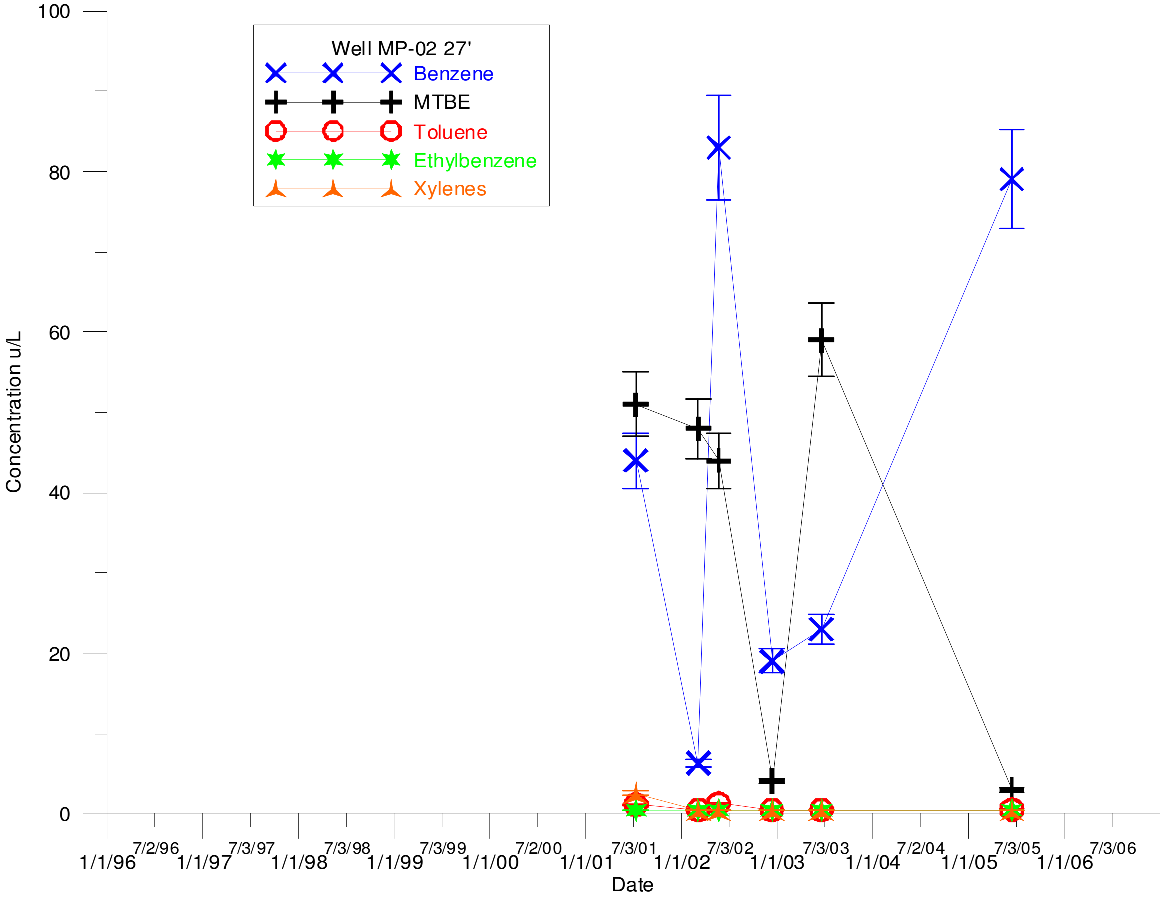
Well MP-01 25'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
4000
3000
2000
1000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

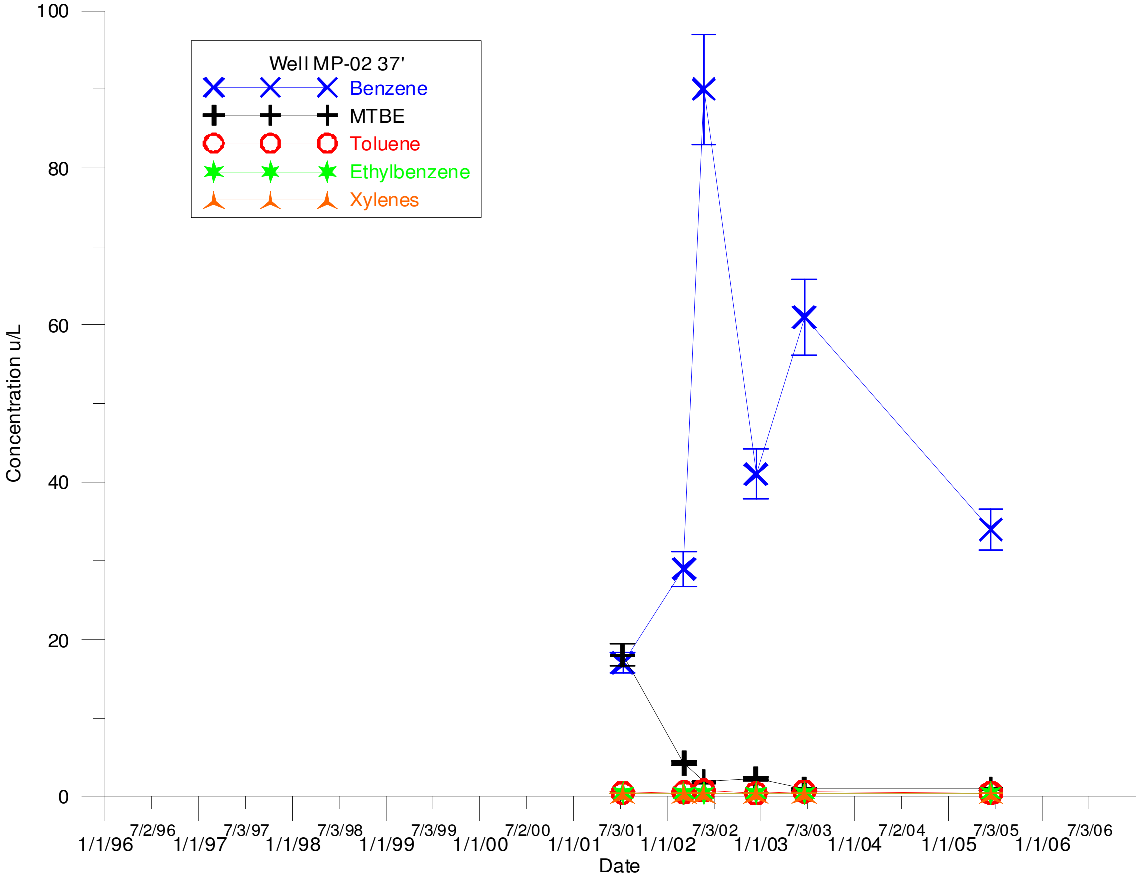

Well MP-01 35'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
160
120
80
40
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

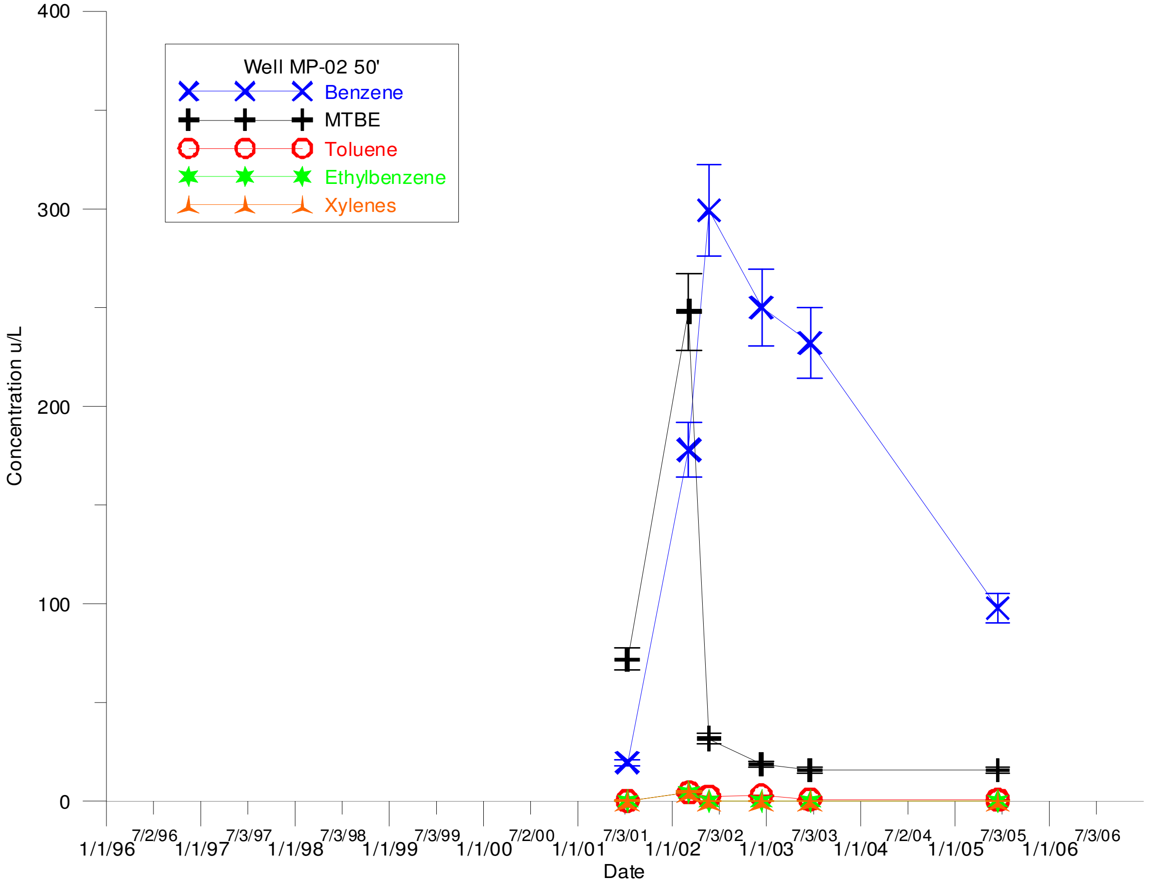

Well MP-01 53'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
2000
1600
1200
800
400
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

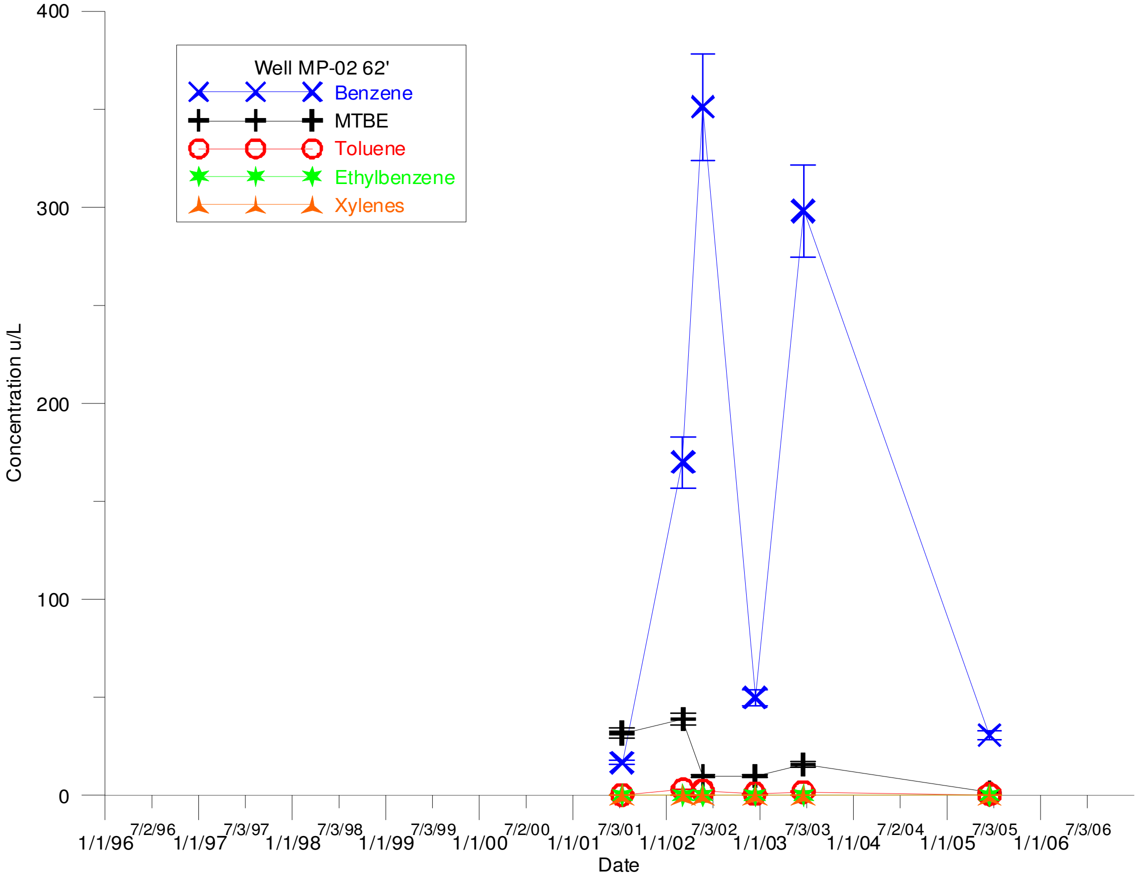

Well MP-01 64'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
2000
1600
1200
800
400
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

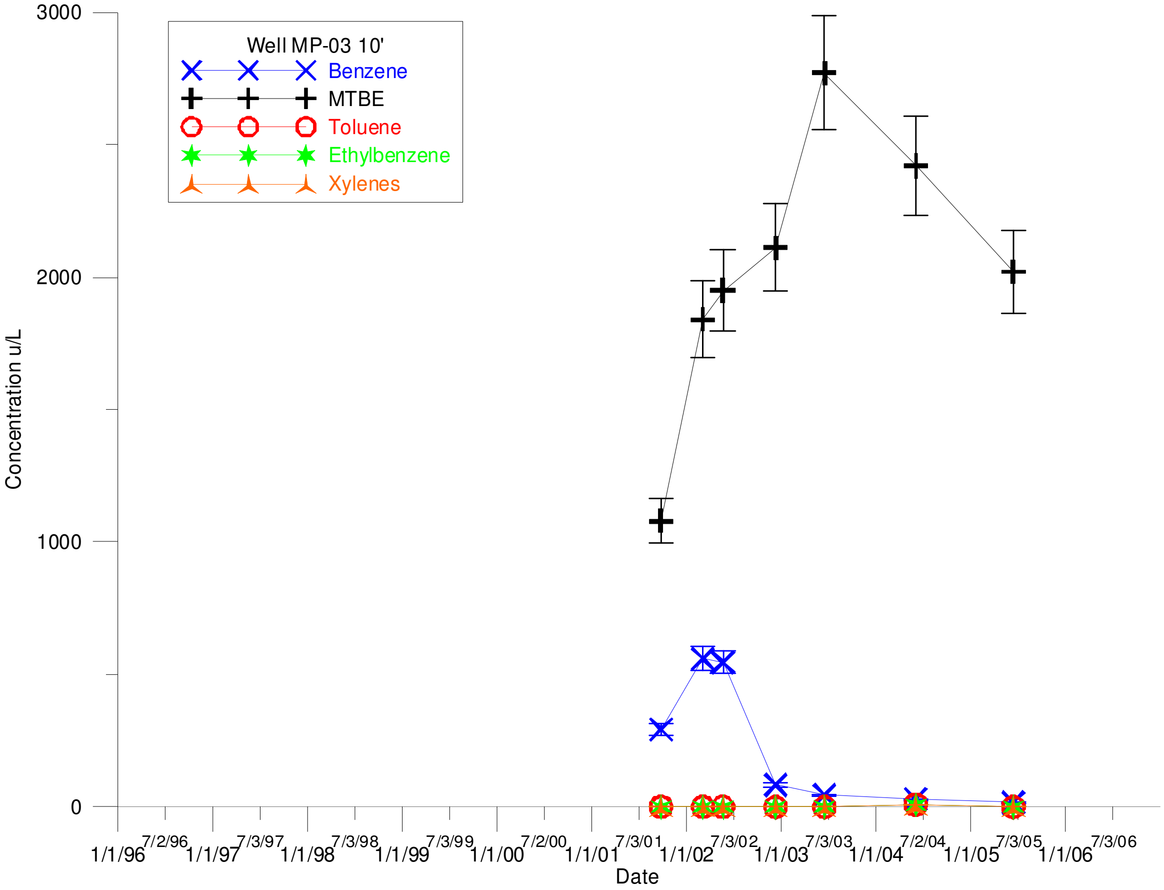

Well MP-01 72'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
5000
4000
3000
2000
1000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

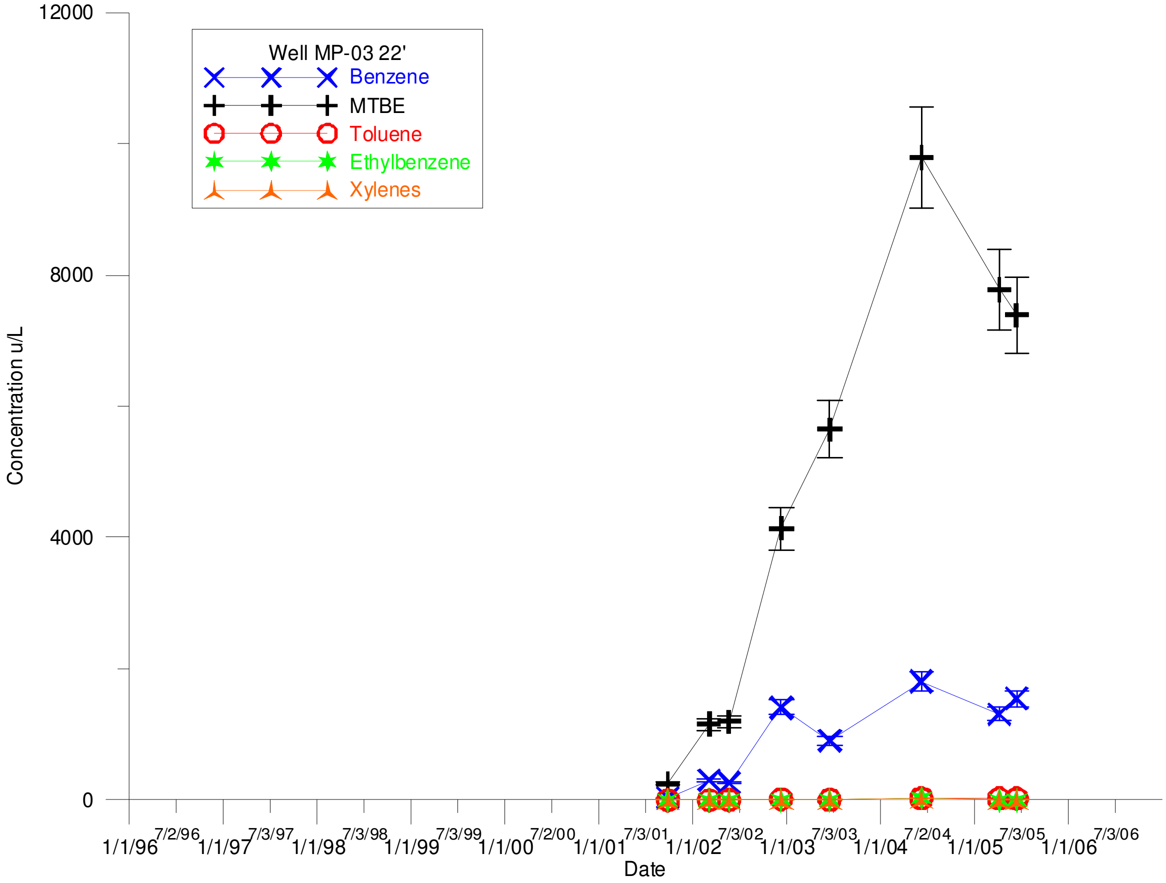

Well MP-02 27'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
100
80
60
40
20
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

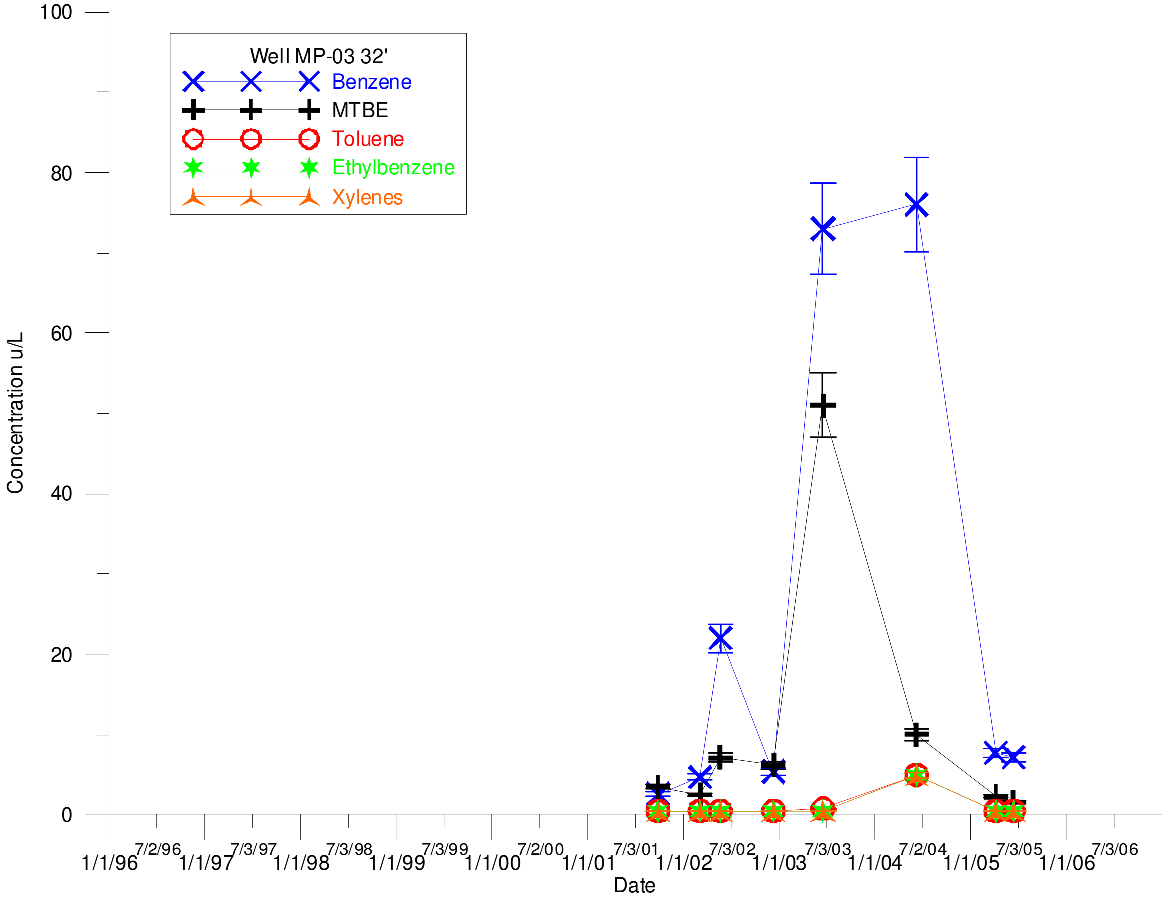

Well MP-02 37'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
100
80
60
40
20
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

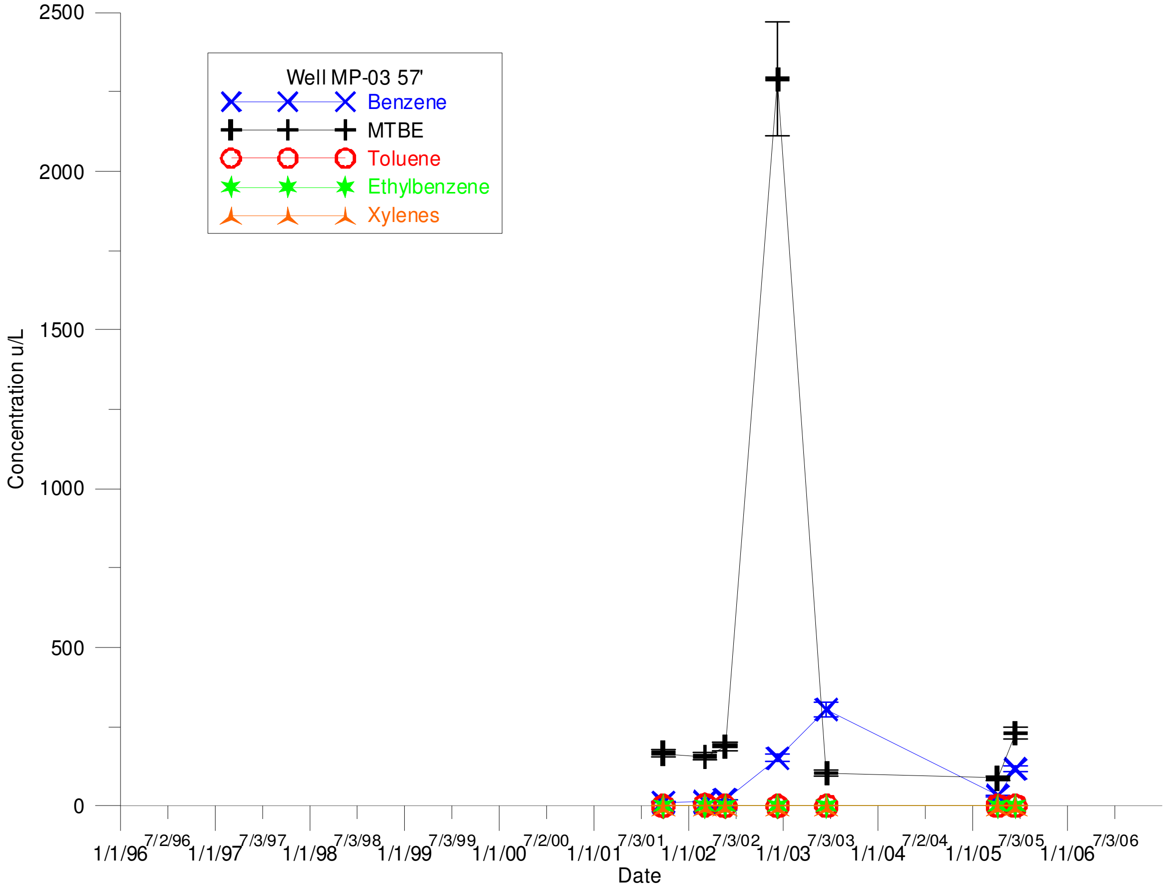

Well MP-02 50'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
400
300
200
100
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP-02 62'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
400
300
200
100
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP-03 10'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
3000
2000
1000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

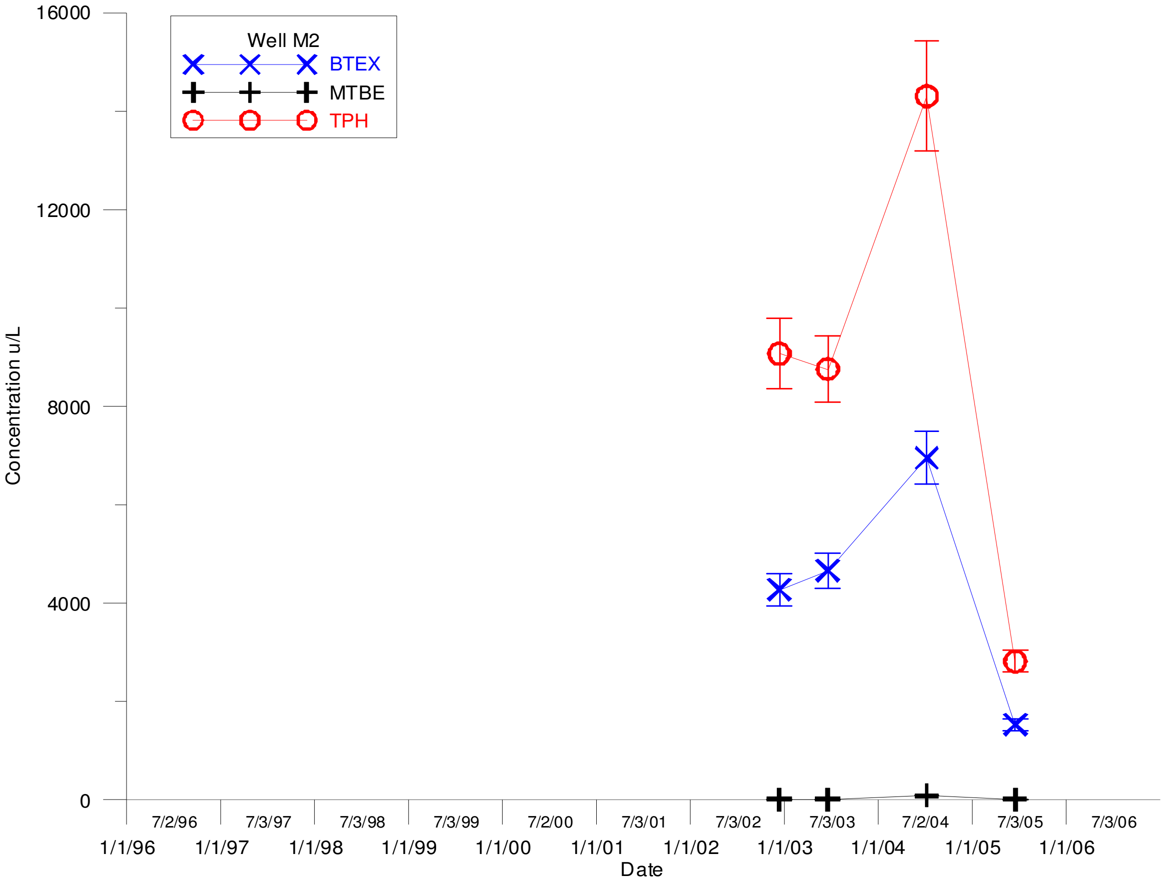

Well MP-03 22'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
12000
8000
4000
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

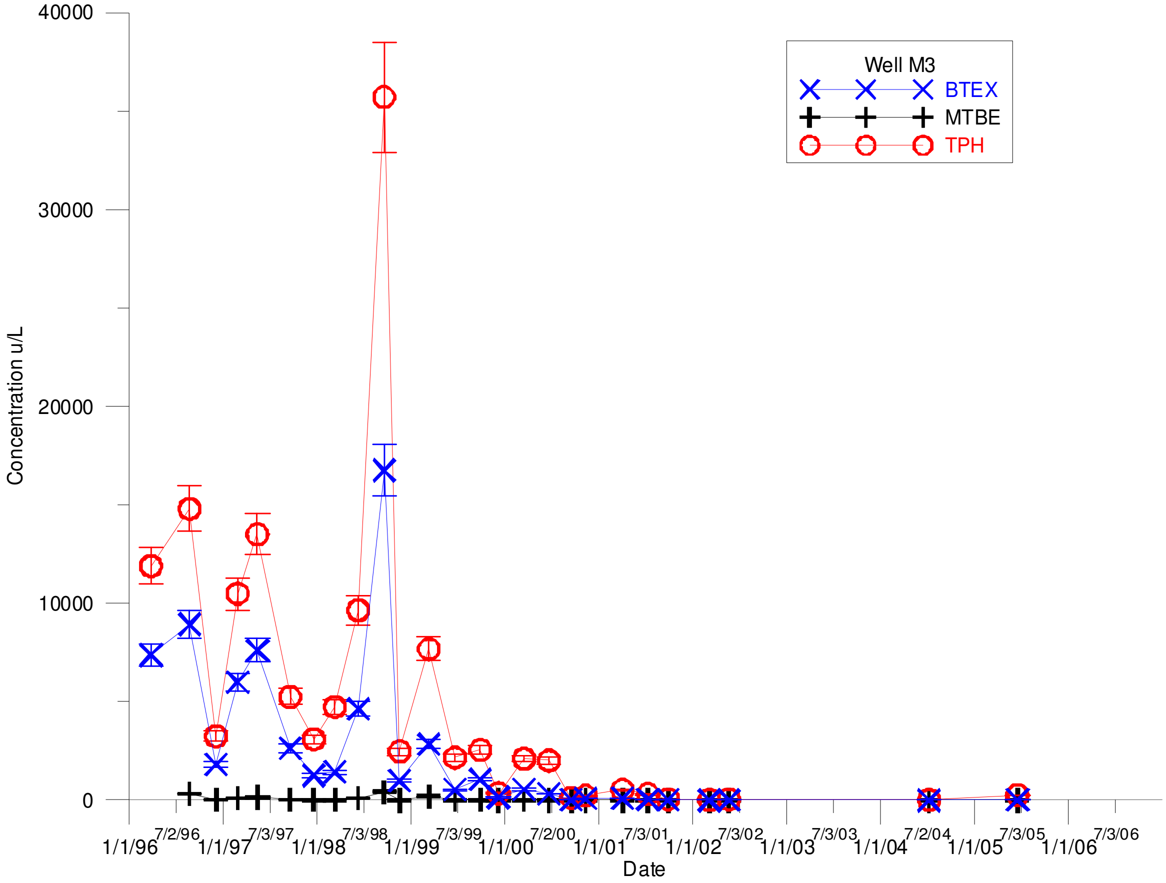

Well MP-03 32'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
100
80
60
40
20
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

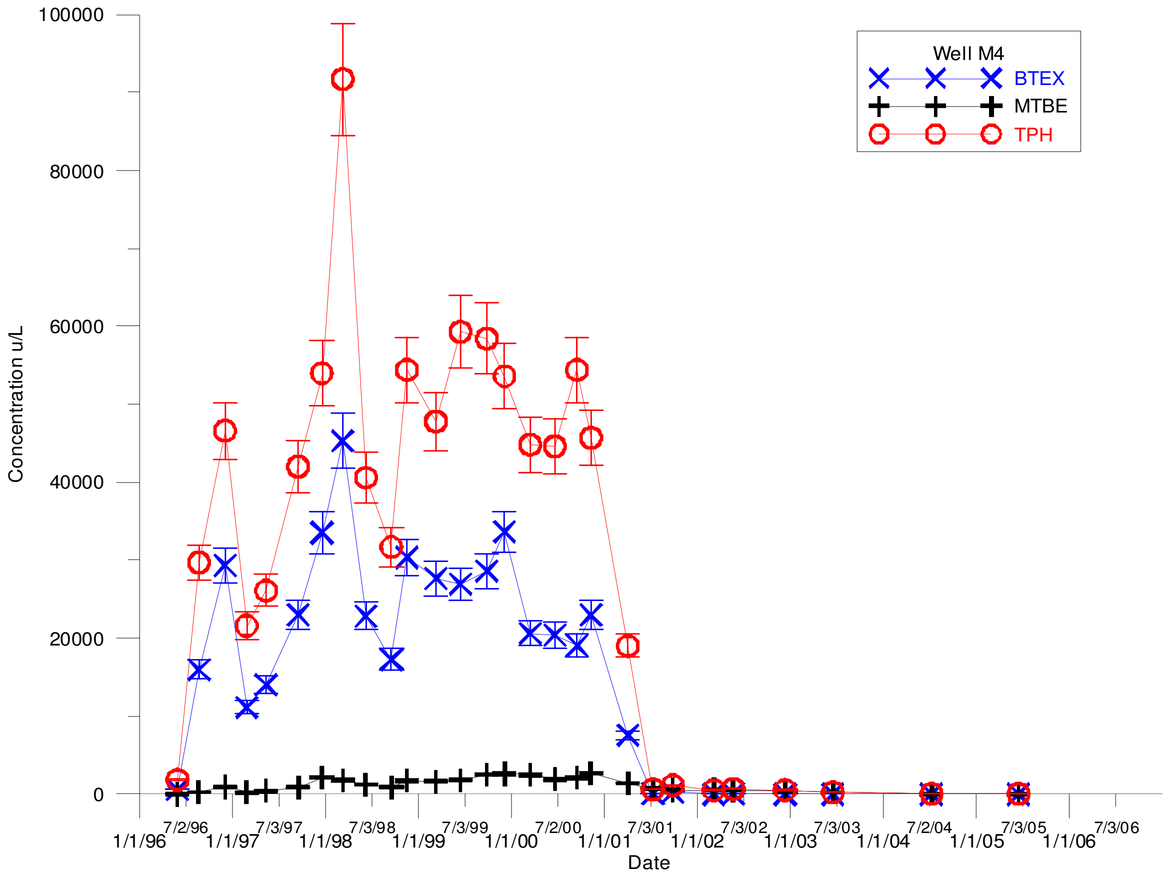

Well MP-03 57'
Benzene
MTBE
Toluene
Ethylbenzene
Xylenes
Concentration u/L
2500
2000
1500
1000
500
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

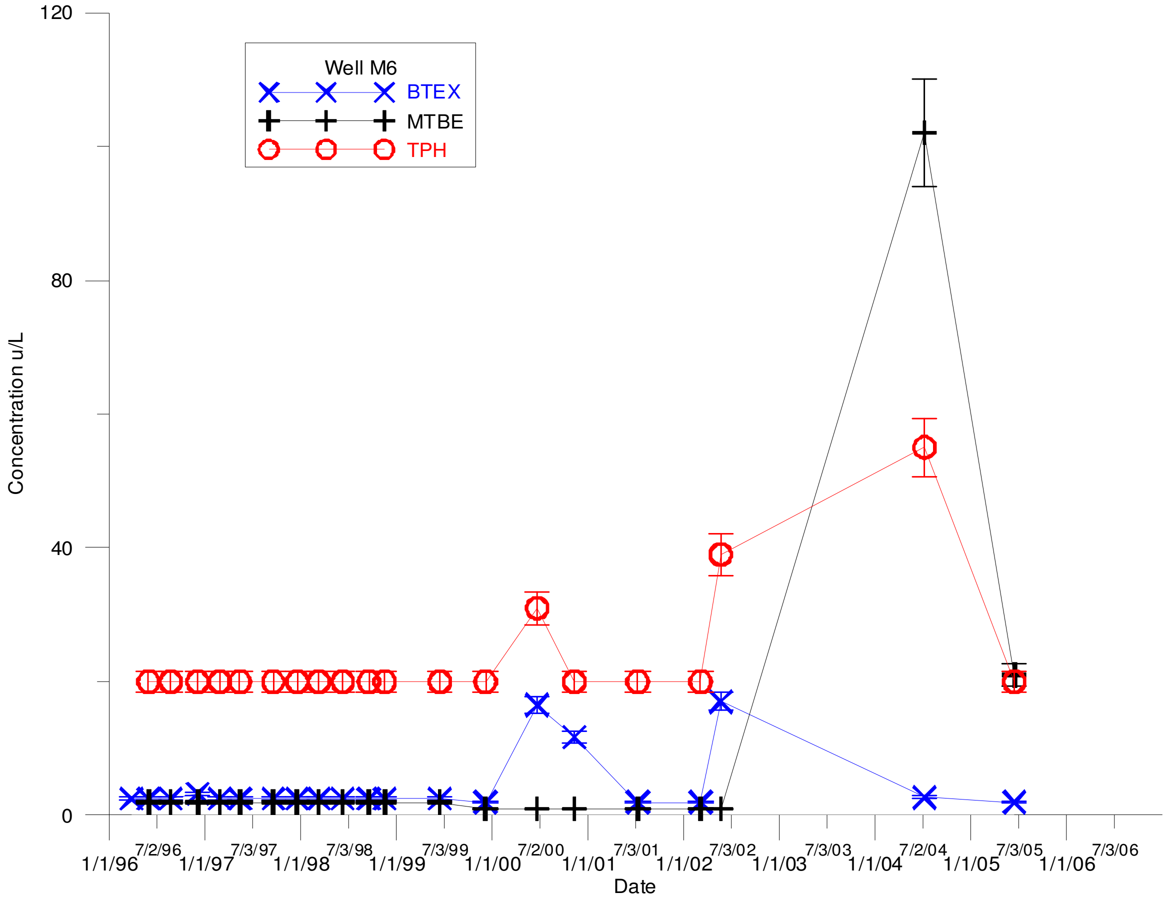
TPH, BTEX, and MTBE over Time

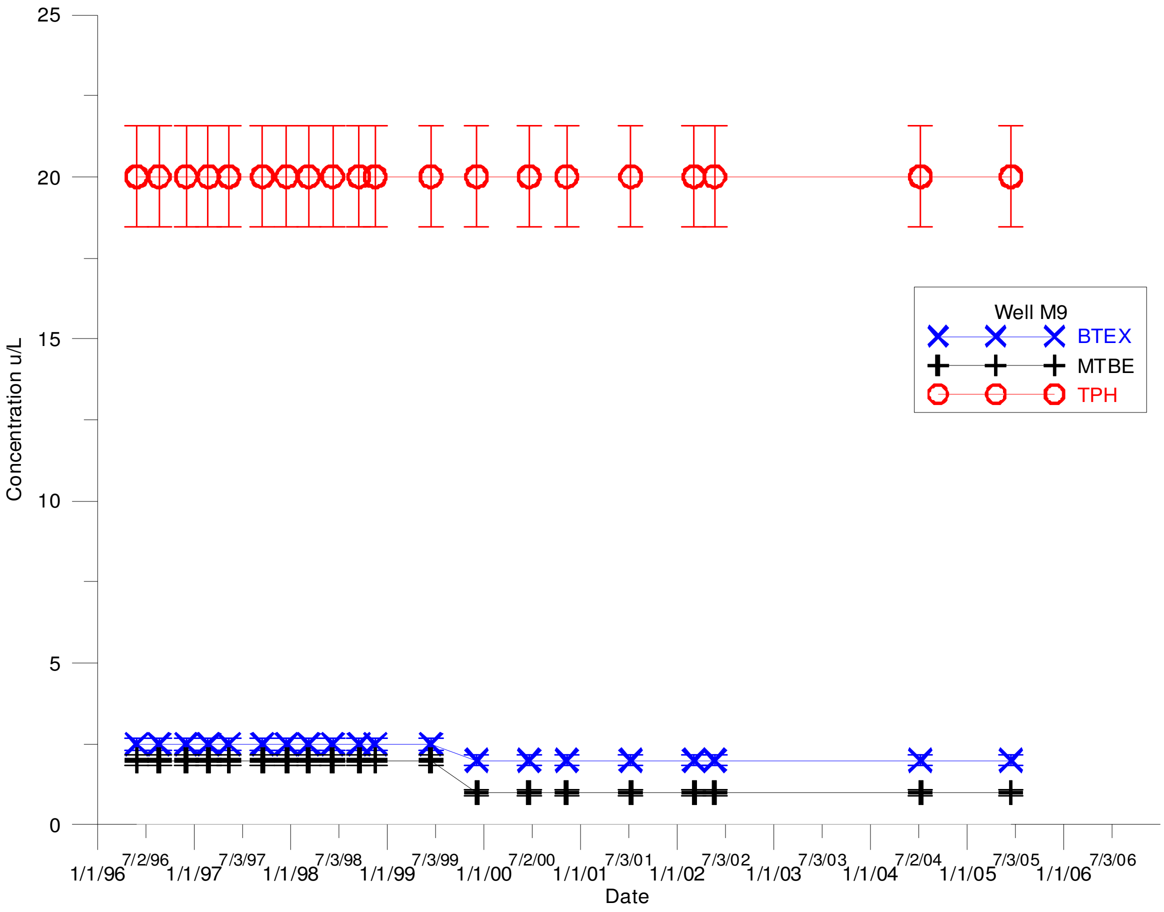
Data was compiled from HKM 2003, 2005, 2006 and Loustaunau 2003. Graphical analysis represents sampling data presented in this appendix. Error bars reflect uncertainty in field and laboratory analysis.


Well M2
BTEX
MTBE
TPH
16000
12000
8000
4000
0
Concentration u/L
7/2/96
7/3/97
7/3/98
7/3/99
7/2/00
7/3/01
7/3/02
7/3/03
7/2/04
7/3/05
7/3/06
1/1/96
1/1/97
1/1/98
1/1/99
1/1/00
1/1/01
1/1/02
1/1/03
1/1/04
1/1/05
1/1/06
Date

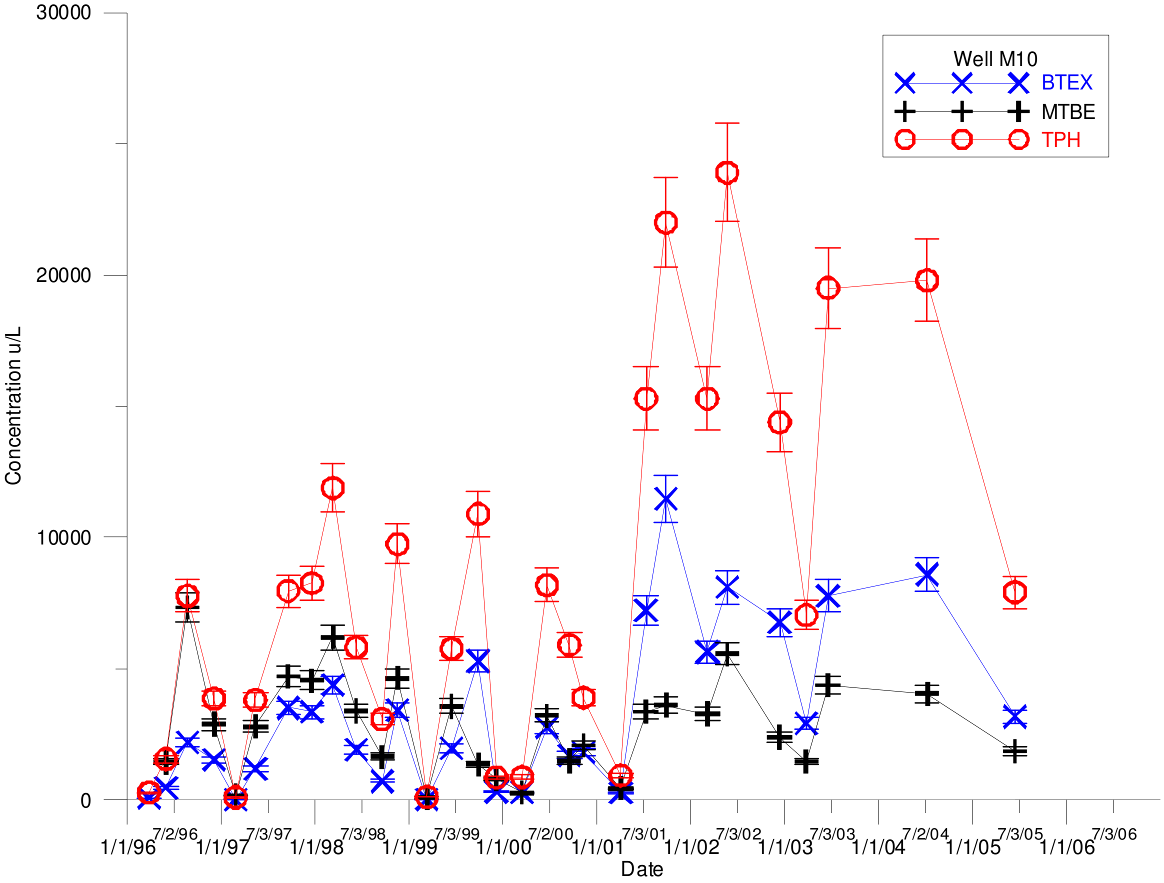

Well M3
BTEX
MTBE
TPH
Concentration u/L
40000
30000
20000
10000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

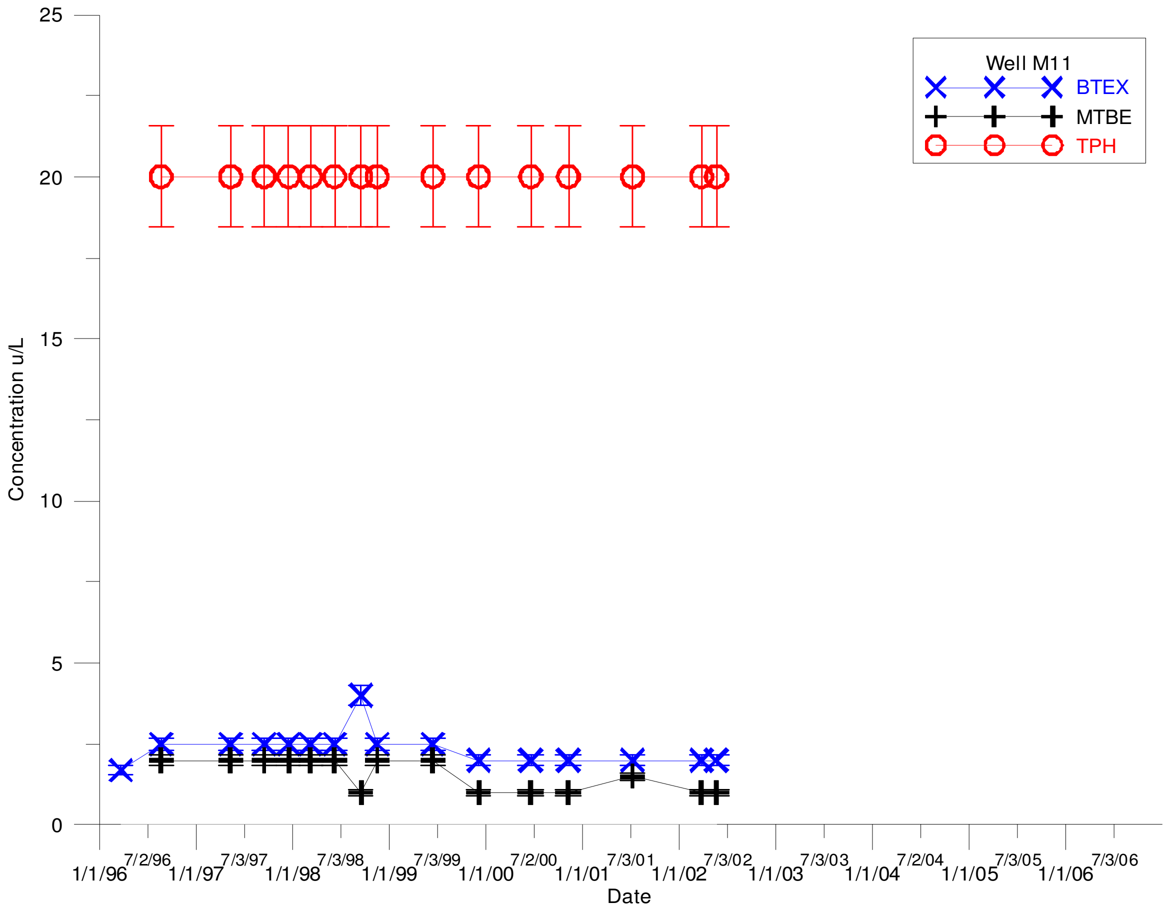

Well M4
BTEX
MTBE
TPH
Concentration u/L
100000
80000
60000
40000
20000
0
7/2/96
7/3/97
7/3/98
7/3/99
7/2/00
7/3/01
7/3/02
7/3/03
7/2/04
7/3/05
7/3/06
1/1/96
1/1/97
1/1/98
1/1/99
1/1/00
1/1/01
1/1/02
1/1/03
1/1/04
1/1/05
1/1/06
Date


Well M6
BTEX
MTBE
TPH
Concentration u/L
120
80
40
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

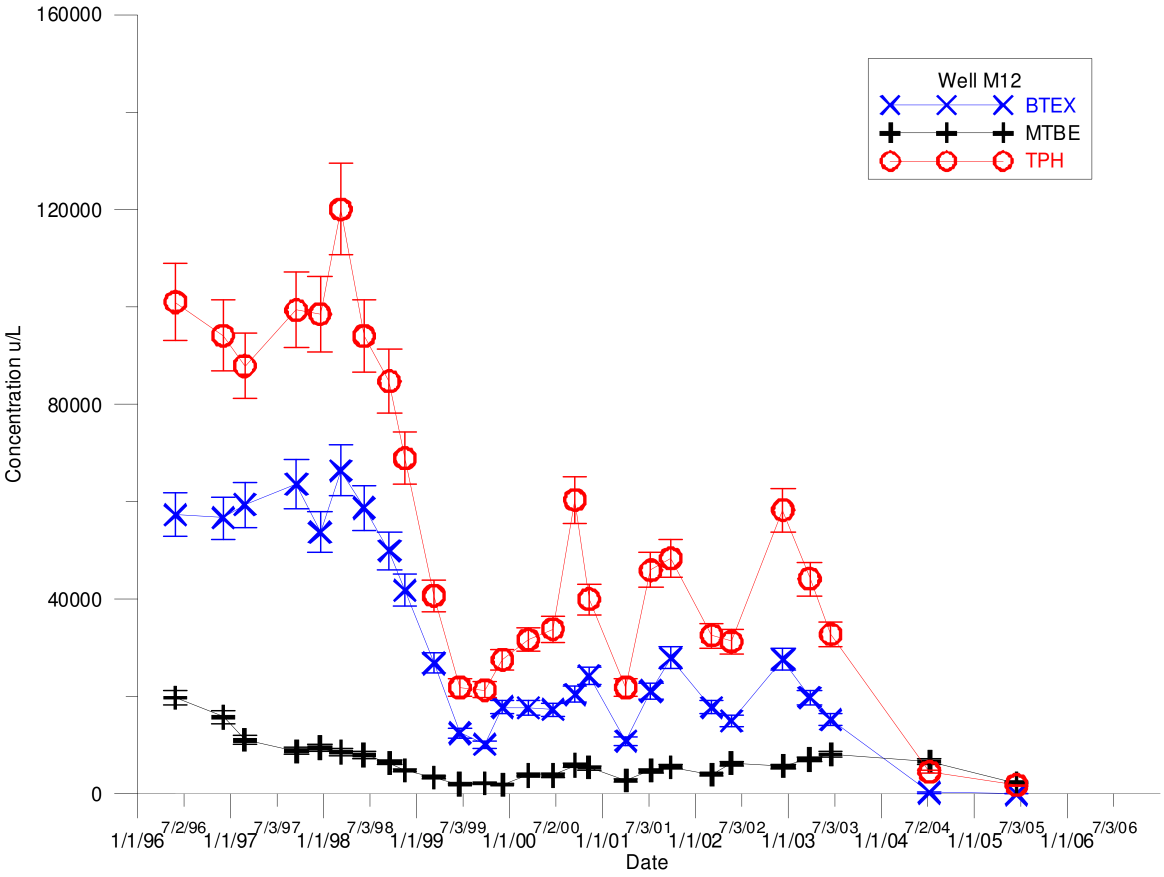


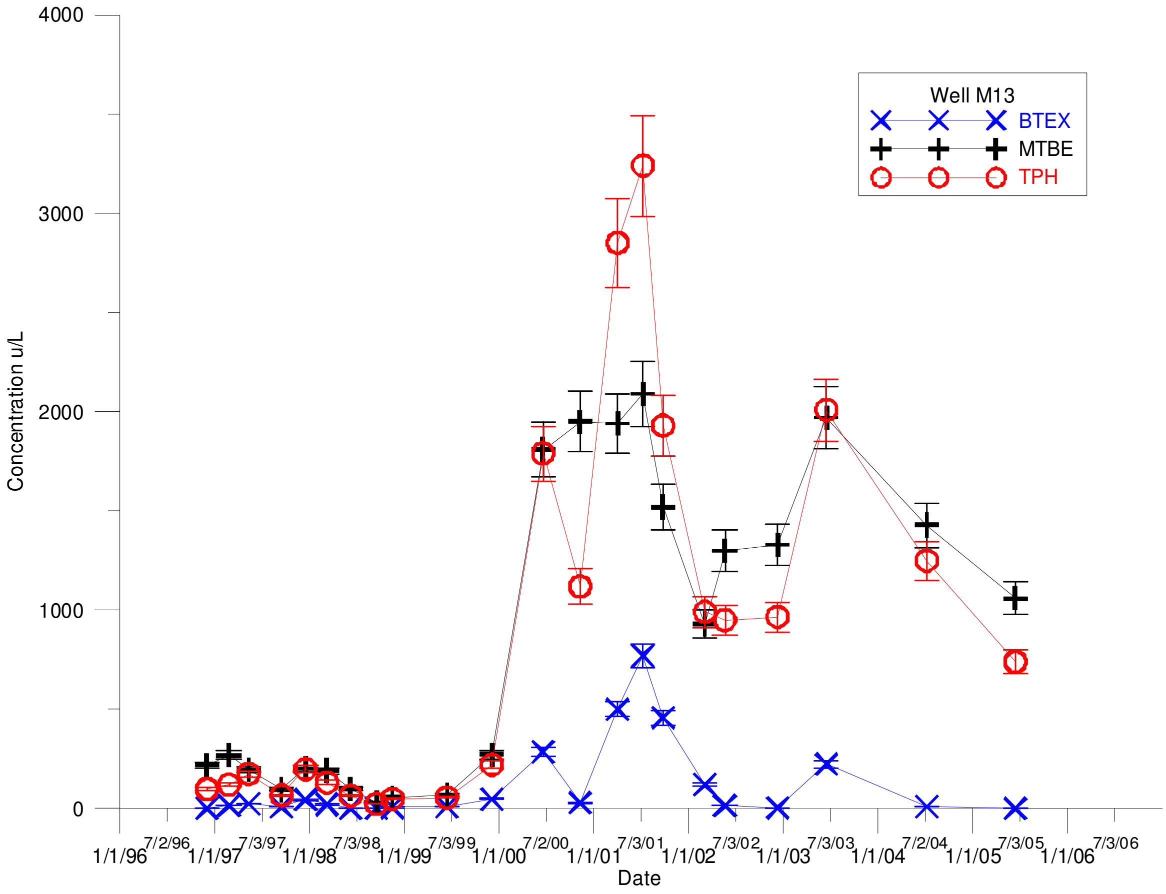
Well M9
BTEX
MTBE
TPH
Concentration u/L
25
20
15
10
5
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

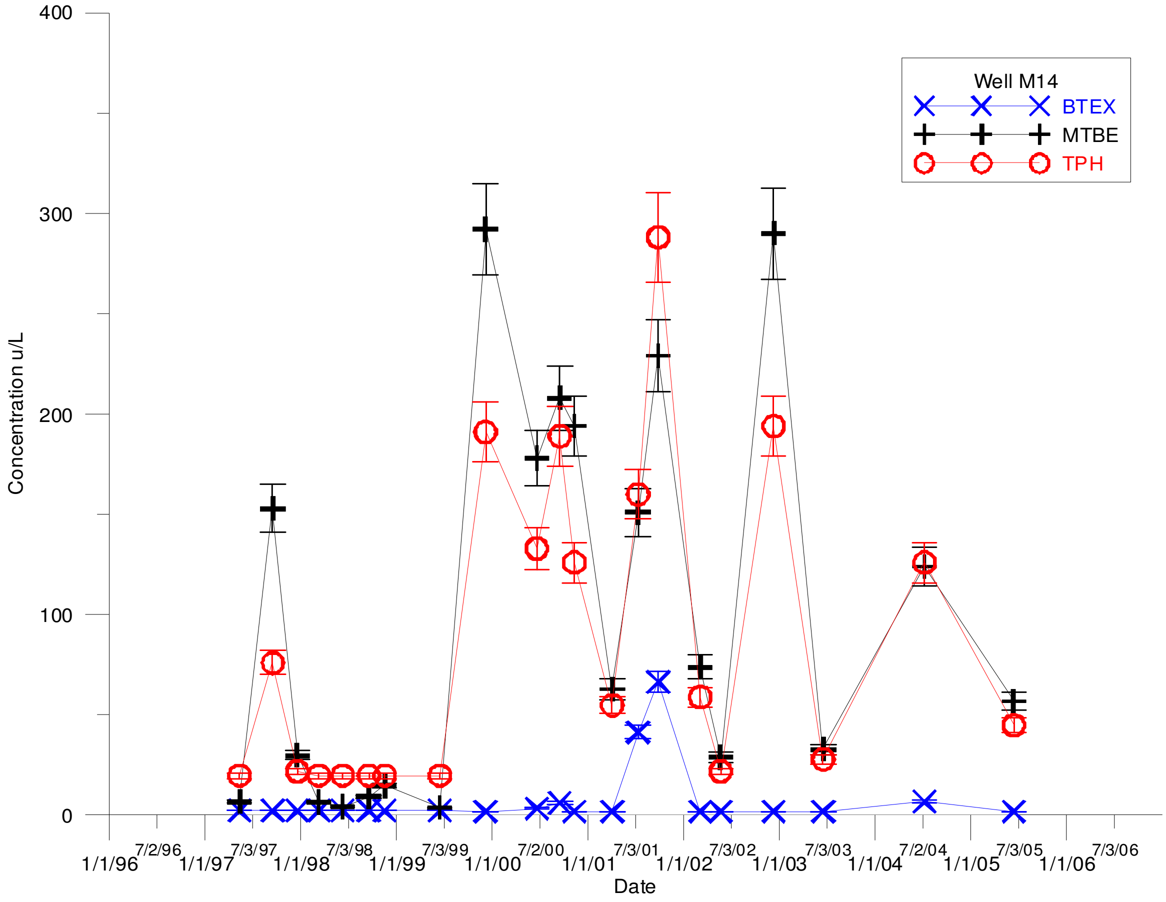

Well M10
BTEX
MTBE
TPH
Concentration u/L
30000
20000
10000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date



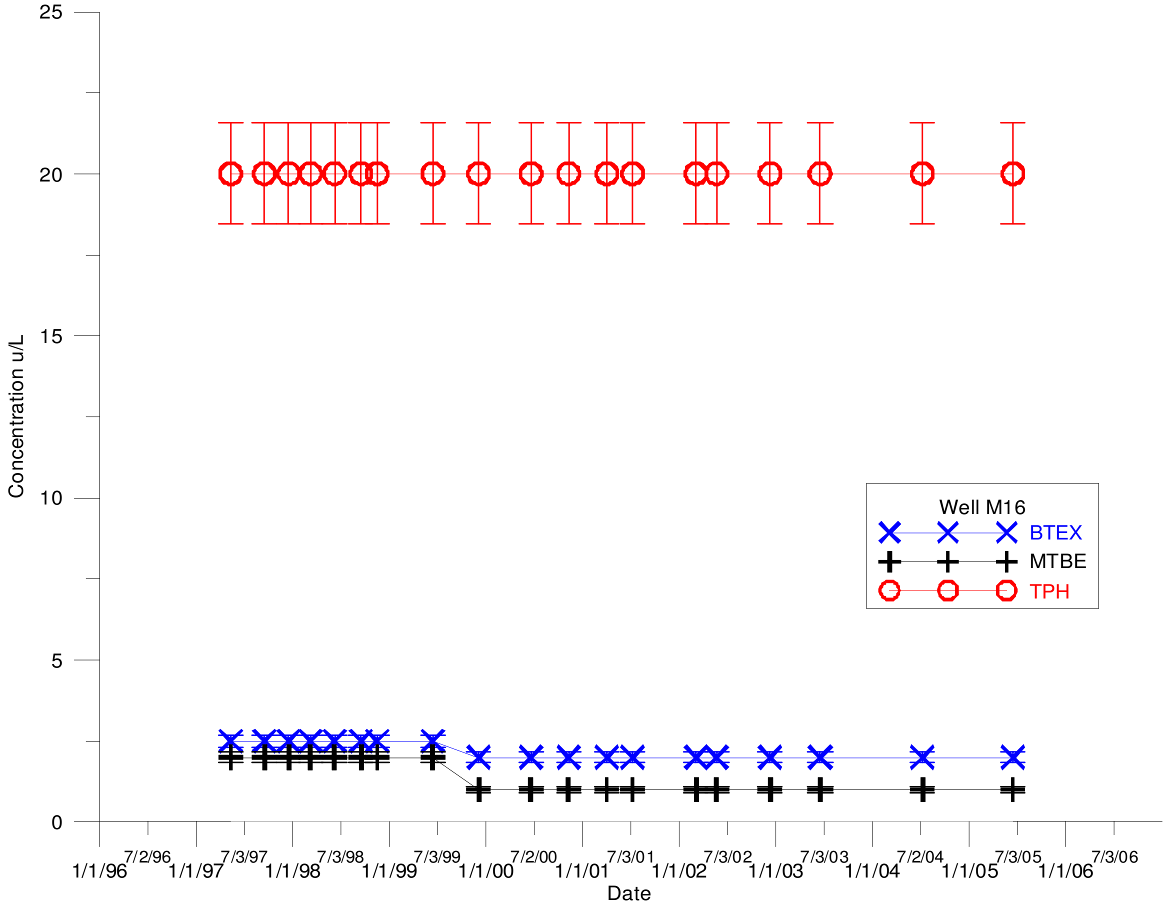
Well M11
BTEX
MTBE
TPH
Concentration u/L
25
20
15
10
5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


160000
120000
80000
40000
0
Concentration u/L
Well M12
BTEX
MTBE
TPH
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

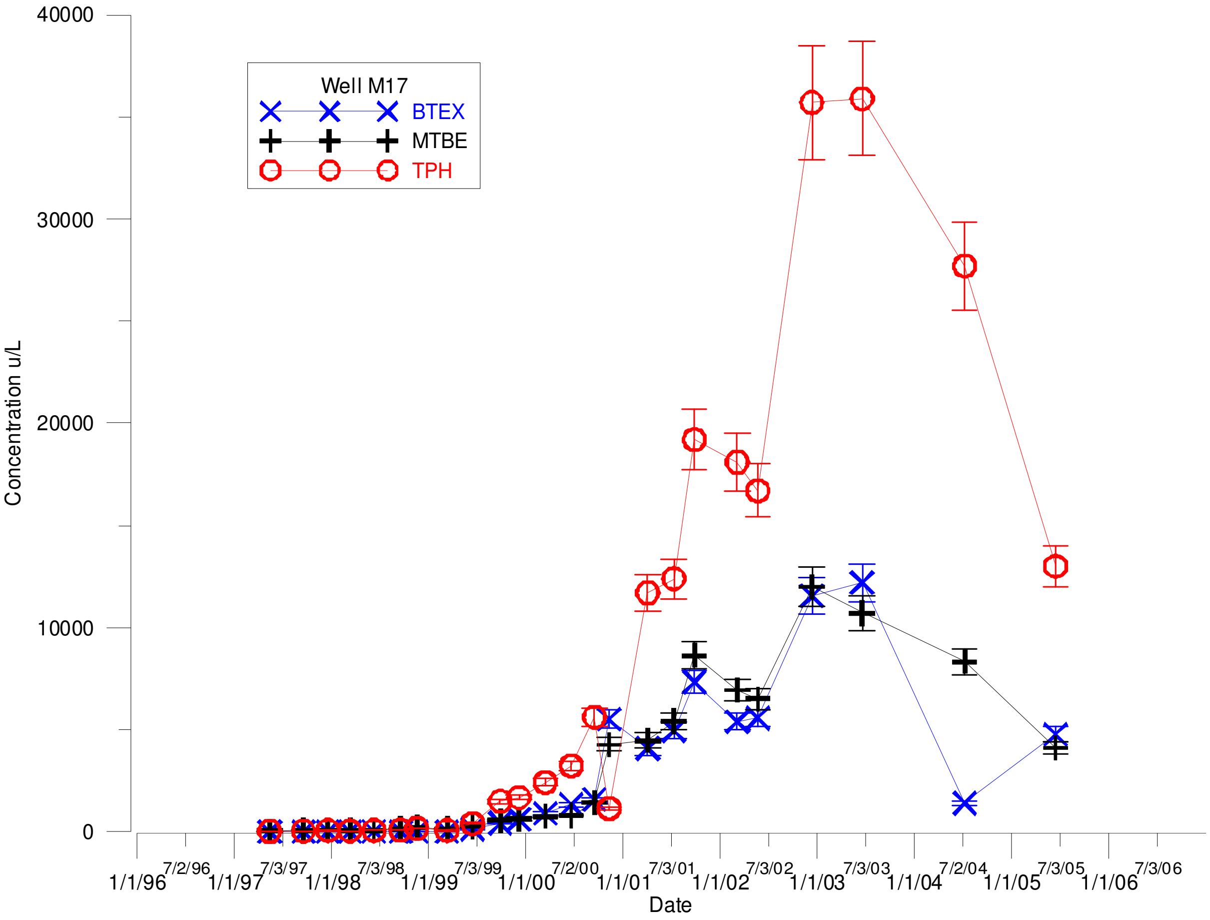

Well M13
BTEX
MTBE
TPH
Concentration u/L
4000
3000
2000
1000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date



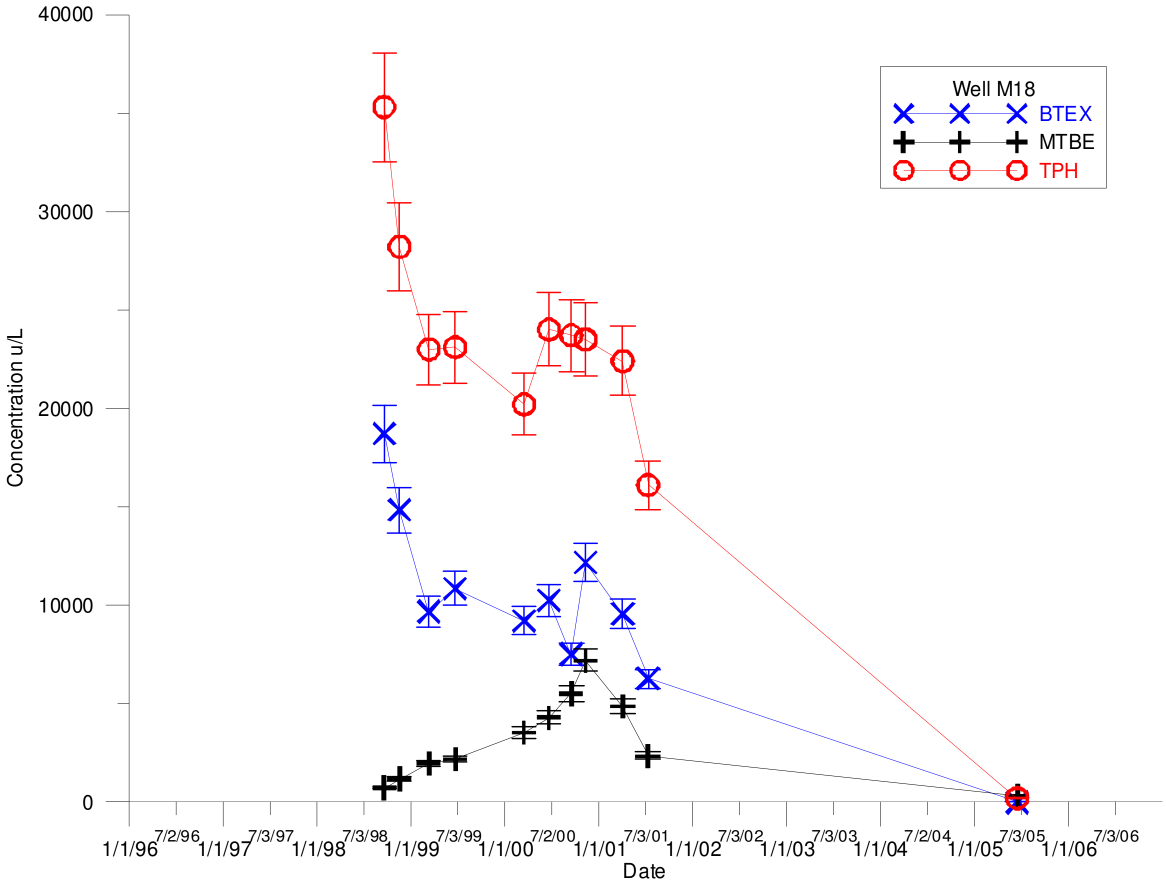
Well M14
BTEX
MTBE
TPH
Concentration u/L
400
300
200
100
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

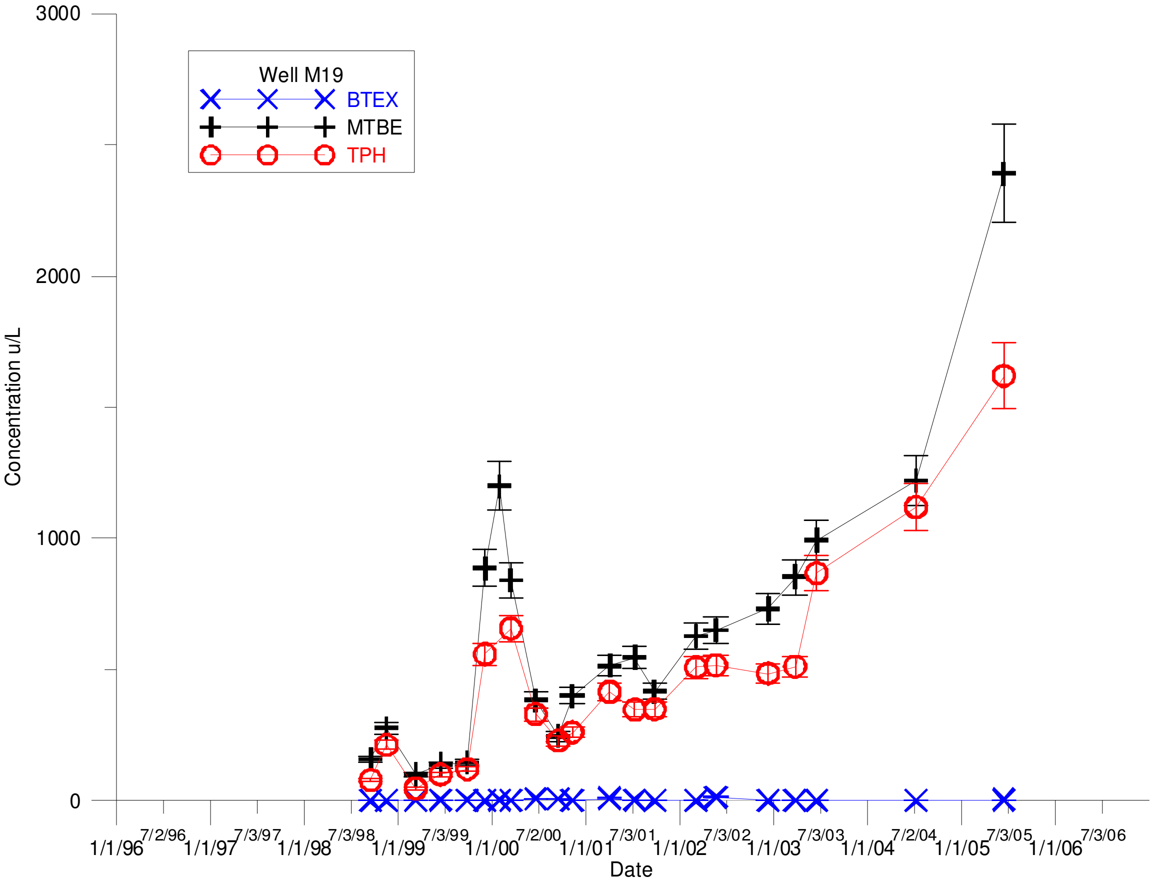


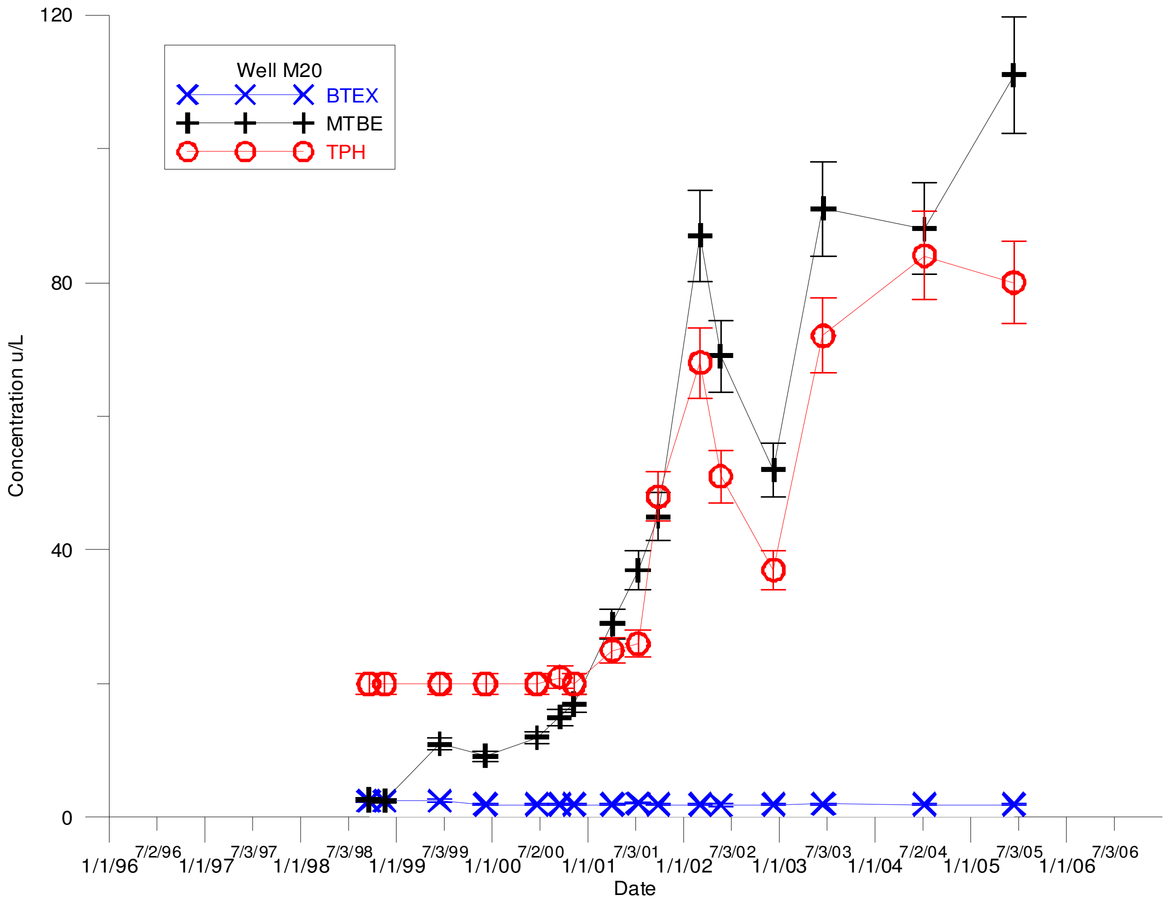
Concentration u/L
25
20
15
10
5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date
Well M16
BTEX
MTBE
TPH

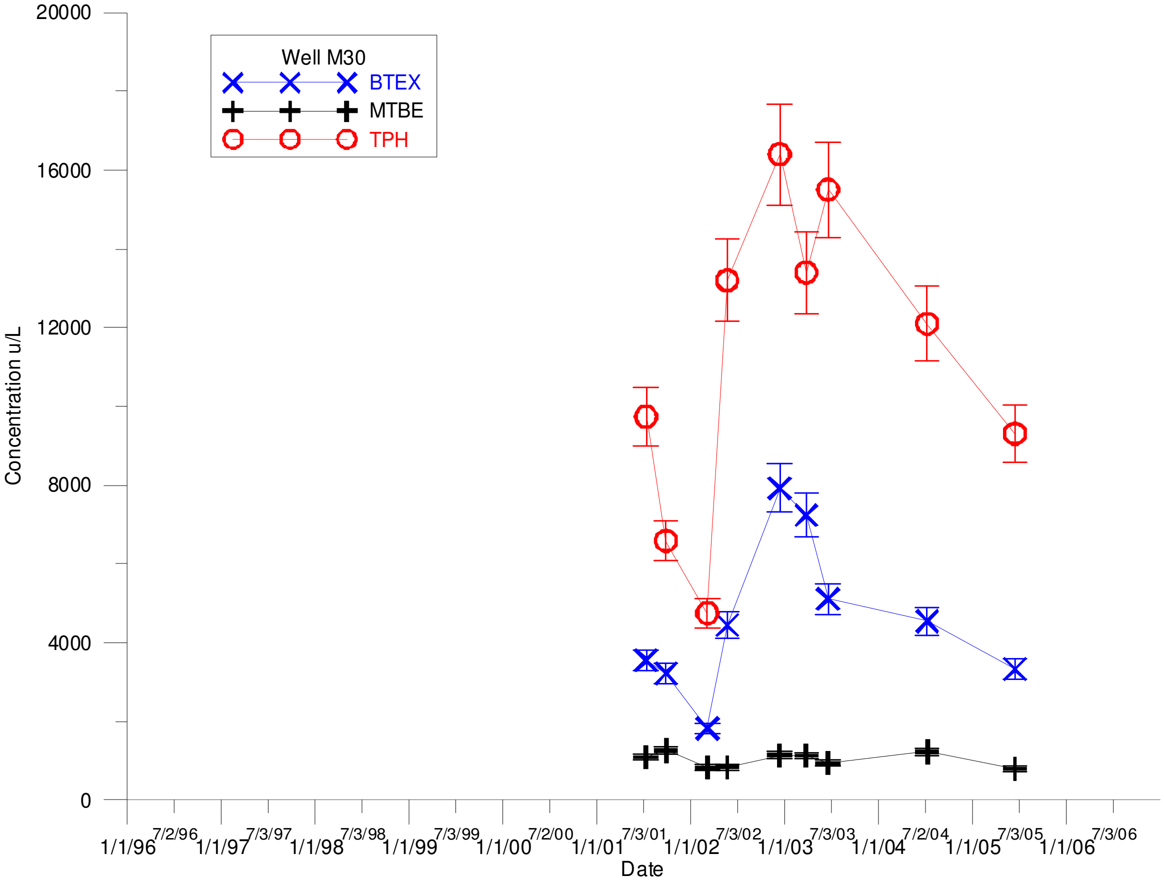


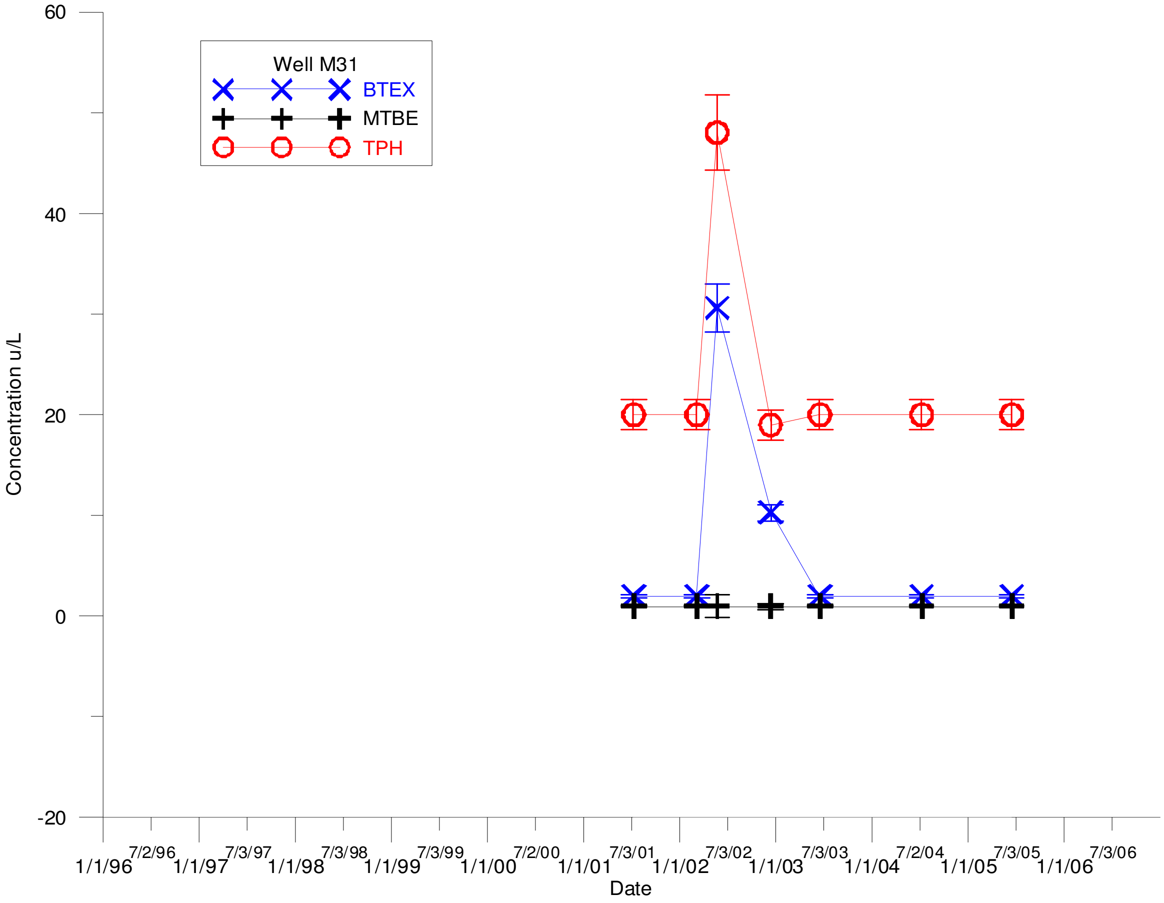
Well M17
BTEX
MTBE
TPH
Concentration u/L
0
10000
20000
30000
40000
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

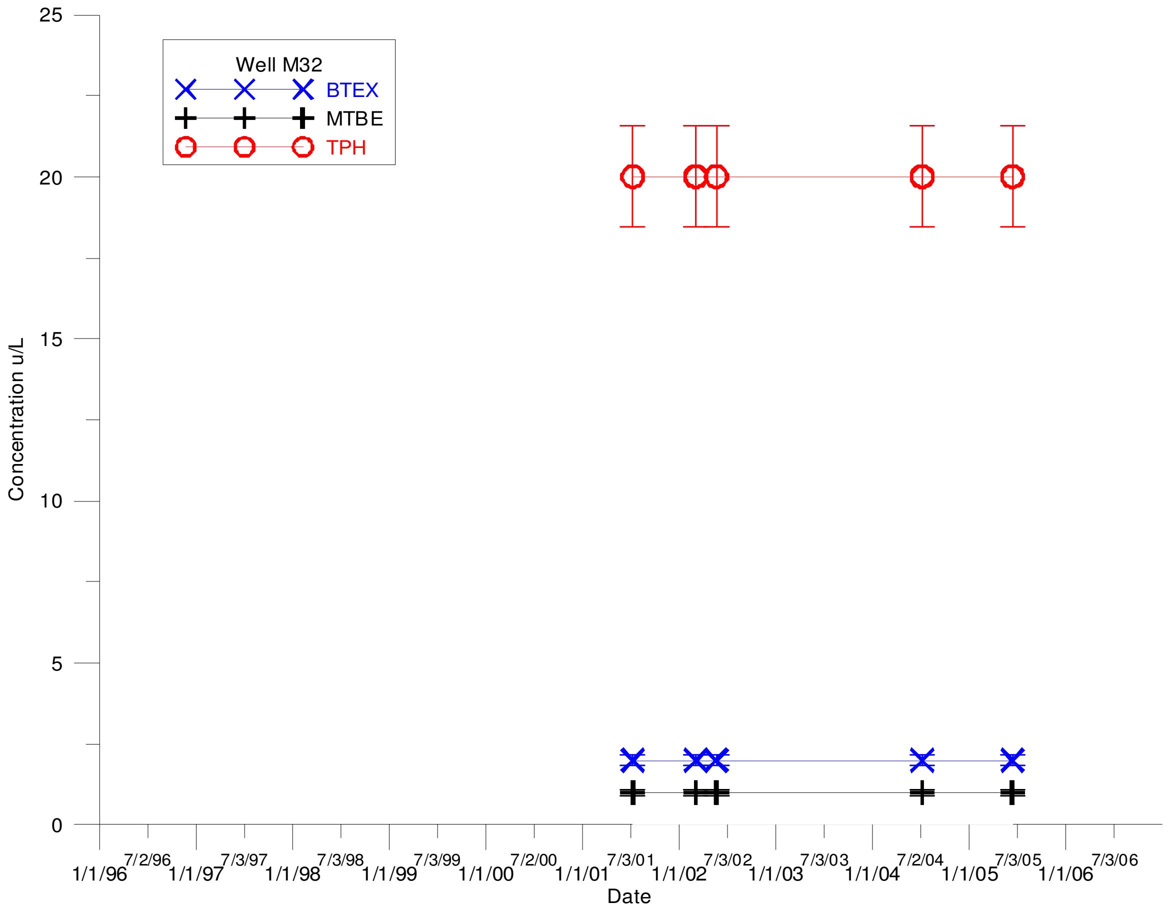

Well M18
BTEX
MTBE
TPH
Concentration u/L
40000
30000
20000
10000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

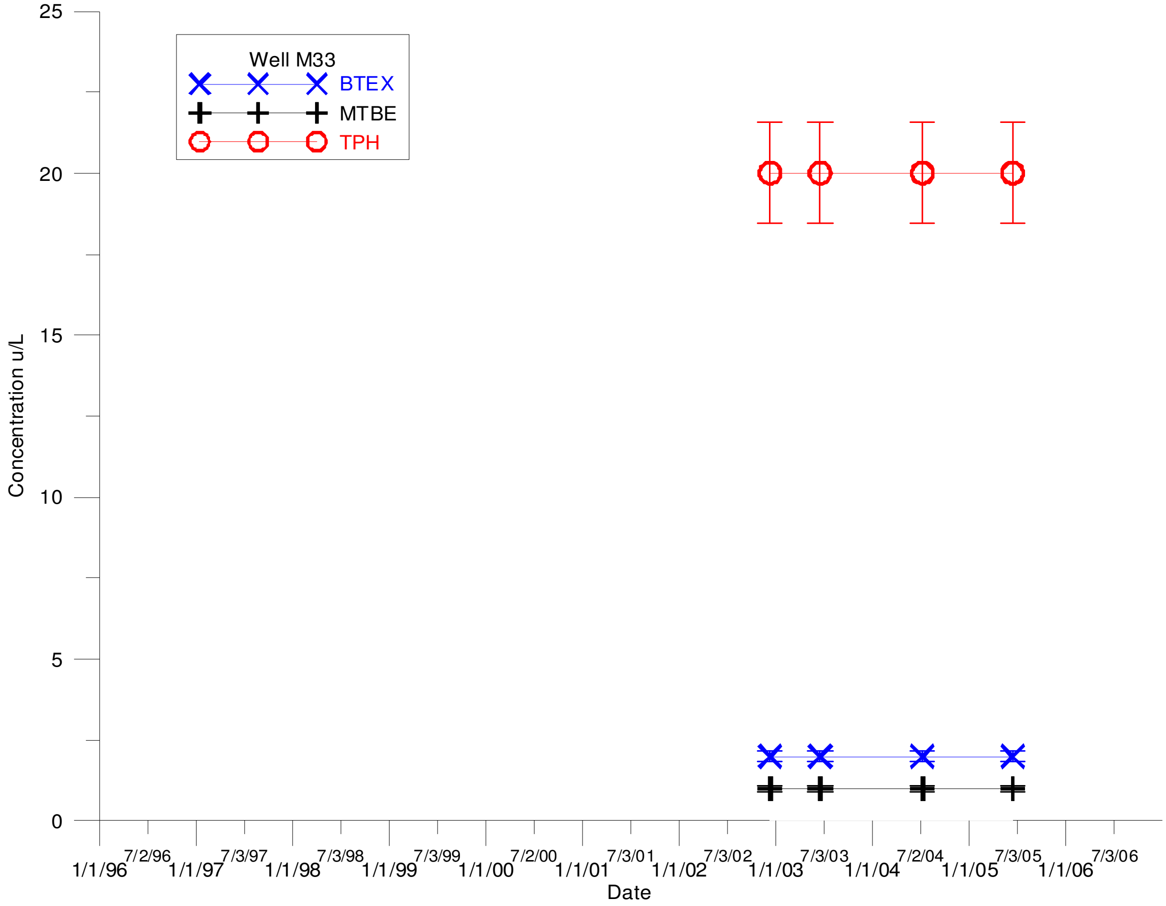

Well M19
BTEX
MTBE
TPH
Concentration u/L
3000
2000
1000
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

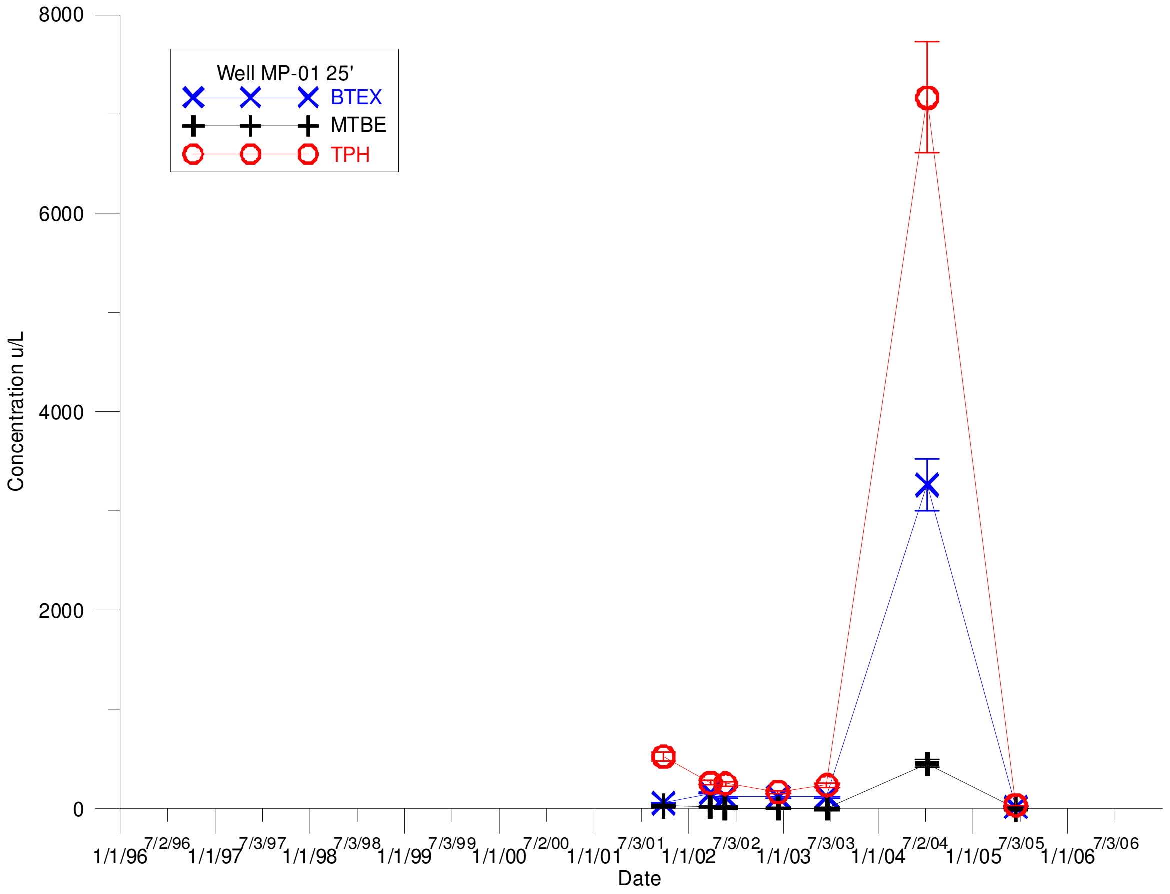

Well M20
BTEX
MTBE
TPH
Concentration u/L
0
40
80
120
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

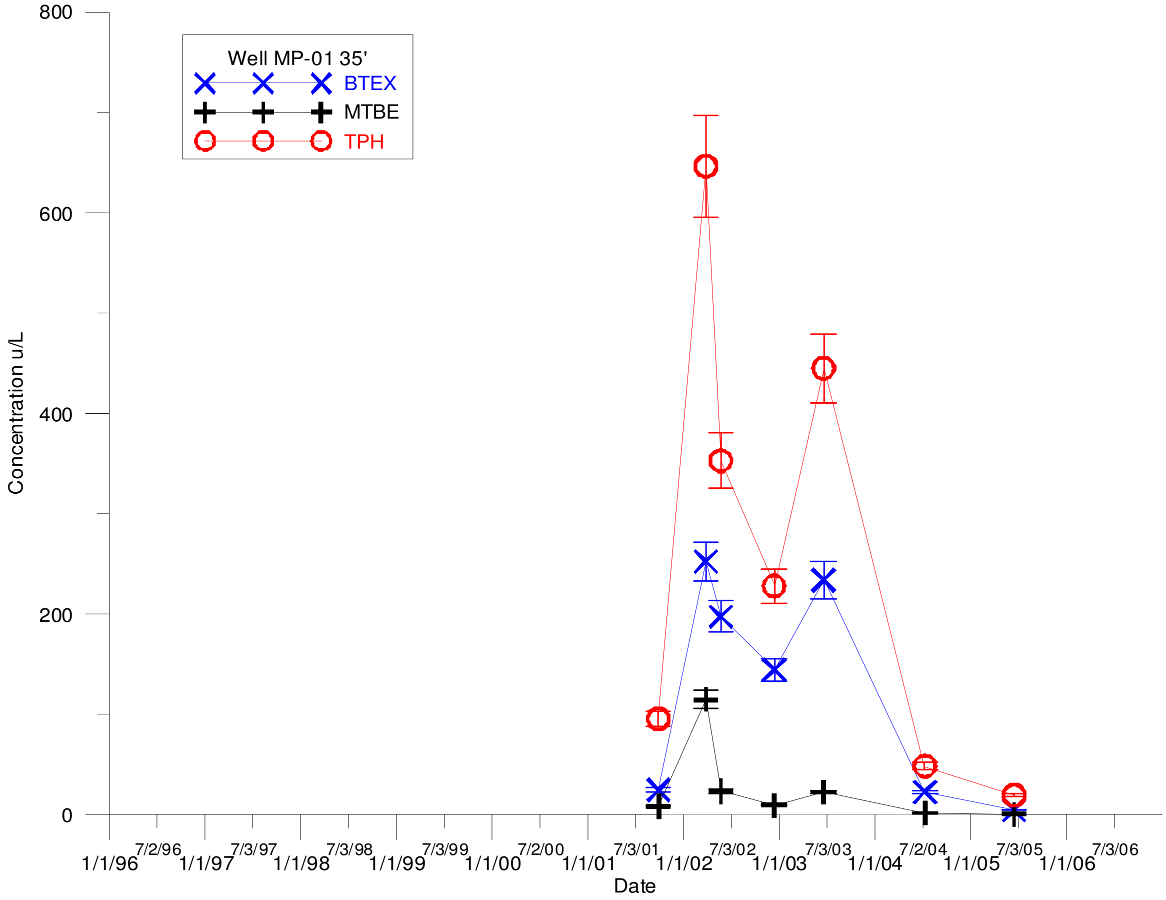

Well M30
BTEX
MTBE
TPH
Concentration u/L
20000
16000
12000
8000
4000
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

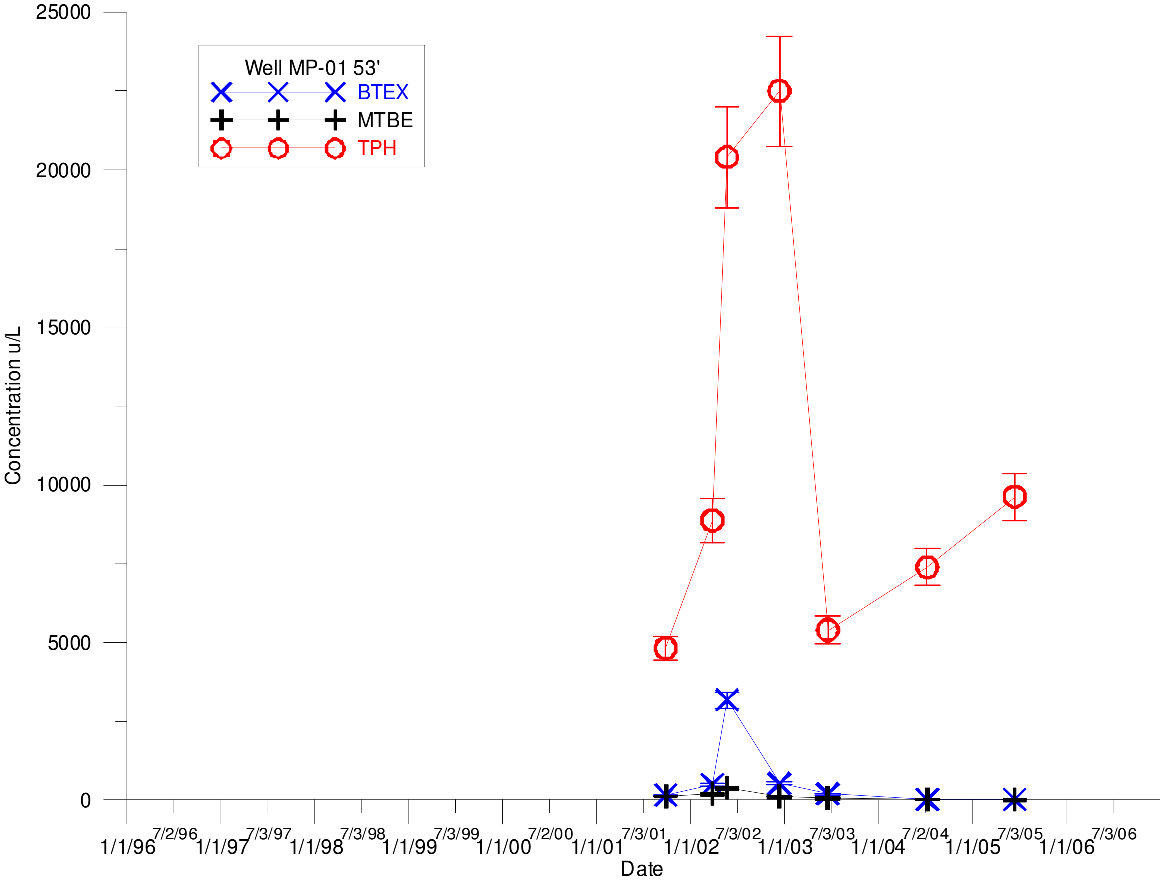

Well M31
BTEX
MTBE
TPH
Concentration u/L
60
40
20
0
-20
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

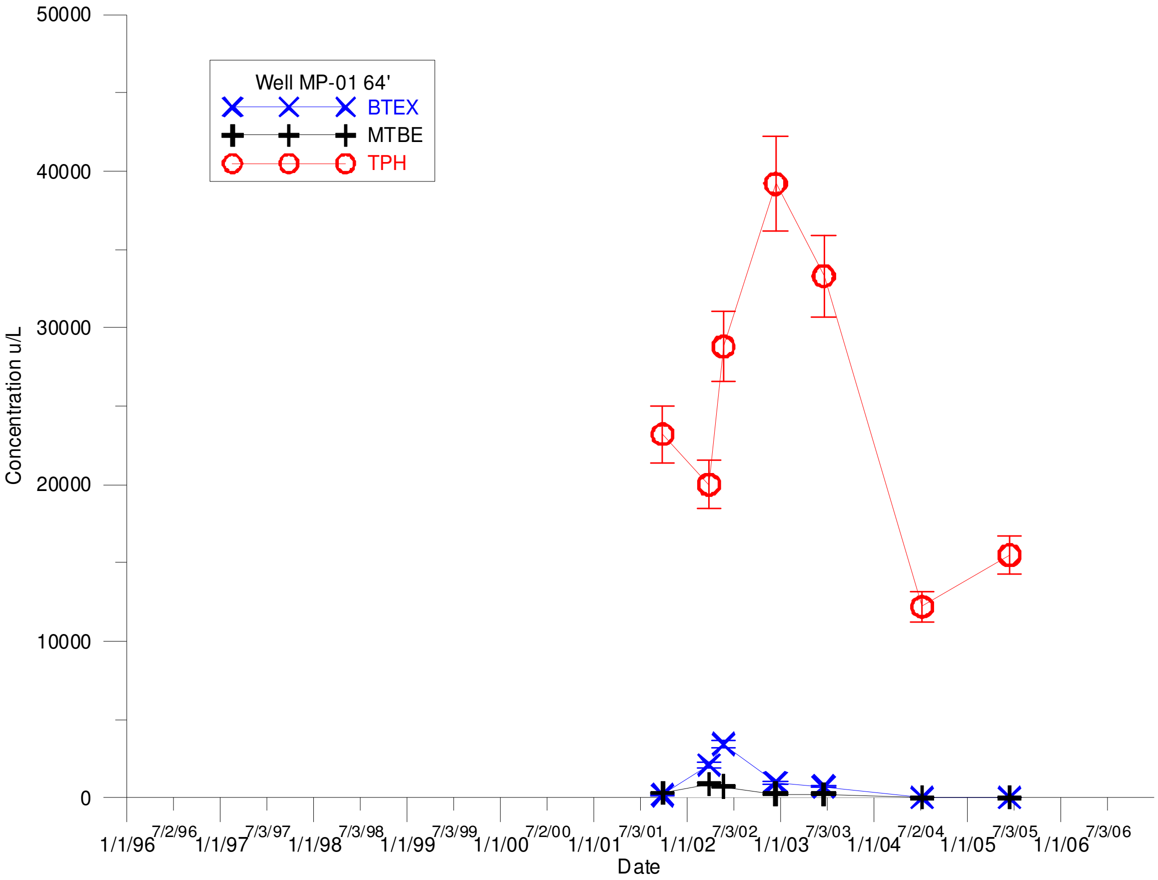

Well M32
BTEX
MTBE
TPH
Concentration u/L
25
20
15
10
5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

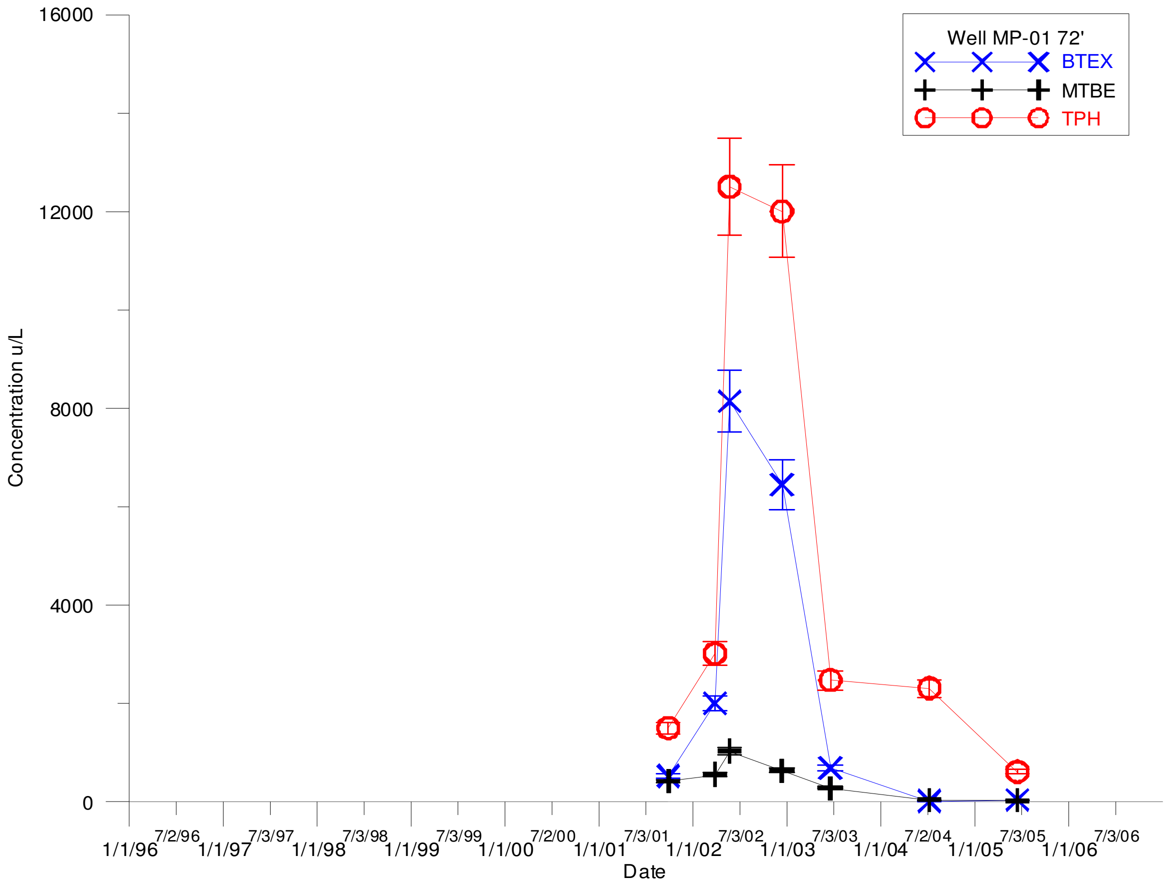

Well M33
BTEX
MTBE
TPH
Concentration u/L
25
20
15
10
5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

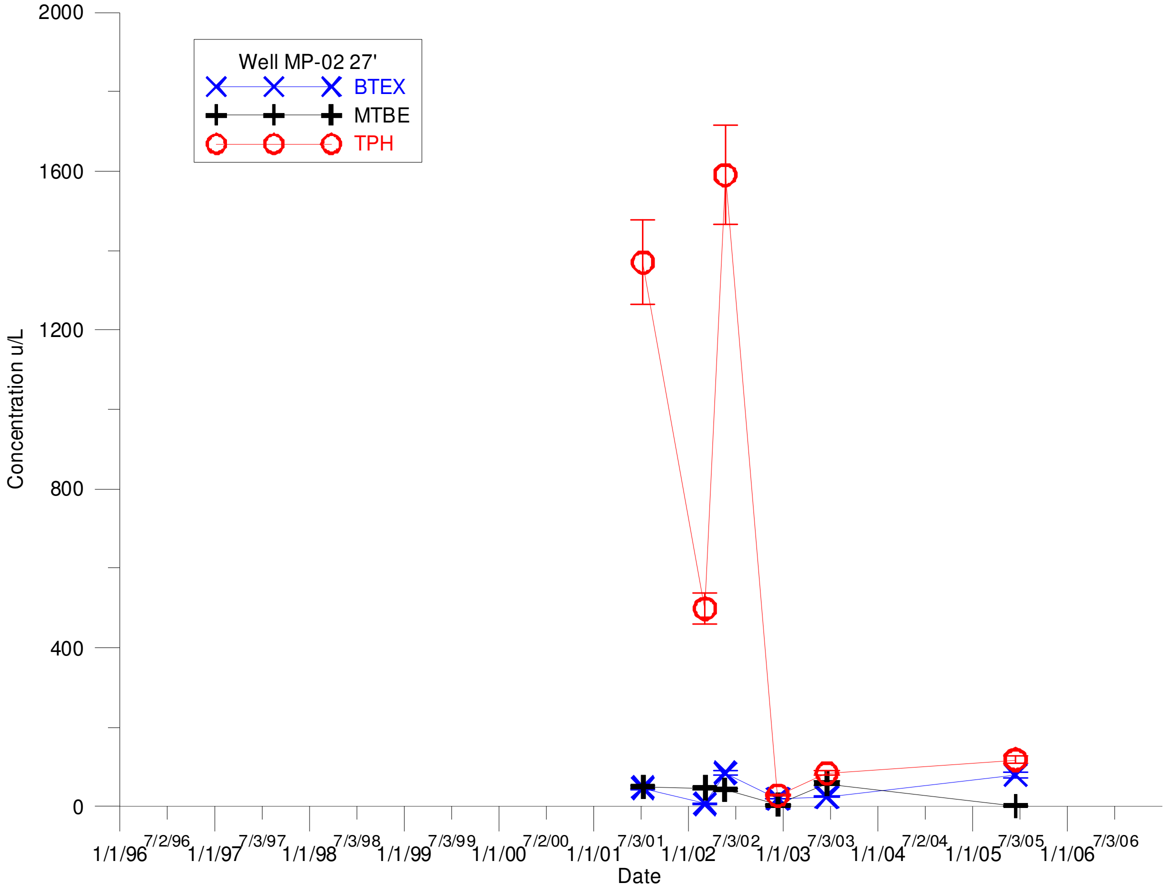

Well MP-01 25'
BTEX
MTBE
TPH
8000
6000
4000
2000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

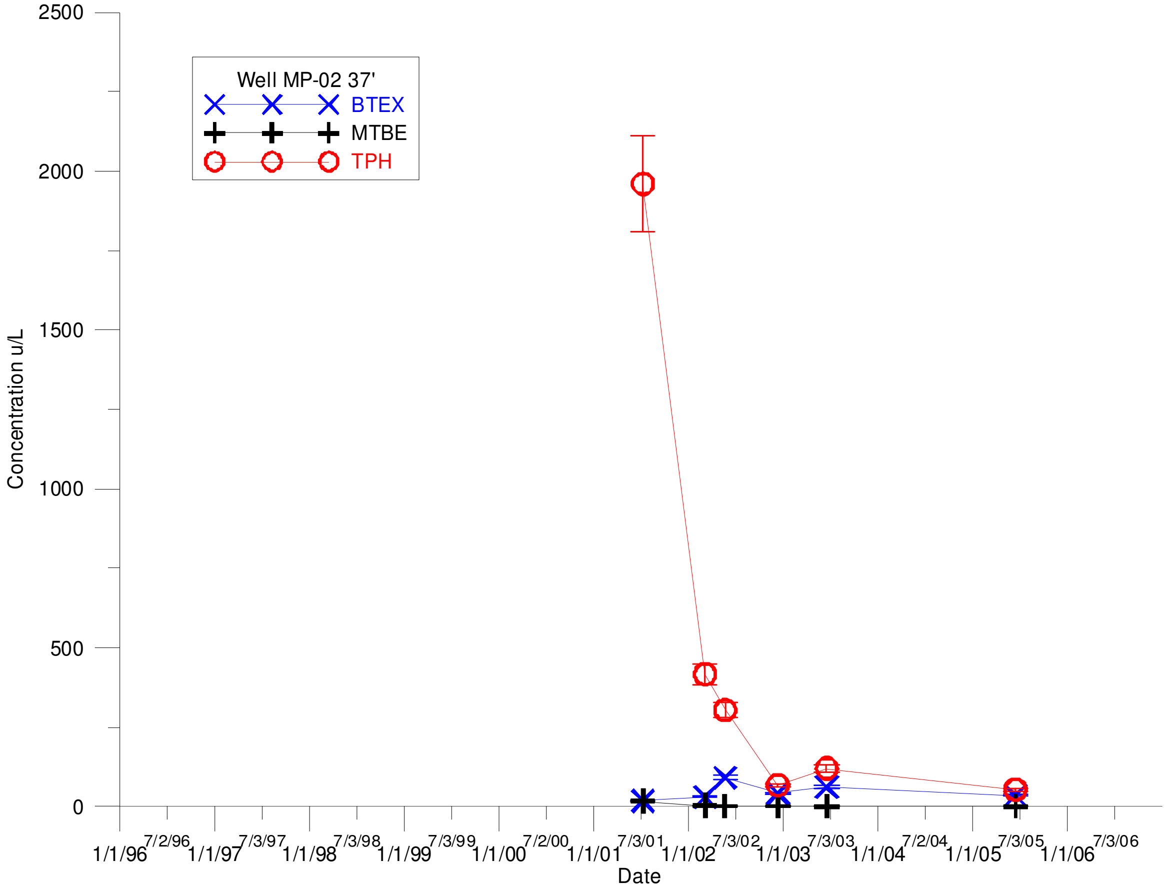

Well MP-01 35'
BTEX
MTBE
TPH
Concentration u/L
800
600
400
200
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

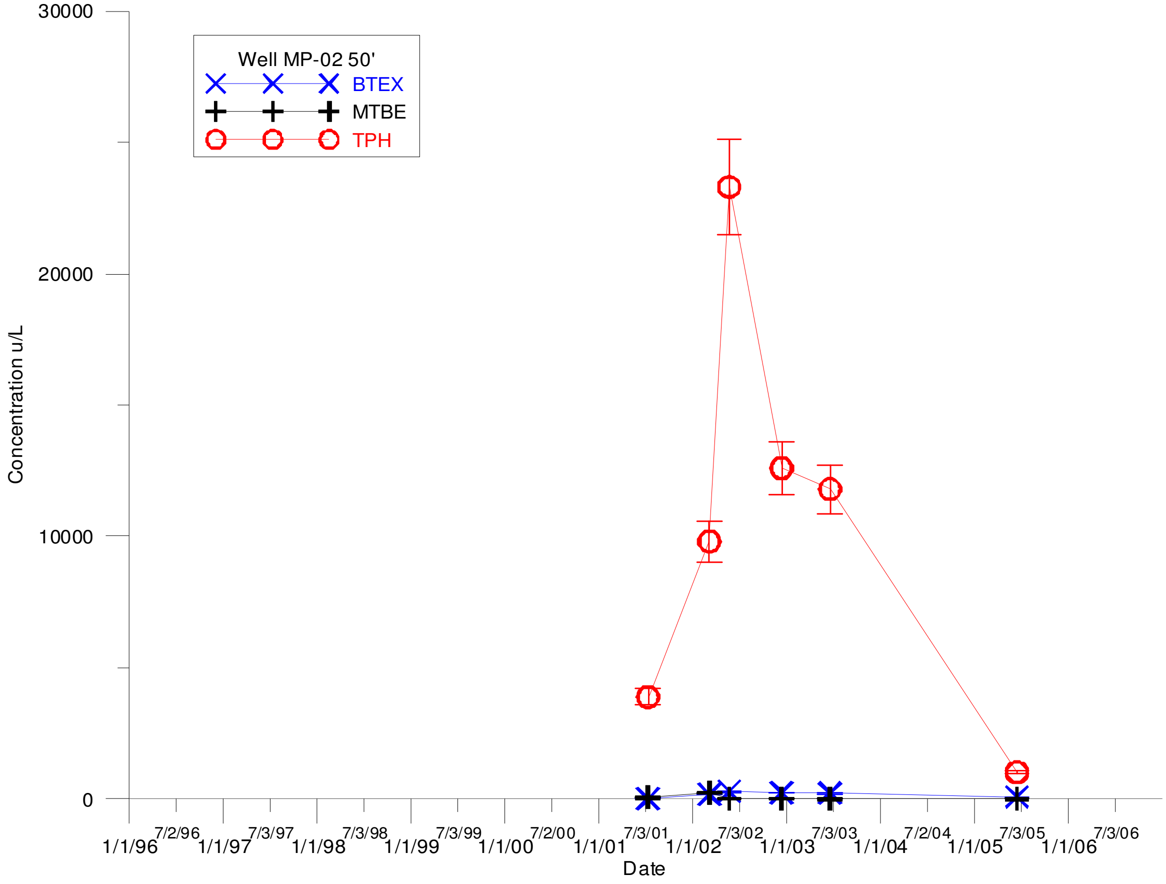

Well MP-01 53'
BTEX
MTBE
TPH
25000
20000
15000
10000
5000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

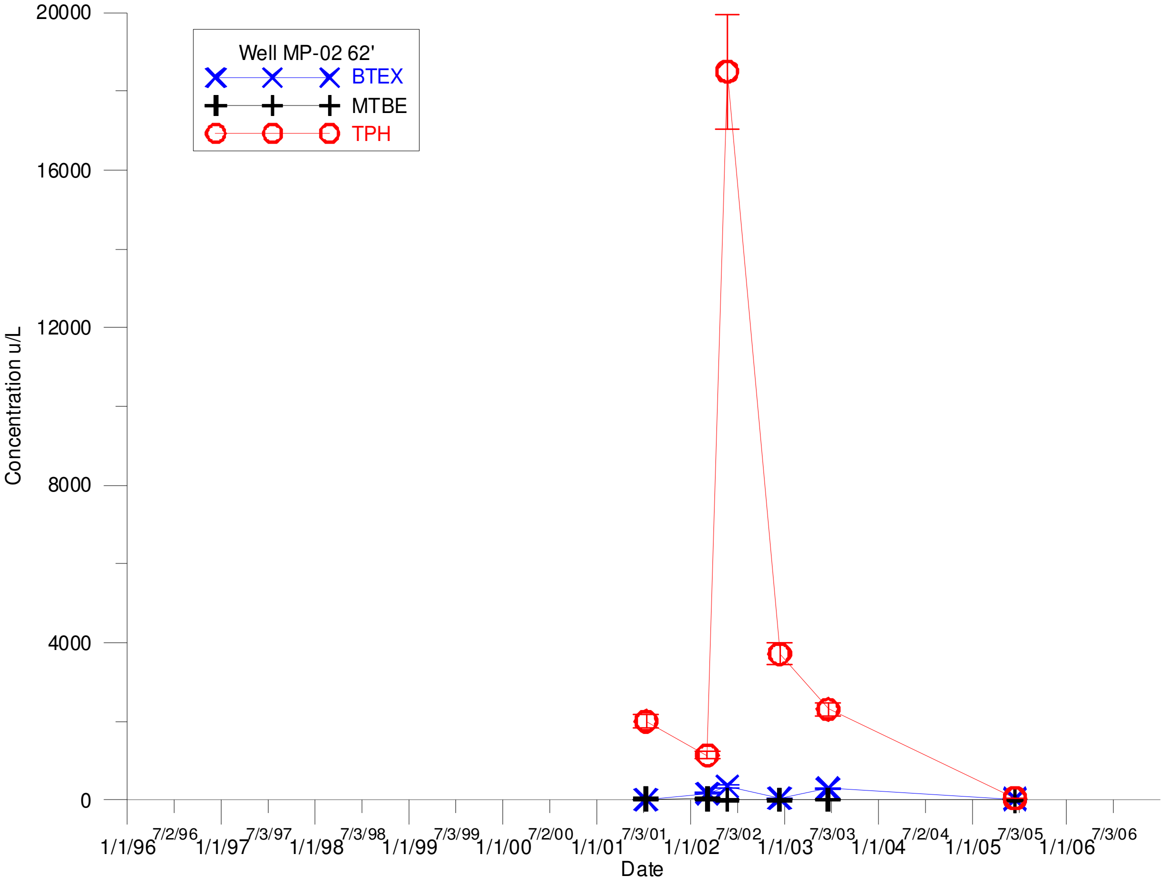

Well MP-01 64'
BTEX
MTBE
TPH
Concentration u/L
50000
40000
30000
20000
10000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

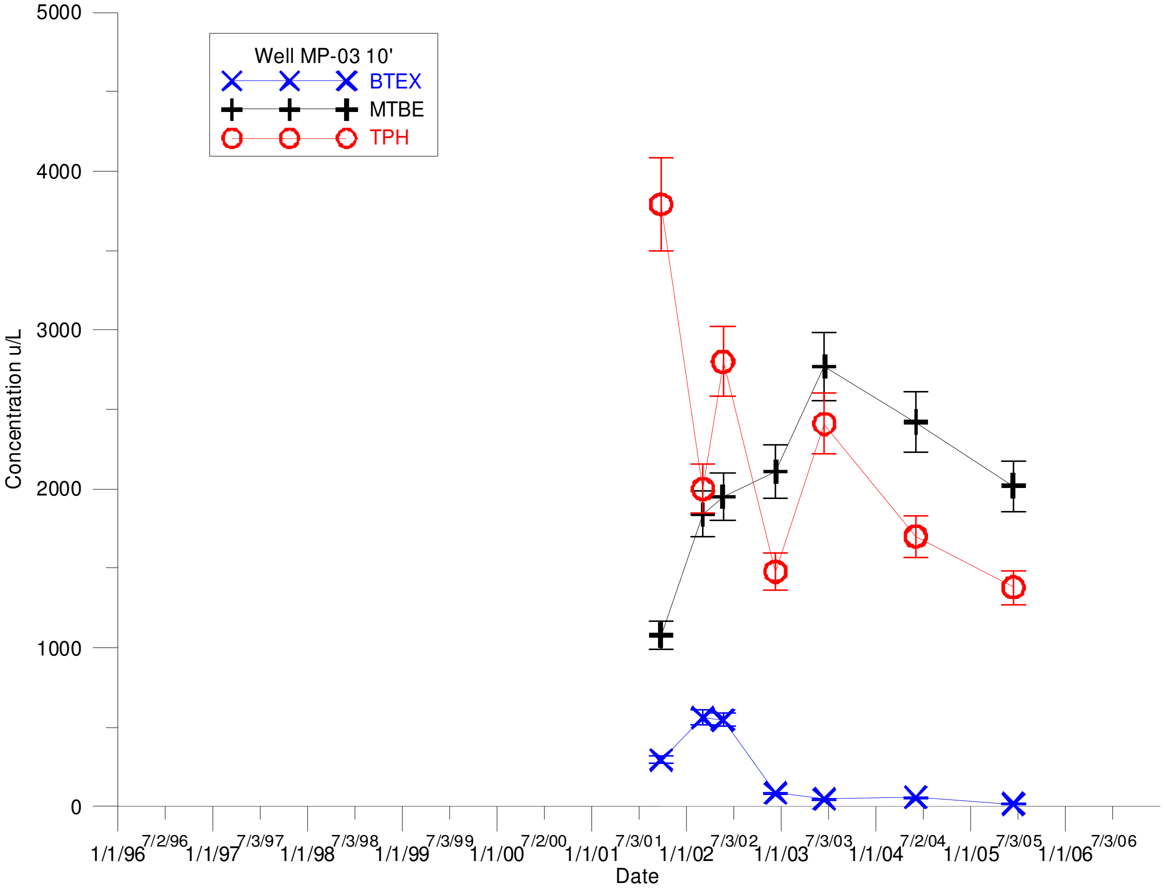

Well MP-01 72'
BTEX
MTBE
TPH
Concentration u/L
16000
12000
8000
4000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

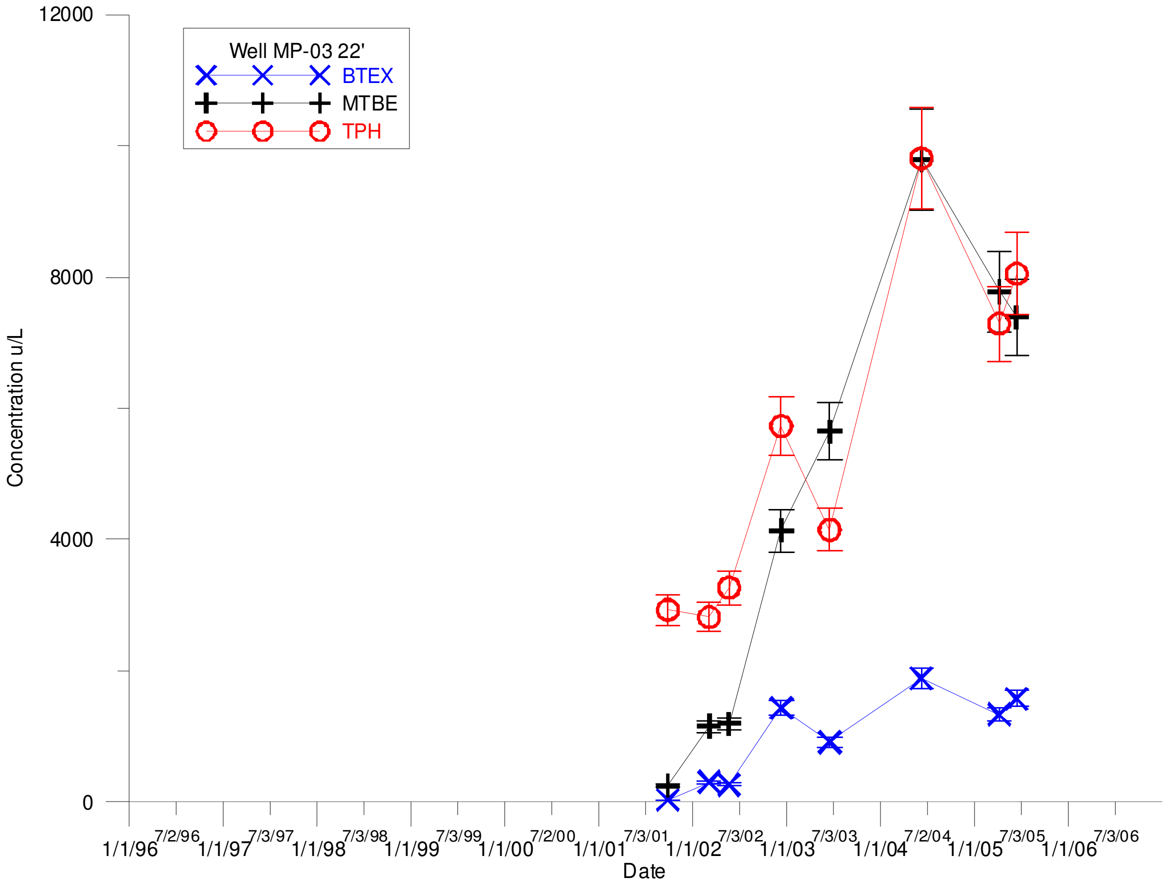

Well MP-02 27'
BTEX
MTBE
TPH
Concentration u/L
0
400
800
1200
1600
2000
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

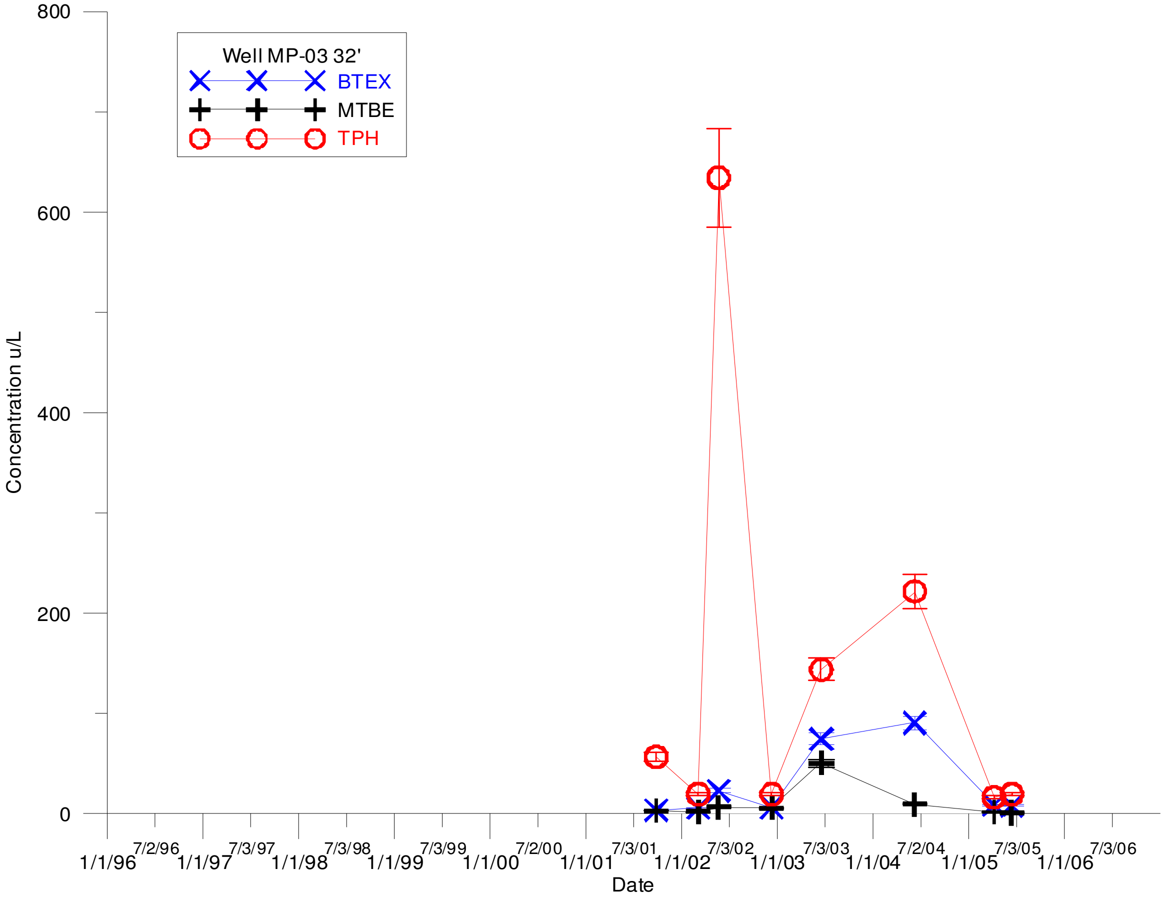

Well MP-02 37'
BTEX
MTBE
TPH
Concentration u/L
2500
2000
1500
1000
500
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

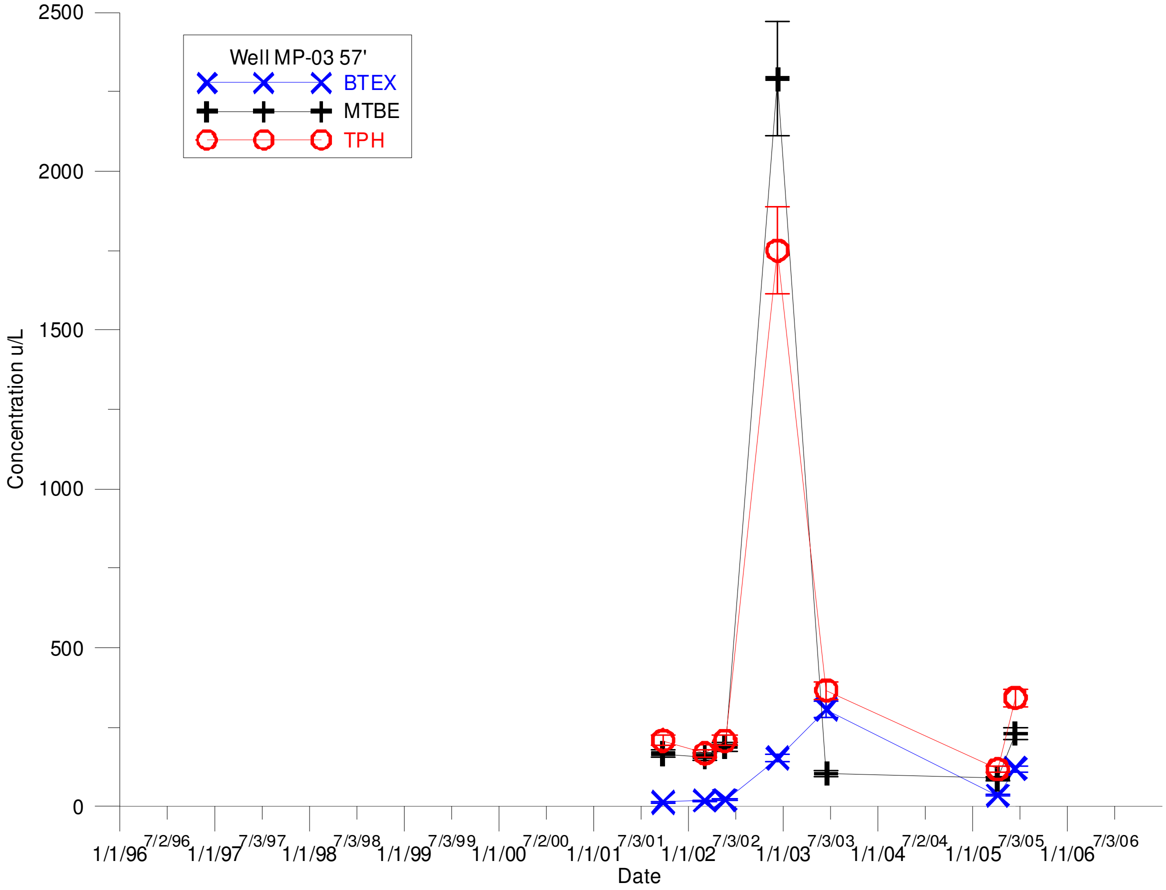

Well MP-02 50'
BTEX
MTBE
TPH
30000
20000
10000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP-02 62'
BTEX
MTBE
TPH
20000
16000
12000
8000
4000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP-03 10'
BTEX
MTBE
TPH
5000
4000
3000
2000
1000
0
Concentration u/L
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

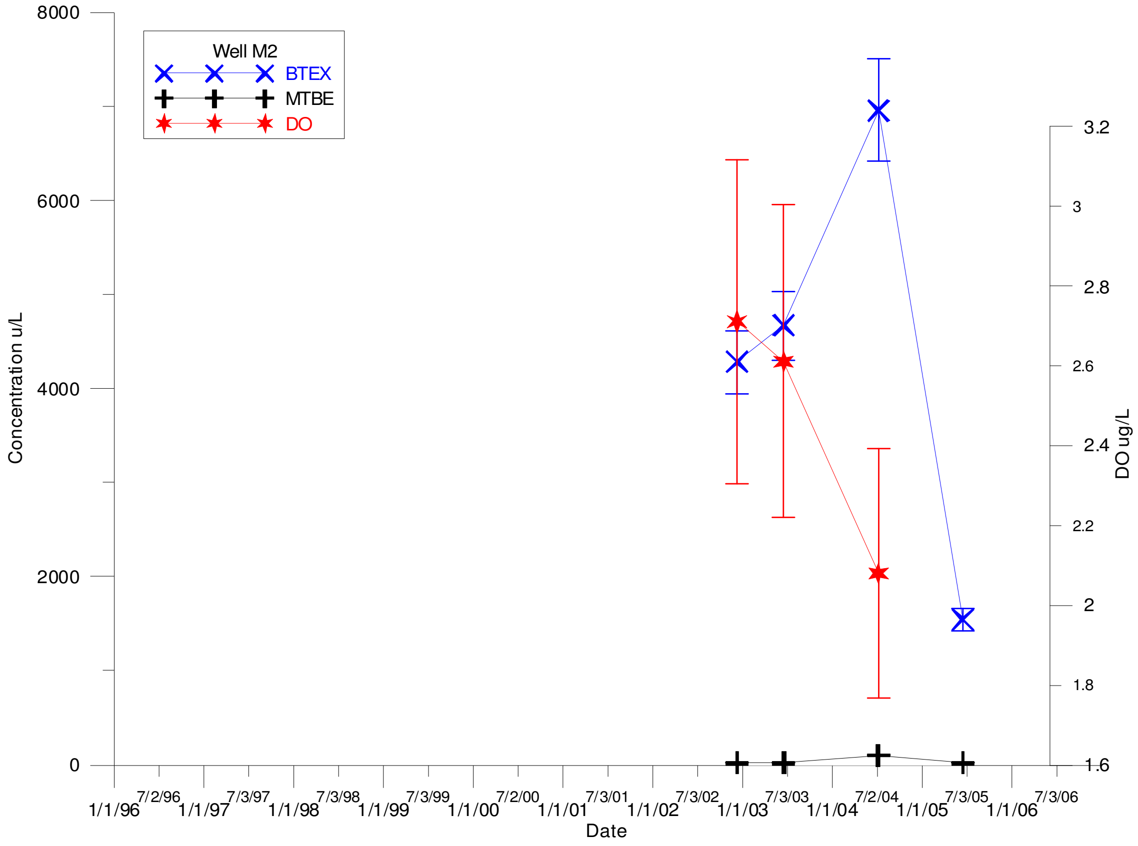

Well MP-03 22'
BTEX
MTBE
TPH
Concentration u/L
12000
8000
4000
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP-03 32'
BTEX
MTBE
TPH
Concentration u/L
800
600
400
200
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

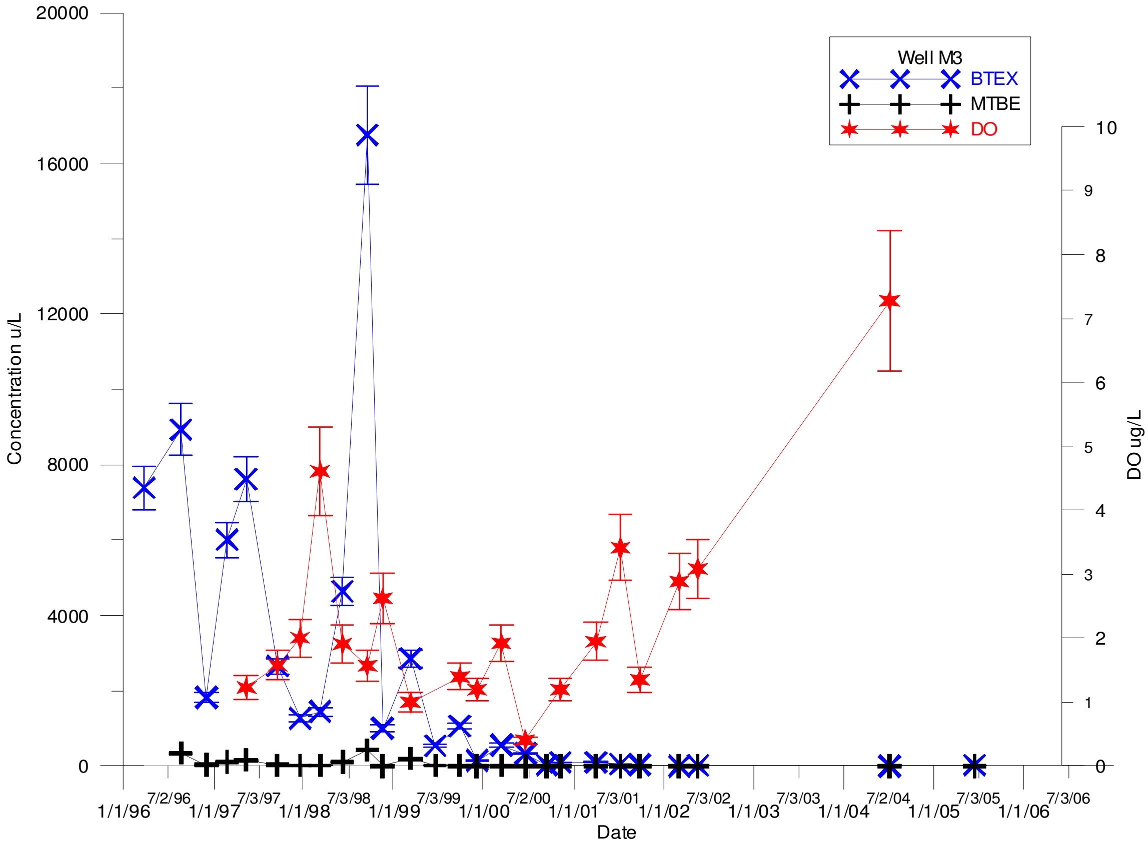

Well MP-03 57'
BTEX
MTBE
TPH
Concentration u/L
2500
2000
1500
1000
500
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

BTEX, MTBE, and DO over Time

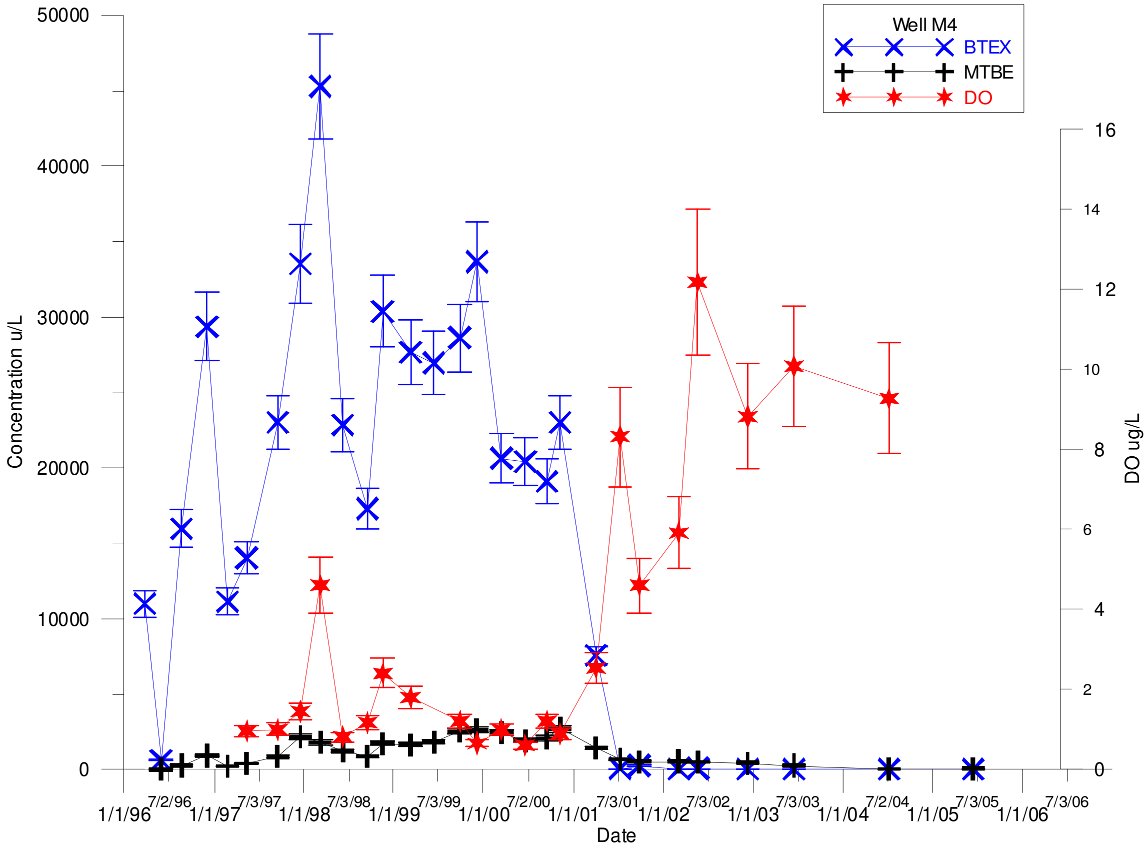
Data was compiled from HKM 2003, 2005, 2006 and Loustaunau 2003. Graphical analysis represents sampling data presented in this appendix. Error bars reflect uncertainty in field and laboratory analysis.

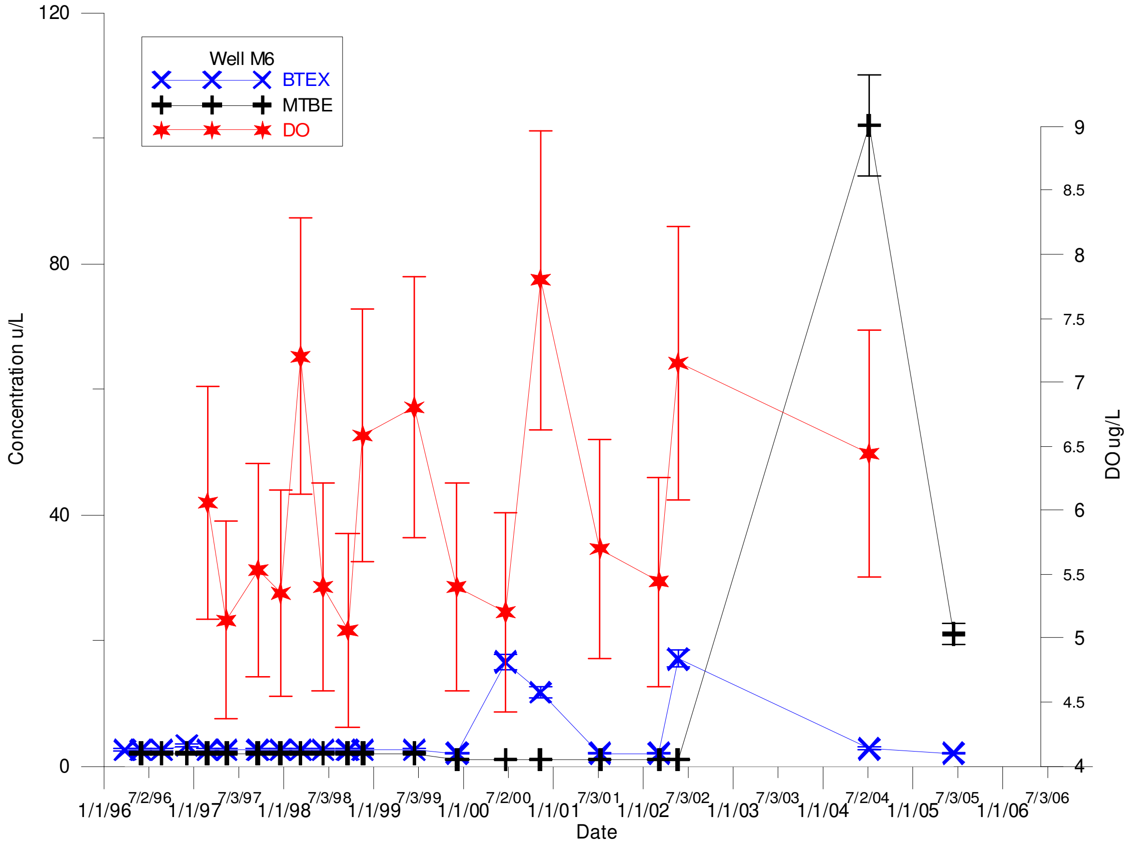


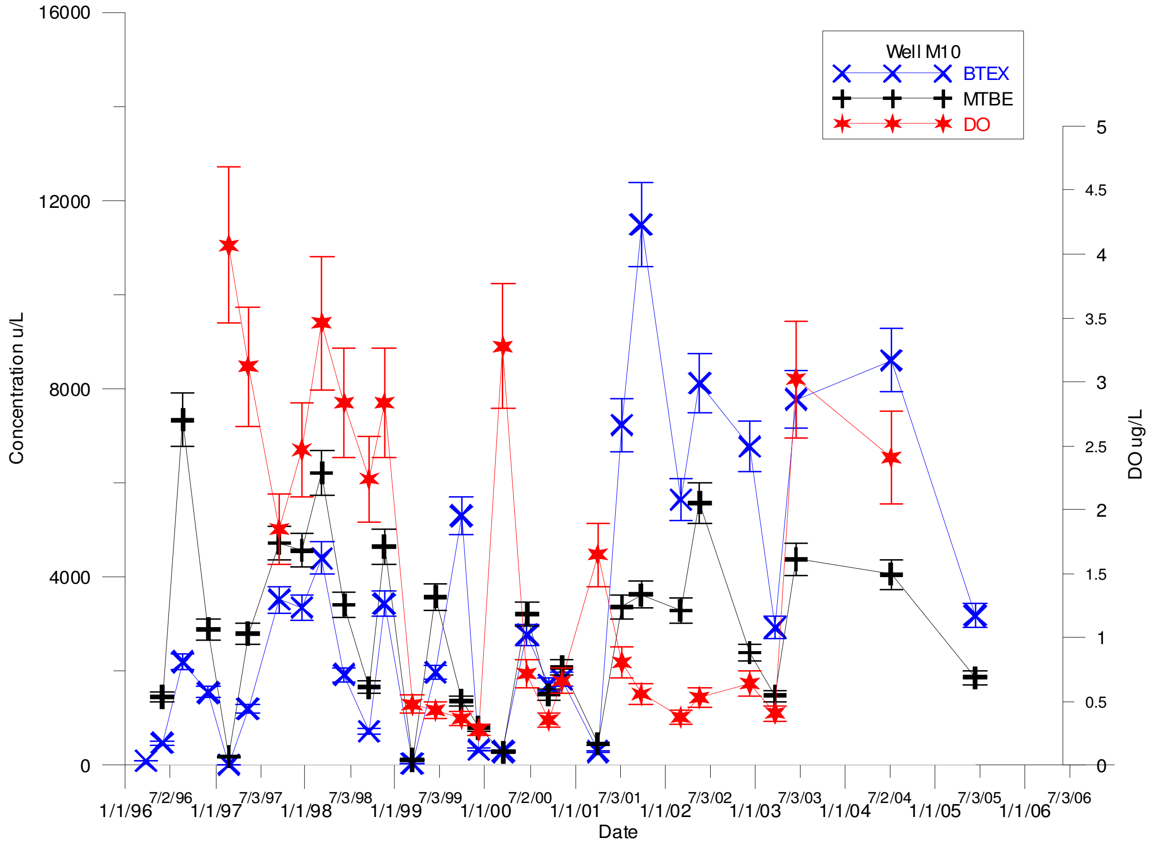
Well M2
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
0
2000
4000
6000
8000
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

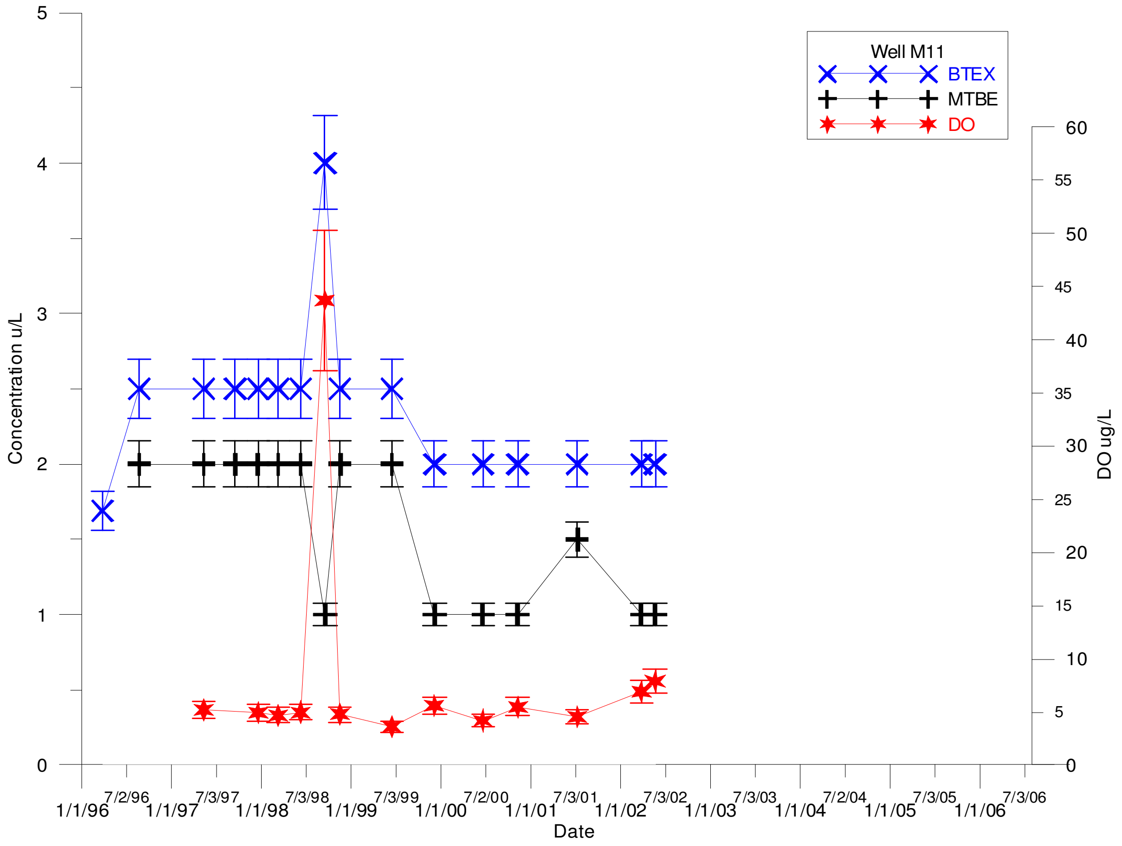


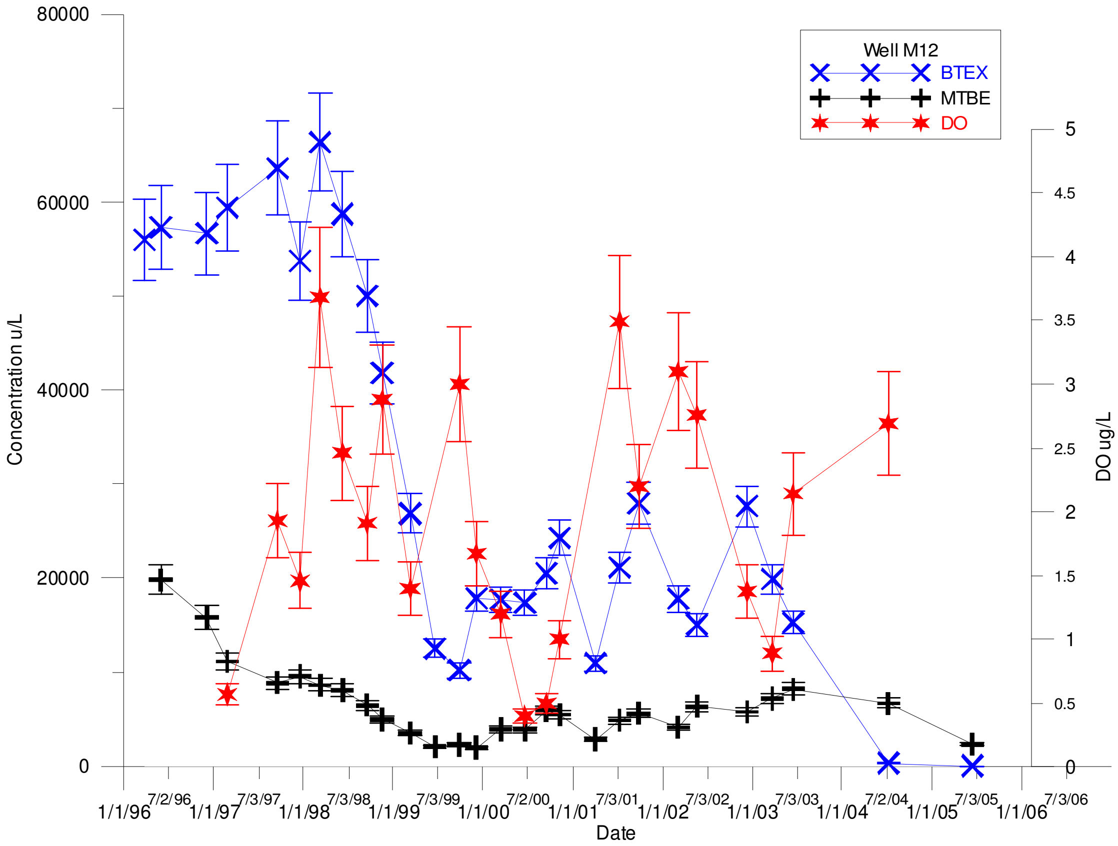
Well M3
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
0
4000
8000
12000
16000
20000
0
1
2
3
4
5
6
7
8
9
10
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

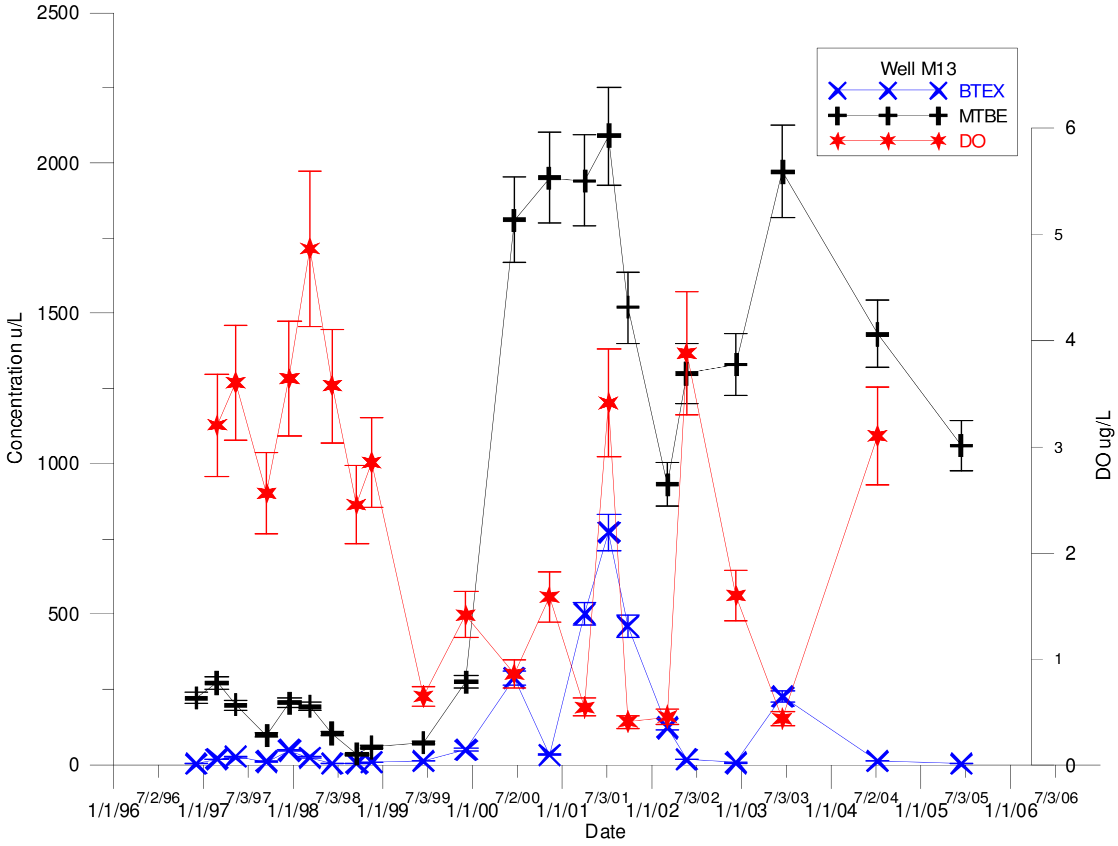

Well M4
BTEX
MTBE
DO
Concentration u/L
50000
40000
30000
20000
10000
0
DO ug/L
16
14
12
10
8
6
4
2
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

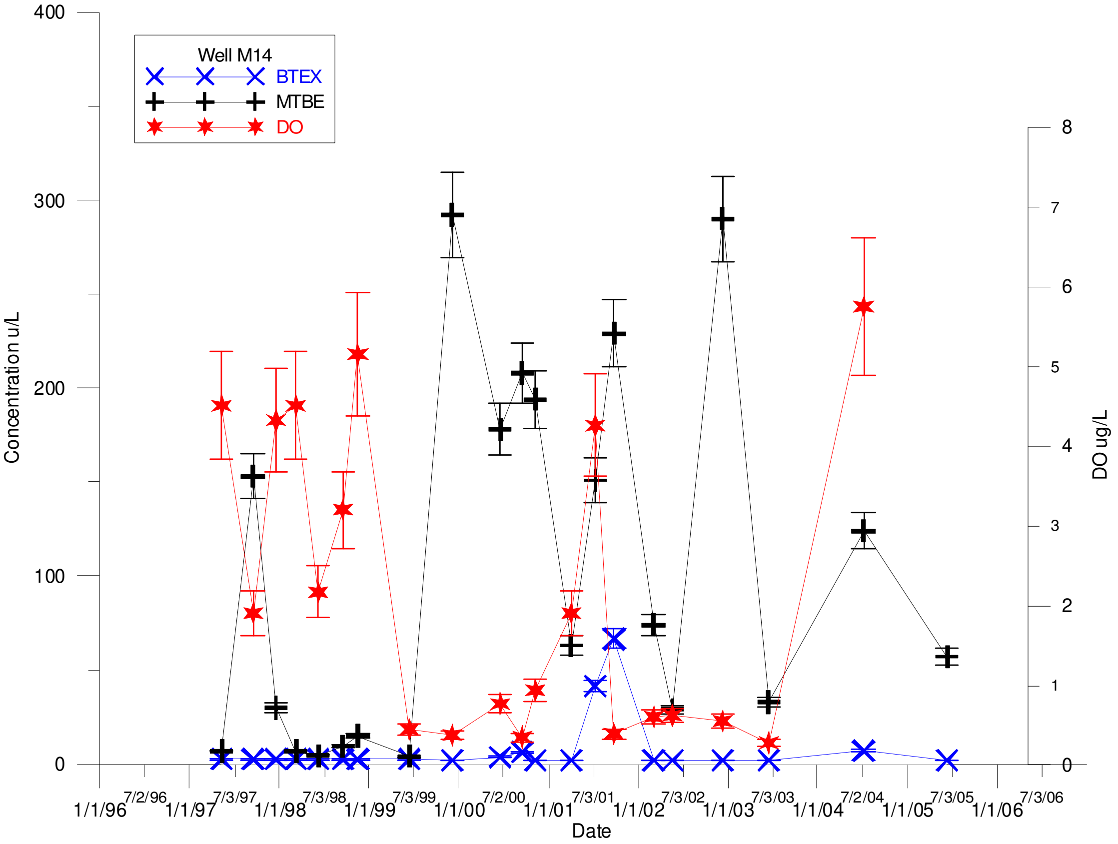

Well M6
BTEX
MTBE
DO
Concentration u/L
120
80
40
0
DO ug/L
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

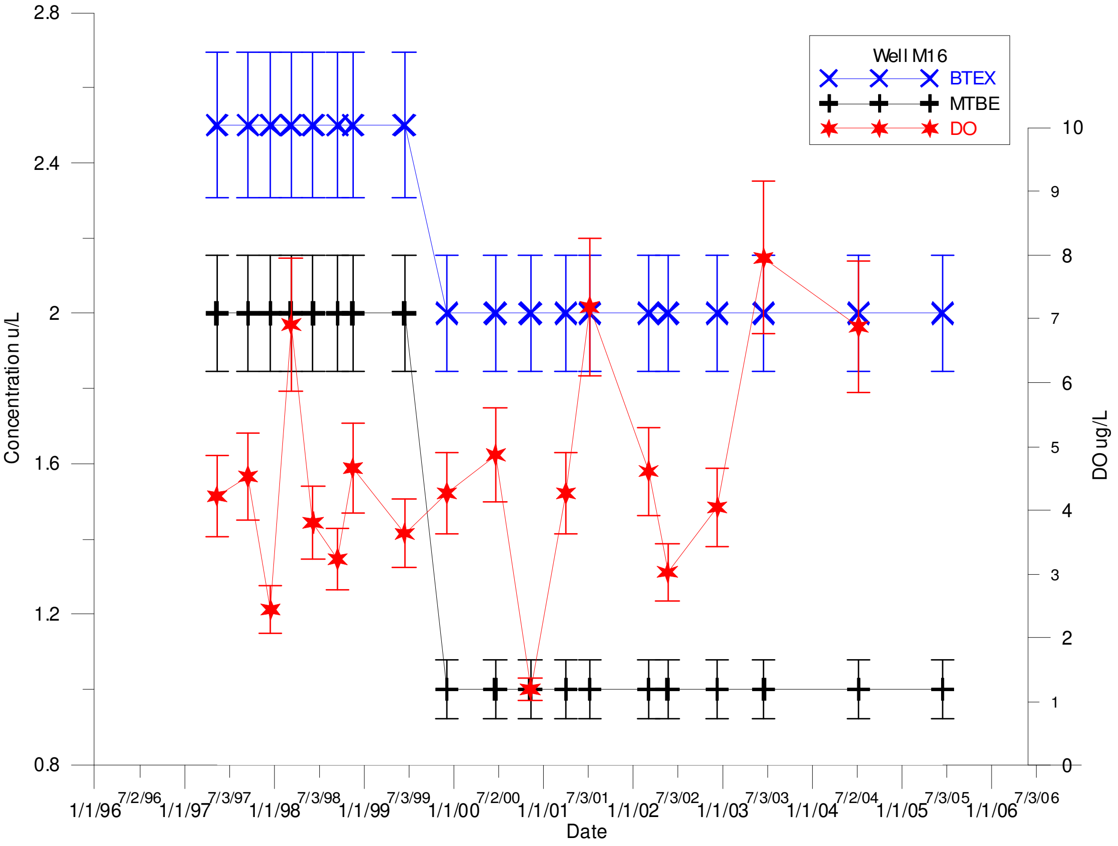

Well M10
BTEX
MTBE
DO
Concentration u/L
16000
12000
8000
4000
0
DO ug/L
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

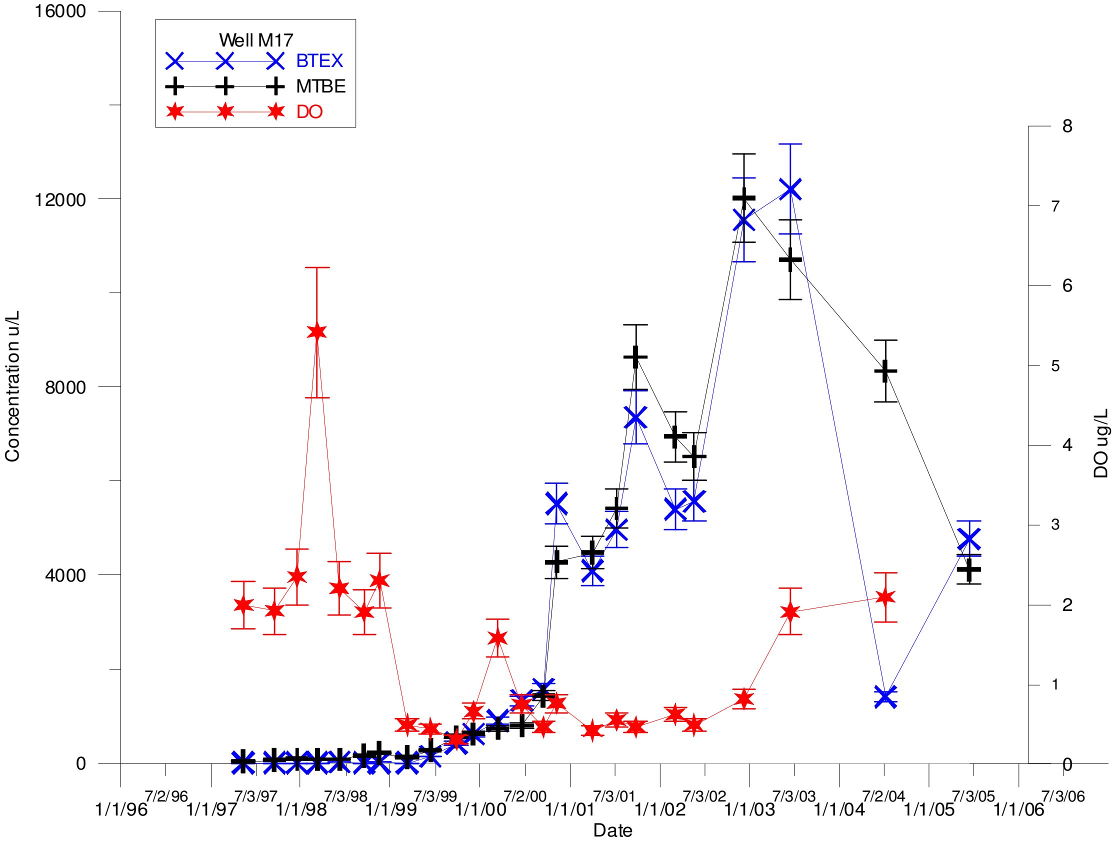

Well M11
BTEX
MTBE
DO
Concentration u/L
5
4
3
2
1
0
DO ug/L
60
55
50
45
40
35
30
25
20
15
10
5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

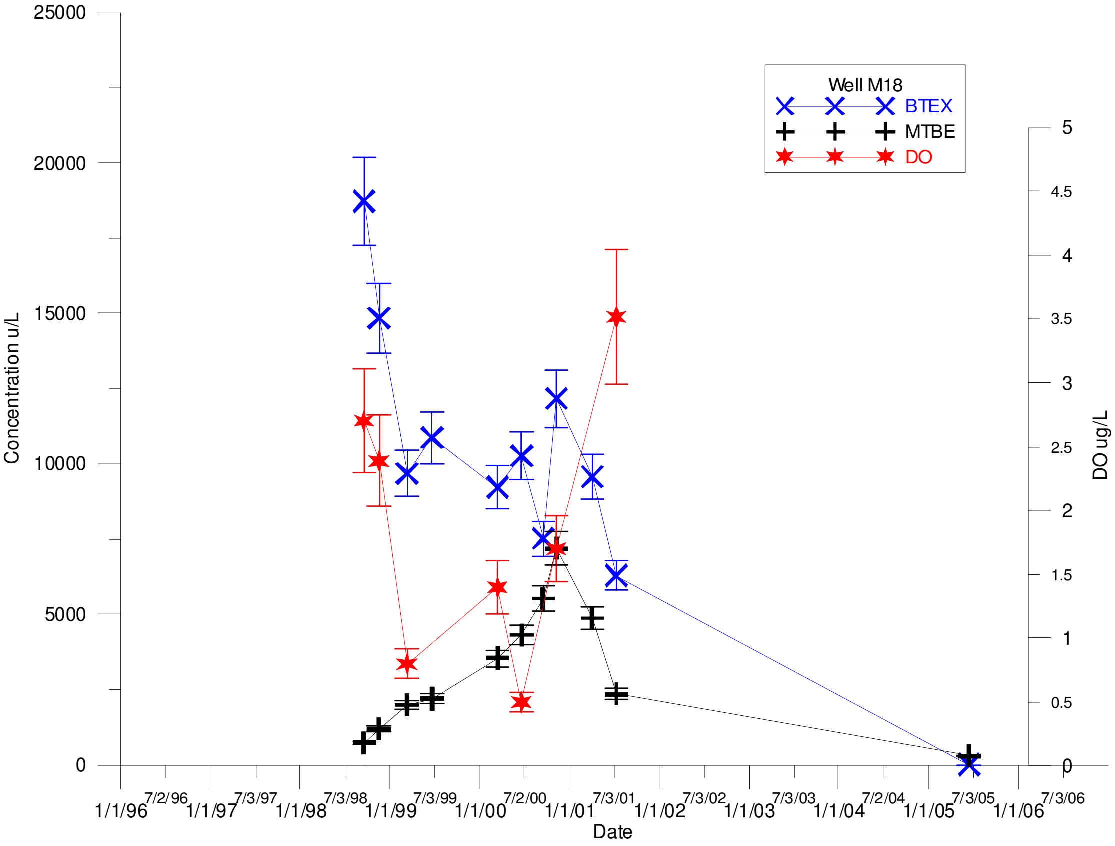

Well M12
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
80000
60000
40000
20000
0
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

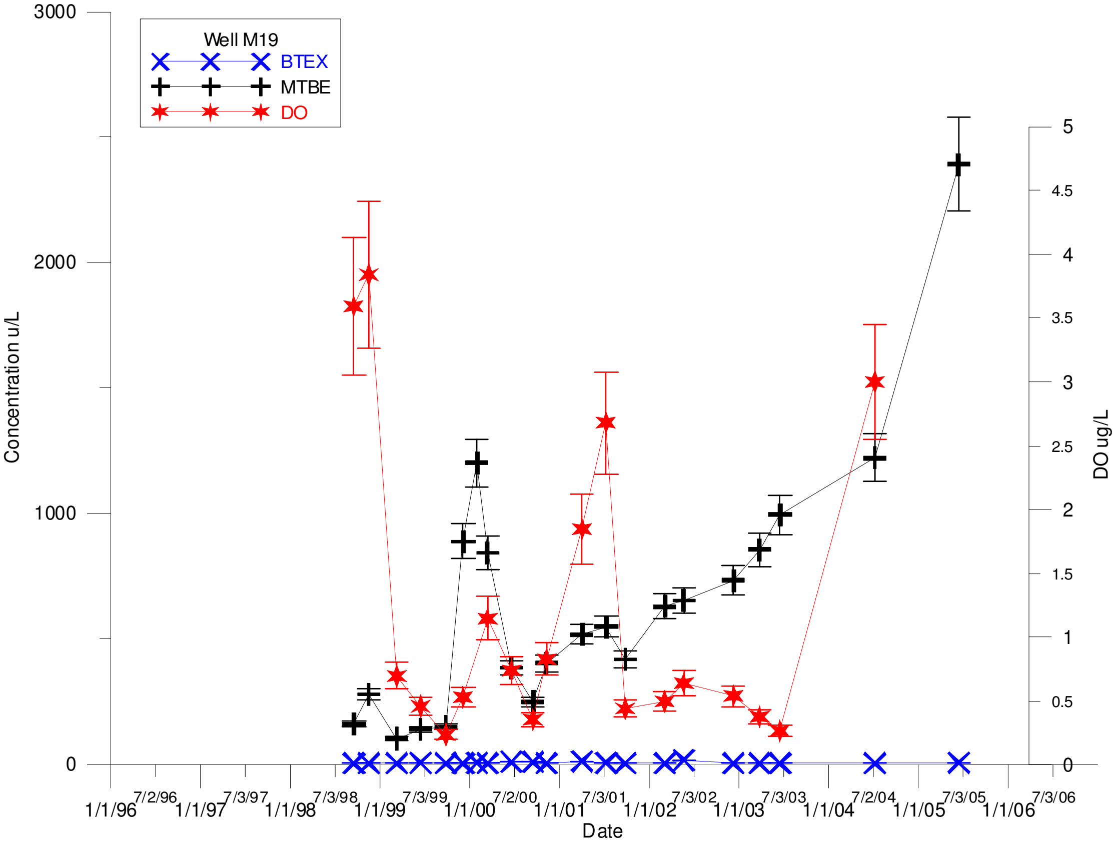

Well M13
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
2500
2000
1500
1000
500
0
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06


Well M14
BTEX
MTBE
DO
Concentration u/L
400
300
200
100
0
DO ug/L
8
7
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

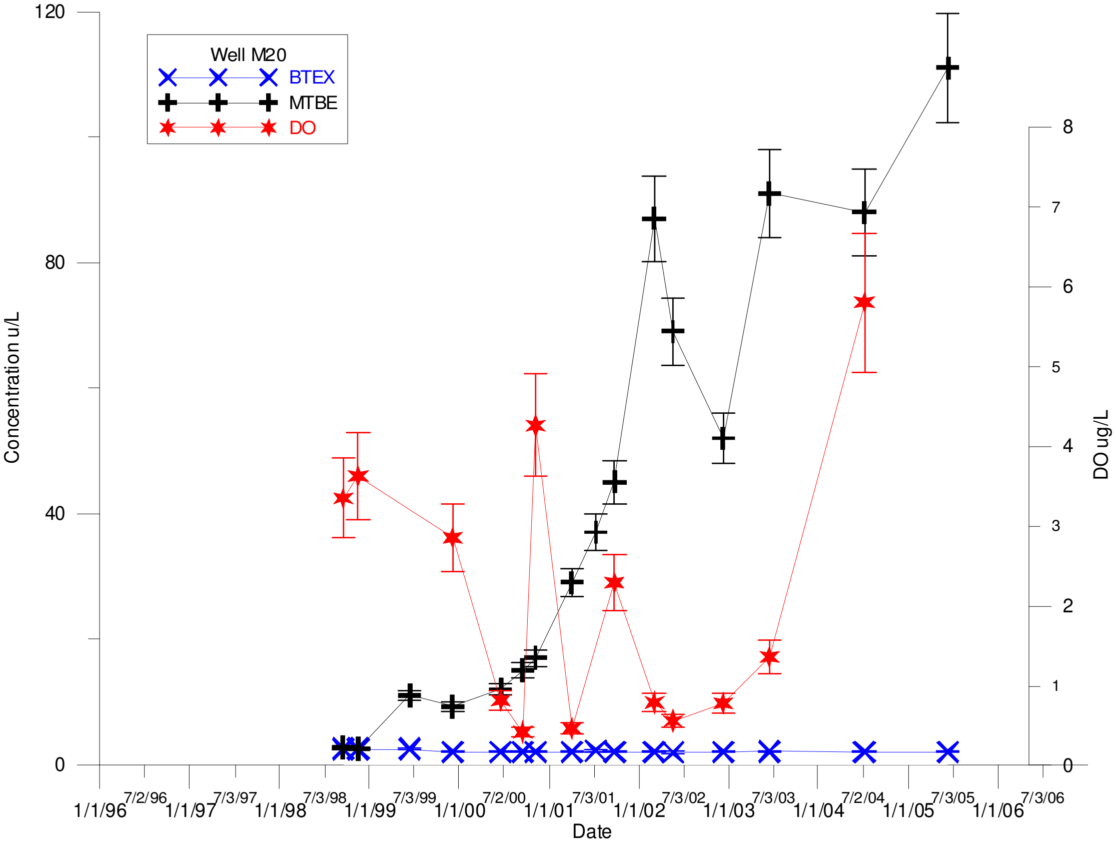

Well M16
BTEX
MTBE
DO
Concentration u/L
2.8
2.4
2
1.6
1.2
0.8
DO ug/L
10
9
8
7
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well M17
BTEX
MTBE
DO
Concentration u/L
DO ug/L
16000
12000
8000
4000
0
8
7
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

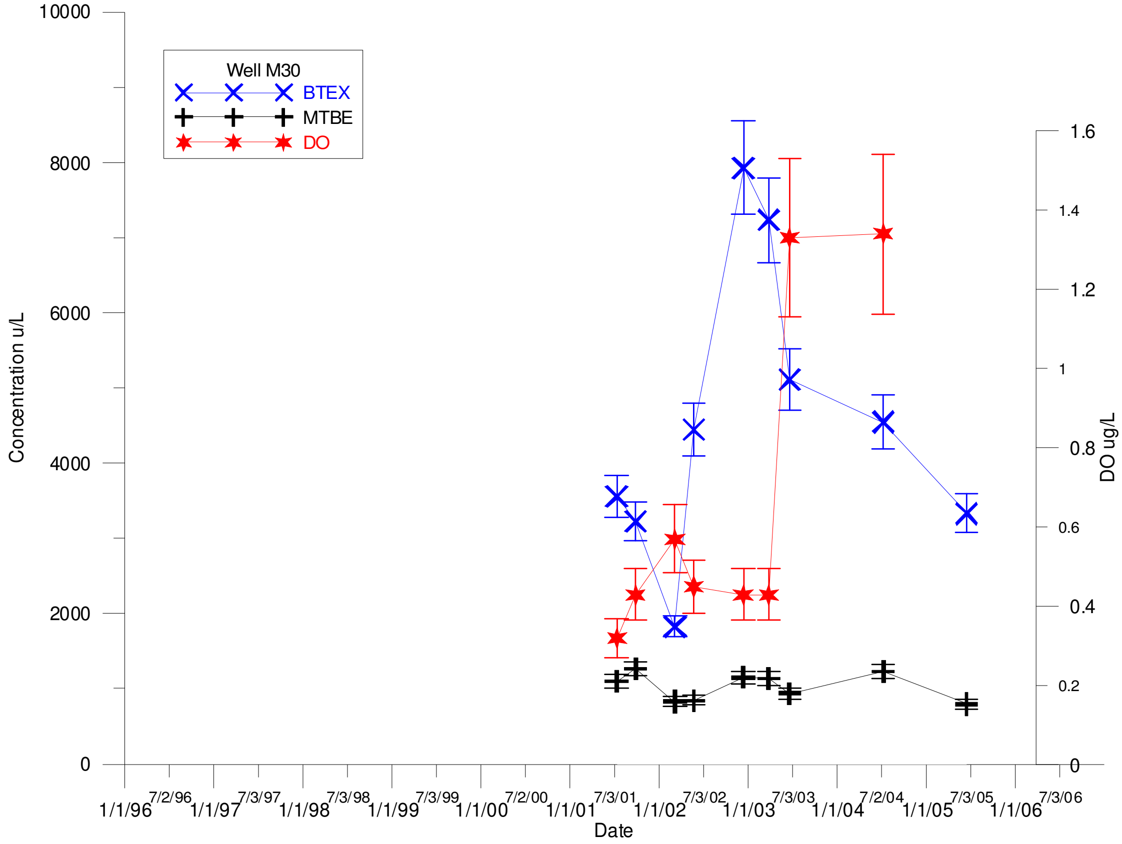

Well M18
BTEX
MTBE
DO
Concentration u/L
DO ug/L
25000
20000
15000
10000
5000
0
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date



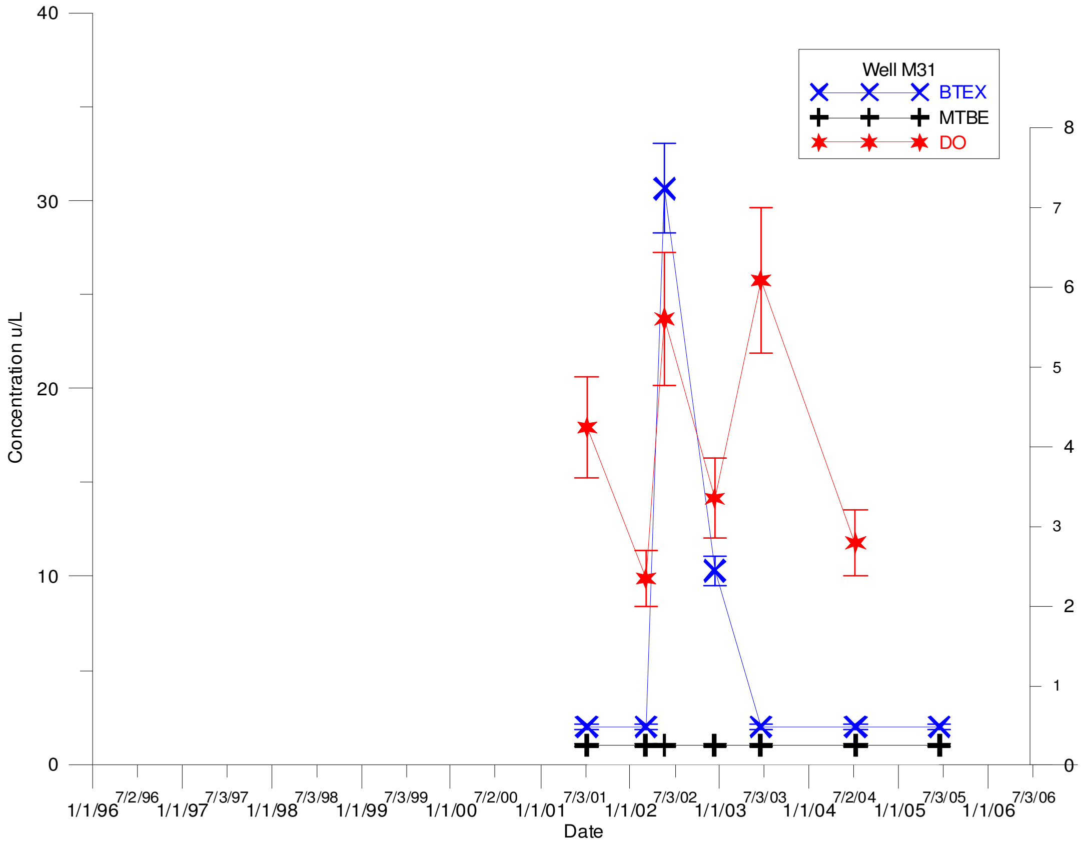
Well M19
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
3000
2000
1000
0
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06



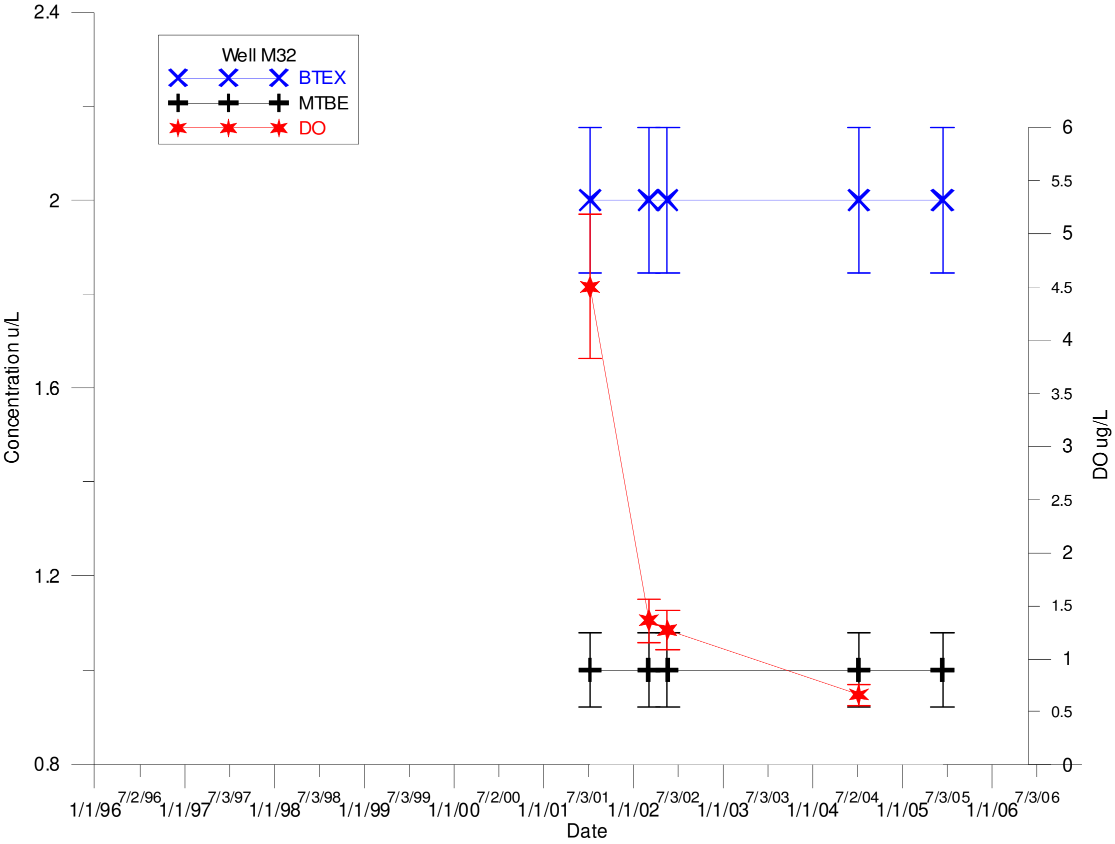
Well M20
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
120
80
40
0
8
7
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

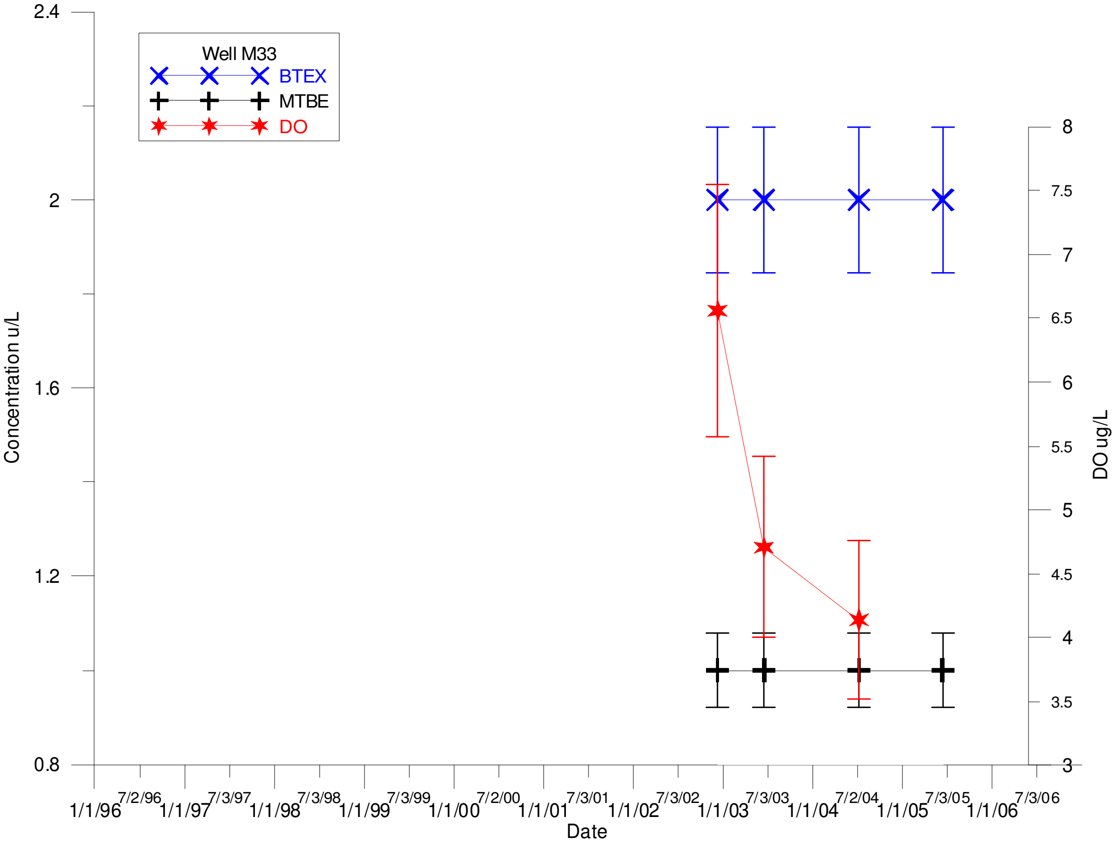


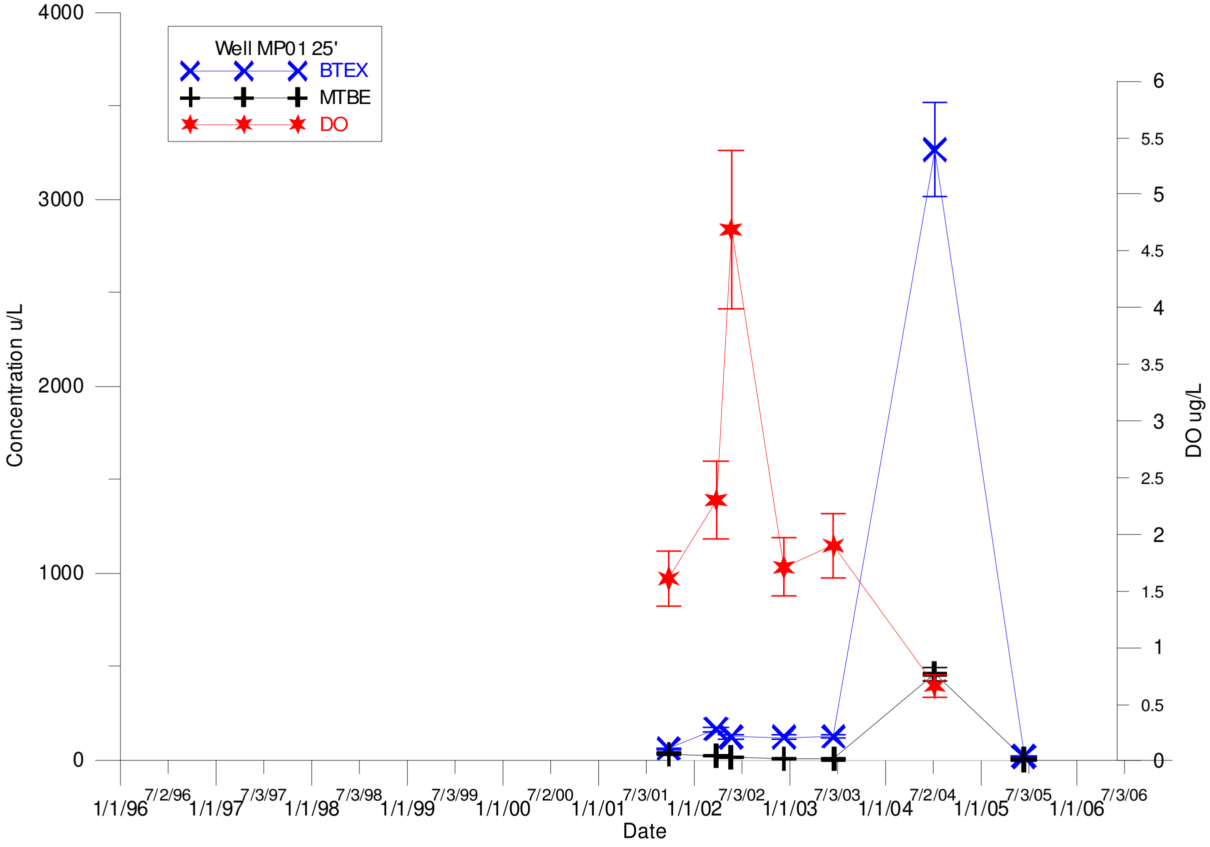
Well M30
BTEX
MTBE
DO
Concentration u/L
10000
8000
6000
4000
2000
0
DO ug/L
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

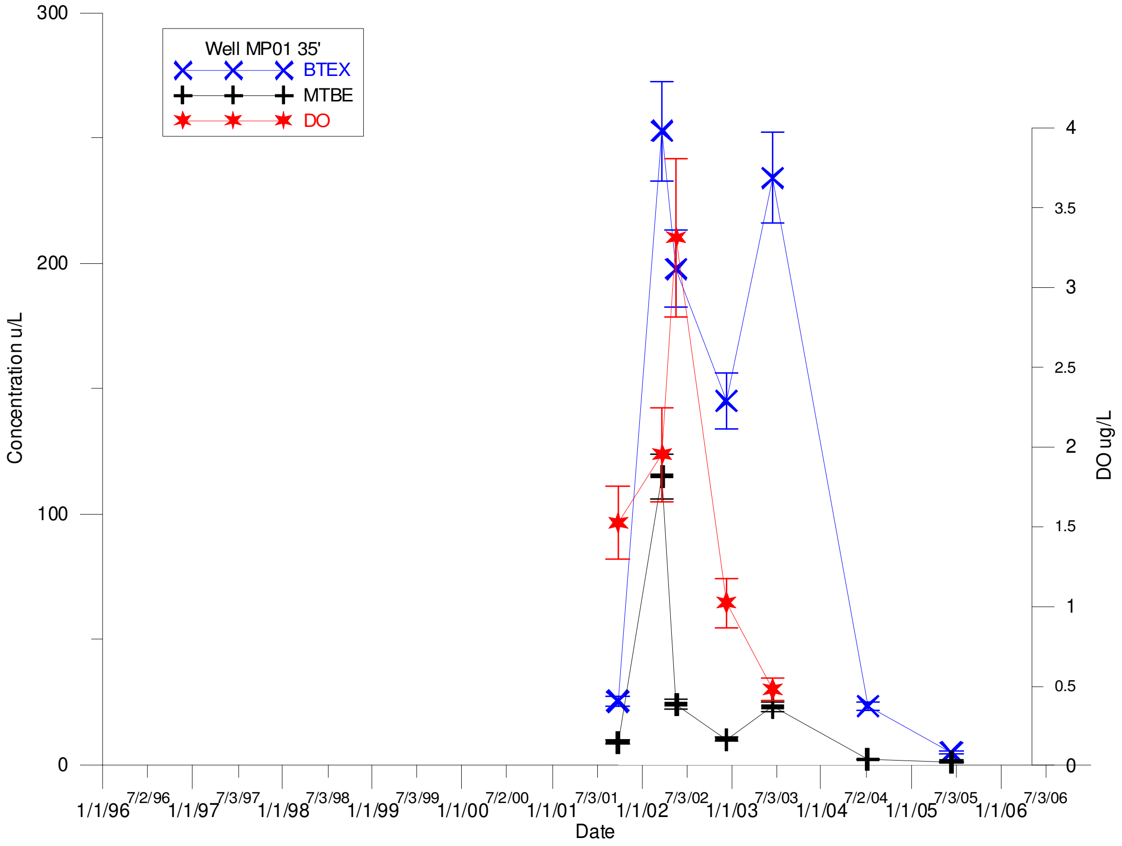


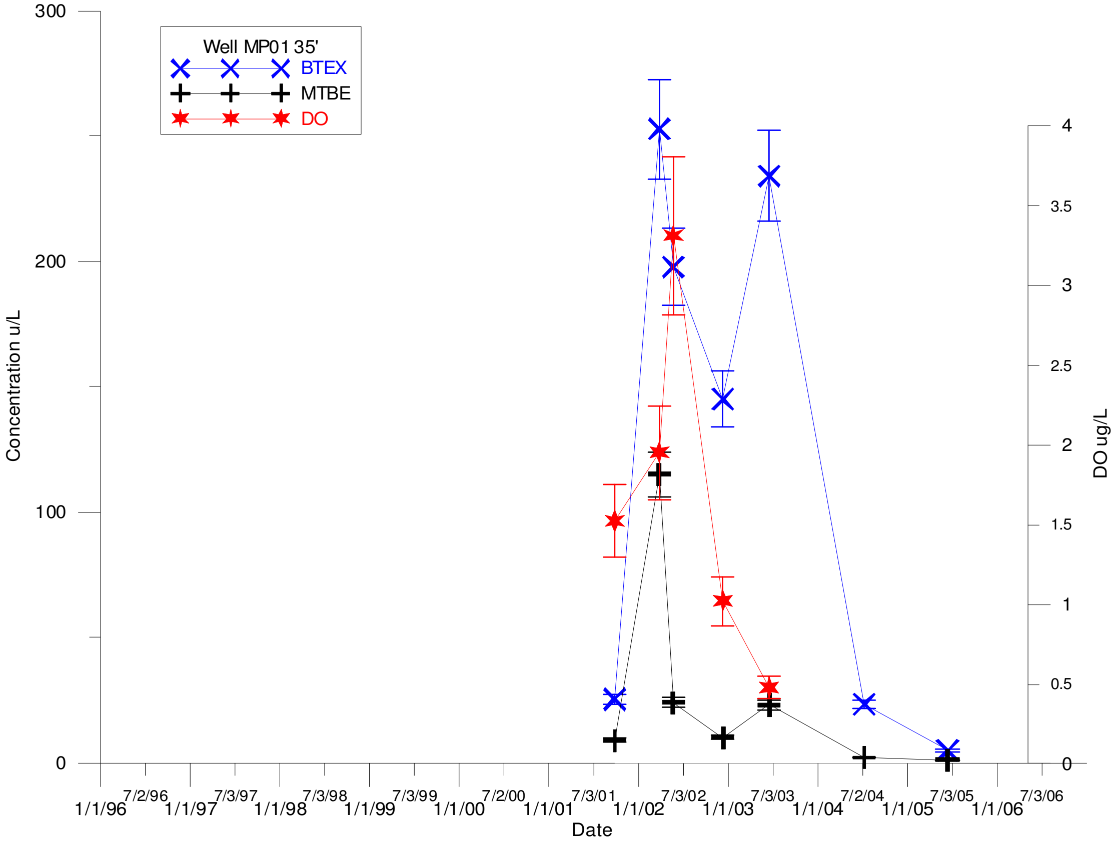
Well M31
BTEX
MTBE
DO
Concentration u/L
40
30
20
10
0
DO ug/L
8
7
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

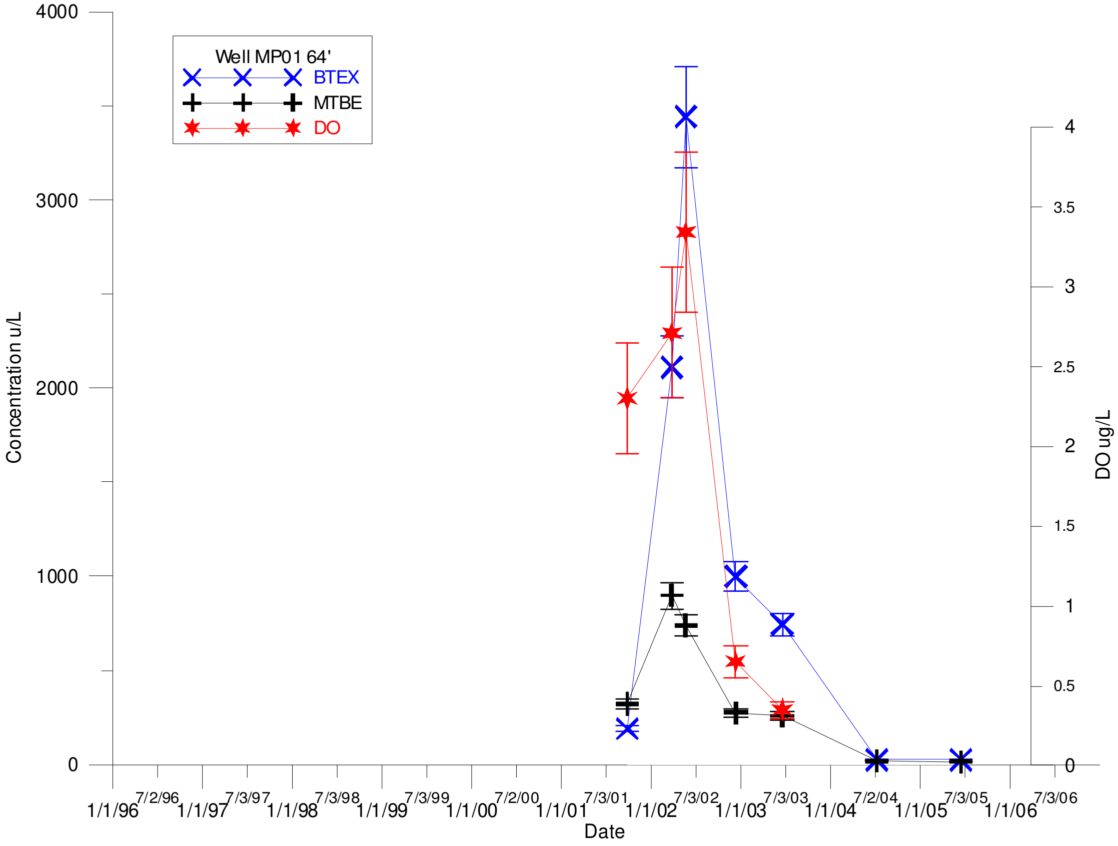

Well M32
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
2.4
2
1.6
1.2
0.8
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

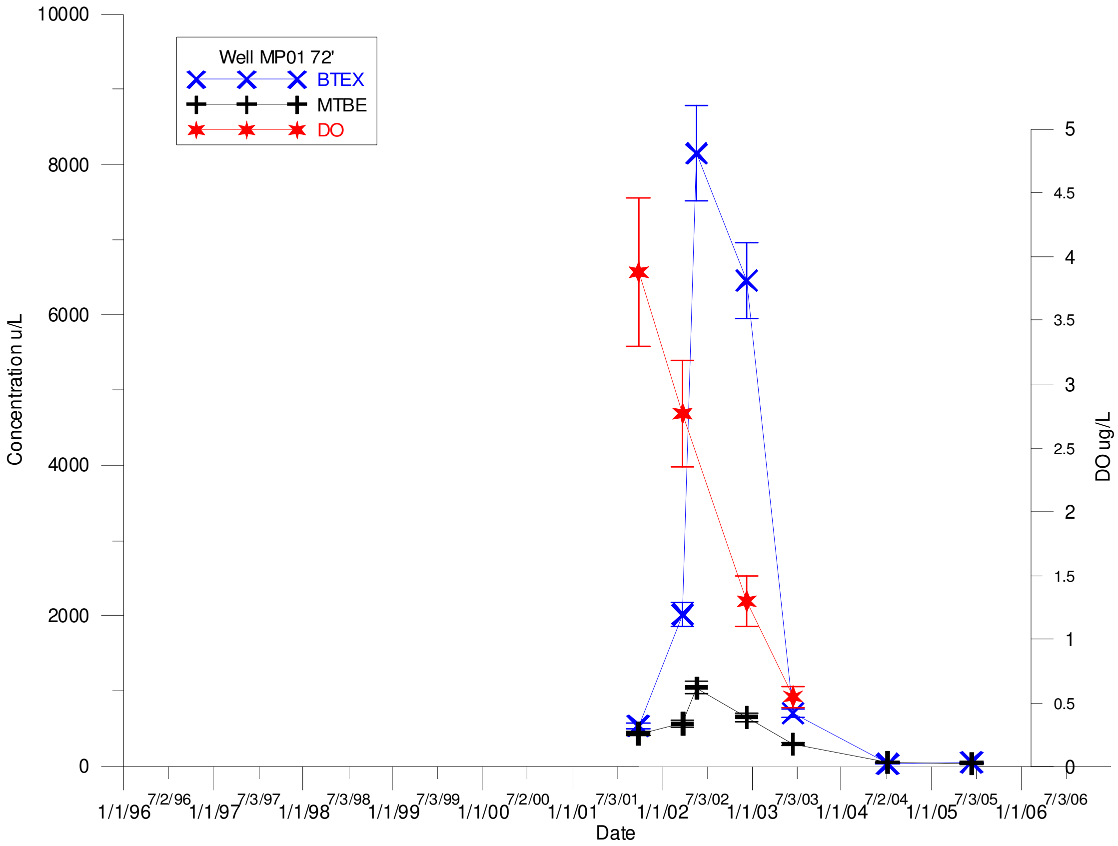

Well M33
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
2.4
2
1.6
1.2
0.8
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

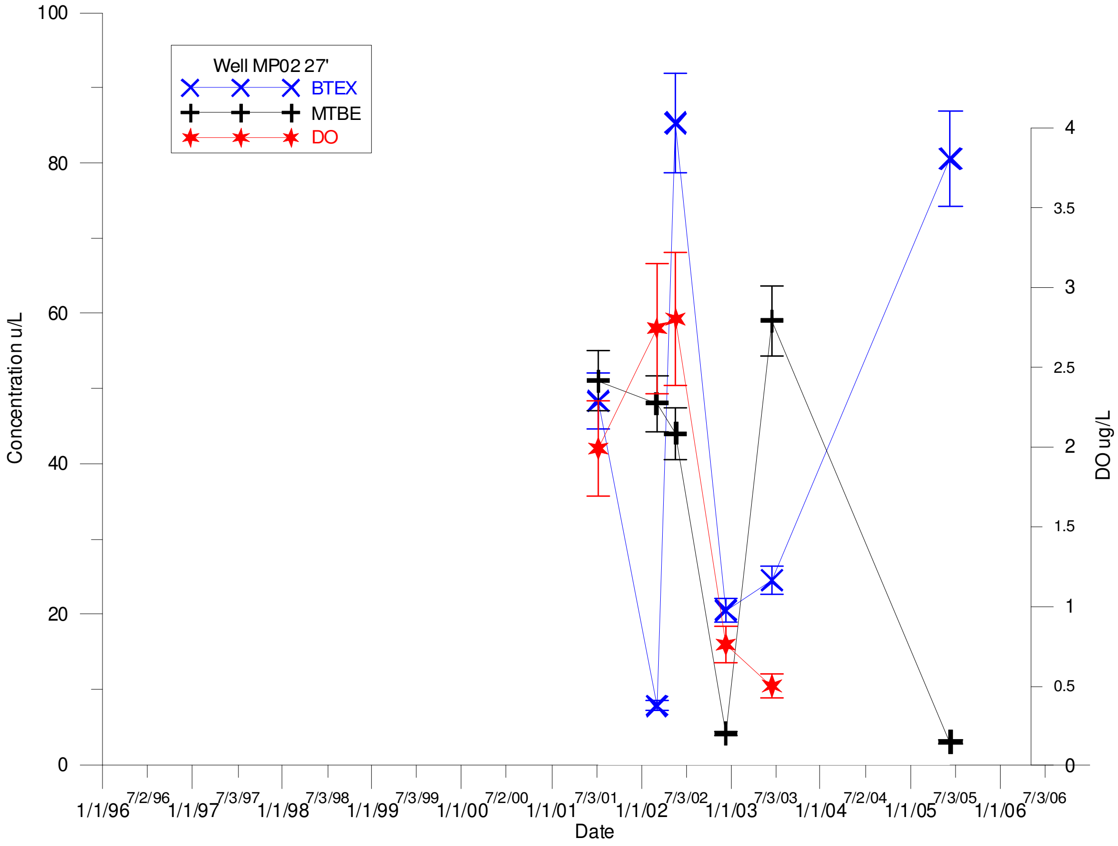

Well MP01 25'
BTEX
MTBE
DO
Concentration u/L
DO ug/L
4000
3000
2000
1000
0
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

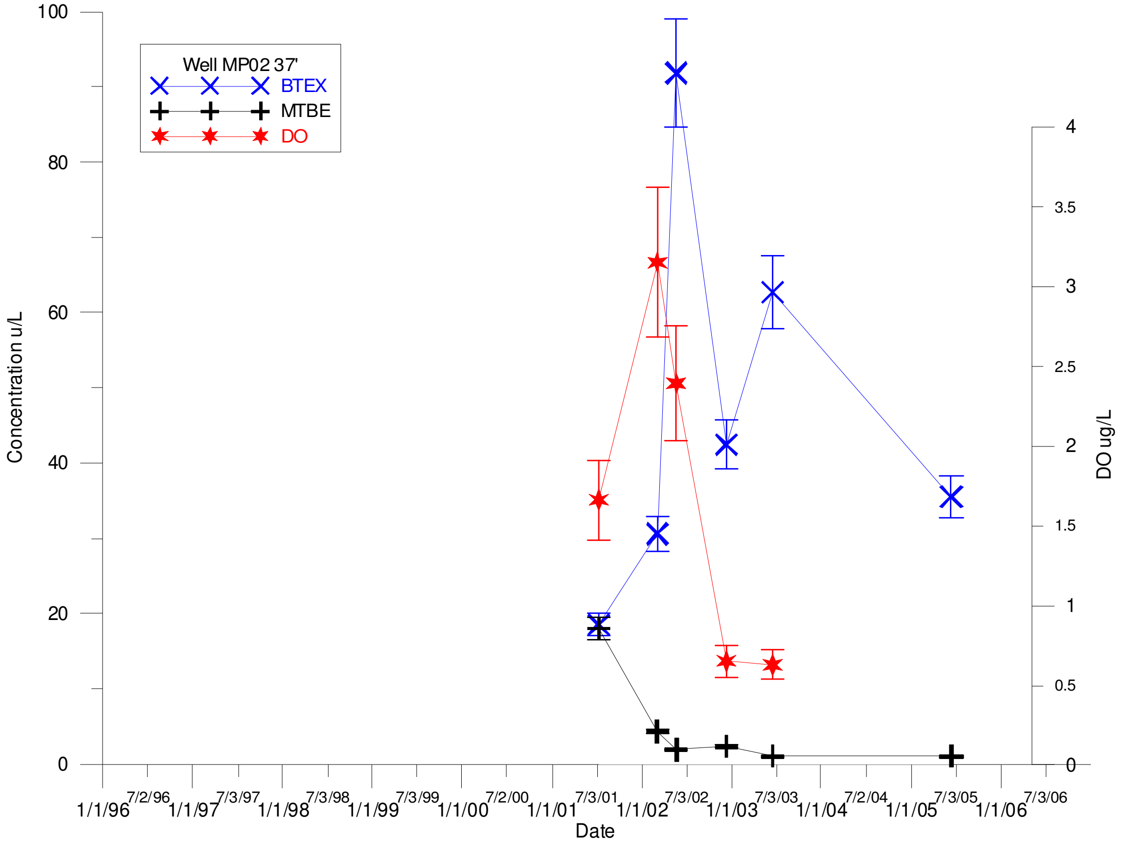

Well MP01 35'
BTEX
MTBE
DO
Concentration u/L
DO ug/L
300
200
100
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

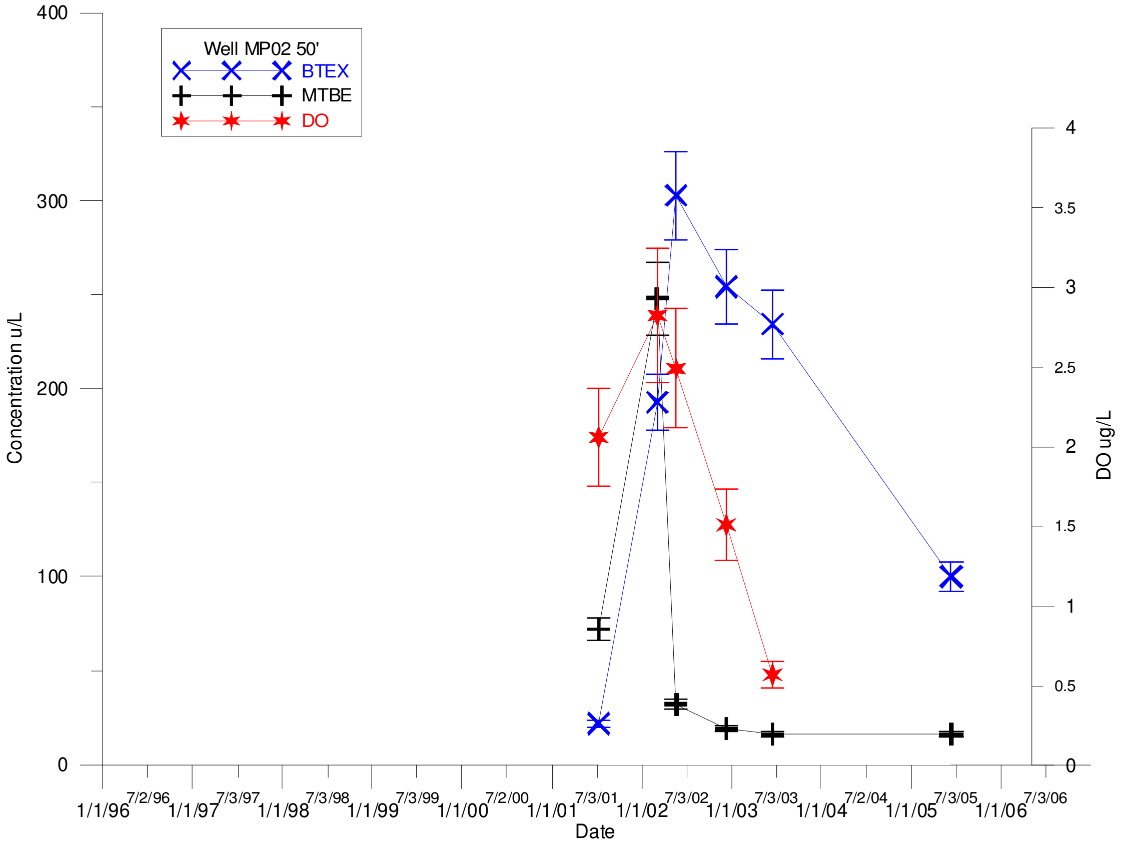

Well MP01 35'
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
300
200
100
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

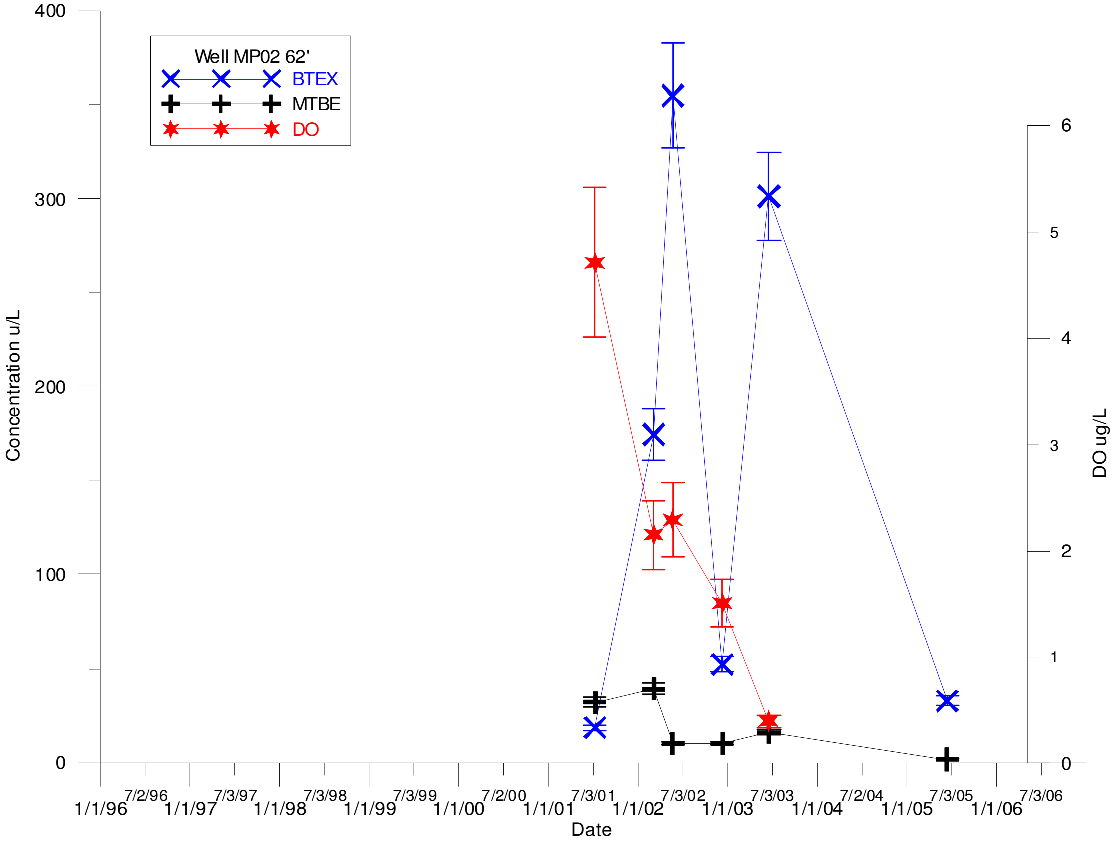

Well MP01 64'
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
4000
3000
2000
1000
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

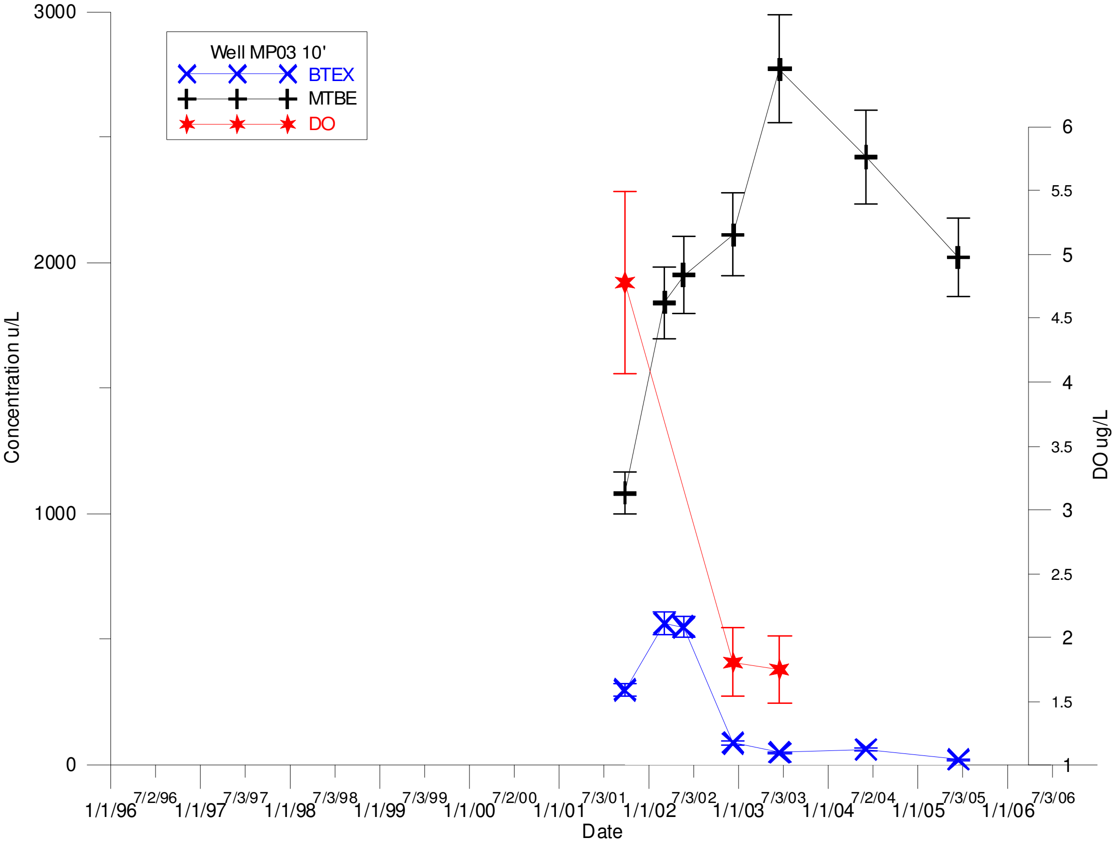

Well MP01 72'
BTEX
MTBE
DO
Concentration u/L
10000
8000
6000
4000
2000
0
DO ug/L
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

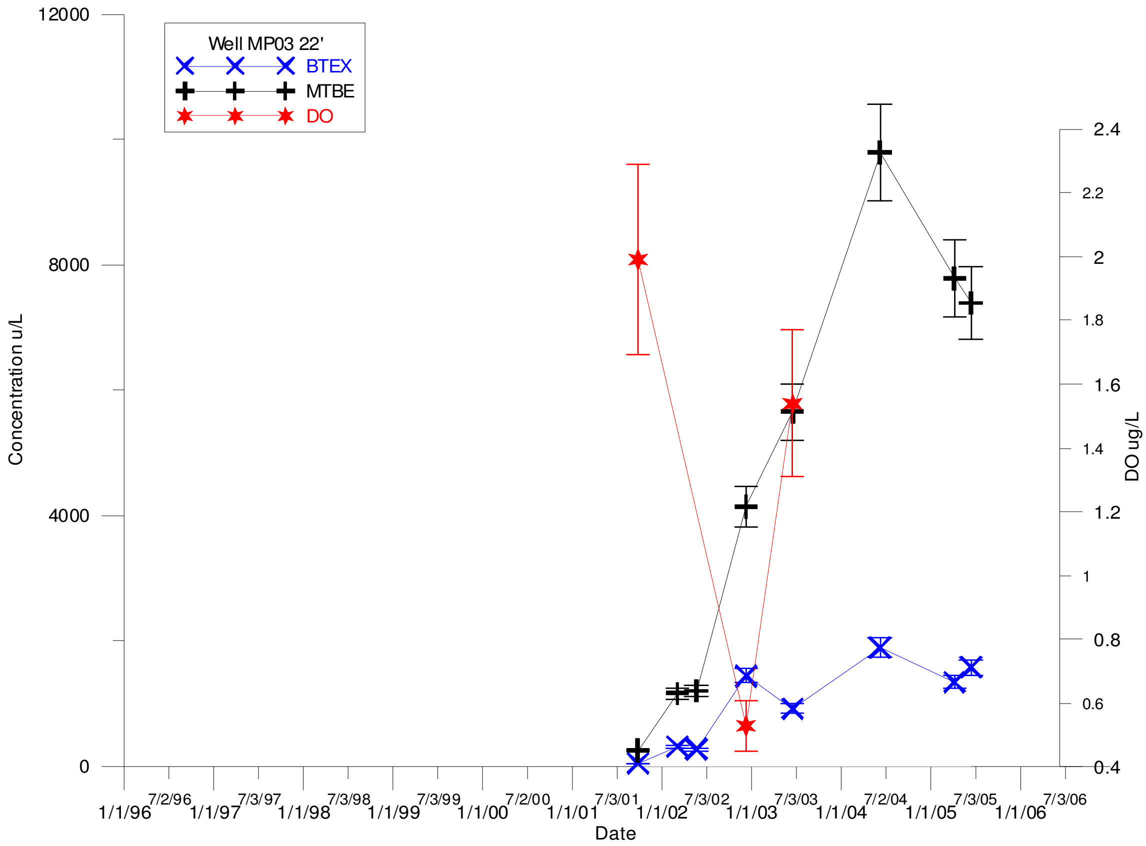

Well MP02 27'
BTEX
MTBE
DO
Concentration u/L
100
80
60
40
20
0
DO ug/L
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

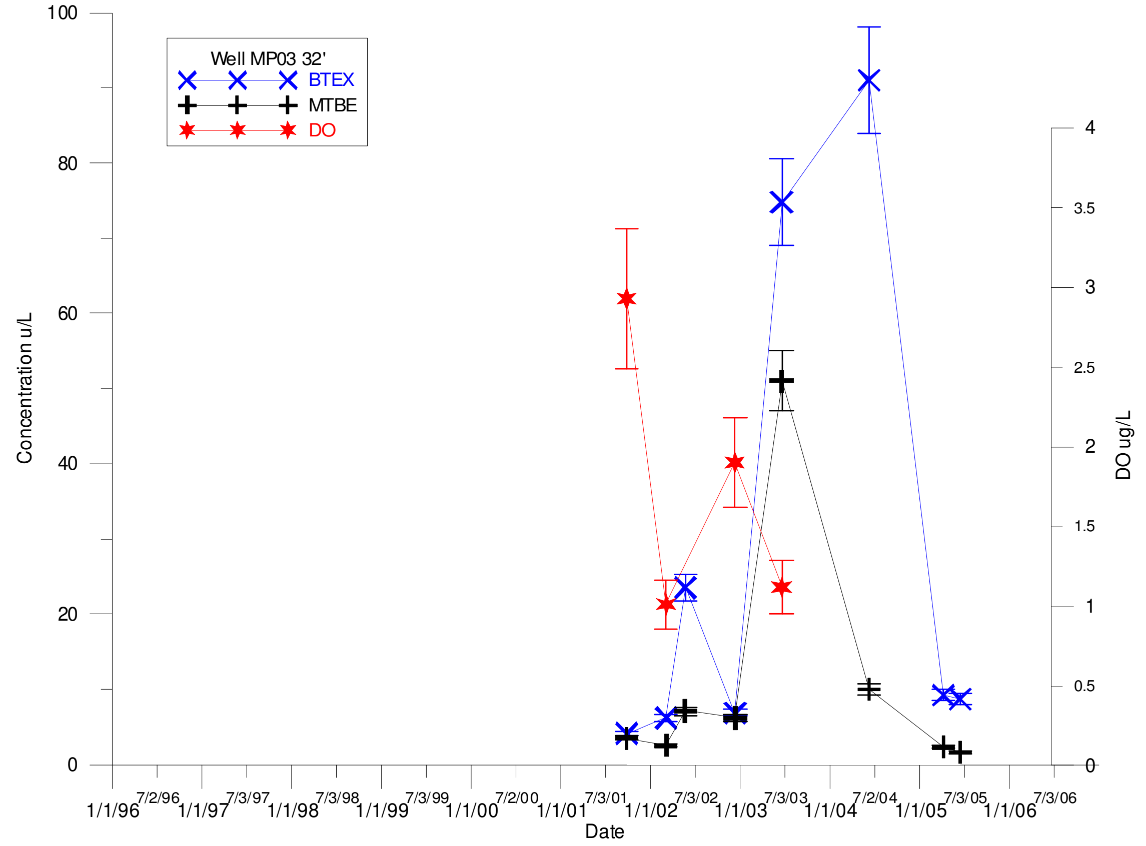

Well MP02 37'
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
100
80
60
40
20
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06

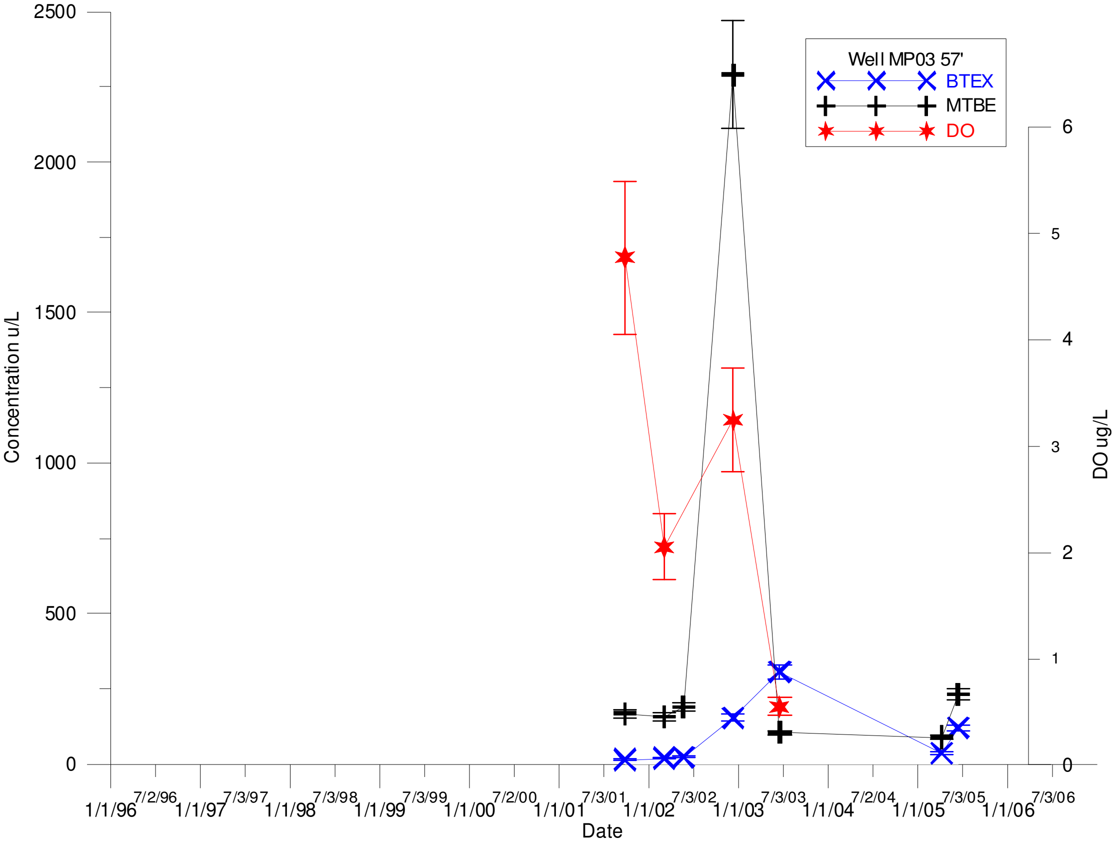

Well MP02 50'
BTEX
MTBE
DO
Concentration u/L
DO ug/L
Date
400
300
200
100
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06


Well MP02 62'
BTEX
MTBE
DO
Concentration u/L
400
300
200
100
0
DO ug/L
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP03 10'
BTEX
MTBE
DO
Concentration u/L
3000
2000
1000
0
DO ug/L
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date


Well MP03 22'
BTEX
MTBE
DO
Concentration u/L
12000
8000
4000
0
DO ug/L
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06


Well MP03 32'
BTEX
MTBE
DO
Concentration u/L
100
80
60
40
20
0
DO ug/L
4
3.5
3
2.5
2
1.5
1
0.5
0
Date
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06



Well MP03 57'
BTEX
MTBE
DO
Concentration u/L
2500
2000
1500
1000
500
0
DO ug/L
6
5
4
3
2
1
0
1/1/96
7/2/96
1/1/97
7/3/97
1/1/98
7/3/98
1/1/99
7/3/99
1/1/00
7/2/00
1/1/01
7/3/01
1/1/02
7/3/02
1/1/03
7/3/03
1/1/04
7/2/04
1/1/05
7/3/05
1/1/06
7/3/06
Date

Appendix D
MIP Analyses

Components of the Membrane interface probe:

The photo ioniztation detector (PID) is a non-destructive detector used for identifying aromatic compounds, and it is accurate to 100's of ppb's (compound specific). This detector excites electrons with an UV lamp and monitors adsorbance to the lamp signal. Certain compounds cannot be recognized by this method, for example, hexane is too difficult to ionize although it is a common gasoline constituent (McInnes, personal communication, 2003).

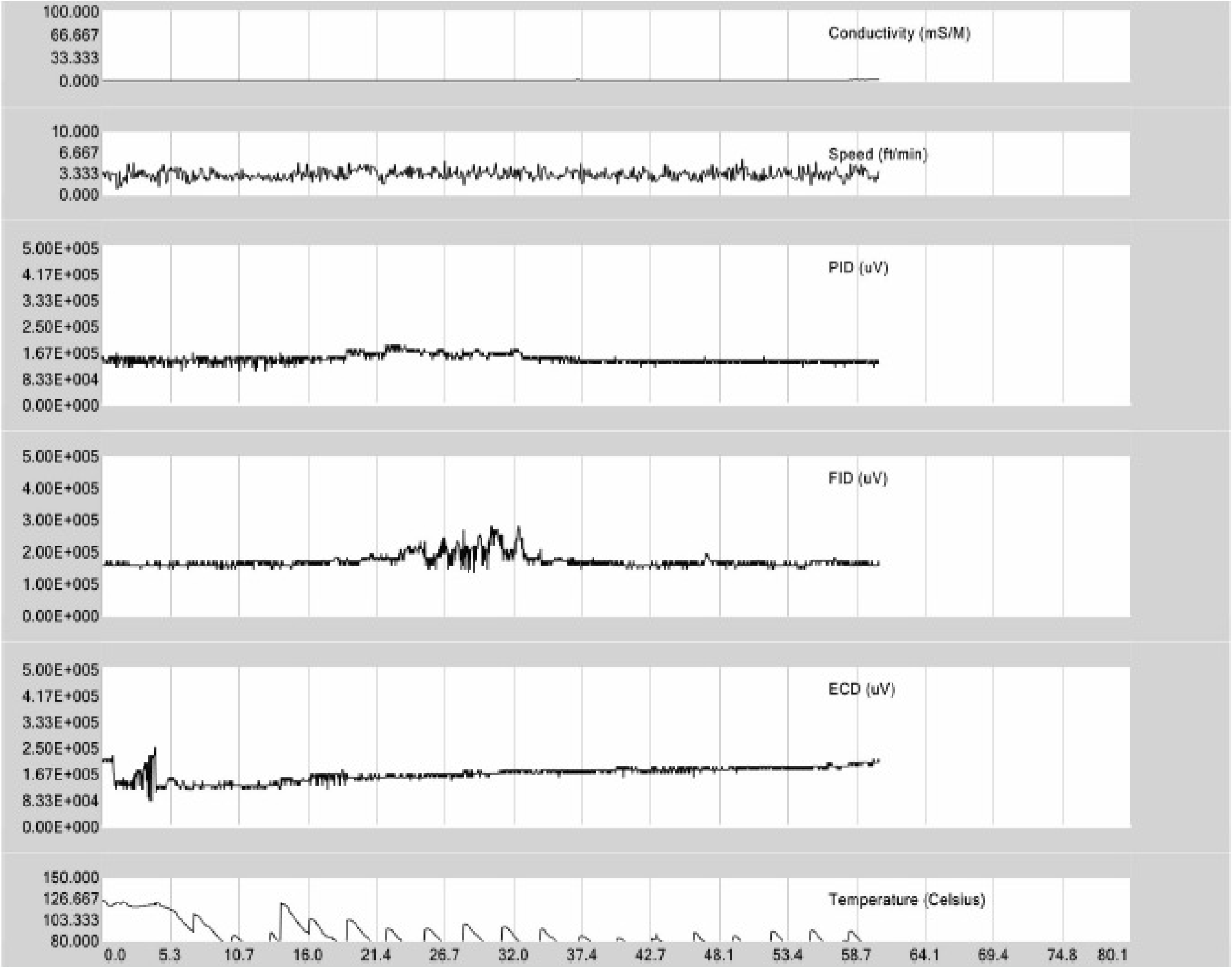
The electron capture detector (ECD) is also a non-destructive detector used for identifying halogenated compounds such as dry cleaning solvents. The Ni^{63} source gives off beta radiation that creates an electron cloud, which is maintained by a pulse of current. Electrons withdrawing from the compounds deplete the cell, forcing the current to pulse faster in order to maintain the number of electrons in the cloud. By monitoring the pulse rate, the energy drawn away from the cell is measured, making this the most sensitive of the three detectors. Because the current can only pulse so fast, the detector can become saturated at increased concentrations, and the detector is also sensitive to noise. This method does not recognize aromatic hydrocarbons although it can detect halogens at the ppb level. This method is most commonly applied to dry cleaning solvents and was not particularly useful at this site (McInnes, personal communication, 2005).

The flame ionization detector (FID) is a destructive detector that detects all of the organic hydrocarbons. A hydrogen flame burns the CHO ion in the hydrocarbons, which gives off an electrical signal. The signal is collected by an antenna contained in the chamber with the flame. This detector can recognize aliphatic hydrocarbons that other detectors fail to recognize, however, because it is a destructive detector must be the last to analyze the sample. In combination, the PID and FID detectors were able to accurately measure the nature and extent of the hydrocarbon plume. This proved very useful in identifying the depth to which the plume extended and in identifying the lateral fringes of the plume (McInnes, personal communication, 2005).

The depth of the peizocone is shown on the X axis.

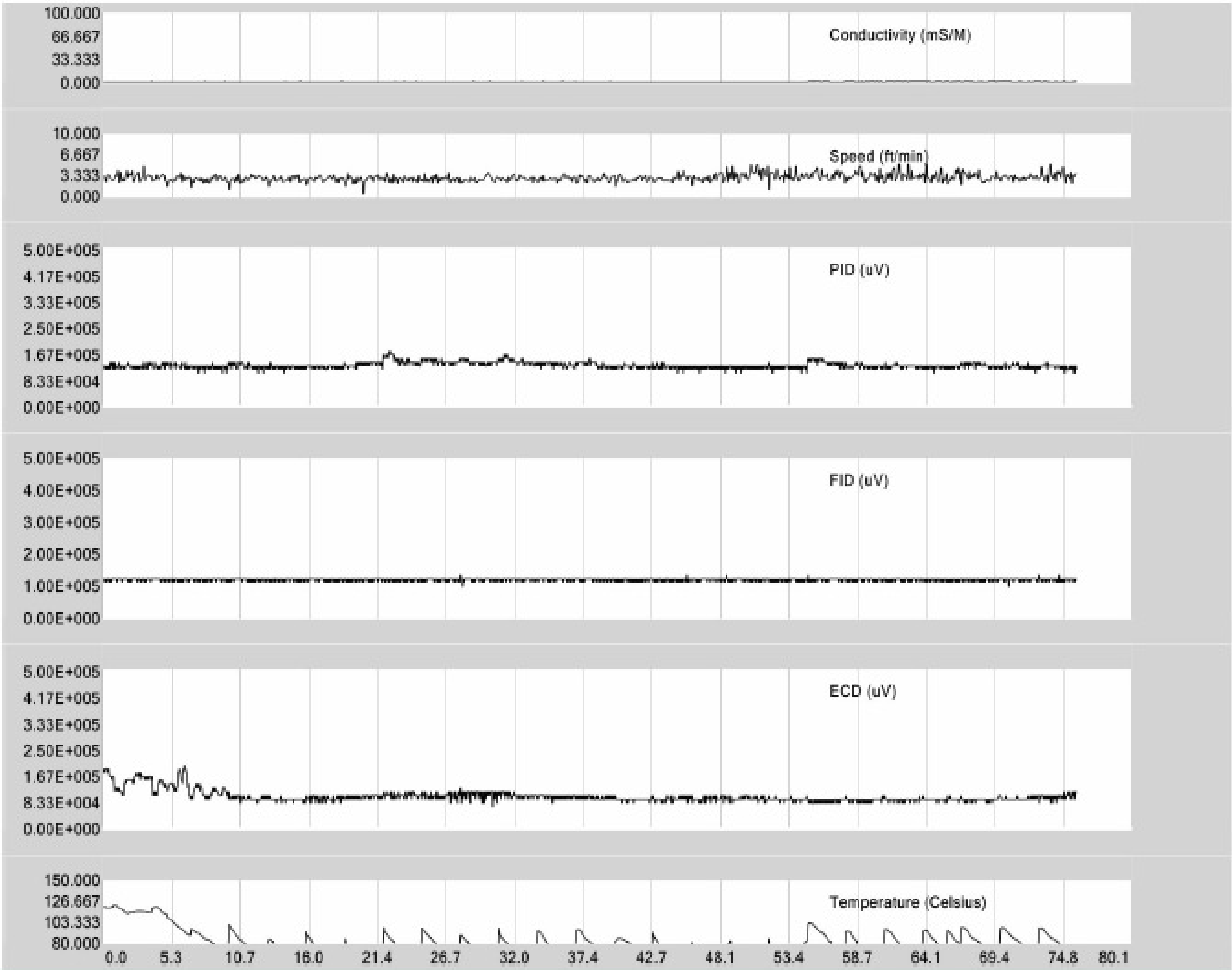
Location of the sites is found in Figure 4.

MIP-01



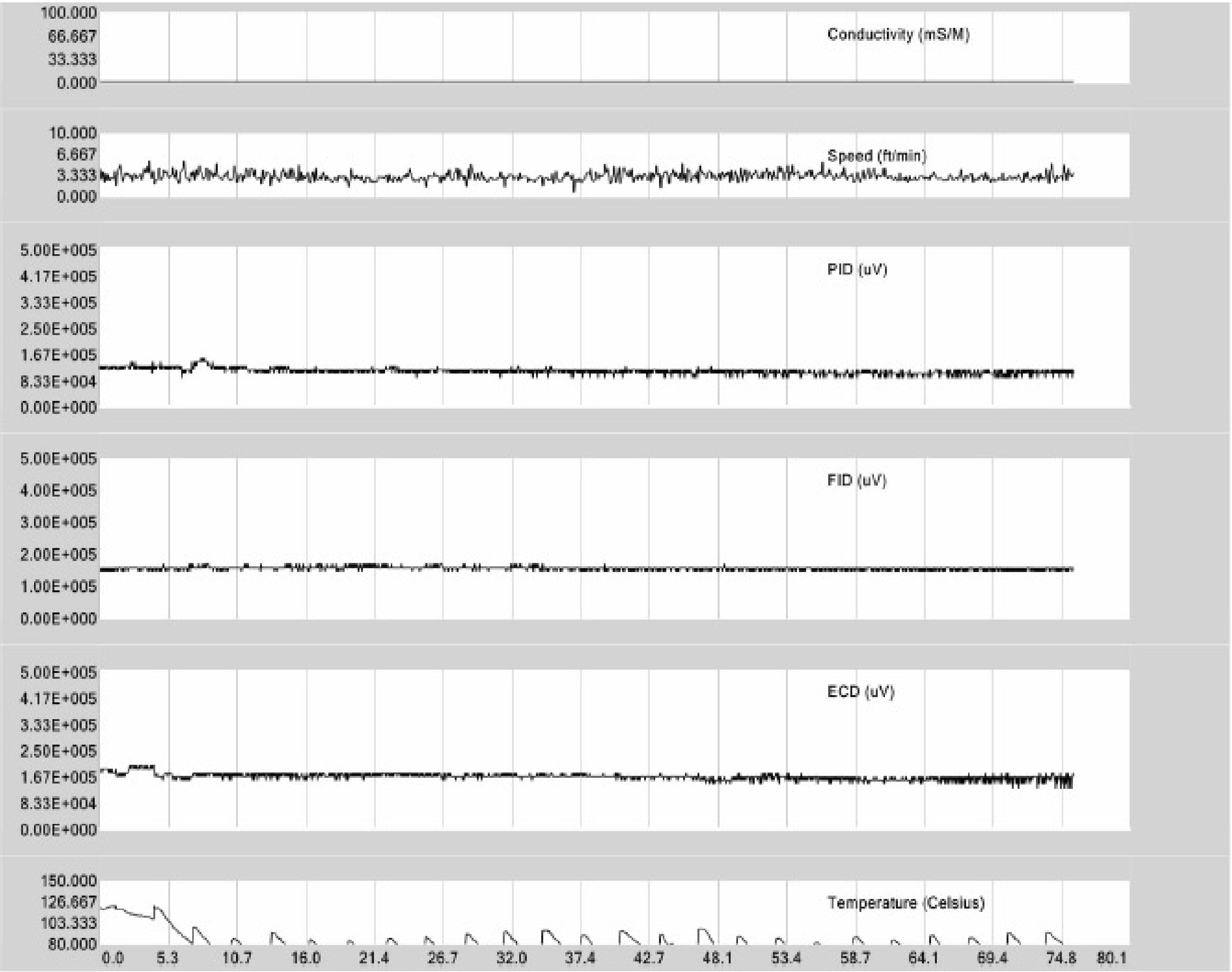
American Petroleum Institute
MTBE Study
01/31/05

MIP-02



American Petroleum Institute
MTBE Study
01/31/05

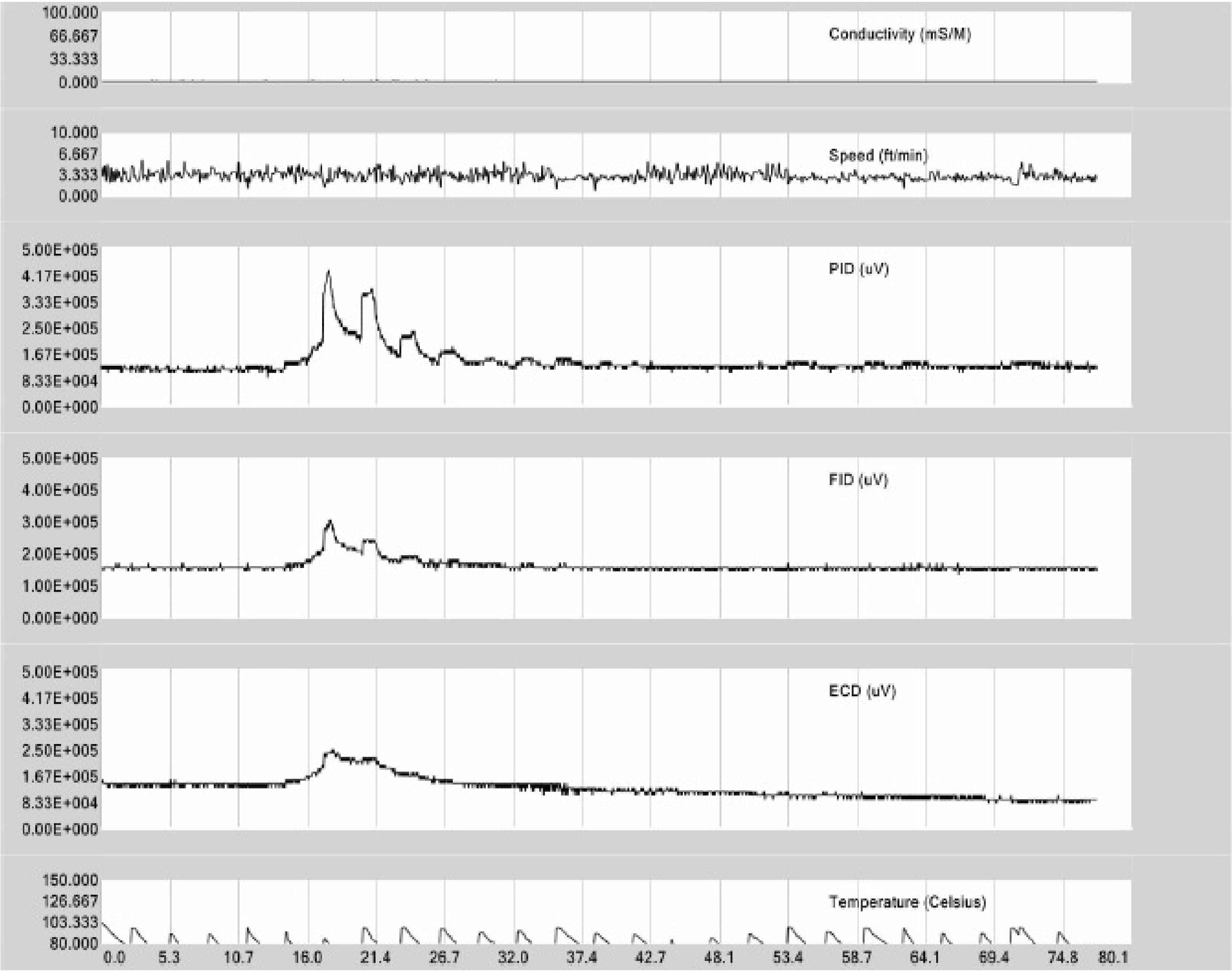
MIP-03



American Petroleum Institute
MTBE Study
01/31/05

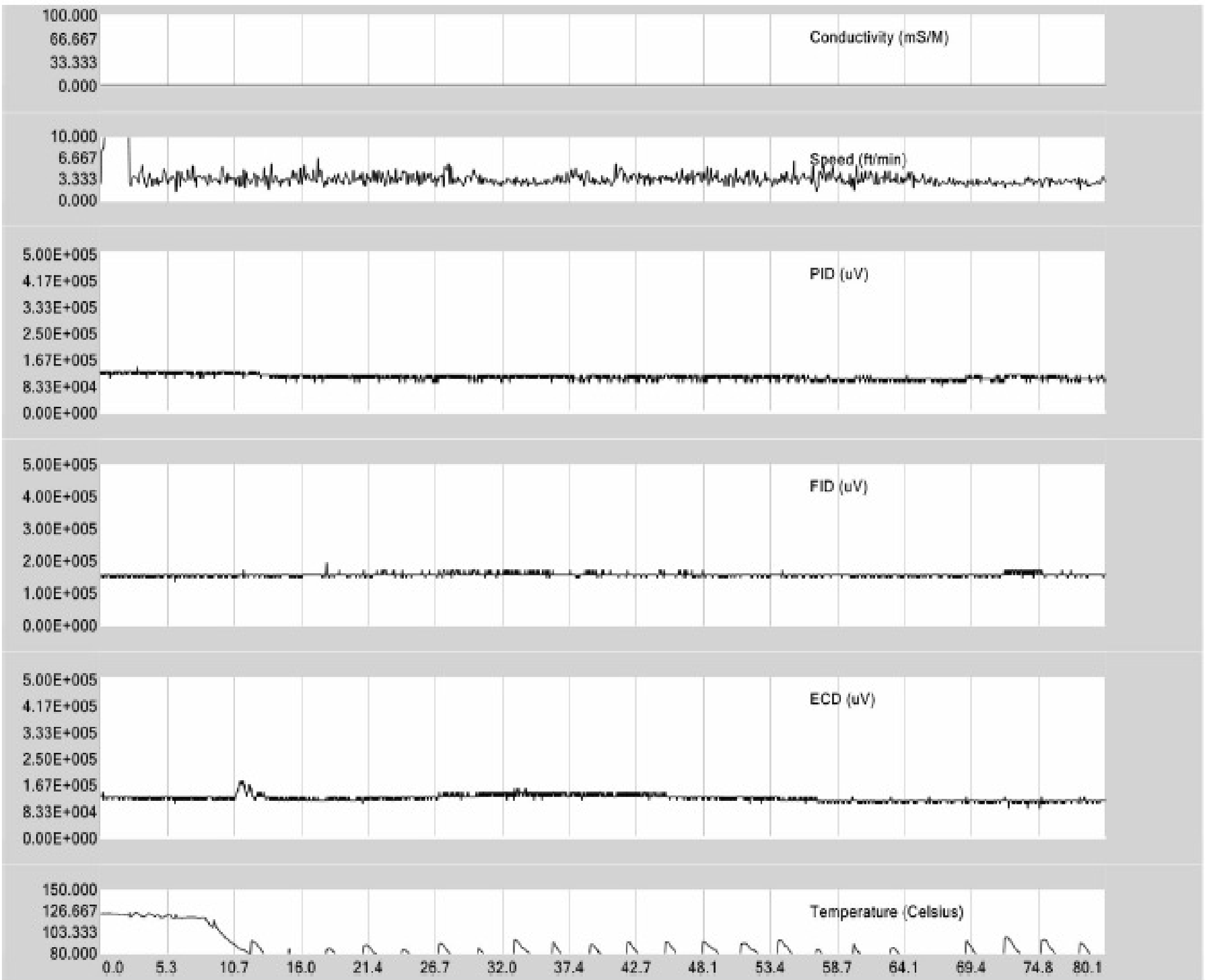
COLUMBIA TECHNOLOGIES

MIP-04



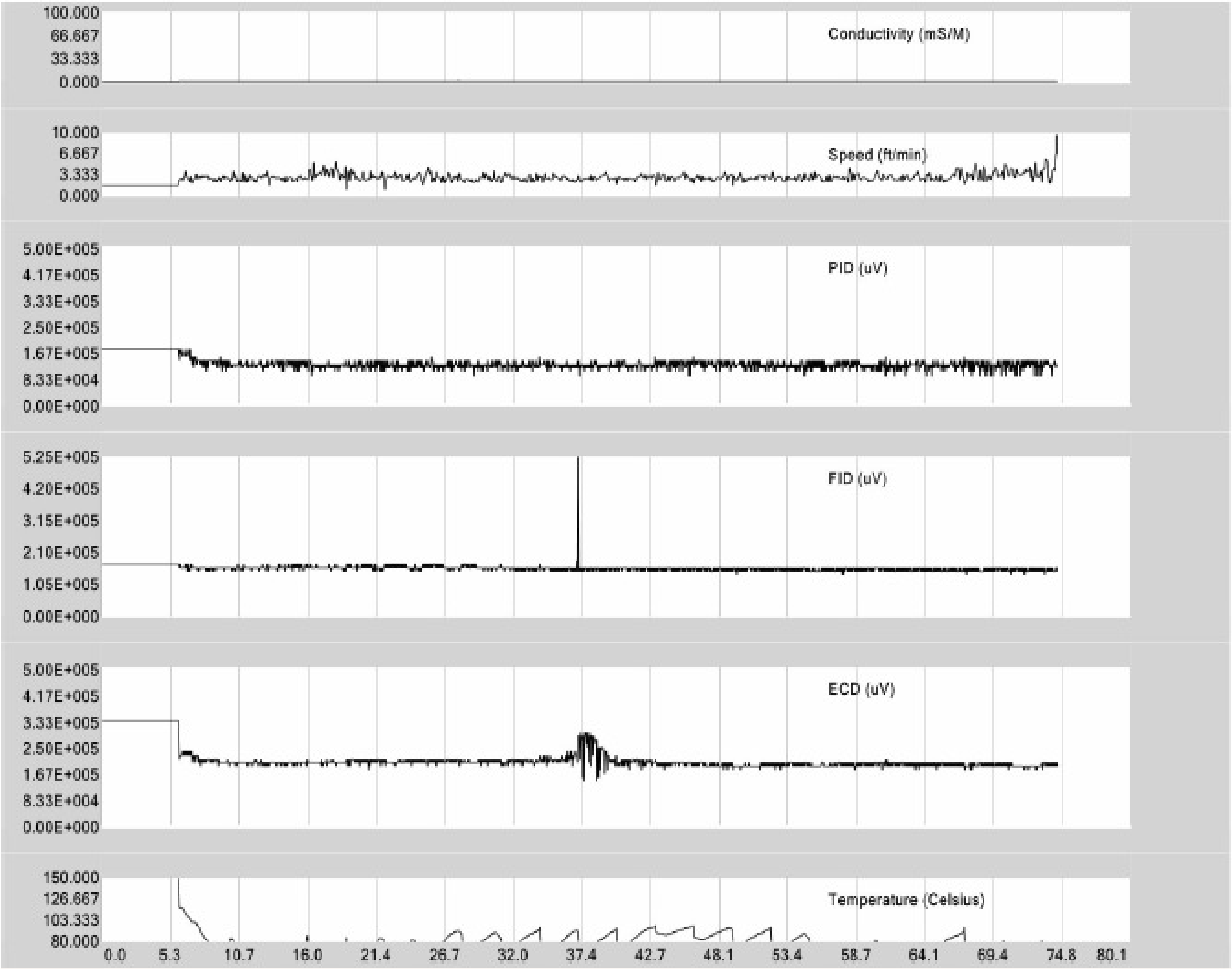
American Petroleum Institute
MTBE Study
01/31/05

MIP-05



American Petroleum Institute
MTBE Study
01/31/05

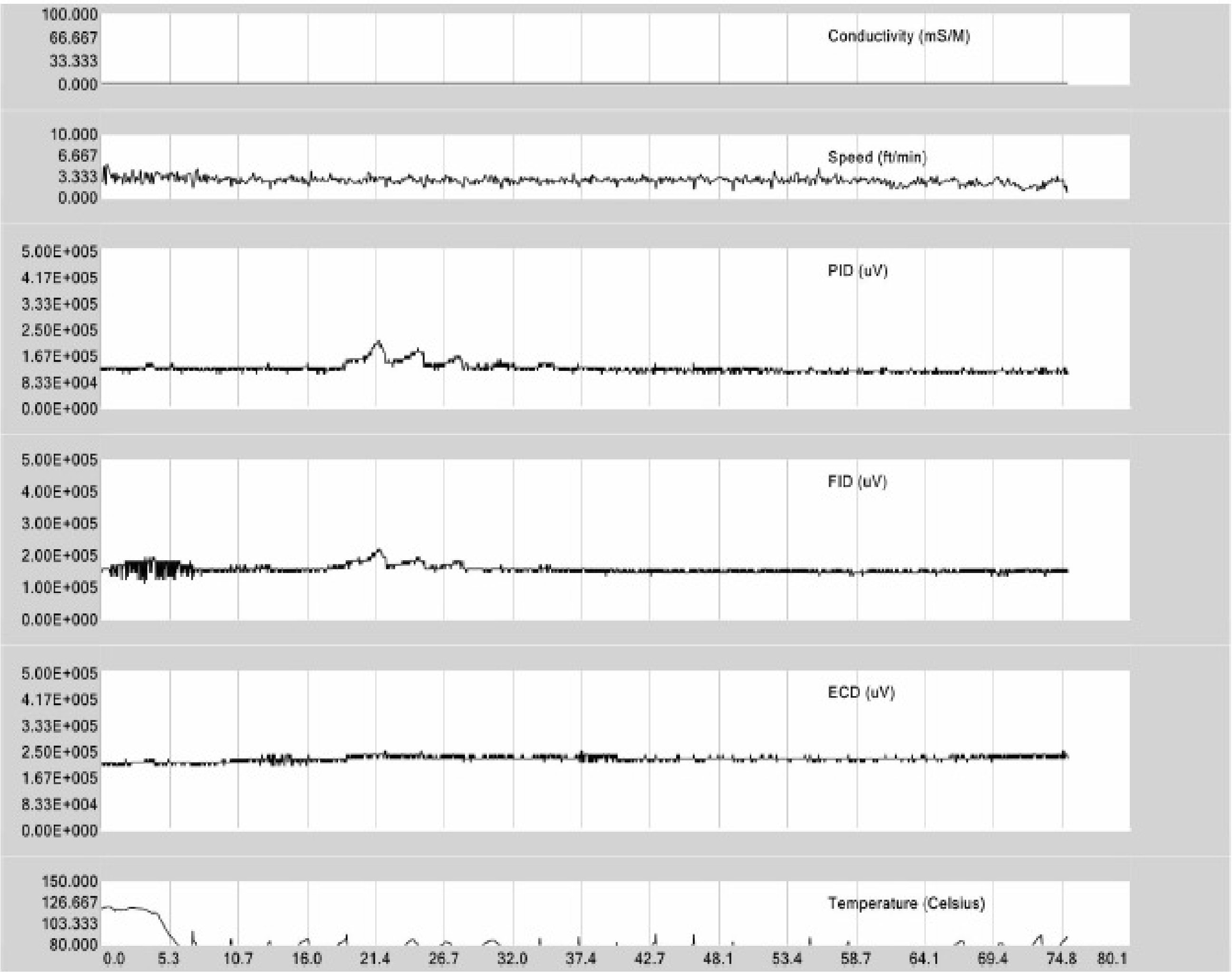
MIP-06



American Petroleum Institute
MTBE Study
02/01/05

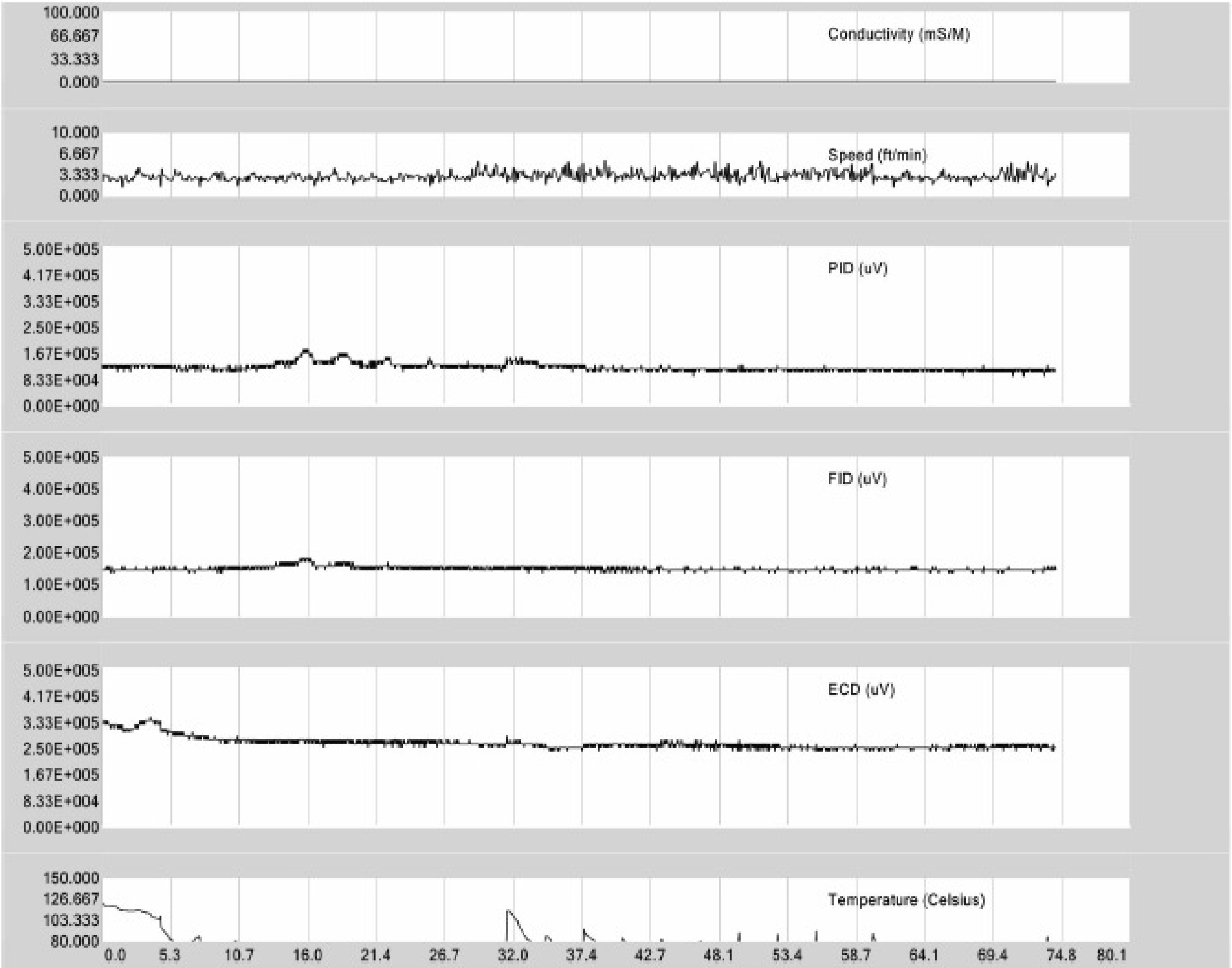
COLUMBIA
TECHNOLOGIES

MIP-07



American Petroleum Institute
MTBE Study
02/01/05

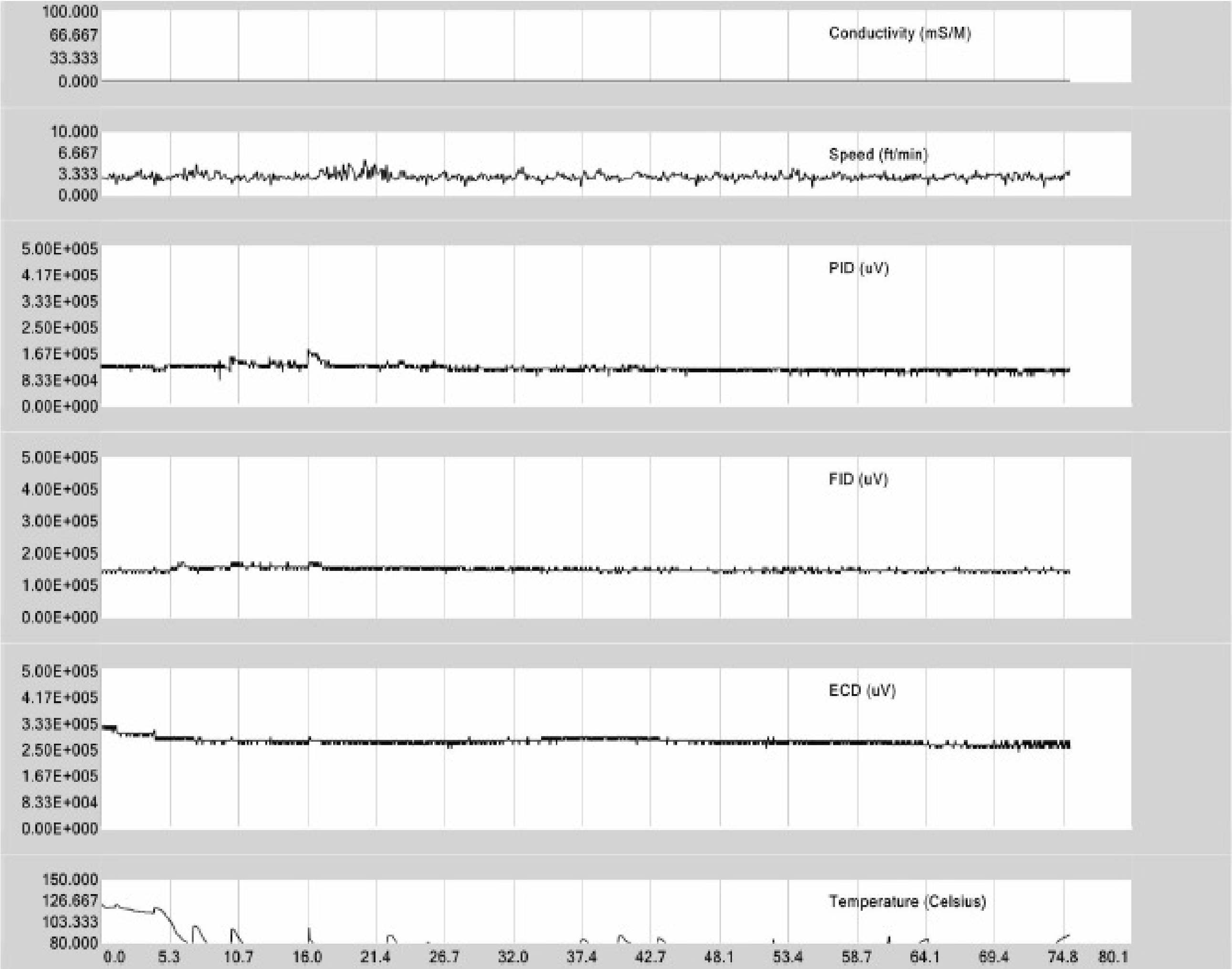
MIP-08



American Petroleum Institute
MTBE Study
02/01/05

COLUMBIA TECHNOLOGIES

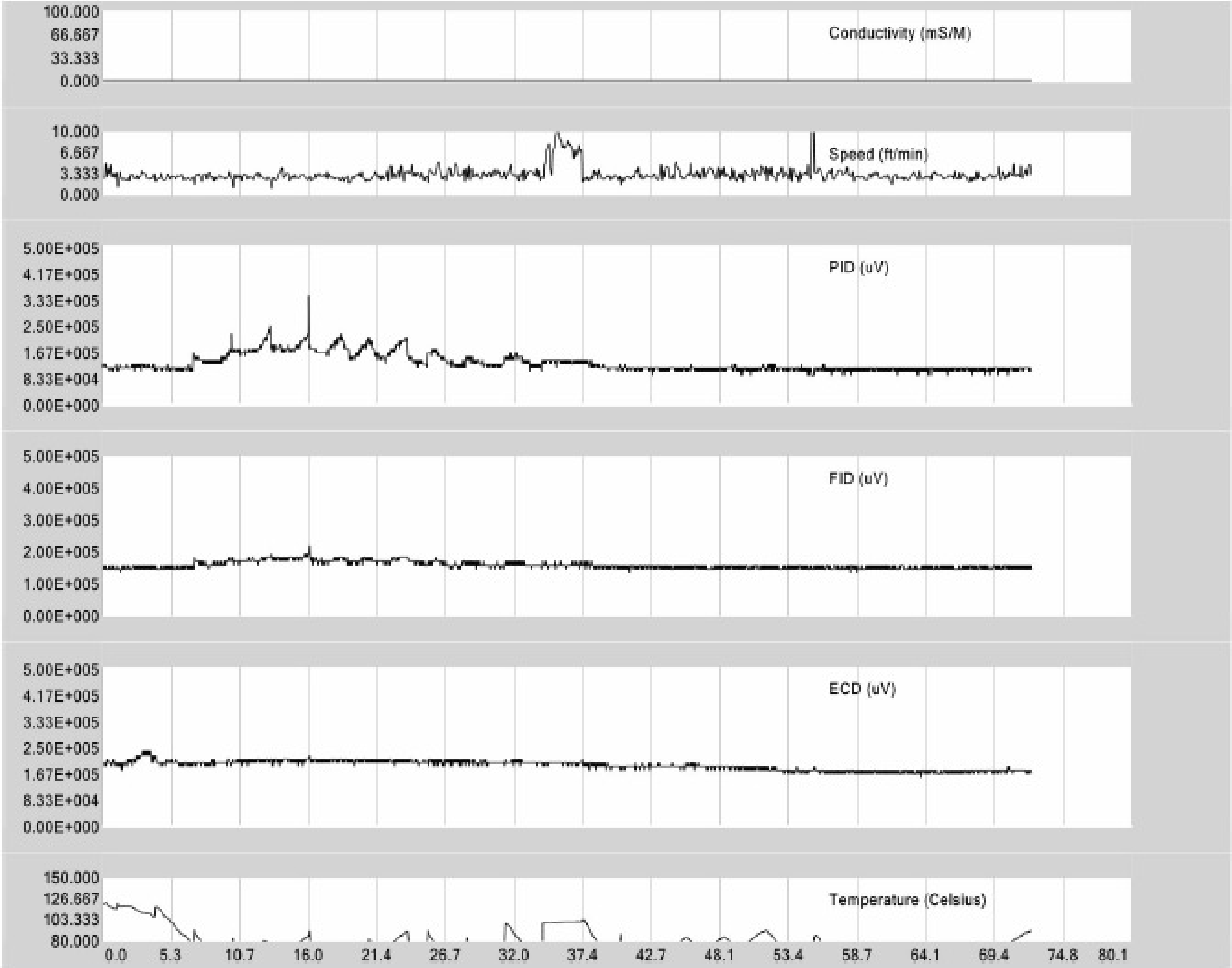
MIP-09



American Petroleum Institute
MTBE Study
02/01/05

COLUMBIA TECHNOLOGIES

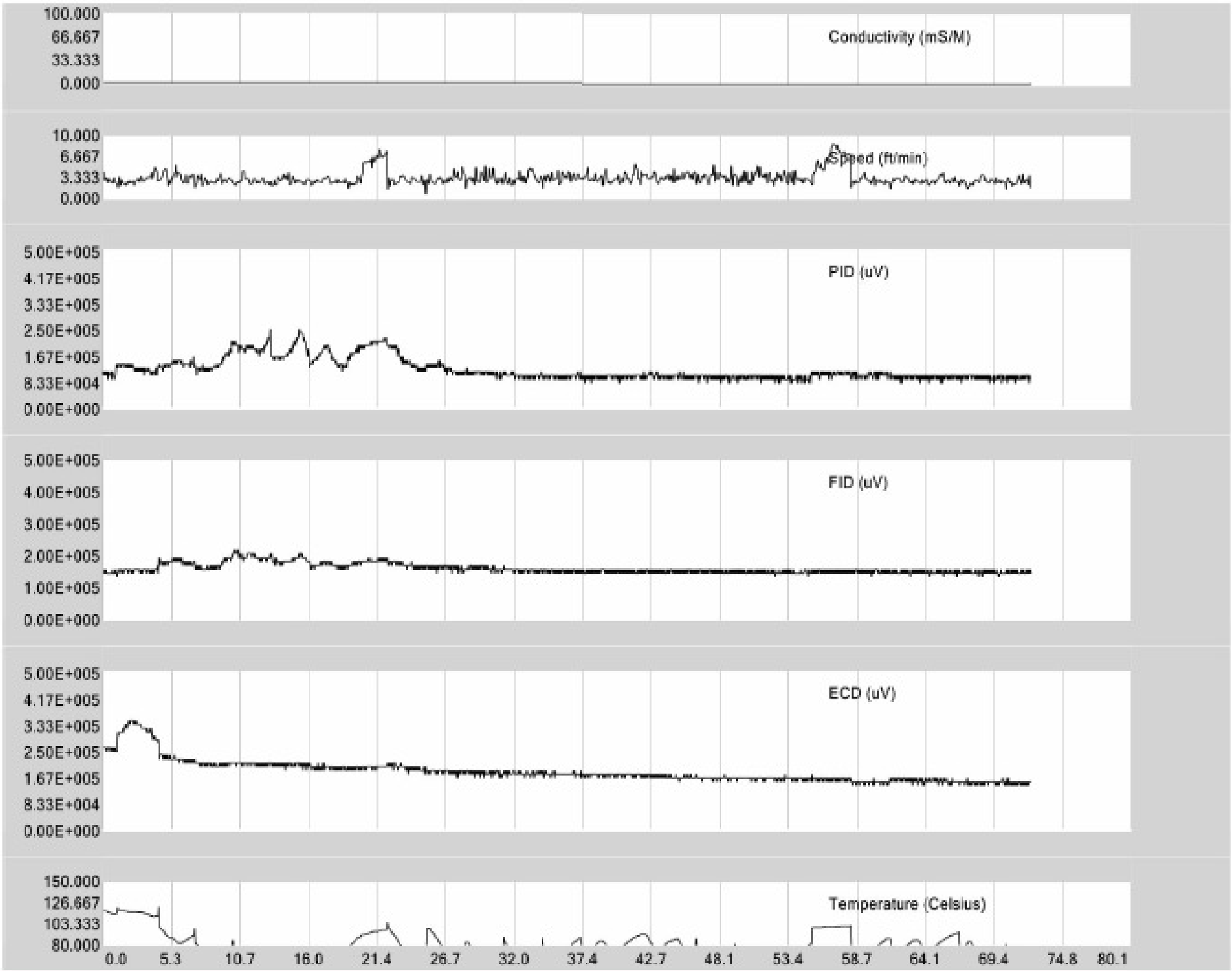
MIP-10



American Petroleum Institute
MTBE Study
02/01/05

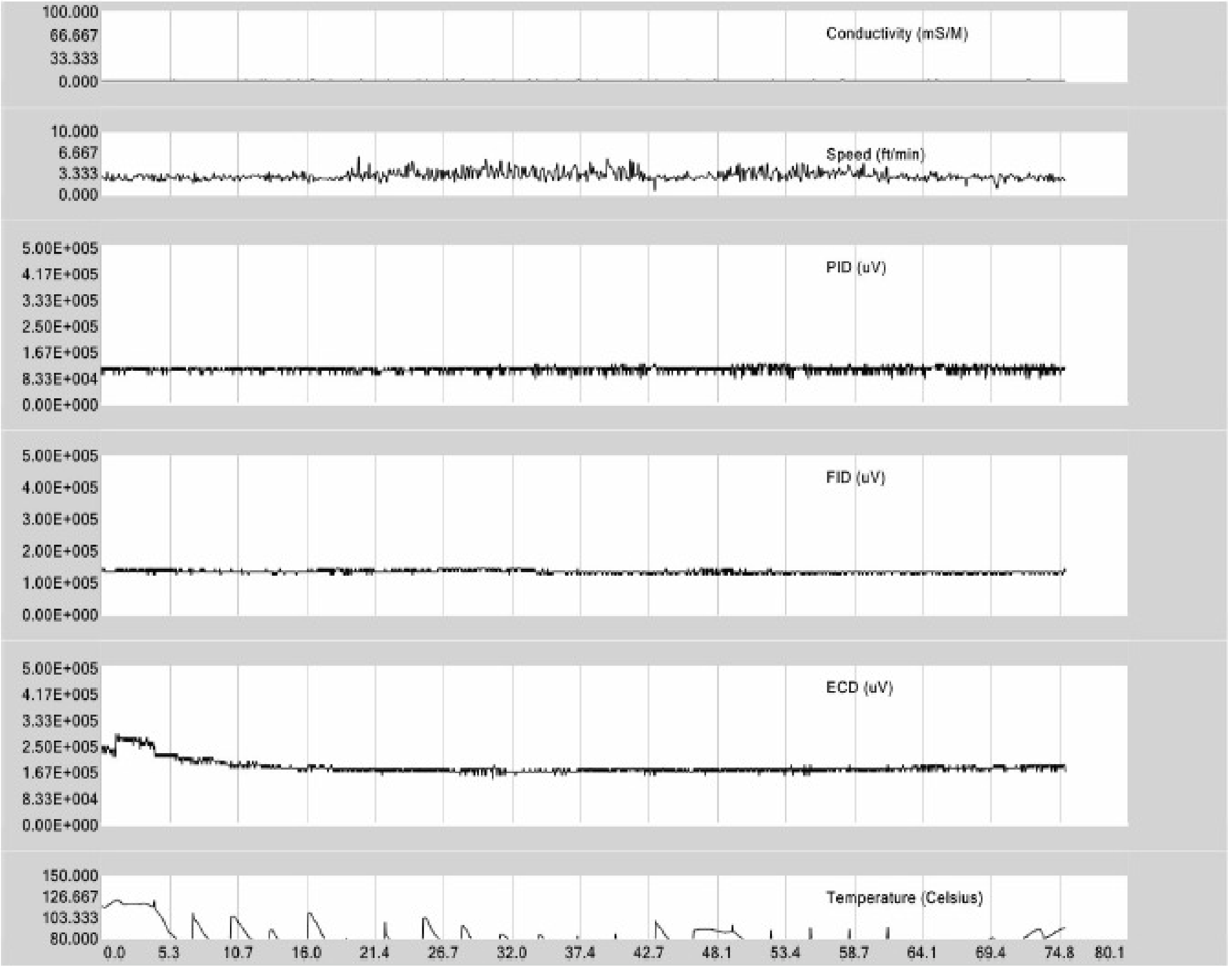
COLUMBIA
TECHNOLOGIES

MIP-11



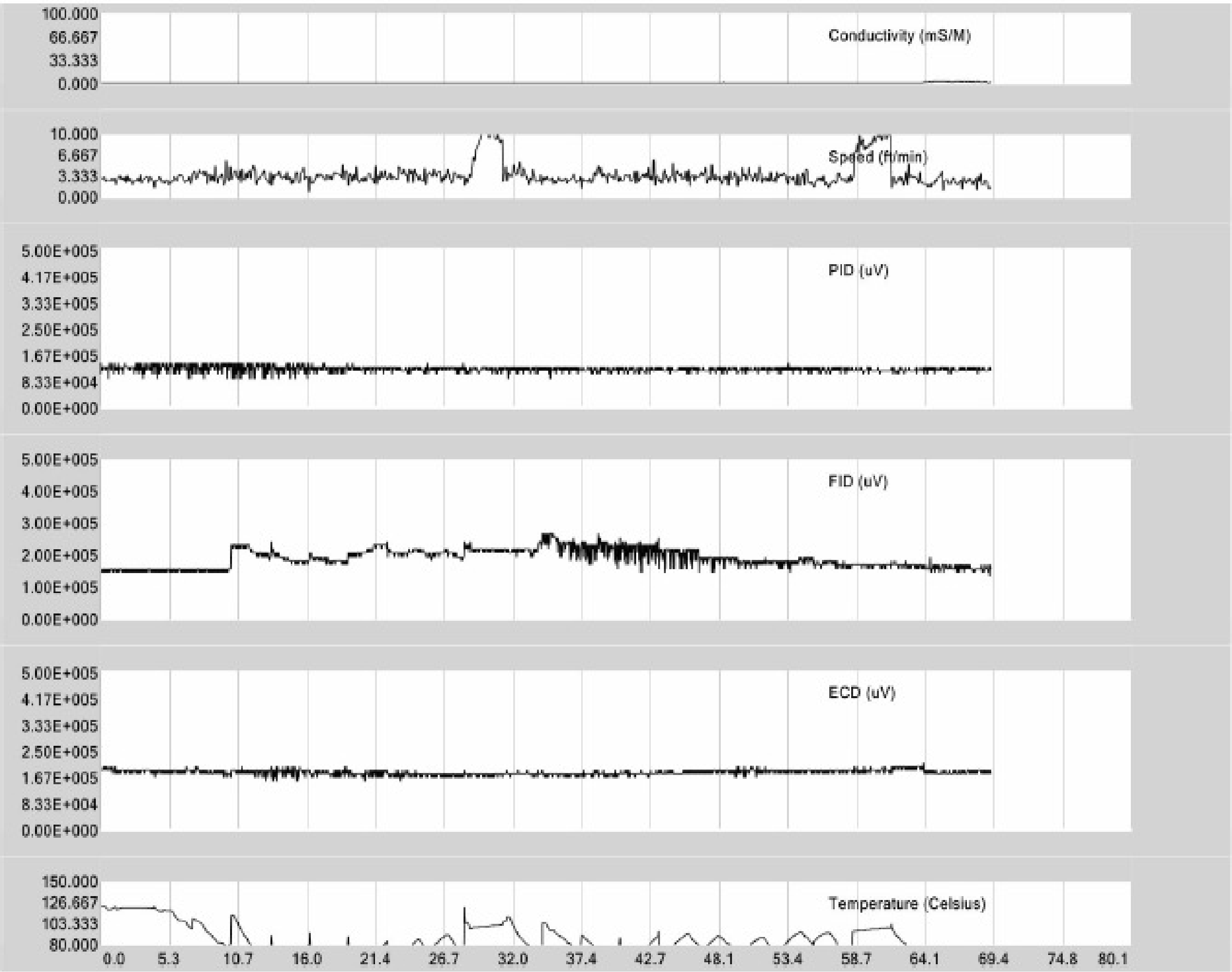
American Petroleum Institute
MTBE Study
02/01/05

MIP-12



American Petroleum Institute
MTBE Study
02/02/05

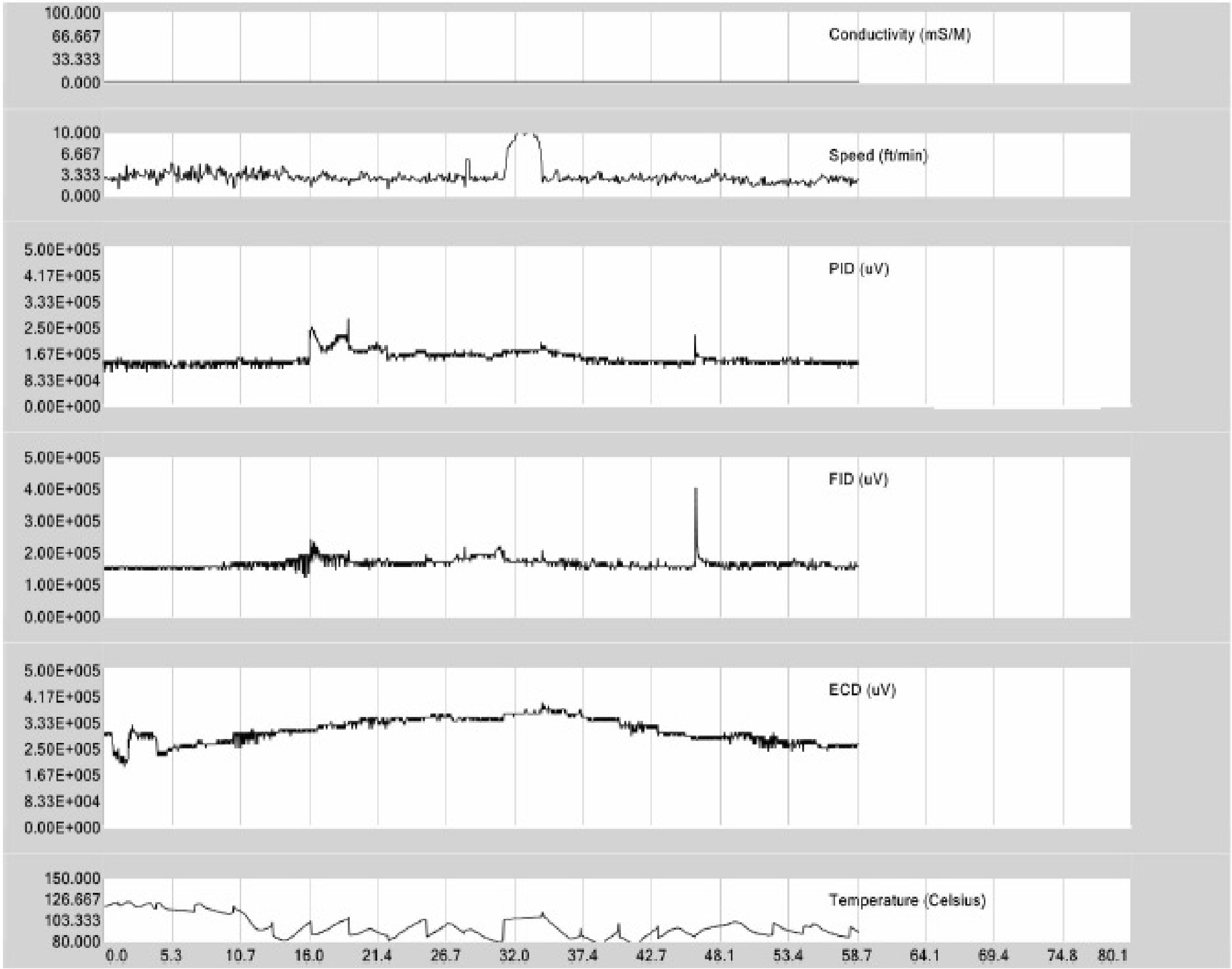
MIP-13



American Petroleum Institute
MTBE Study
02/02/05

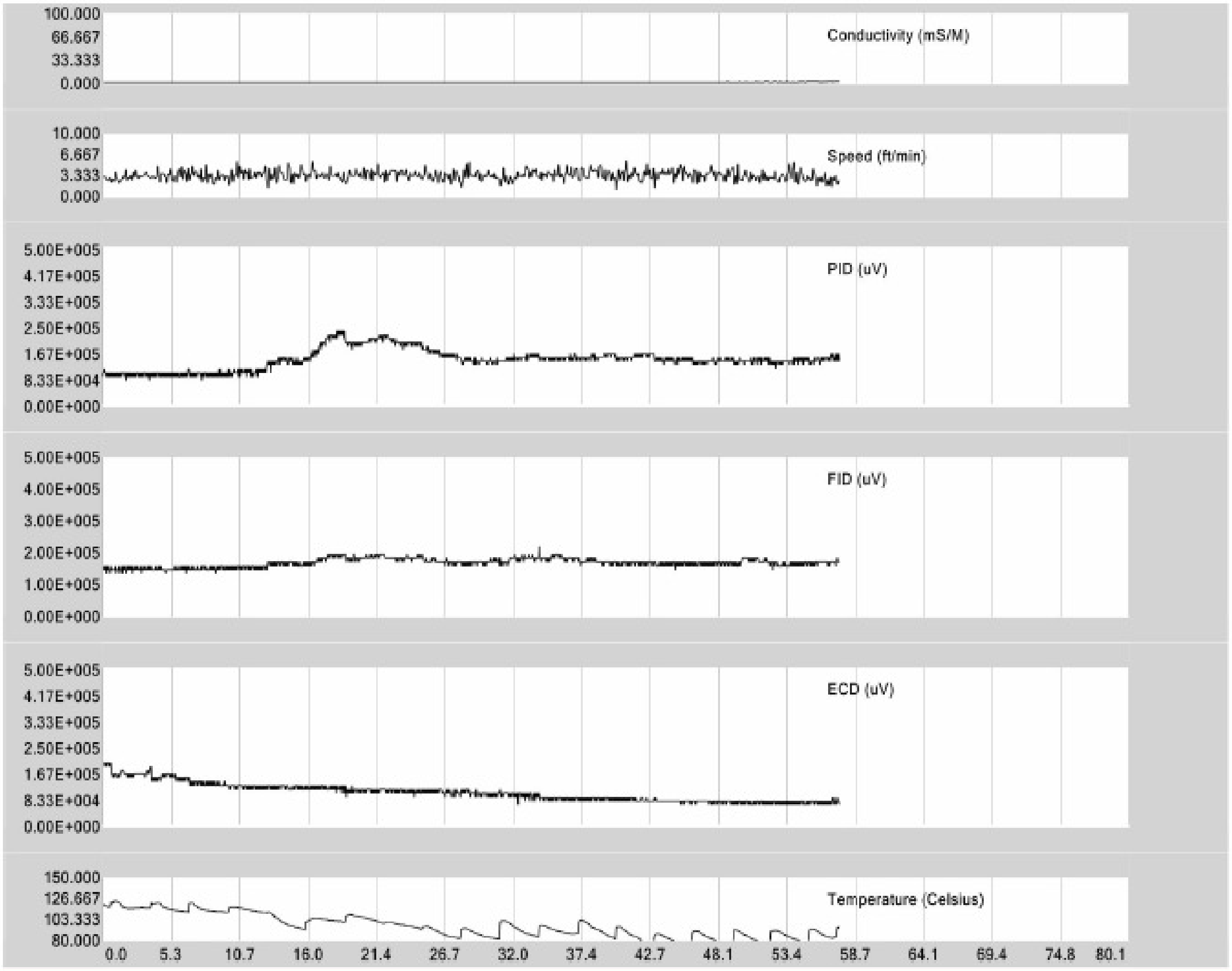
COLUMBIA TECHNOLOGIES

MIP-14



American Petroleum Institute
MTBE Study
02/02/05

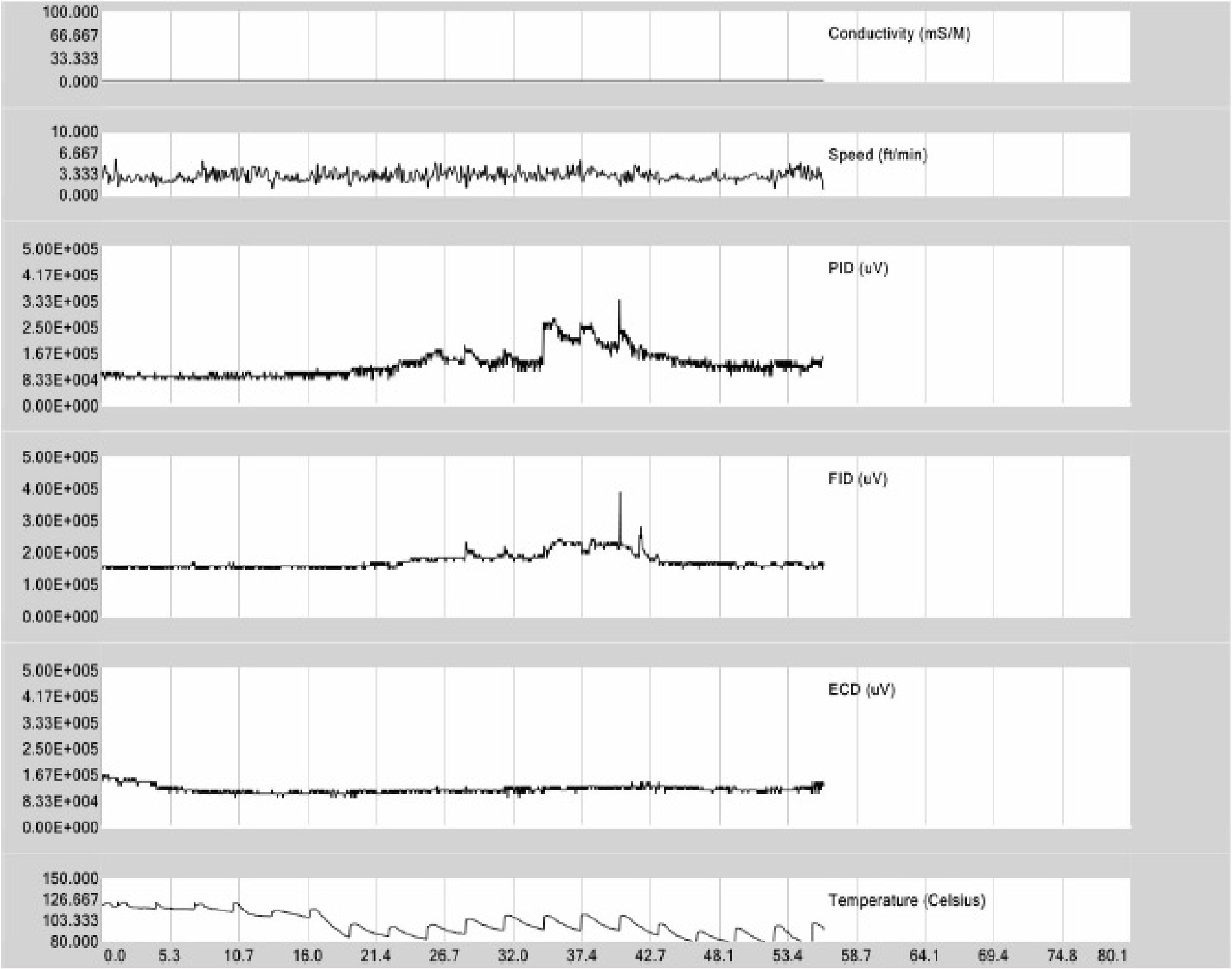
MIP-15



American Petroleum Institute
MTBE Study
02/02/05

COLUMBIA TECHNOLOGIES

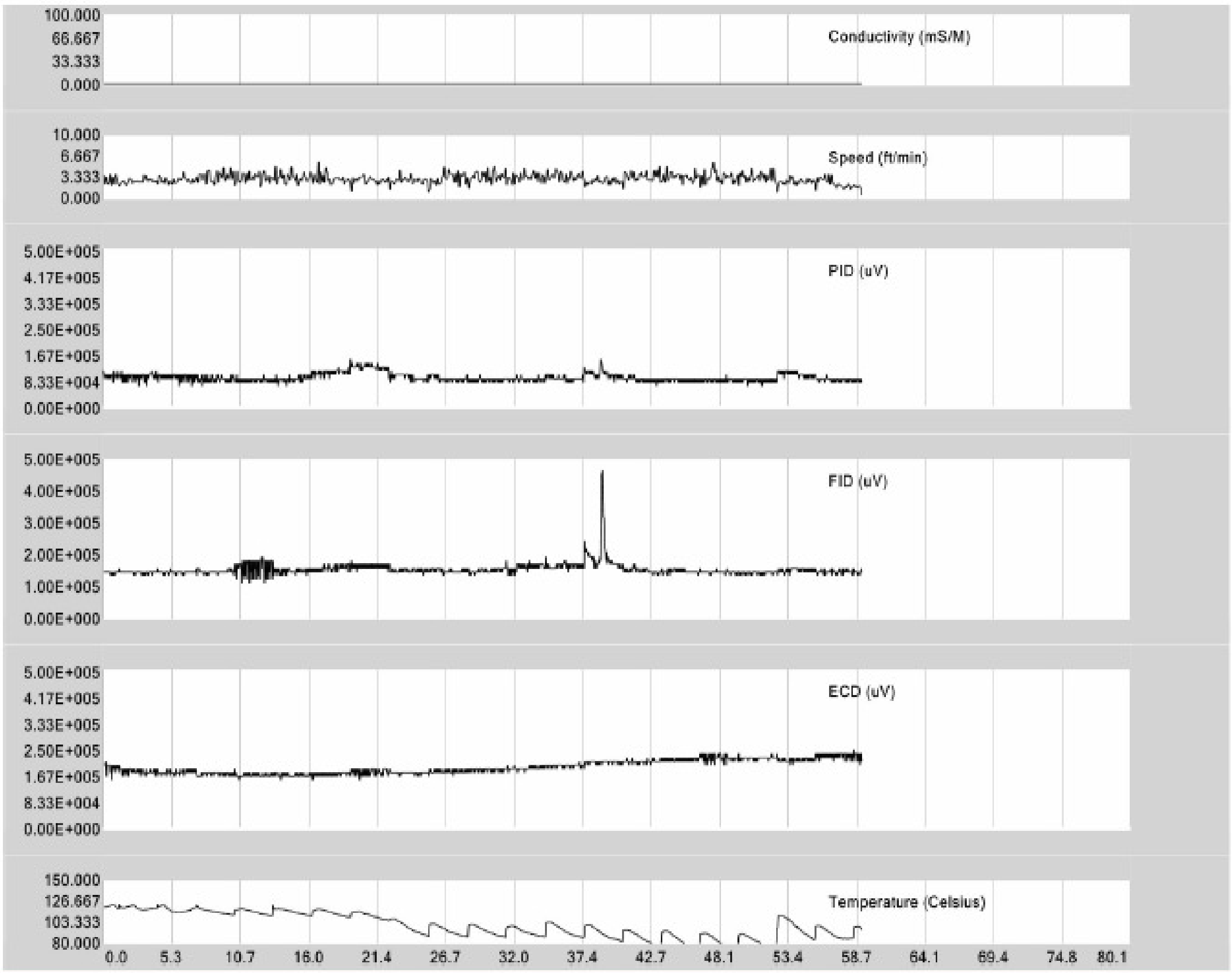
MIP-16



American Petroleum Institute
MTBE Study
02/03/05

COLUMBIA
TECHNOLOGIES

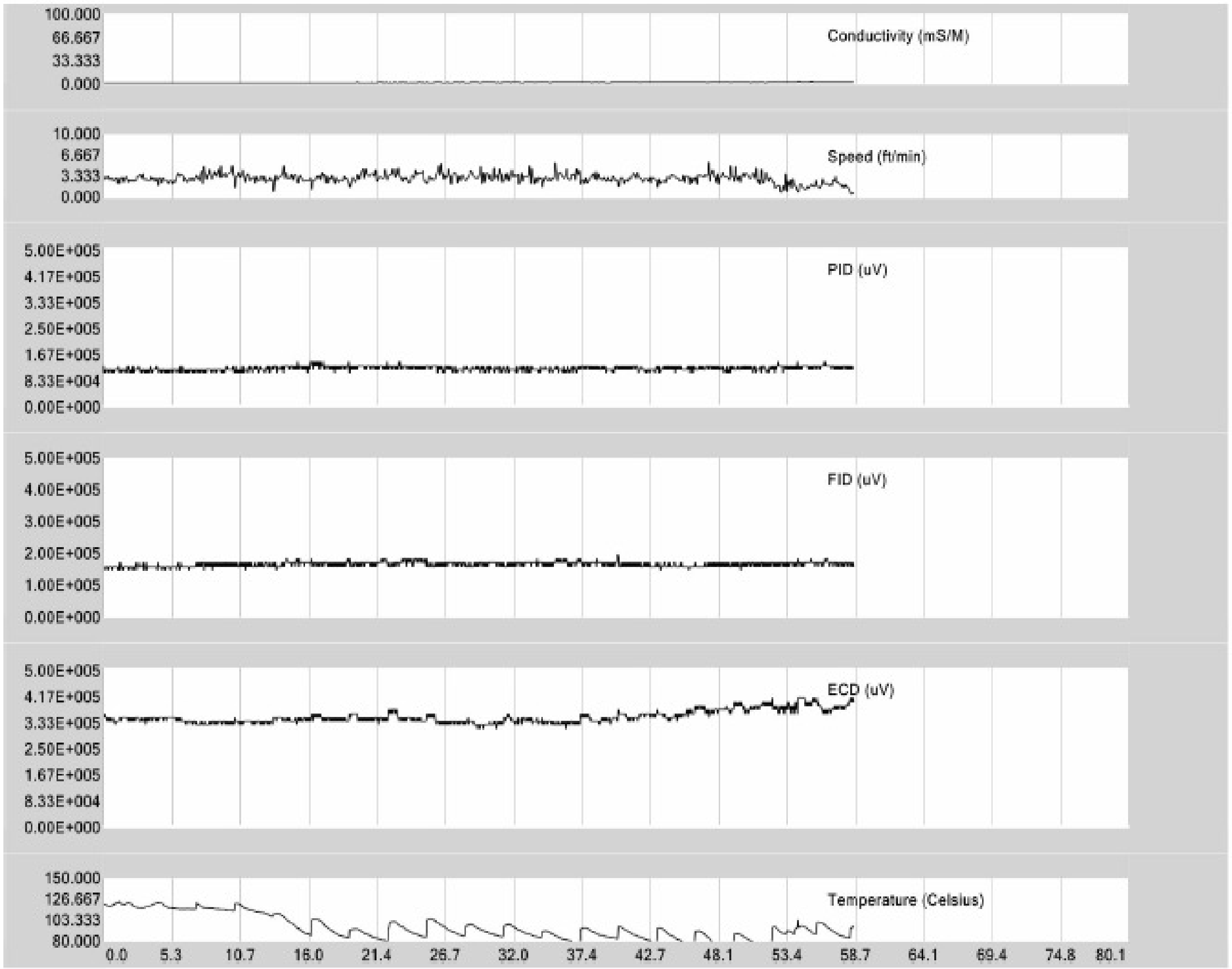
MIP-17



American Petroleum Institute
MTBE Study
02/03/05

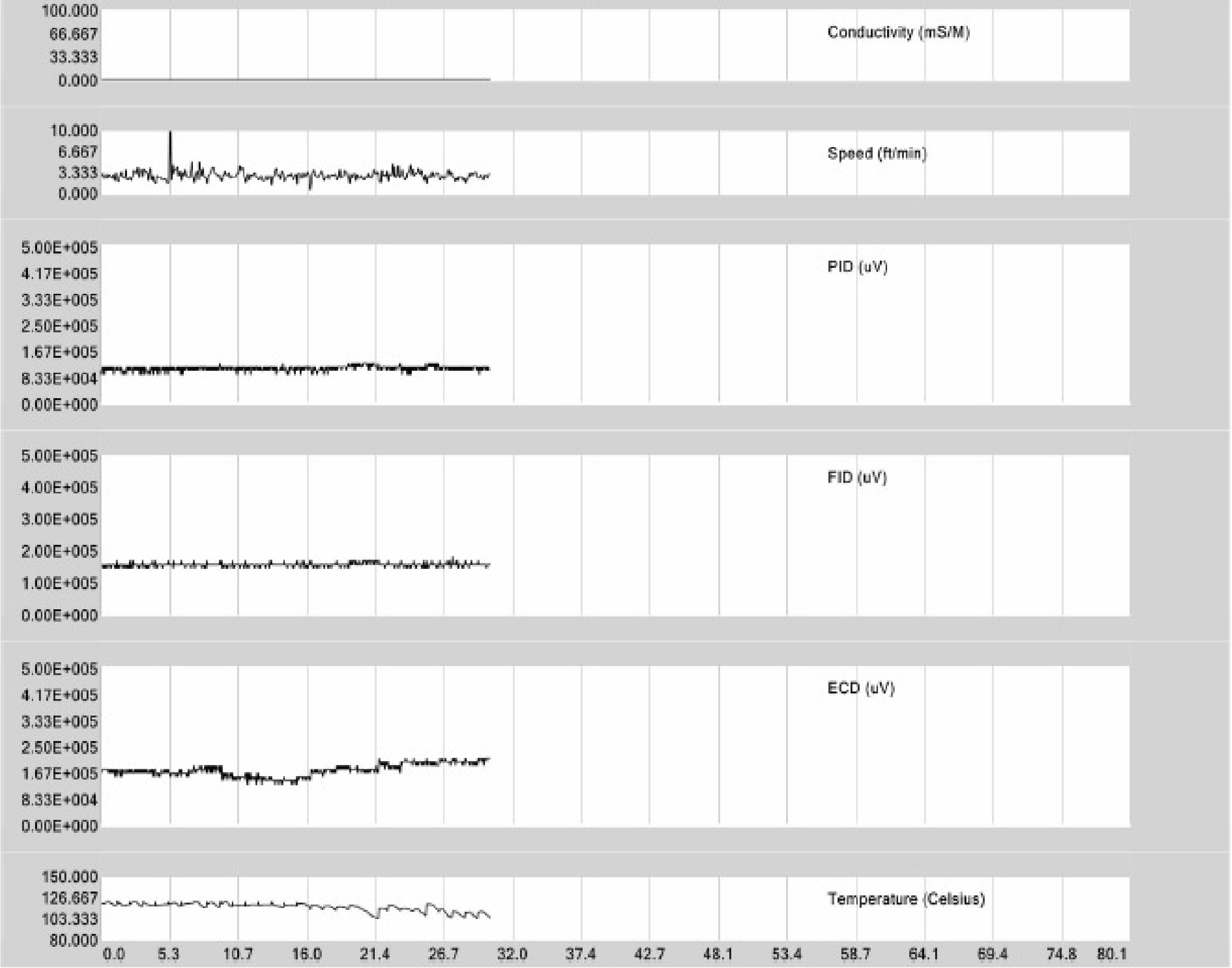
COLUMBIA TECHNOLOGIES

MIP-18



American Petroleum Institute
MTBE Study
02/03/05

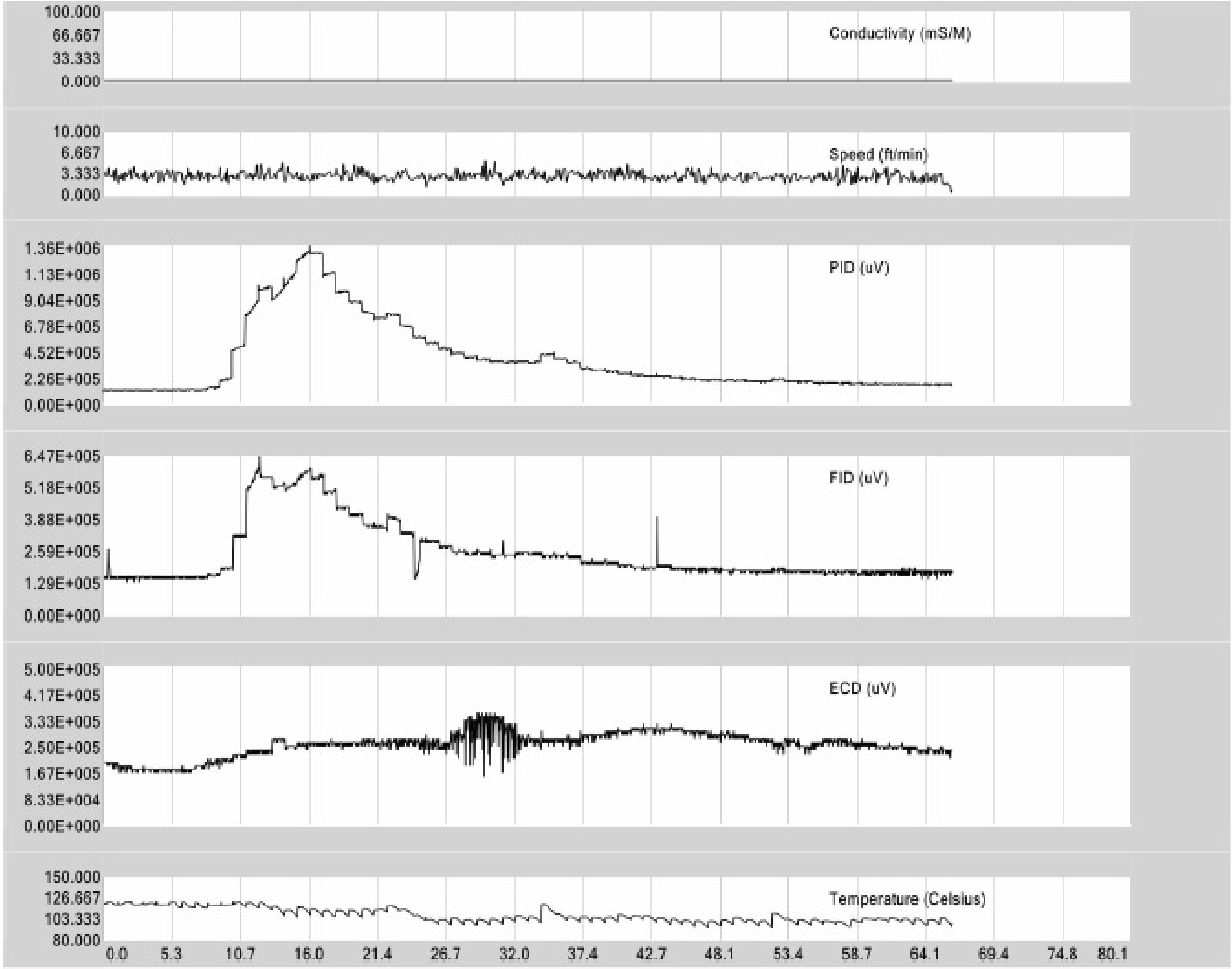
MIP-19



American Petroleum Institute
MTBE Study
02/03/05

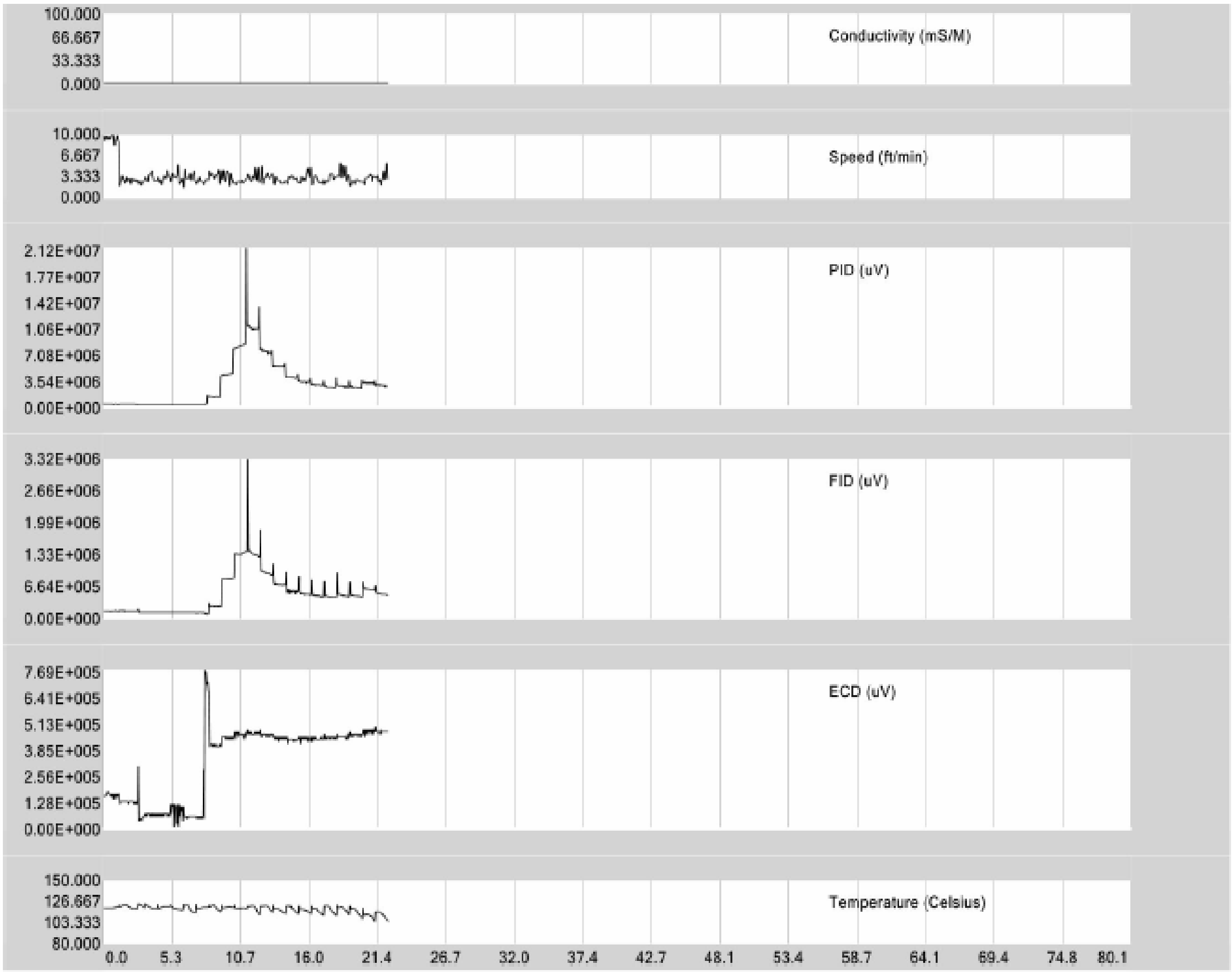
COLUMBIA
TECHNOLOGIES

MIP-20



American Petroleum Institute
MTBE Study
02/03/05

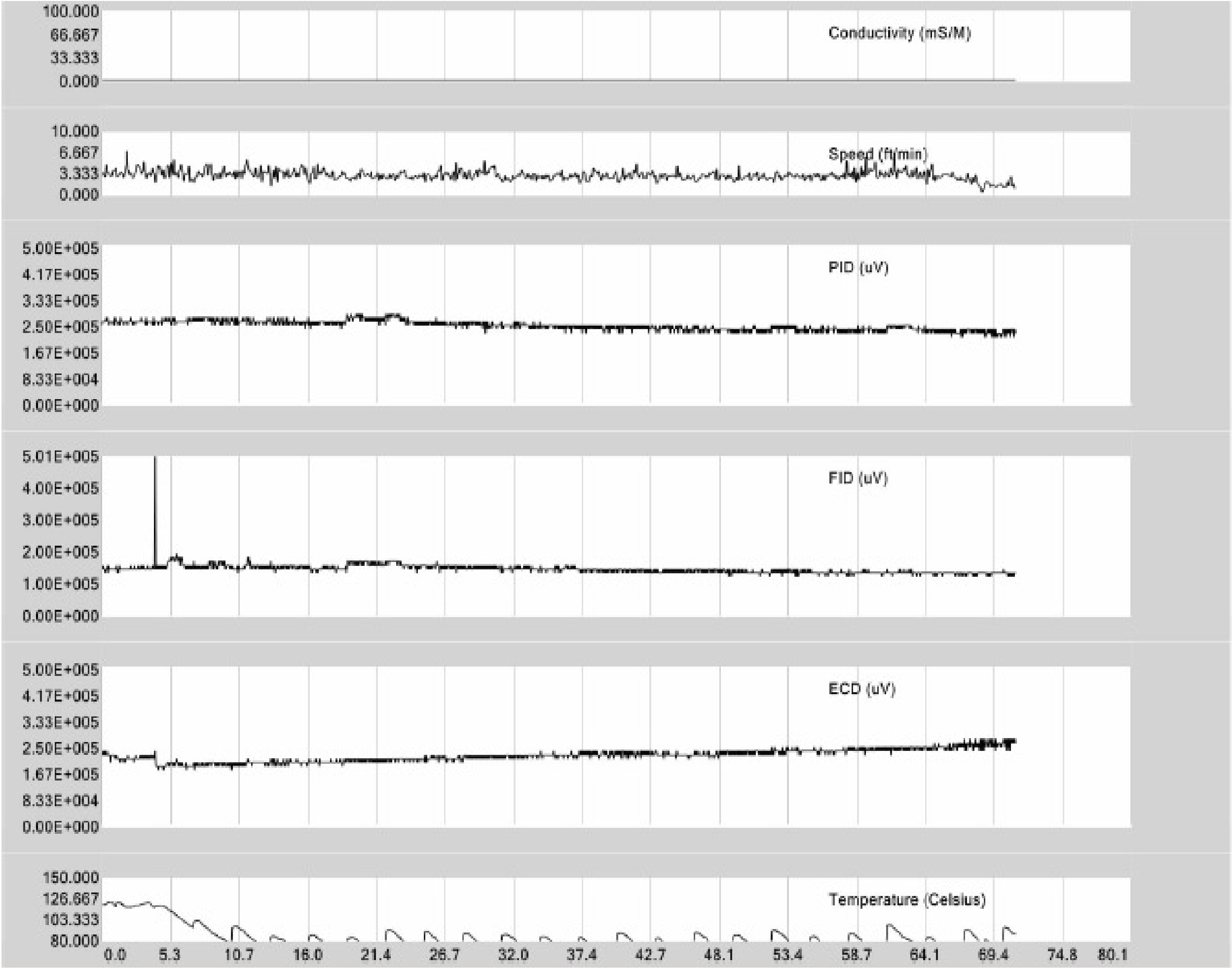
MIP-22



American Petroleum Institute
MTBE Study
02/04/05

COLUMBIA TECHNOLOGIES

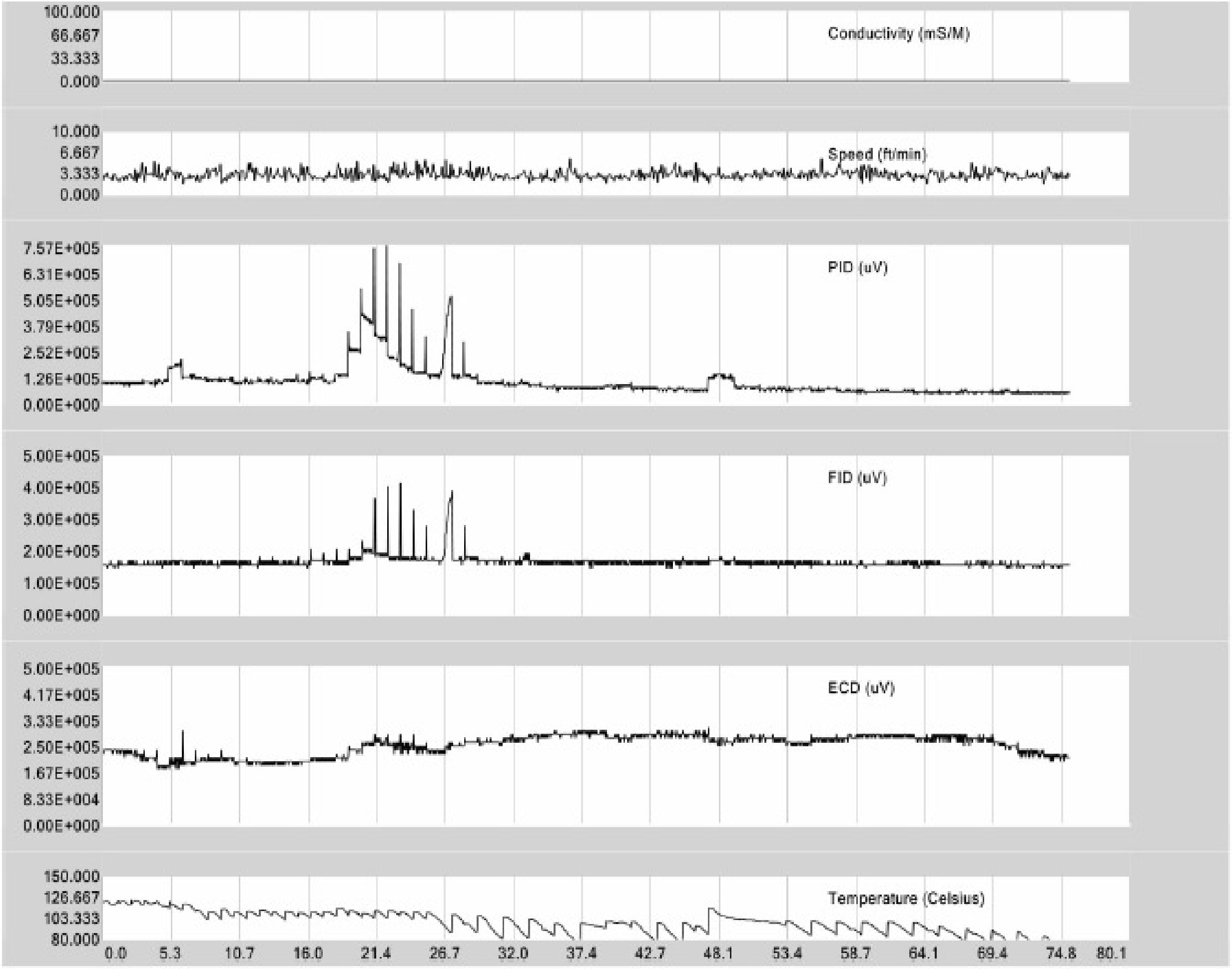
MIP-24



American Petroleum Institute
MTBE Study
02/04/05

COLUMBIA TECHNOLOGIES

MIP-25



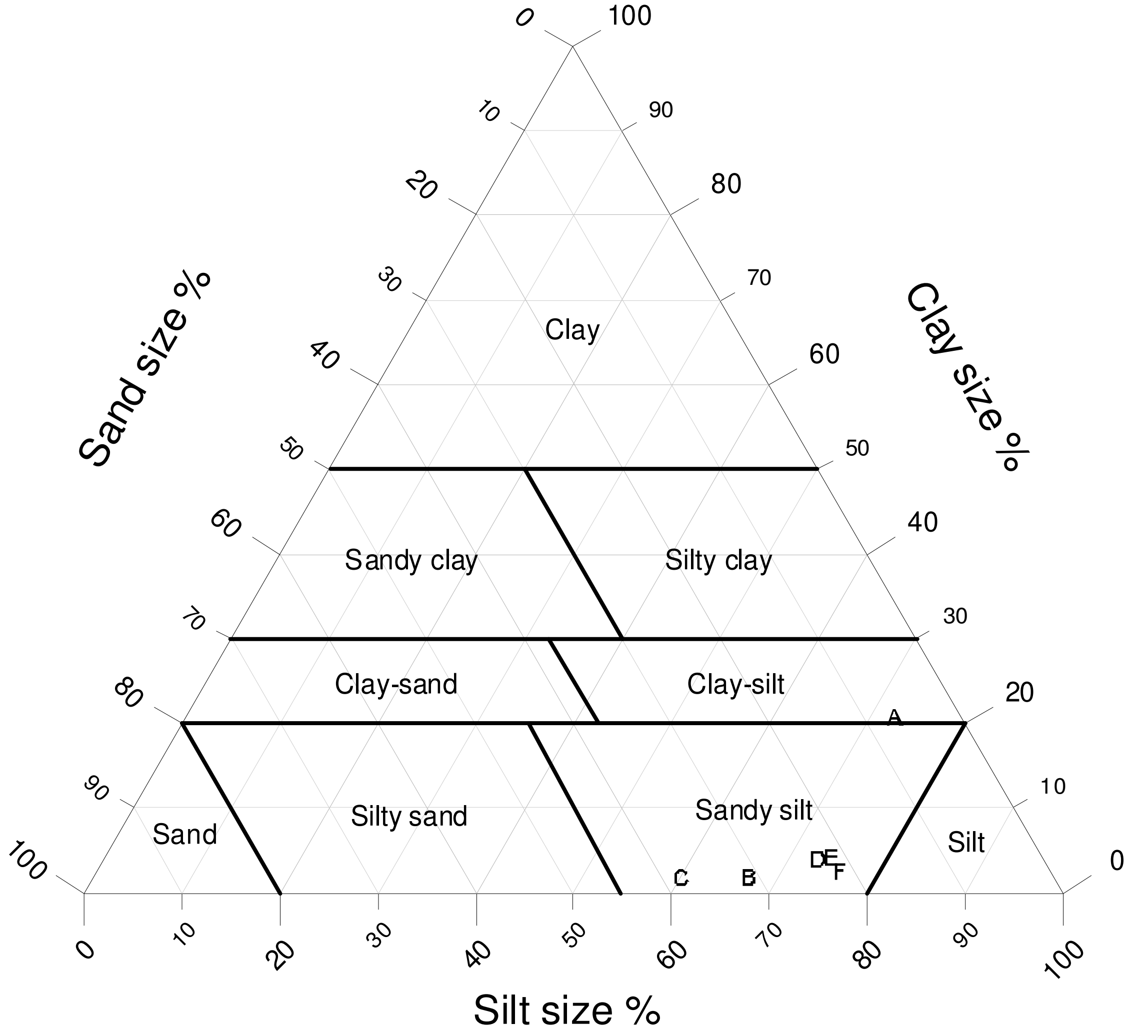
American Petroleum Institute
MTBE Study
02/04/05

COLUMBIA TECHNOLOGIES

Appendix E
Grain Size Analyses

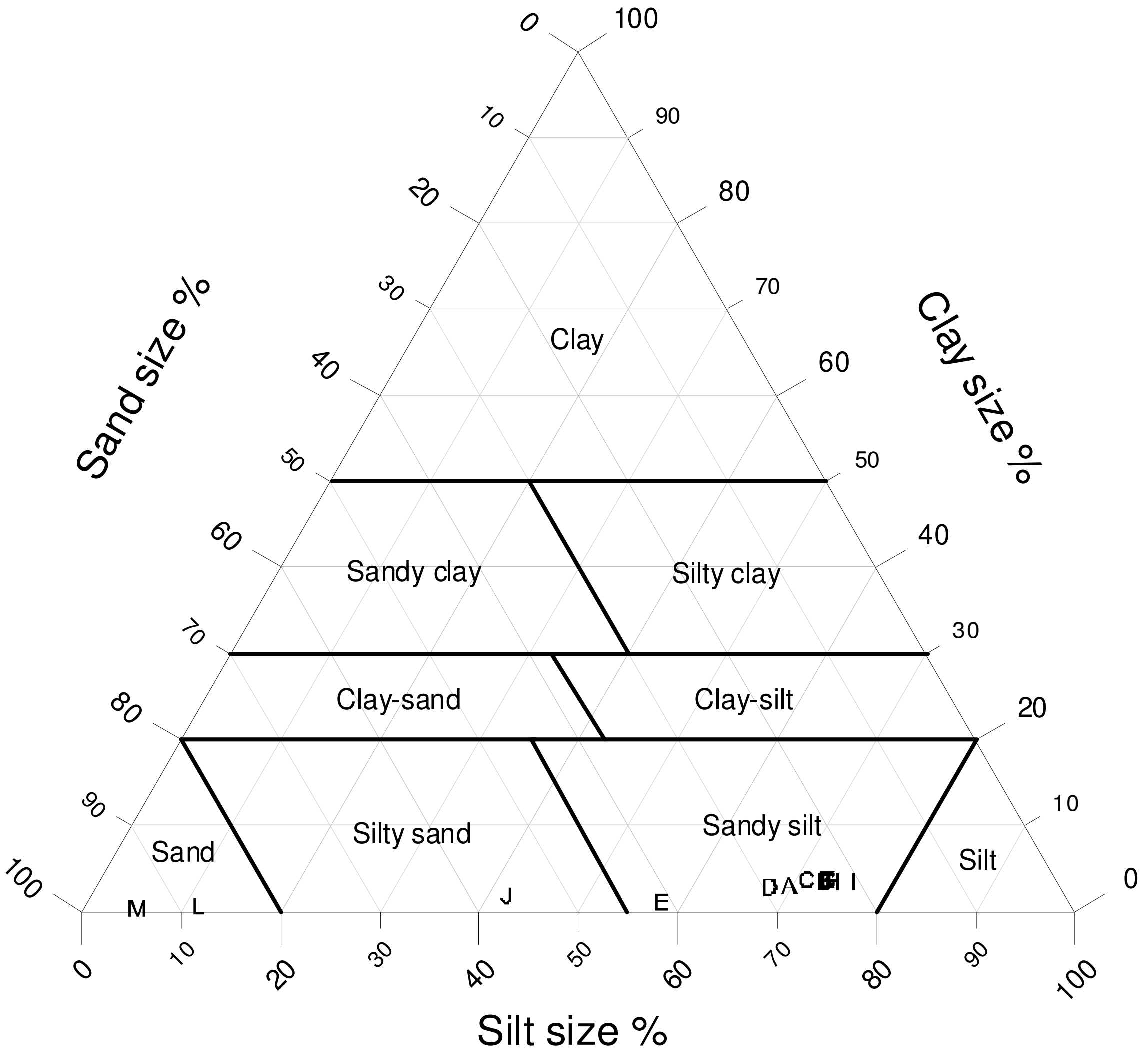
CPT 08		Clay %	Silt %	Sand %
A	(102-108")	20.787	72.445	6.766
B	(108-114")	1.883	66.991	31.126
C	(114-120")	1.728	60.139	38.134
D	(120-126")	3.954	73.031	23.015
E	(126-132")	2.564	75.949	21.487
F	(132-139")	2.994	69.69	27.318

Textural classification triangle
showing the grain size analyses for each
mapped unit in the Geoprobe core
corresponding to CPT 08



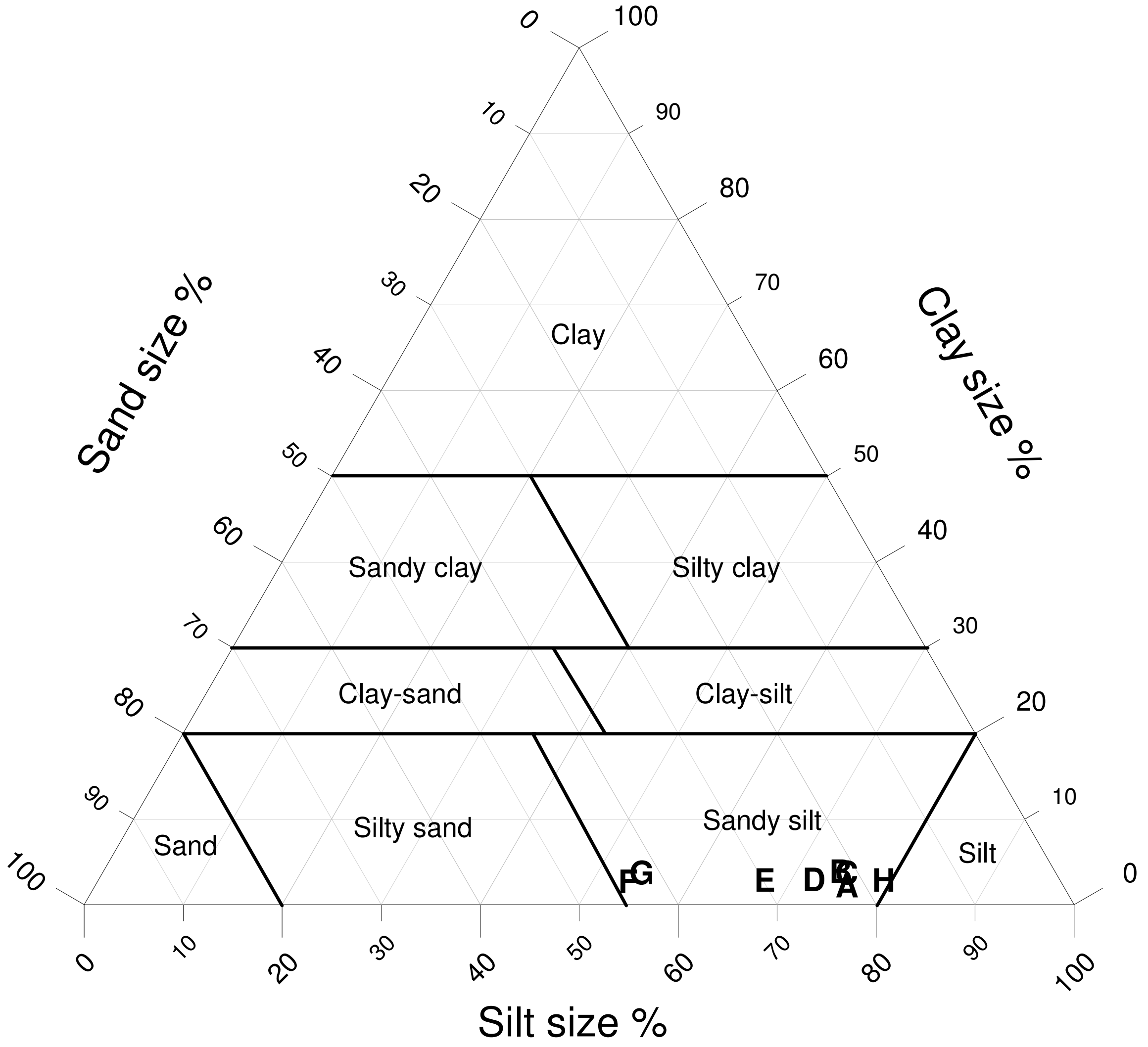
	CPT 10	Clay %	Silt %	Sand %
A	(81-87")	4.229	64.832	30.939
B	(87-93")	3.447	73.063	23.491
C	(93-99")	3.654	71.126	25.22
D	(99-105")	2.827	67.835	29.338
E	(105-111")	1.098	57.866	41.037
F	(111-117")	3.498	73.232	23.271
G	(117-125")	3.493	73.765	22.743
H	(131-137")	3.489	75.96	20.55
I	(137-143")	1.835	41.791	56.375
J	(143-149")	3.688	73.238	23.073
K	(149-155")	0.662	11.434	87.905
L	(155-161")	0.282	5.414	94.305
M	(161-167")	0.423	7.252	92.324

Textural classification triangle showing the grain size analyses for each mapped unit in the Geoprobe core corresponding to CPT 10



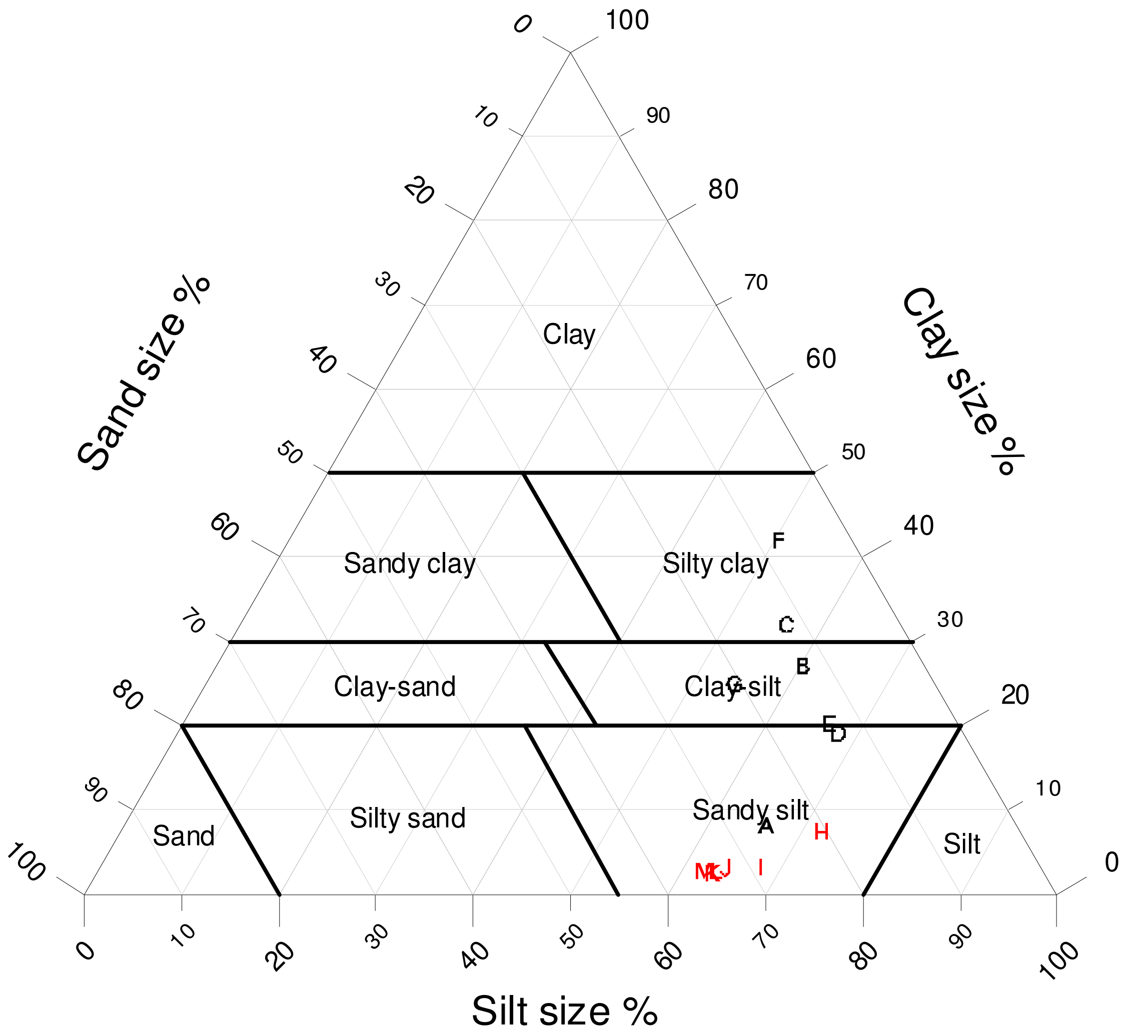
	CPT 12	Clay %	Silt %	Sand %
A	(78-83")	2.158	75.958	21.884
B	(83-89")	3.854	74.491	21.656
C	(89-95")	3.734	75.144	21.123
D	(95-101")	2.889	72.257	24.855
E	(101-107")	2.841	67.318	29.841
F	(107-113")	2.677	53.554	43.769
G	(113-119")	3.724	54.431	41.846
H	(119-125")	2.847	79.312	17.84

Textural classification triangle
showing the grain size analyses for each
mapped unit in the Geoprobe core
corresponding to CPT 12



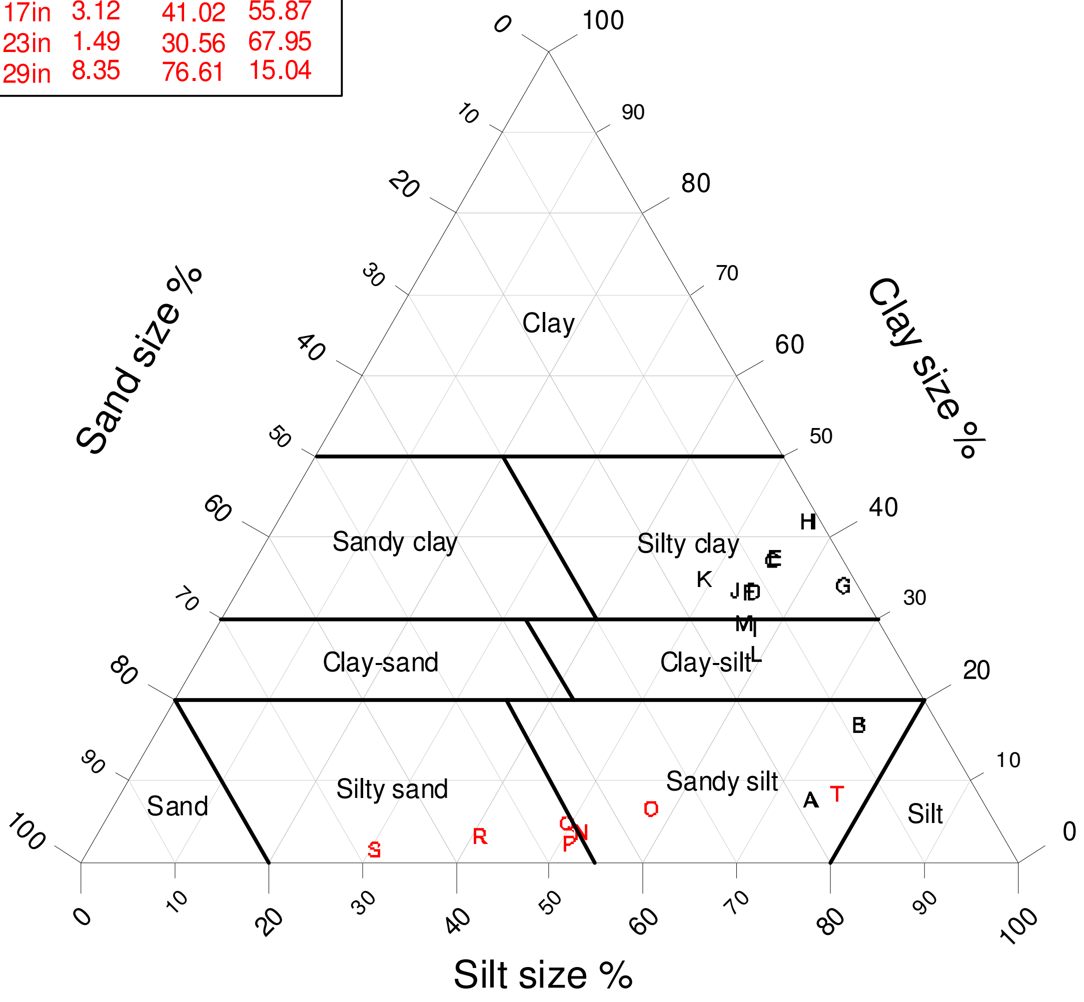
CPT 18		Clay %	Silt %	Sand %
A	9in	8.11	66.01	25.89
B	15in	27.14	60.27	12.59
C	21in	31.96	56.16	11.88
D	27in	19.11	67.94	12.95
E	33in	20.15	66.43	13.42
F	39in	42.01	50.33	7.67
G	45in	24.93	54.30	20.78
H	51in	7.42	72.09	20.50
I	57in	3.15	67.90	28.96
J	63in	3.08	64.31	32.62
K	69in	2.59	63.29	34.12
L	75in	2.82	63.55	33.64
M	81in	2.81	62.27	34.92

Textural classification triangle showing the grain size analyses for each mapped unit in the Geoprobe core corresponding to CPT 18



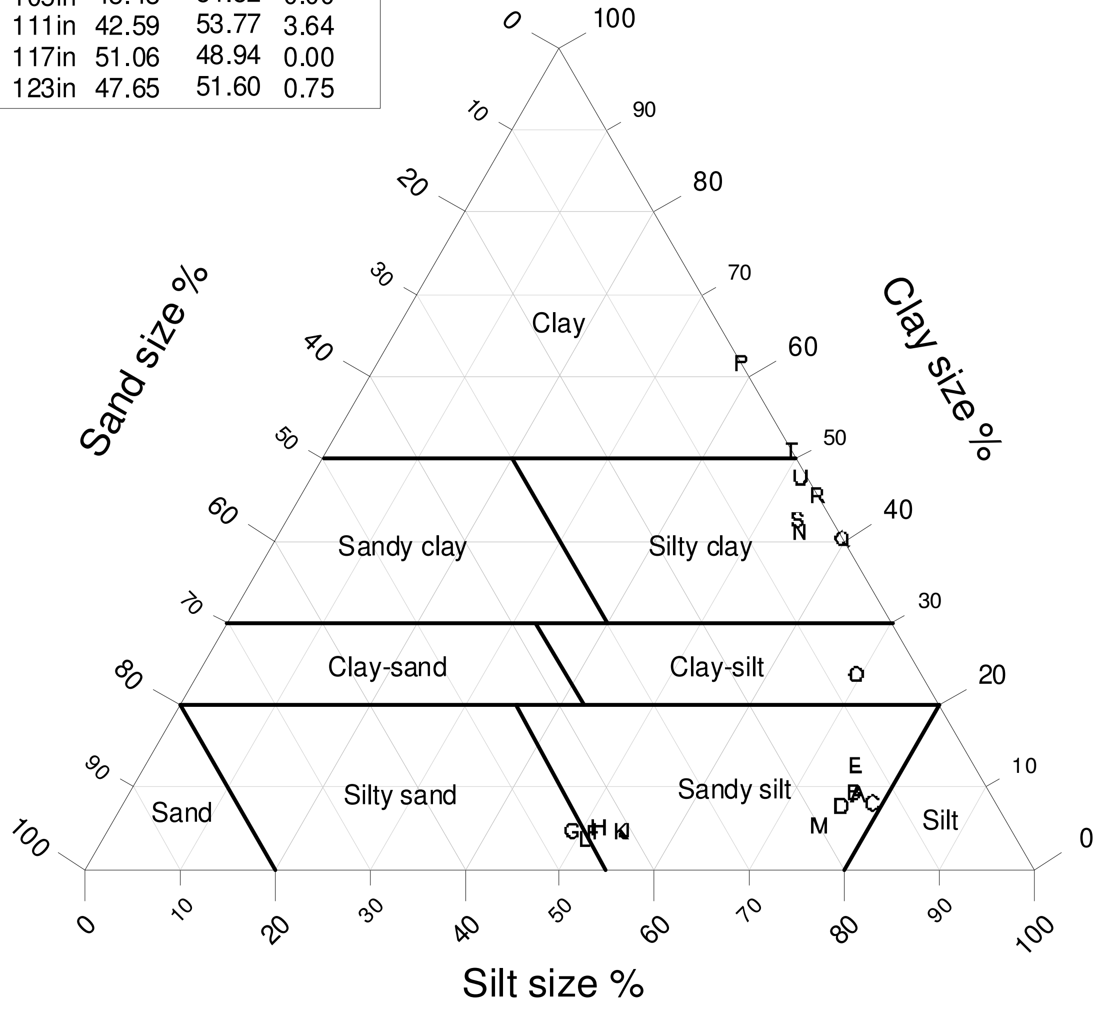
CPT 28		Clay %	Silt %	Sand %
A	9in	7.61	74.13	18.26
B	15in	16.94	74.61	8.45
C	21in	37.18	55.21	7.61
D	27in	33.35	55.15	11.51
E	33in	37.54	55.40	7.06
F	39in	33.24	54.82	11.94
G	45in	34.06	64.36	1.58
H	51in	42.04	56.62	1.34
I	61in	28.84	57.45	13.71
J	69in	33.56	53.01	13.43
K	75in	34.98	49.12	15.90
L	81in	25.59	59.39	15.02
M	87in	29.52	56.00	14.49
N	93in	3.66	51.51	44.83
O	99in	6.59	57.55	35.86
P	105in	2.32	50.94	46.74
Q	111in	4.72	49.54	45.75
R	117in	3.12	41.02	55.87
S	123in	1.49	30.56	67.95
T	129in	8.35	76.61	15.04

Textural classification triangle
showing the grain size analyses for each
mapped unit in the Geoprobe core
corresponding to CPT 28



	CPT 30	Clay %	Silt %	Sand %
A	3in	9.20	76.89	13.91
B	9in	9.42	76.37	14.22
C	15in	8.07	78.95	12.99
D	21in	7.68	75.93	16.39
E	27in	12.62	74.86	12.52
F	33in	4.37	51.41	44.22
G	39in	4.71	48.94	46.35
H	45in	5.19	51.54	43.27
I	51in	4.57	51.40	44.03
J	57in	4.69	54.45	40.87
K	63in	4.73	54.17	41.11
L	69in	3.70	50.83	45.47
M	75in	5.28	74.75	19.97
N	81in	41.14	54.76	4.10
O	87in	23.72	69.44	6.84
P	93in	61.74	38.26	0.00
Q	99in	59.71	40.24	0.06
R	105in	45.48	54.52	0.00
S	111in	42.59	53.77	3.64
T	117in	51.06	48.94	0.00
U	123in	47.65	51.60	0.75

Textural classification triangle
showing the grain size analyses for each
mapped unit in the Geoprobe core
corresponding to CPT 30



Sample Name		Clay %	Silt %	Sand %	Type
CPT 18					
(9") - Average	**A**	8.11	66.01	25.89	sandy silt
(15") - Average	**B**	27.14	60.27	12.59	clay silt
(21") - Average	**C**	31.96	56.16	11.88	silty clay
(27") - Average	**D**	19.11	67.94	12.95	sandy silt
(33") - Average	**E**	20.15	66.43	13.42	clay silt
(39") - Average	**F**	42.01	50.33	7.67	silty clay
(45") - Average	**G**	24.93	54.30	20.78	clay silt
(51") - Average	**H**	7.42	72.09	20.50	sandy silt
(57") - Average	**I**	3.15	67.90	28.96	sandy silt
(63") - Average	**J**	3.08	64.31	32.62	sandy silt
(69") - Average	**K**	2.59	63.29	34.12	sandy silt
(75") - Average	**L**	2.82	63.55	33.64	sandy silt
(81") - Average	**M**	2.81	62.27	34.92	sandy silt
CPT 28					
(9") - Average	**A**	7.61	74.13	18.26	sandy silt
(15") - Average	**B**	16.94	74.61	8.45	sandy silt
(21") - Average	**C**	37.18	55.21	7.61	silty clay
(27") - Average	**D**	33.35	55.15	11.51	silty clay
(33") - Average	**E**	37.54	55.40	7.06	silty clay
(39") - Average	**F**	33.24	54.82	11.94	silty clay
(45") - Average	**G**	34.06	64.36	1.58	silty clay
(51") - Average	**H**	42.04	56.62	1.34	silty clay
(61") - Average	**I**	28.84	57.45	13.71	clay-silt
(69") - Average	**J**	33.56	53.01	13.43	silty clay
(75") - Average	**K**	34.98	49.12	15.90	silty clay
(81") - Average	**L**	25.59	59.39	15.02	clay-silt
(87") - Average	**M**	29.52	56.00	14.49	clay-silt
(93") - Average	**N**	3.66	51.51	44.83	sandy silt
(99") - Average	**O**	6.59	57.55	35.86	sandy silt
(105") - Average	**P**	2.32	50.94	46.74	silty sand
(111") - Average	**Q**	4.72	49.54	45.75	silty sand
(117") - Average	**R**	3.12	41.02	55.87	silty sand
(123") - Average	**S**	1.49	30.56	67.95	silty sand
(129") - Average	**T**	8.35	76.61	15.04	sandy silt

Grain size analysis for CPT 18 and CPT 28

CPT 30					
(3") - Average	**A**	9.20	76.89	13.91	sandy silt
(9") - Average	**B**	9.42	76.37	14.22	sandy silt
(15") - Average	**C**	8.07	78.95	12.99	sandy silt
(21") - Average	**D**	7.68	75.93	16.39	sandy silt
(27") - Average	**E**	12.62	74.86	12.52	sandy silt
(33") - Average	**F**	4.37	51.41	44.22	sandy silt
(39") - Average	**G**	4.71	48.94	46.35	silty sand
(45") - Average	**H**	5.19	51.54	43.27	sandy silt
(51") - Average	**I**	4.57	51.40	44.03	sandy silt
(57") - Average	**J**	4.69	54.45	40.87	sandy silt
(63") - Average	**K**	4.73	54.17	41.11	sandy silt
(69") - Average	**L**	3.70	50.83	45.47	silty sand
(75") - Average	**M**	5.28	74.75	19.97	sandy silt
(81") - Average	**N**	41.14	54.76	4.10	silty clay
(87") - Average	**O**	23.72	69.44	6.84	clay silt
(93") - Average	**P**	61.74	38.26	0.00	clay
(99") - Average	**Q**	59.71	40.24	0.06	silty clay
(105") - Average	**R**	45.48	54.52	0.00	silty clay
(111") - Average	**S**	42.59	53.77	3.64	silty clay
(117") - Average	**T**	51.06	48.94	0.00	clay
(123") - Average	**U**	47.65	51.60	0.75	silty clay

Grain size analysis for CPT 30

Body of paper begins here.