SUGGESTED OPERATING PROCEDURE
SOIL GAS PROBE PURGING AND SAMPLE COLLECTION

1. INTRODUCTION

Soil gas sample collection requires purging to flush stagnant gas from the soil gas probe prior to collection of a sample for laboratory analysis, much the same as purging stagnant water from a well prior to collection of a groundwater sample. Soil gas sampling for assessment of subsurface vapor intrusion to indoor air requires much lower detection limits than historic uses of soil gas sampling for assessing presence or absence of releases of volatile and semi-volatile organic chemicals (VOCs and SVOCs); therefore, soil gas sampling methods have evolved considerably in the past decade. This protocol is intended to provide representative and reproducible samples with documentation via field screening readings and pneumatic data gathered during the purging and sample collection process. This is analogous to the Low-Flow Groundwater Sampling procedure (Puls and Barcelona, 1996), which is generally accepted as the current state of the art for groundwater purging and sampling.

The most common sources of bias in soil gas sampling are leaks that allow atmospheric air to enter the sample (typically imparting a negative bias), or desorption of vapors from equipment that was previously used for sampling in an area of higher soil gas concentrations (positive bias). Variability can occur naturally due to weather conditions (temperature, rainfall, barometric pressure), or artificially due to inconsistent sampling procedures. This document specifies procedures for purging, sample collection, storage and handling to the degree needed to minimize artificial data bias and variability to the levels required when working with very low detection limits (<1 part per billion by volume [ppbv]).

2. STATIC PRESSURE OR VACUUM

Prior to sampling, the static vacuum or pressure in the soil gas probe should be measured and recorded. This is analogous to measuring a static water level in a groundwater monitoring well. These data can be used to assess whether and to what extent pressure gradients might influence soil gas flow (Auer, et. Al., 1996, Carrigan et. Al., 2000, Neeper, 2001, Parker, 2003, and Weeks, 1979).

Connect a vacuum gauge to the valve at the top of the soil gas probe using tubing provided with the vacuum gauge. Level and zero the gauge. Open the valve and record the average reading. It may be necessary to shield the vacuum gauge from any wind, which can cause the readings to fluctuate. Record the static pressure or vacuum, along with the date, time, temperature and weather conditions. A form for recording field data is attached.

In some circumstances it may be advantageous to record static pressure or vacuum over a longer period of time, for example a period long enough to include one or more cycles in atmospheric pressure. This may be accomplished using micro-manometers with pressure transducers and data-logging capabilities. Most of these devices record gauge pressure (difference between soil gas pressure and atmospheric pressure), so a separate digital barometer is required to record absolute atmospheric pressure for interpretation of the micro-manometer gauge pressure data. Alternatively, this information may be obtained from local weather monitoring stations (e.g. airports) for a minimal fee. Micro-manometers, pressure transducers and data loggers are available from several manufacturers, and should be operated according to manufacturer’s instructions.

3. LEAK CHECKS

The sampling train (**Figure 1**) should be checked for leaks after it is assembled in the field and before purging and sampling begins. It may also be appropriate to conduct a tracer test to assess whether atmospheric air is drawn into the probe during purging and sampling, particularly if the soil gas permeability is relatively low (>10 inches of water column [in-H_2O] vacuum is required to achieve a flow of >200 milliliters per minute [mL/min]), the probe tip is relatively shallow (<5 ft), or field screening readings of VOCs or CO_2 show decreasing concentrations in successive purge volumes, while O_2 concentrations increase toward atmospheric levels.

The sampling train can be leak-tested two ways:

7.1 a “shut-in” test, where the pump is used to exert a pressure or vacuum on the sampling train, then all valves are closed and the pressure or vacuum is observed over time to ensure it does not dissipate. A target vacuum or pressure level of 100 in-H20 is appropriate, to maximize the resolution of the observations, and the stress on the sample train;

7.1 a mock sample collection of span gas from a Tedlar bag, through a valve opened only enough to allow the span gas to flow at a rate and vacuum similar to the flow and vacuum from the soil gas probe. If a field screening reading of the sample collected by this method has a concentration lower than the span gas, a leak is indicated.

If either of the above tests of the sampling train indicates a leak, the connections should be disconnected and carefully reconnected one at a time until the leak is corrected, with repeat leak testing of each connection in turn.

The probe seal can be leak tested by injecting a tracer gas into a shroud around the top of the soil gas probe, and measuring the concentration of the tracer in the shroud and the soil gas sample. Ideally, the sample will contain <5% of the tracer gas concentration in the shroud, indicating that the sample is >95% representative of subsurface gas. It may be feasible to use the tracer gas to perform a mass balance calculation to correct for any atmospheric air dilution that may be significant, retrofit the probe by installing additional seal materials, or it may be preferable to install a new probe and take extra care with the seal placement.

The shroud can consist of a clear plastic container (e.g. large Tupperware™ container) or a clear plastic sheet large enough to surround the soil gas probe and valves and fittings at the top of the probe. One hole in the shroud is required to allow ¼-inch high-density polyethylene (HDPE) or Nylon tubing to extend from the probe inside the shroud to the lung-box outside the shroud. Ports for tracer gas injection and monitoring are also helpful.

The recommend tracer gas is helium because it is non-toxic, readily available (toy stores and party supply stores), inexpensive, easily measured using portable detectors available for rental with 4 orders of magnitude ranges in readings, and generally not present in the subsurface at concentrations that might interfere with the test. Injecting helium from a pressurized cylinder for several seconds will generally be sufficient to create concentrations in the shroud in the range of 60% to 100% by volume. The air under the shroud should be screened with the portable monitoring device after adding the tracer, which can be done through a small hole in the shroud. Purging into a Tedlar bag in the lung box yields a soil gas sample that should also be screened using the helium meter to confirm the absence of any significant leaks. Other tracer gases may be used (e.g. isobutylene, butane, propane, SF6), providing a field screening reading is available that can provide at least two orders of magnitude range, and the selected tracer is not present in the subsurface at levels that might pose an interference. The ionization potential of butane and propane is higher than most photoionization detector (PID) lamps, so a flame ionization detector (FID) would be required.

4. FLOW AND VACUUM CHECK

A simple test of soil gas flow and vacuum should be conducted after seals are set. Analysis of this data can be used to calculate the gas permeability of the subsurface materials. If the result is a much lower permeability than expected, this test may provide valuable information about possible plugging of the soil gas probe. Periodic checks (e.g. at the beginning of each sampling event) can be used to demonstrate consistency in the pneumatic conditions at the probe, which may also be informative.

Soil gas samples for field screening or laboratory analysis typically require a volume of approximately 1 to 6 liters (L). Sample collection over 10 minutes to 1 hour is a reasonable period of time; therefore, a reasonable flow rate should be at least 200 mL/min.   The flow rate will be proportional to the applied vacuum. Excessive vacuum can change the partitioning of vapors between pore water and soil gas; therefore, it should be avoided. Excessive vacuum will also increase the risk of leakage at the connection between the probe and the sample container, which can result in sample bias by the ingress of indoor air. Vacuum levels less than 1 to 10 in-H_2O should be low enough to avoid both concerns. Higher-level vacuum may be acceptable, but should be recorded and discussed with the data interpretation. Where a flowrate of at least 200 mL/min cannot be sustained with a vacuum less than 100 in-H_2O, it may be advisable to install and monitor an additional soil gas probes to increase the confidence in the data.

To measure the soil gas flow and corresponding vacuum, connect to the valve at the top of the soil gas probe using ¼-inch tubing. Connect to the vacuum gauge and a rotameter-style flowmeter. Connect the vacuum pump to the rotameter. Open the soil gas probe valve. With the valve at the inlet of the pump closed, start the pump, and gradually open the valve until there is a measurable flow. Preferably about 100 mL/min. The vacuum should stabilize almost instantaneously. Record the flow and corresponding vacuum. Increase the flow to a higher level, preferably about 500 mL/min, and record the steady flow. This test requires no more than 1 minute of pumping, and will remove less than ½ L of soil gas, so no unacceptable bias to the soil gas chemistry will be posed.

The data will be analyzed using the method of Johnson et al, 1990, equation 11, which is as follows:

$$Q = H * \left[{(k * \pi)}\big/{\mu} \right] * P_W * \frac{\left[1 - \left({P_{ATM}}\big/{P_W} \right)^2 \right]}{\left[\ln\left({R_W}\big/{R_I} \right) \right]}$$

Where, Q = Standard Vapor Flowrate at Wellhead (m^3/s)
H = Well Screen Length through Vadose Zone (m)
k = Permeability (m^2/s)
π = 3.1416
μ = Dynamic Viscosity (typically 0.0182 centipoise for air at STP)
P_W = Absolute Pressure at Wellhead (P_{ATM} minus wellhead vacuum)
P_{ATM} = Atmospheric Pressure (about 390 inches H_2O)
R_W = Radius of Well (m)
R_I = Radius of Influence (ROI) (estimated, typically 1 to 10 m)

The ROI is not uniquely determined from this test, so it must be estimated. Fortunately, the solution is not particularly sensitive to the ROI value chosen, so this estimation does not impose significant uncertainty in the test results. For tests of this nature, where flow and vacuum are maintained at modest levels, the ROI should be on the order of 1 to 10 meters. It is recommended to calculate the permeability using more than 1 ROI value to demonstrate the uncertainty imposed by this estimated value.

Rearranging the equation above to solve for permeability results in the following equation:

$$k = \left(\frac{Q}{H}\right) * \left(\frac{\mu}{\pi}\right) * \frac{\left[\ln\left(\frac{R_W}{R_I}\right)\right]}{\left[P_W * \left\{1 - \left(\frac{P_{ATM}}{P_W}\right)^2\right\}\right]}$$

5. SOIL GAS PROBE PURGING

Soil gas sampling requires purging prior to sample collection in order to ensure the sample is representative of soil gas contained within the geologic materials outside the soil gas probe and filter sand surrounding the soil gas probe screen. Excessive purging may reduce the resolution in vertical profiles of concentrations measured for samples from multi-level or nested soil gas probes. In the extreme case, excessive purging may result in dilution of the soil gas sample with atmospheric air, although this is seldom a concern for probes of 2-inch diameter or less, unless the screened interval is very shallow (less than a few feet). Generally, a larger purge volume increases the representative elemental volume of the sample, and reduces artifacts of small-scale spatial variability. Purging more than 10 probe volumes (the internal volume of the probe itself) is seldom necessary to collect a representative sample, and should only be done if steps are taken to address the potential for atmospheric air entry. For a ¼-inch probe of 5 ft depth, 10 casing volumes is a total volume of only ½ liter (L). In a porous media with a 30% air-filled porosity, ½ L of soil gas is contained within a sphere about the size of a softball. Purging of such a small volume of gas is unlikely to cause unacceptable atmospheric air entry in most circumstances. Field screening with a PID, FID, oxygen (O_2), carbon dioxide (CO_2), and methane meters may require as much as 1 L of soil gas per set of measurements. If a minimum of three measurements of field parameters is desired to assure stabilization prior to sample collection, then the total purge volume prior to sampling may be 3 L, and a subsequent sample for laboratory analysis may be another 1 L. A total of 4 L of soil gas can be contained within a sphere of soil a little larger than a basketball, which will not be excessive in most cases. For deeper probes, a larger volume of gas can be purged without causing excessive mixing of soil gas from different intervals. For example, a 1-inch diameter probe 10 feet deep has a probe volume of about 1.5 L. Three to five casing volumes can be withdrawn during purging and sampling without drawing gas from farther than about 1 foot from the probe tip.

If the soil gas probe is located inside a building and if indoor air sampling is also planned as part of the scope of work, purged soil gas should not be directly vented into the air inside the building because it may contribute a positive bias to the indoor air samples. The outlet of the vacuum pump used with the lung box should be routed through a tube to an outdoor location. Any soil gas remaining in the Tedlar bag after screening should be evacuated using this pump, prior to collection of subsequent bag samples.

Soil gas purging is performed using a Tedlar™ bag and lung box apparatus, as shown on **Figure 1**. The Tedlar bag is placed inside the lung-box and connected to the soil gas probe using a new and disposable length of HDPE, Nylon or Teflon™ tubing. The tubing should be as short as practicable to minimize the dead volume of the tubing. The Tedlar bag is sealed inside the lung box, and a pump is used to evacuate the region inside the lung box and outside of the Tedlar bag. With the valves on the Tedlar bag and on top of the soil gas probe both in the open position, this will induce soil gas flow from the probe into the Tedlar bag, without flowing through a pump, which could cause sample contamination. The Tedlar bag should be filled with sufficient volume of soil gas for field screening using portable instruments (described below). The valve on the top of the soil gas probe must be closed before disconnecting the Tedlar bag and conducting the field screening. Otherwise, there may be residual negative pressure in the soil gas that can draw atmospheric air back into the probe, and cause a potential negative bias for subsequent screening.

Tedlar bags are available in various volumes, ranging from 0.5 L to 10 L, but generally, either 1 L or 3 L bags are appropriate. If the sampling program proceeds from soil gas probes with low concentrations to probes with higher concentrations, it may be acceptable to re-use Tedlar bags, after flushing several times with atmospheric air. However, it is necessary to use dedicated or new bags to reduce the potential for cross-contamination between samples if subsequent laboratory analyses are planned via sub-sampling out of the Tedlar bag, as described below.

After screening, the Tedlar bag should be emptied and the purging process repeated until the volume of soil gas removed from the probe is greater than the dead-volume of the probe, plus the porosity of the sand filter pack around the screen of the soil gas probe at a minimum. Generally three to five probe volumes is sufficient to achieve steady readings on the portable instruments and provide sufficient documentation for a third-party data quality review.

Vacuum and flow rate should be monitored during purging, using the apparatus shown in **Figure 1**. In moderate to high-permeability soils, a soil gas flow rate in the range of 200 to 2,000 milliliters per minute (mL/min) can be achieved with a vacuum of less than 10 in-H_2O. Flow rates and vacuum in these ranges are not likely to cause bias on sample concentrations. Excessive vacuum can induce volatilization and cause a positive bias in sample concentrations, as well as increase the risk of leaks. Low flow rates increase the residence time of the soil gas in the sample train and can lead to biases attributable to interactions with the sampling materials. If the geologic materials have low gas permeability, higher vacuum levels will be required to achieve acceptable flowrates. If a vacuum greater than 100 in-H_2O is required to generate a flow of 0.1 L/min, it is questionable whether a soil gas sample can be collected by advection without disturbing the local equilibrium phase partitioning between the solid, liquid and gas phases, and any sample collected under such conditions should be qualified at a minimum.

The flowrate during purging should be controlled by moderating the vacuum applied to the lung box to fill the 1L Tedlar bag at a rate not to exceed 2L/min (i.e. 1L Tedlar bag filled in 30 seconds). Vacuum levels less than 10 in-H_2O are preferred, and vacuum > 100 in-H_2O should be avoided. The flow rate and corresponding vacuum should be recorded on the attached form. When multiple sampling events are planned, the consistency of the ratio of flow divided by the applied vacuum should be assessed to qualitatively evaluate the pneumatic conductivity, which should remain relatively constant for a given probe over time. Significant increases in flow may indicate a leak in the sample train.

6. FIELD SCREENING

Field screening of total VOC vapor concentrations is conducted during purging to verify stable readings before collection of soil gas samples for laboratory analysis. Stable readings will typically be defined as reading that vary by less than 10% from previous readings and show no consistent trend in either increasing or decreasing concentrations.

Samples of the extracted soil gas should be collected for field screening using a portable FID or PID after every purge volume removed (or 1 L if the purge volume is smaller). The FID or PID should be calibrated according to manufacturer's instructions to a span gas (i.e. isobutylene or hexane) of known concentration (typically 50 or 100 ppmv) and to zero gas (in areas of poor outdoor air quality) or ambient outdoor air, immediately prior to use. The calibrations should be confirmed several times during the day to assess potential instrument drift. If the readings show more than 10% drift against the standard gas, or more than +/- 1 parts per million by volume (ppm_v) of zero gas or ambient air, the instrument should be recalibrated. The FID or PID reading will be made by connecting the Tedlar bag to the instrument and allowing the instrument to draw a sub-sample at ambient pressure (the bag must not be squeezed because this can cause a bias in the calibration). The time and the steady reading are recorded.

Samples of soil gas may also be screened for concentrations of carbon dioxide (CO_2), oxygen (O_2), and methane (CH_4), using a landfill gas meter, particularly if the VOCs of concern are susceptible to natural biodegradation under aerobic conditions (e.g. hydrocarbons). Readings should be made by connecting the Tedlar bag to the instrument and allowing the instrument to draw a sub-sample at ambient pressure. The instrument should be calibrated according to manufacturers instructions. The time and the steady reading are recorded. Ambient air readings should also be recorded.

Between readings, the instruments should be confirmed to return to ambient levels, and not display any indication of sample carry-over.

7. COLLECTION OF SAMPLES FOR LABORATORY ANALYSIS

Soil gas samples for laboratory analysis should be collected in Summa™ canisters, provided by the analytical laboratory. Summa™ canisters are stainless steel vessels with a fused silica passivated inner surface that facilitates complete recovery of most VOCs. They are widely available in 6 L volume, but are also available in 1L “mini-Summa canister” size, which is easier to ship and handle, and is capable of providing sufficient sample for analysis with standard TO-15 reporting limits (0.5 ppbv). The added advantage of the mini-Summa canister is that it can be used to draw a sample from a 1L Tedlar bag, without exceeding the capacity of the bag, or requiring multiple bags for a sample. Collecting a mini-Summa canister sample from a Tedlar bag allows an opportunity for field screening the residual volume of the Tedlar bag after the mini-Summa canister collection, which can be compared to the field screening data collected during purging to provide assurance that the sample drawn into the mini-Summa canister is directly comparable to the steady purging soil gas quality.

7.1 SUMMA CANISTERS

Summa canisters are cleaned in the laboratory and evacuated to typically 25 to 30 inches of Hg vacuum. The initial vacuum is confirmed prior to sampling by removing the Swagelock™ cap, attaching the vacuum gauge securely (1/4-turn past snug), and opening the Summa canister valve. The Summa canister valve will then be closed and the vacuum gauge disconnected. The initial vacuum will be recorded on the attached form.

A new 5-micron stainless steel particulate filter is then connected to the Summa canister, which is then connected to the Tedlar Bag sample using a stainless steel compression fitting. The valve on the Summa canister should be opened slowly to draw about 2/3rds of the volume of the Tedlar bag into the canister, then closed tightly. A 1L Tedlar bag works well with mini-Summa canisters, and 3L Tedlar bag works well with 6L Summa canisters. Note that the particulate filter provides some resistance to flow, which is desirable; otherwise, the Summa canister vacuum would extract the entire contents of the Tedlar bag nearly instantaneously, which is not desireable, because the risk of a leak increases if the Summa canister draws a vacuum against an emptied Tedlar bag.

After the sample is collected, remove the particulate filter and replace securely with the vacuum gauge, after which the mini-Summa canister valve should be re-opened, and the vacuum measured and recorded. This reading will also be confirmed upon receipt of the mini-Summa canister by the laboratory to ensure sample integrity during shipping. The mini-Summa canister valve should be closed before the vacuum gauge is removed, and the Swagelock™ cap should be securely replaced prior to shipping.

The remaining contents of the Tedlar bag should be screened immediately after the collection of the mini-Summa canister. If the screening reading is different than the steady field screening readings at the end of the purging process by more than 10%, this should be noted and an appropriate correction should be considered during data interpretation. If the screening reading is different than the steady field screening readings at the end of the purging process by more than a factor of 10, the mini-Summa canister sample should not be analyzed and the purging and sampling procedure should be repeated.

Summa canister samples may also be collected after purging is complete by connecting the Summa canister directly to the soil gas probe, with 5-micron filter and flow controller in line. The flow controller should be set for a flow rate of about 100 to 1,000 mL/min, depending on the volume of the Summa canister and diameter of the probe. A 6L Summa canister would take almost an hour to fill at 100 mL/minute, and it is questionable as to whether the soil gas chemistry will change via interactions with the surface of the soil gas probe over that length of time. If the soil gas probe is ¼-inch diameter and 5-feet long, the internal volume is only about 50 mL, so the residence time in the probe at a flow rate of 100 mL/min is only about 30 seconds, which is much less likely to lead to surface reactions. The flow rate should also be slow enough to cause minimal vacuum in the probe (preferably less than about 10 in-H_2O), although this may be difficult to predict in advance if the soil type is not known.

8. CHAIN OF CUSTODY AND SAMPLE HANDLING

The label tag on the mini-Summa canister should be filled-out with the site name, sample ID #, sampler’s name, project code, date and time of sample, initial and final vacuum levels, and analysis requested. A chain of custody (COC) form should be completed with each sample shipment. The COC should include the sample ID, canister number, analysis requested, and any special instructions. The laboratory will confirm the final vacuum level for each Summa canister upon receipt to verify that the Summa canister valve and cap did not leak during shipment.

Canisters do not need to be refrigerated, but should be shipped with sufficient padding to prevent damage if the container is accidentally dropped.

The COC form should be signed by the sampler and placed in the shipping container, then the shipping container should be wrapped securely using packing tape. The sampler should sign the packing tape across the seam of the lid of the container, so it cannot be opened without damaging the signature. Upon arrival, the laboratory will confirm the signature to be intact, and complete the COC form. Analyses should be scheduled with the analytical laboratory to be completed within acceptable holding times. Summa canisters should be analyzed within 2 weeks.

9. FIELD QC SAMPLES FOR SOIL GAS SAMPLE COLLECTION

Field quality control (QC) samples should be collected to monitor sampling and analytical performance. A complete record of all QC samples collected must be maintained as a part of the sampling documentation. The definition and purpose of each type of QC sample, and the procedures for their collection and handling are described in the paragraphs below.

Ambient Air Screening: Before field screening at each soil gas probe, an ambient air sample will be screened by drawing ambient air into a PID or FID over a period of at least one minute and recording the range of readings occurring during that time period. This ambient air screening should provide no detectable concentrations, but any readings observed may be useful to identify background conditions and evaluate potential biases.

Equipment Blanks: Prior to purging, an equipment blank should be performed to ensure the absence of measurable VOC vapors. Disconnect the tubing from the valve on top of the soil gas probe, and fill the Tedlar Bag with zero gas (preferred) or outdoor air through the tubing. Equipment blank readings should be made using a PID or FID, calibrated to span gas and zero gas according to manufacturers instructions. Atmospheric air may be used as zero gas in areas of generally good air quality, but should be avoided in high traffic areas, smog areas, or areas with any noticeable odors. If the equipment blank reading is above the FID or PID detection limit, repeat the equipment blank step with a new Tedlar bag and new length of tubing. If this does not result in a blank with no detectable VOCs, the FID or PID calibration should be repeated and the equipment blank process repeated. If this still does not provide an equipment blanks below the FID or PID detection limit, a project management decision will be required regarding whether to proceed with sampling, or whether to replace or perform service on the FID or PID.

Field Duplicate Sample: During the soil gas probe sampling, a field duplicate sample will be collected using regular sampling procedures immediately after collecting the investigative sample. The field duplicate sample will be analyzed to identify sample variability. The duplicate sample will be submitted for analyses without indication of which sample the duplicate represents (i.e., blindly). If the monitoring program includes multiple samples (i.e. Summa canister for VOCs, ATD tube for SVOCs, possibly Radon, etc.), the duplicate should also include the entire suite. Field duplicate samples are recommended at a frequency of one for every 10 investigative samples.

10. EQUIPMENT CLEANING

New or dedicated materials are preferred to minimize the risk of cross-contamination or carry-over from one sample to the next. The Tedlar bag may be re-used for field screening, but should be flushed using atmospheric air and completely drained three times between uses and verified clean by the equipment blank procedure. New or dedicated Tedlar bags are necessary if a Summa canister sample is to be drawn from a Tedlar bag after field screening. Brass and stainless steel valves should be heated and flushed with ample amounts of air to strip any residual VOCs between sampling events.

11. DOCUMENTATION

Field documentation will include instrument calibration information; date, time and location of readings; purging rate and vacuum induced; number of Summa canisters filled; sampler's name; and a detailed description of the equipment set up for each location. The series of field screening readings will be recorded on the sampling log sheets. A list of the soil gas probes sampled and the sampling order for all samples and QA/QC samples will be recorded on the sampling field records. Photographs are recommended to aid in recording equipment set-up.

For each sampling day, the following information will be recorded on the daily field logs

- name and number of project;
- name of field personnel;
- date and time of sampling event;
- list of the primary activities performed;
- identification of probes screened;
- time when soil gas samples were collected; and,
- all related information (weather, attendees, equipment problems, any departures from standard procedures and the reasons and responses) observed throughout the day.
- Field instrument information and calibration data;
- Value of probe dead space volume for each soil gas probe;
- Time, probe soil gas readings (and tubing blank reading) for each probe volume (or Tedlar™ bag filled); and
- Time and reading for each instrument calibration check.

12. REFERENCES AND SUGGESTED READING

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13. ATTACHMENT 1: RECOMMENDED EQUIPMENT

Tubing: High Density Polyethylene (HDPE) tubing is generally acceptable for low sorption (Barcelona et. al., 1983), and works well with compression or barbed fittings. Nyla-Flow™ tubing is considered equally appropriate. Teflon™ tubing is considerably less flexible than HDPE and may not work as well with barbed fittings. Tubing may also be stainless steel or copper, which forms air-tight seals when used with Swagelock™ fittings, but is more expensive and less flexible than HDPE. Soft flexible tubing should be avoided (except for the discharge line from the pump discharge to an outdoor location, if used), because vapors tend to adsorb more strongly to them.

Rotameter-Style Flowmeters: Dwyer Model RMB-5-49 with a range up to 5 standard cubic feet per hour (SCFH) (2.4 L/min), and Model RMB-5-52 with a range up to 50 SCFH (24 L/min).

Vacuum Gauges: Dwyer Magnehelic™ gauges, which are available in several ranges, including zero to 0.25 in-H_2O, zero to 5 in-H_2O, and zero to 100 in-H_2O.

Vacuum Pump: Gast, DOA-P101-AA piston pump

Lung Box: Xitech Instruments, Inc. Model 1060 1 L Bag Sampler

Helium Meter: Mark 9822 helium detector

Portable FID/PID: Foxboro TVA 1000 FID/PID, ppbRAE, MiniRae 2000

Personal Sampling Pump: Sensidyne Gilian GilAir-3 Constant Flow Sampling Pump

ATD Tubes: supplied by laboratory, after discussion of target chemicals, relative concentrations, target detection limits, and potential ranges of concentrations.

Micro-manometer: Logtech DP-Calc digital micro-manometer

Barologger: Barnstead ERTCO Barometric Pressure data recorder.

APPENDIX B

MONITORED NATURAL ATTENUATION TRACKING TREND GRAPHS
CHEVRON CINCINNATI FACILITY, HOOVEN, OHIO

This table is provided as a cross-walk between the graphs presented in this appendix and the sample group assignments for the various monitoring wells. The following graphs are presented in

General Plume Monitoring Wells	Interior Plume Monitoring Wells	MNA Monitoring Wells	Supplemental Dissolved-Phase Monitoring Wells
MW-27	MW-10	L-1RR	L-1RR
MW-33	MW-17	MW-18R	L-3R
MW-48S	MW-18R	MW-20S	MW-21
MW-85S	MW-20S	MW-33	MW-33
MW-94S	MW-22	MW-35	MW-51
MW-95S	MW-58S	MW-38	MW-64
MW-100S	MW-81S	MW-51	MW-80
MW-104S	MW-85D	MW-81S	MW-99
MW-115S	MW-88	MW-85S	
Sentinel Monitoring Wells	MW-96S	MW-96S	
MW-35		MW-100S	
MW-131 (proposed)		MW-112	
MW-132 (proposed)		MW-114	
POC Monitoring Wells		MW-115S	
MW-37			
MW-120			
MW-133 (proposed)			
MW-134 (proposed)			

Notes:

1- Color coding shows wells that are present in more than one sample grouping.

2- No data exists for proposed monitoring wells.

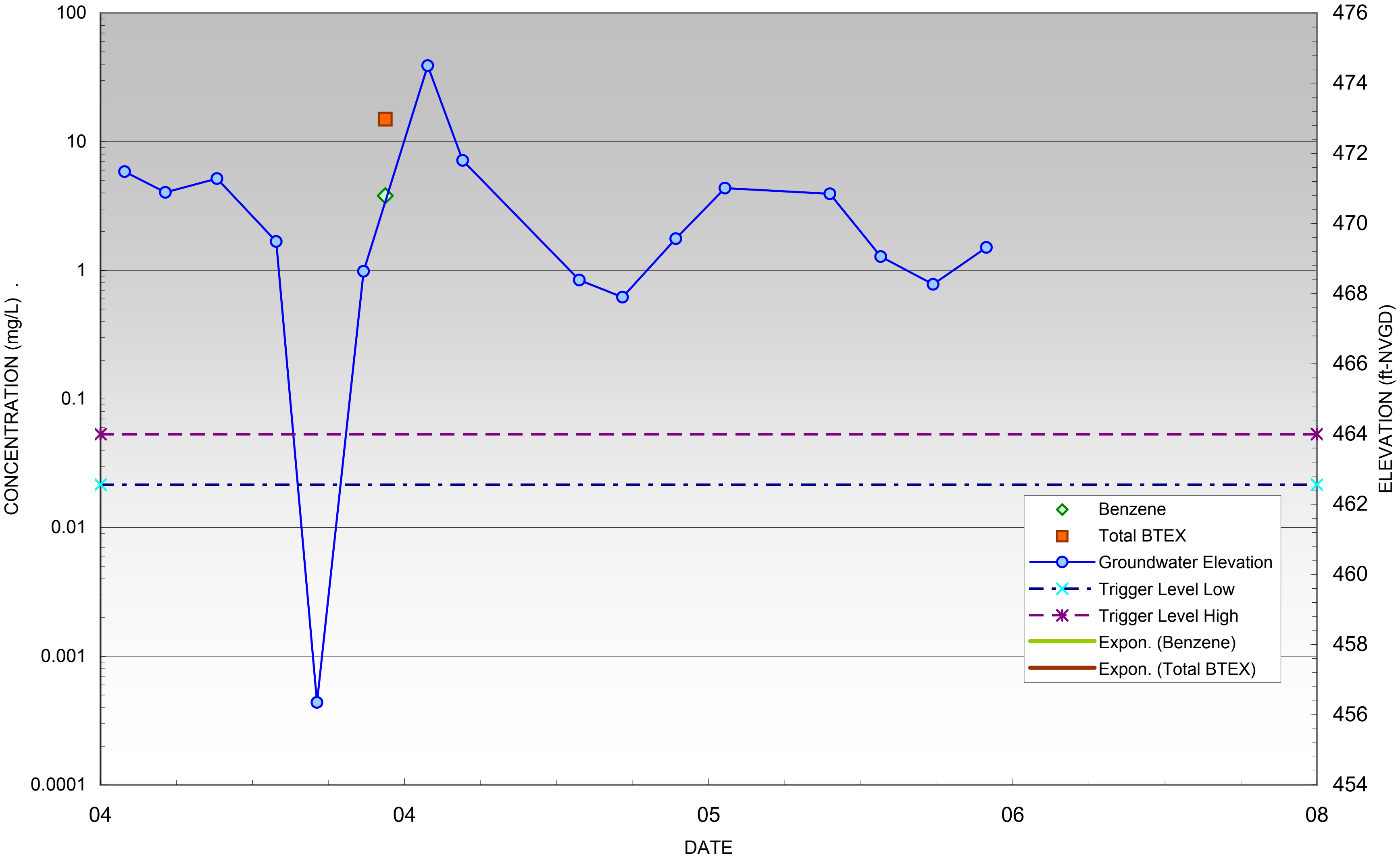

Figure B-1. L1-RR Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

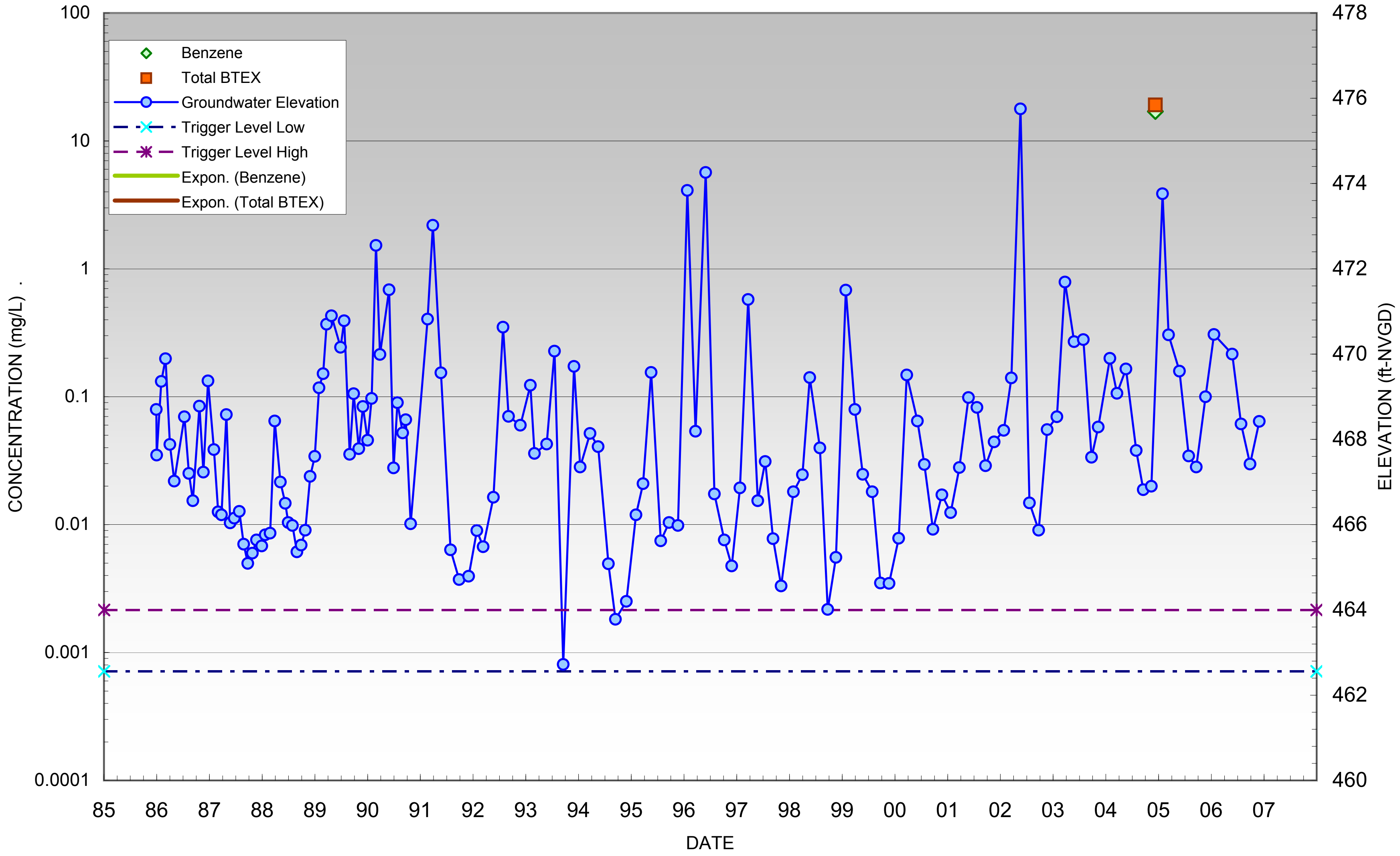

Figure B-2. L3-R Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

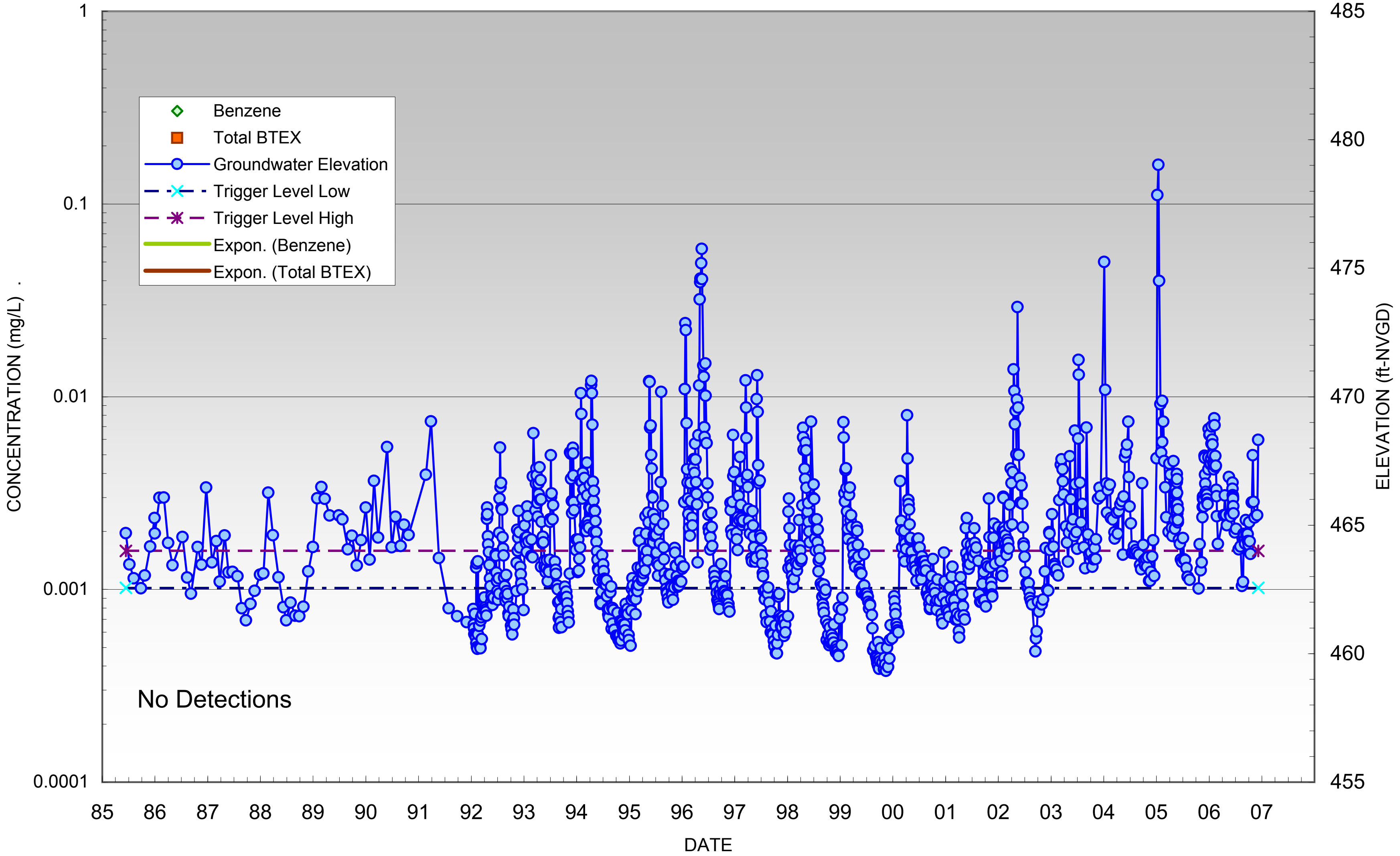

Figure B-3. MW-10 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

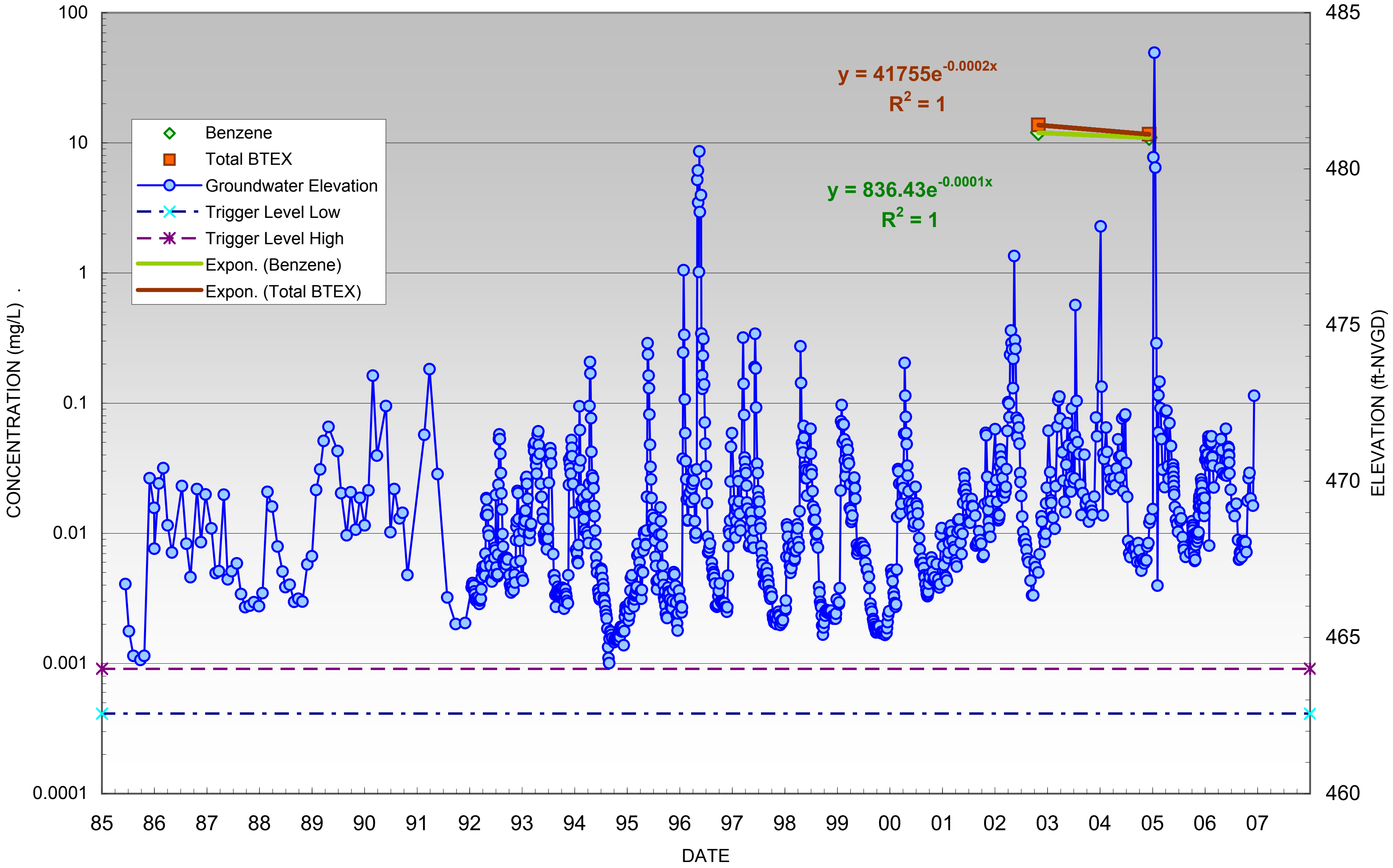

Figure B-4. MW-17 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

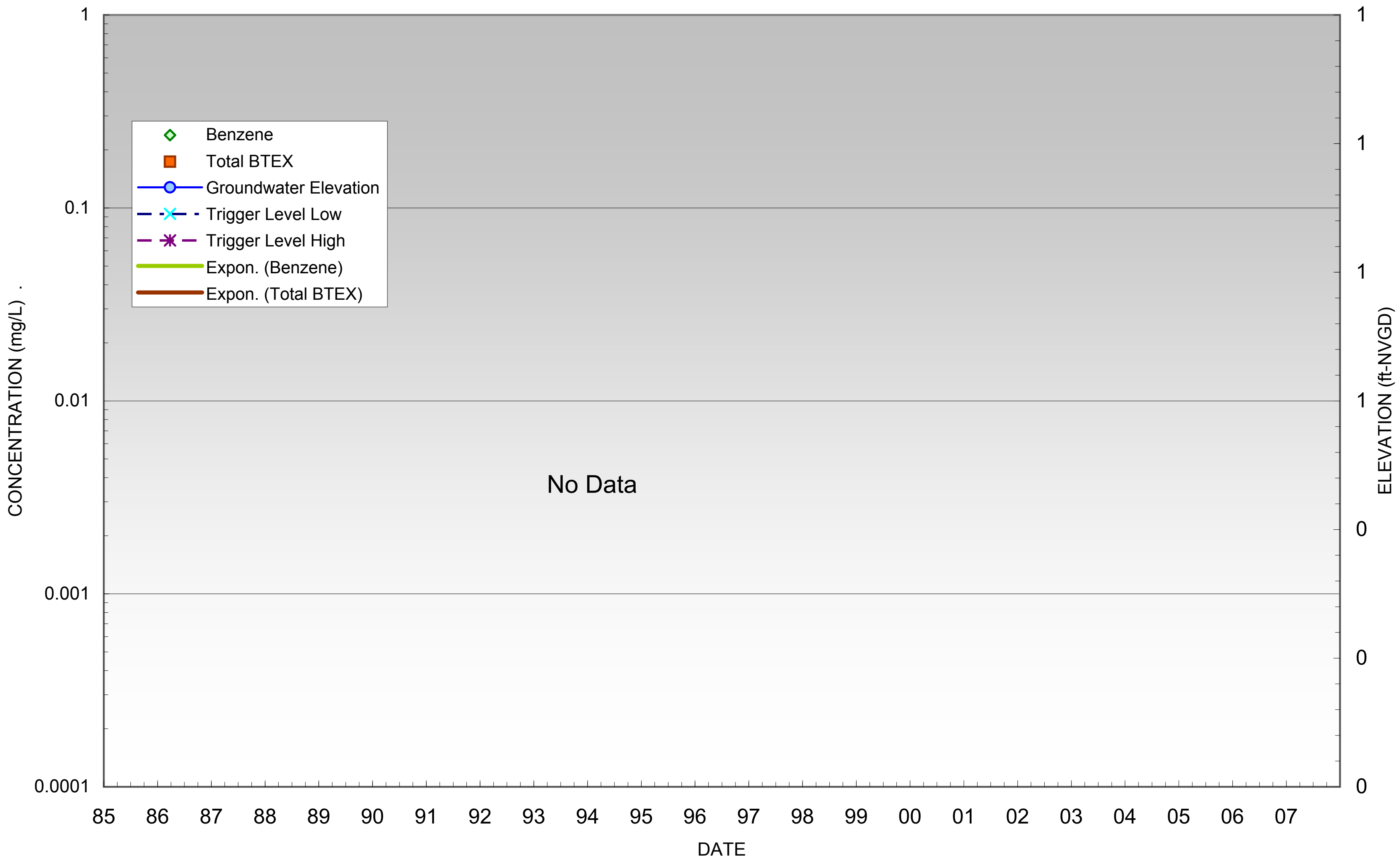

Figure B-5. MW-18R Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

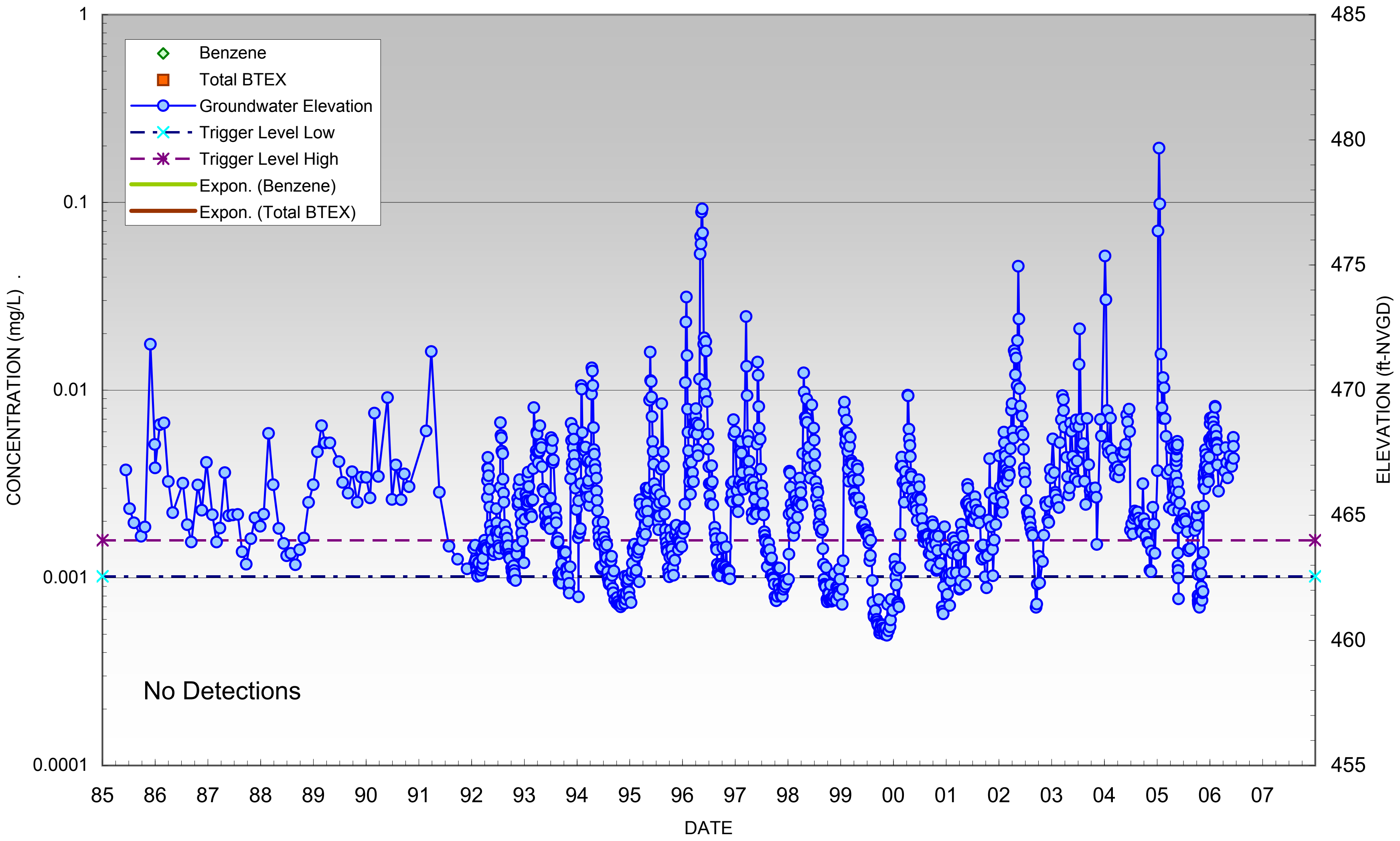

Figure B-6. MW-20S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

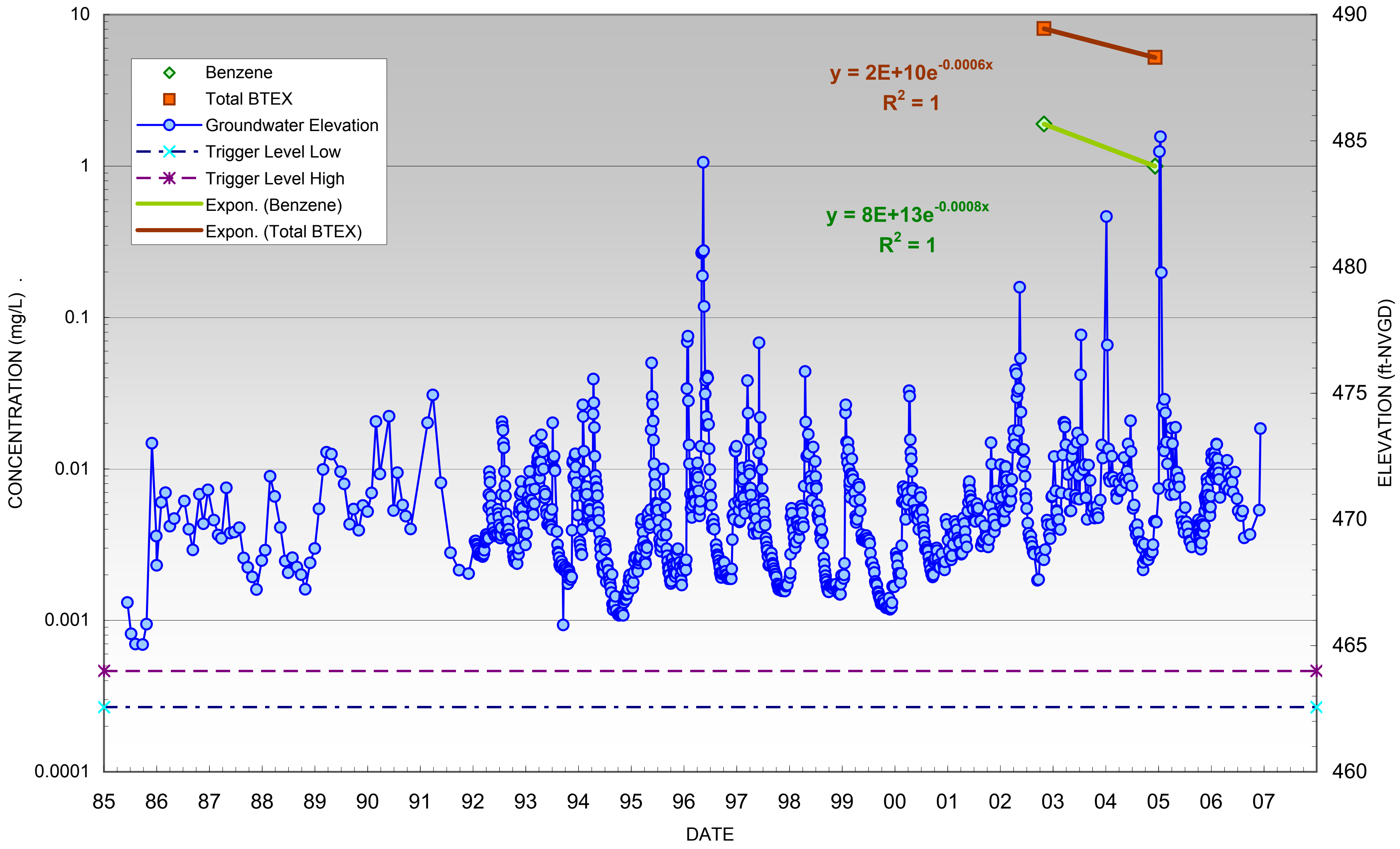

Figure B-7. MW-21 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

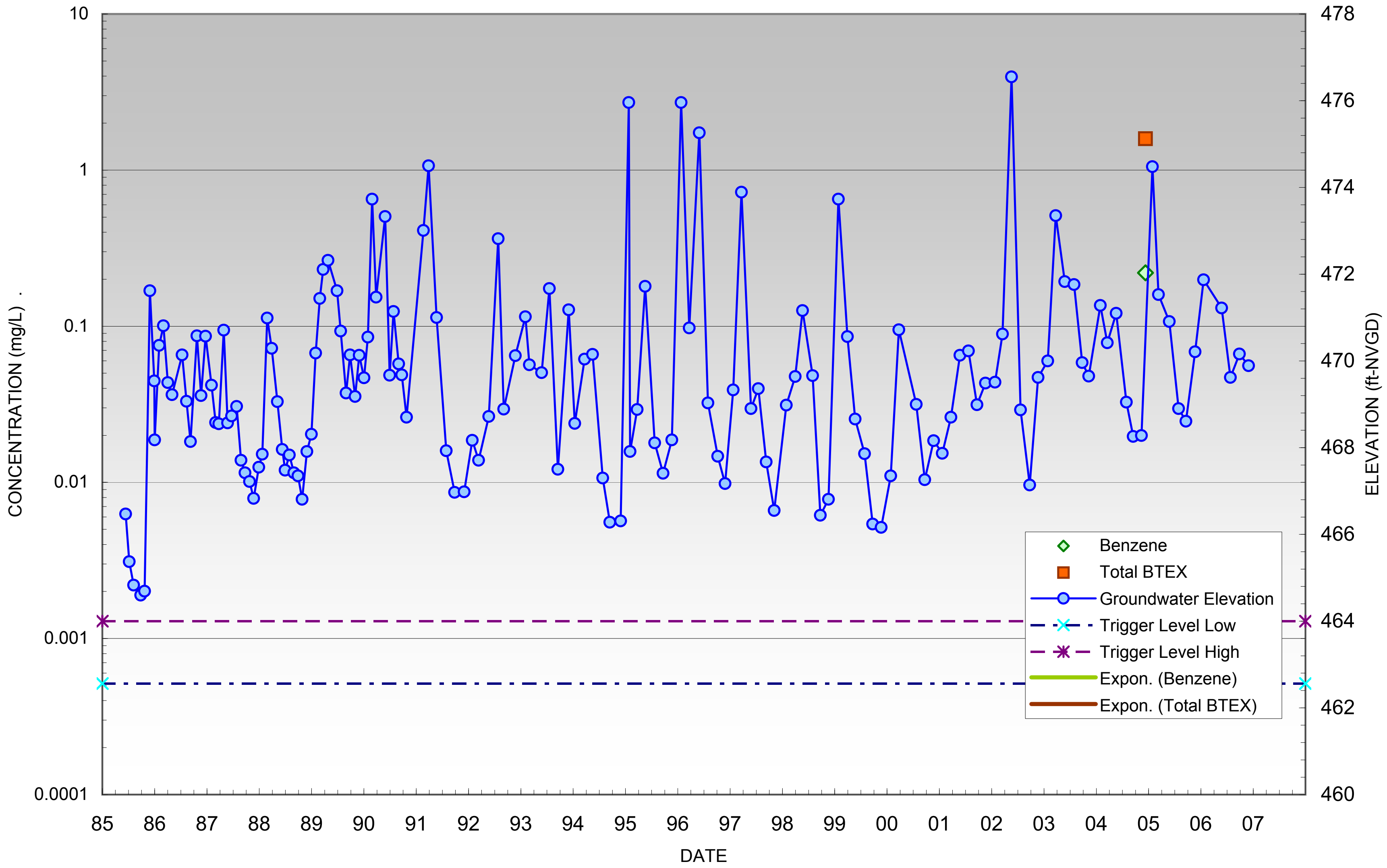

Figure B-8. MW-22 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

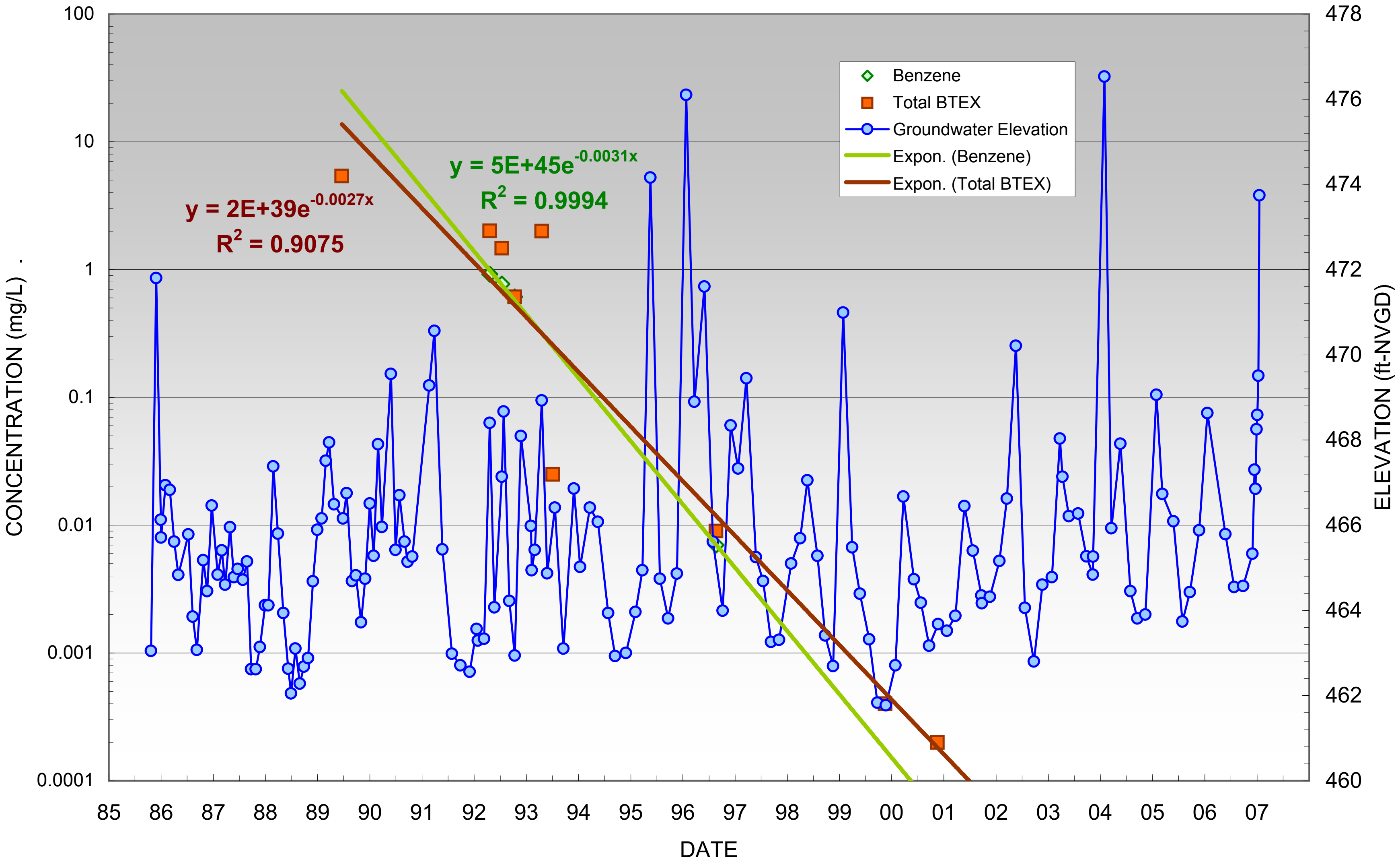

Figure B-9. MW-27 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

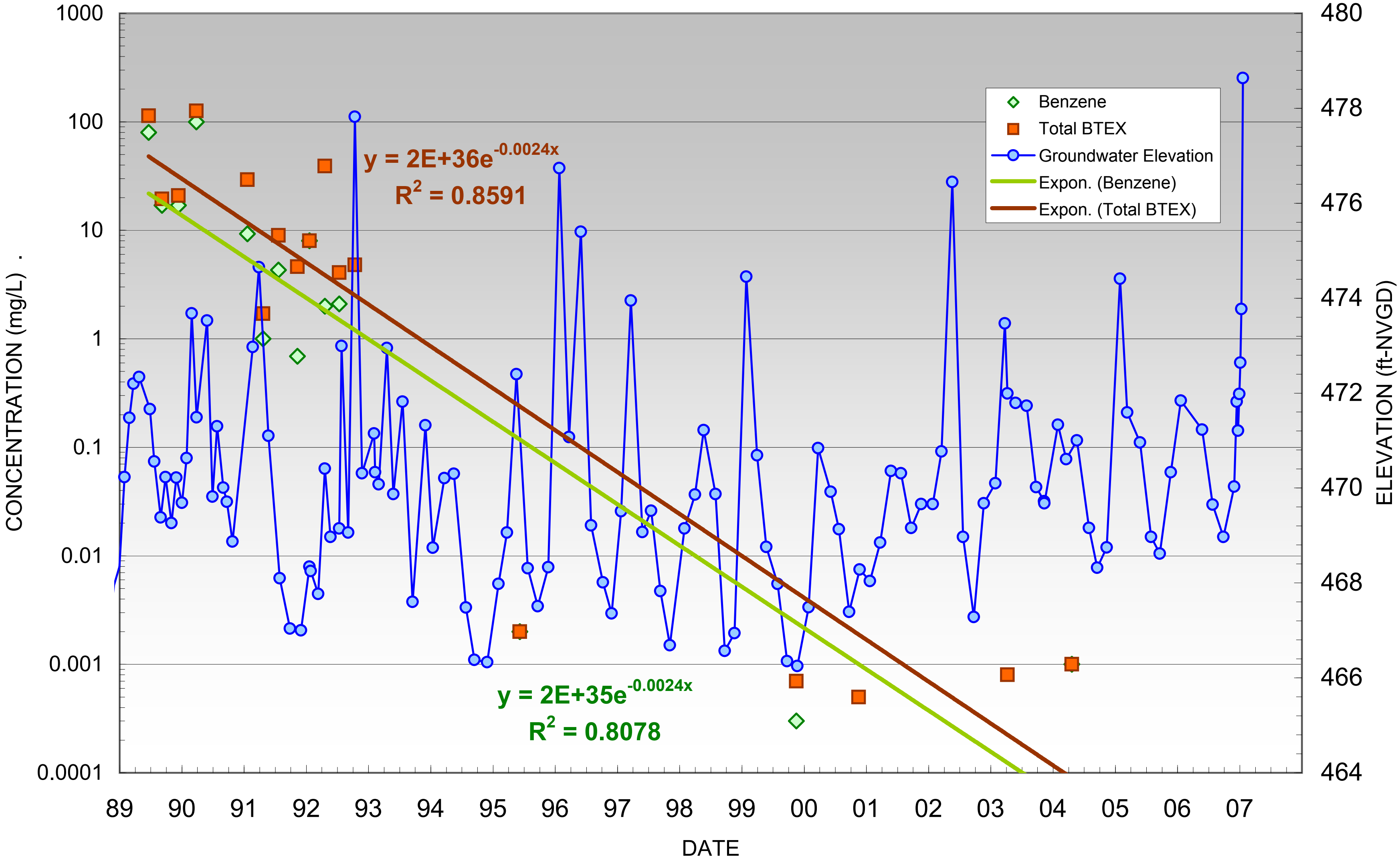

Figure B-10. MW-33 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

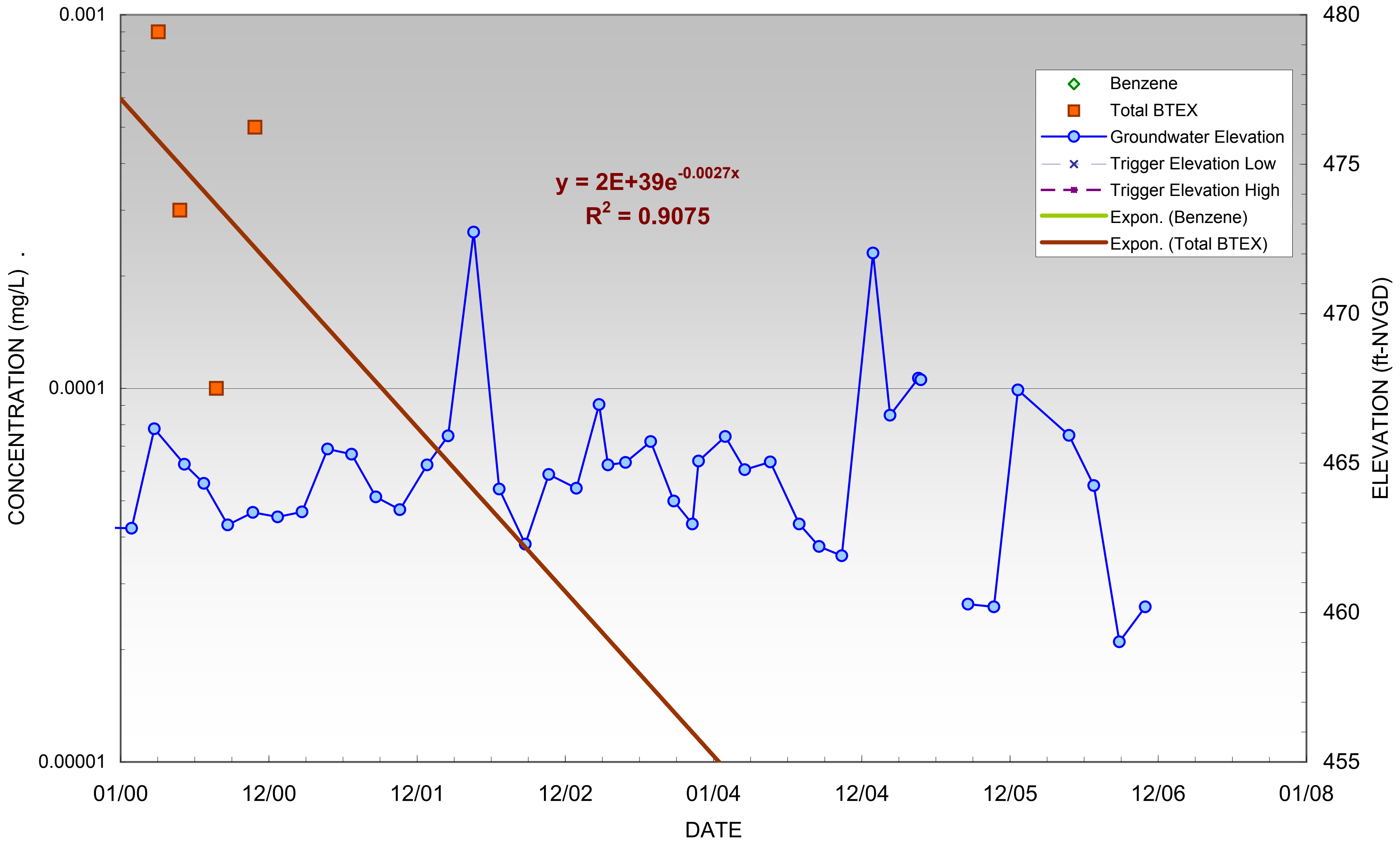

Figure B-11. MW-35 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

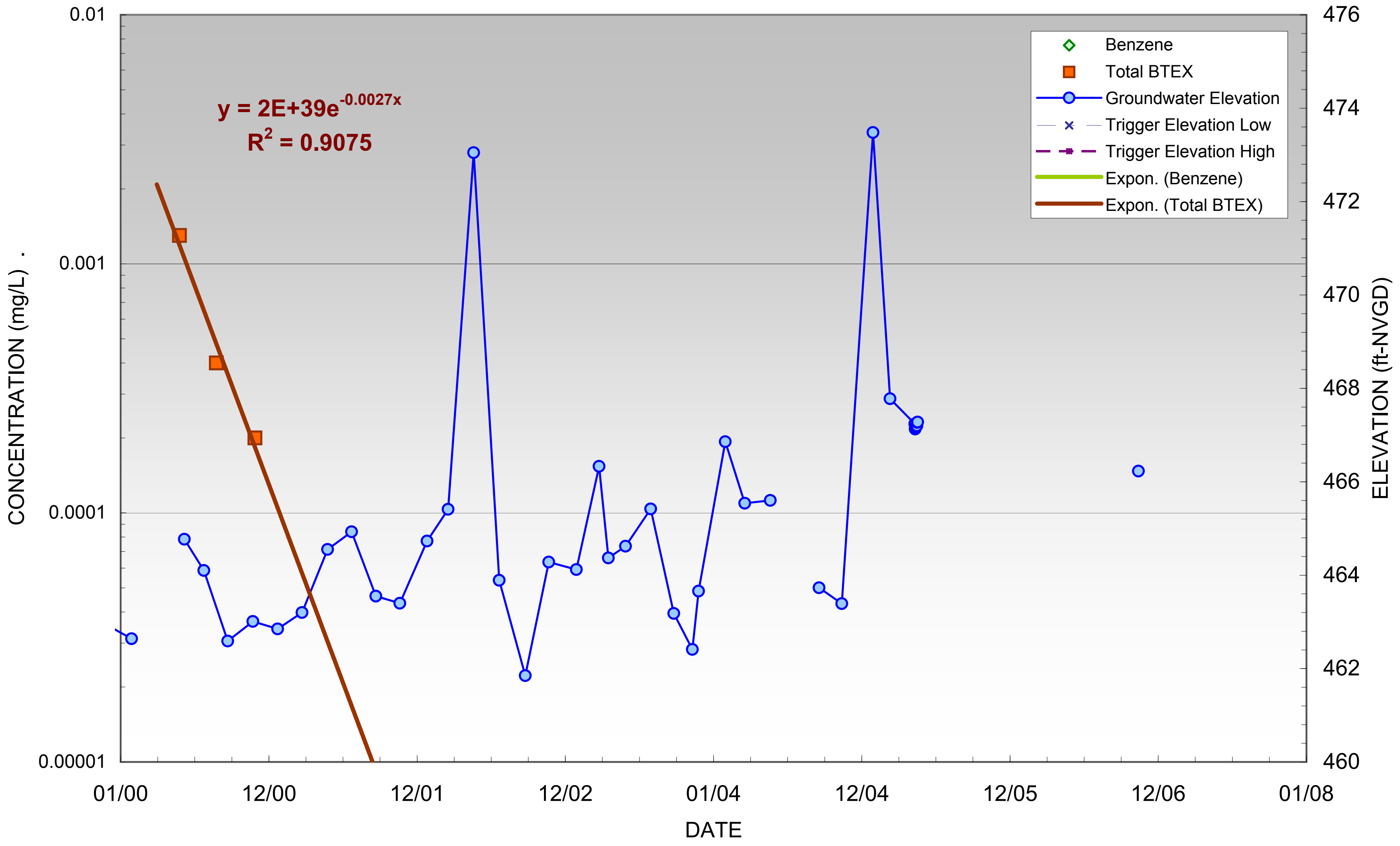

Figure B-12. MW-37 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

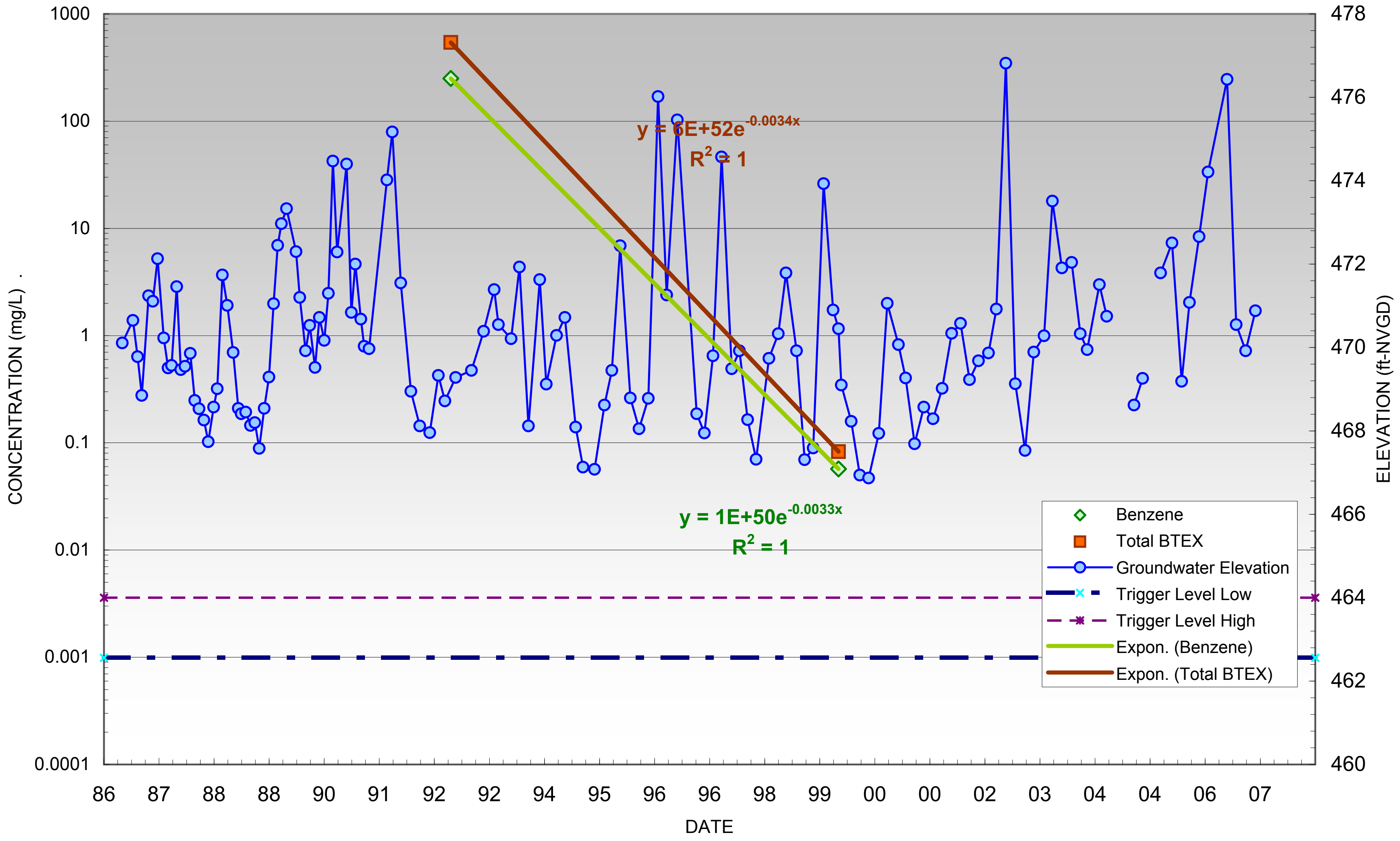

Figure B-13. MW-38 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

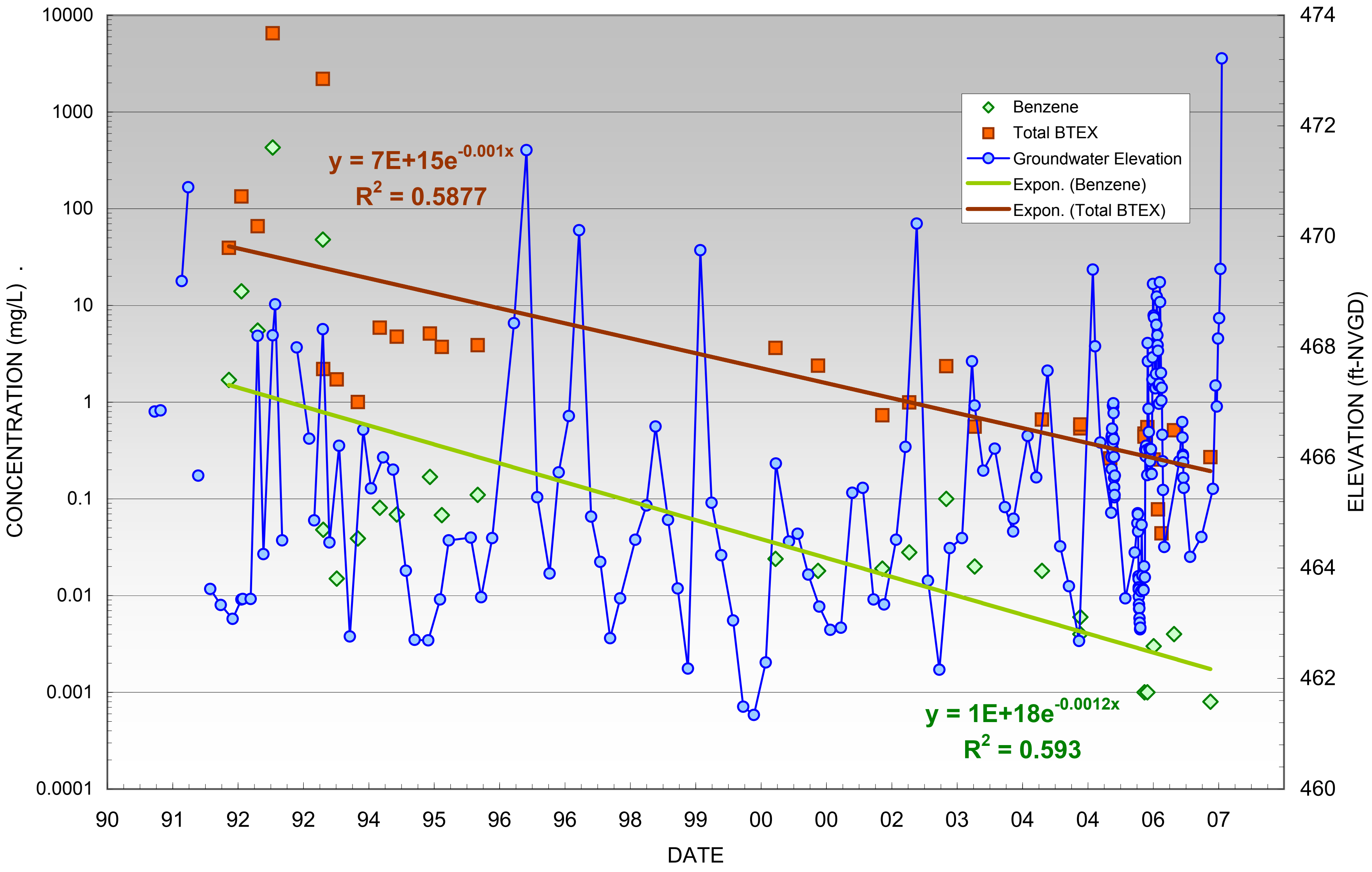

Figure B-14. MW-48S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

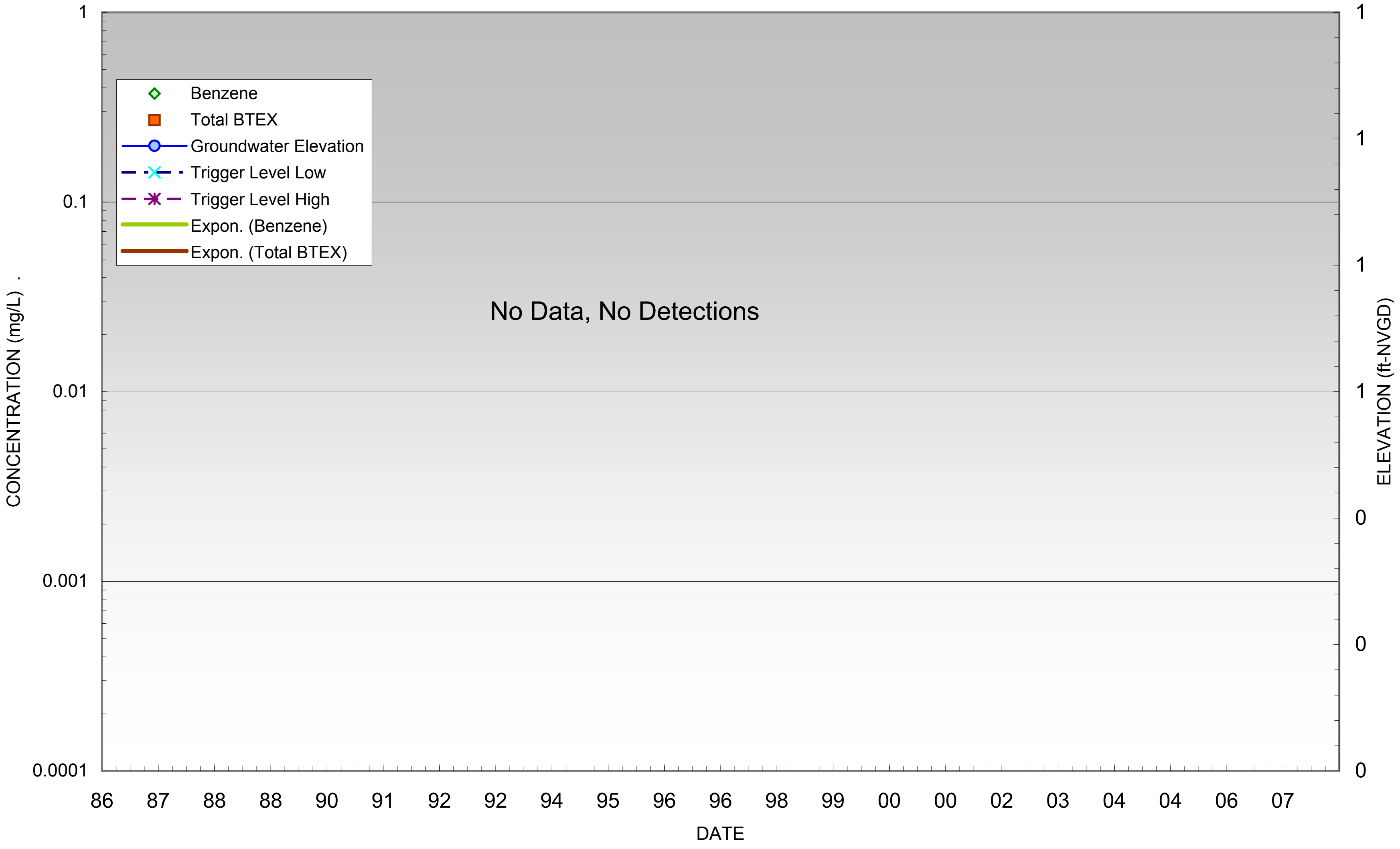

Figure B-15. MW-51 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

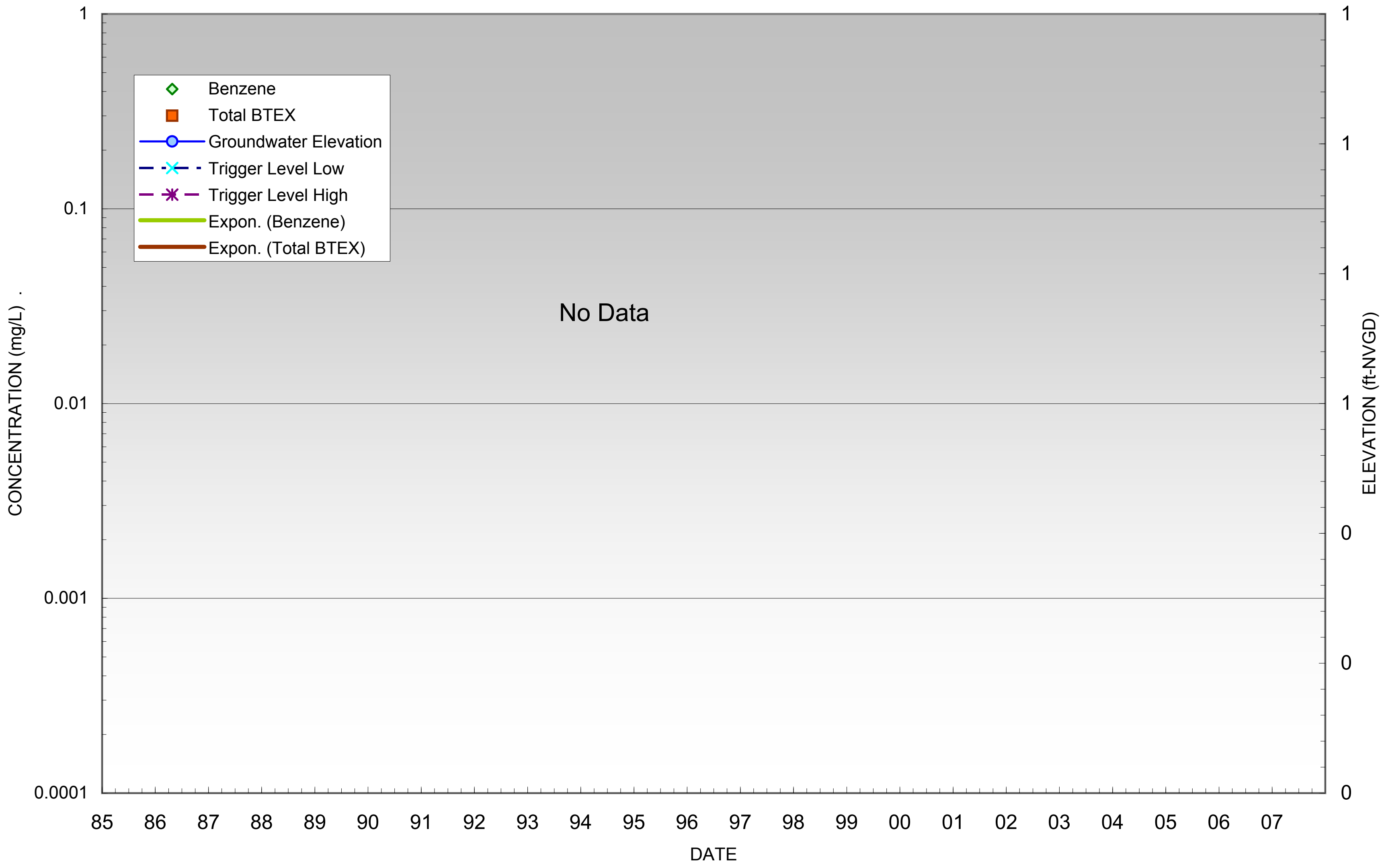

Figure B-16. MW-58S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

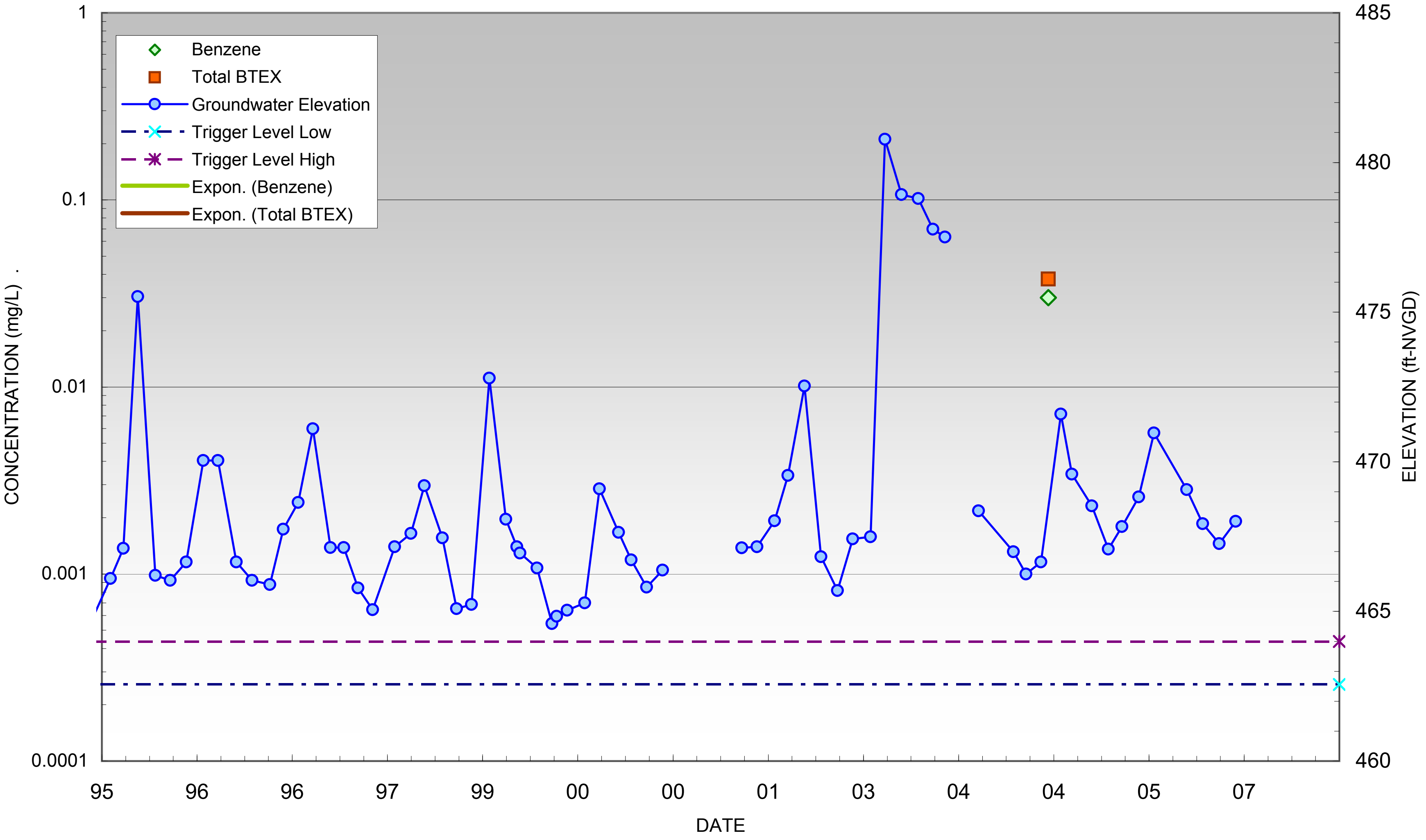

Figure B-17. MW-64 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

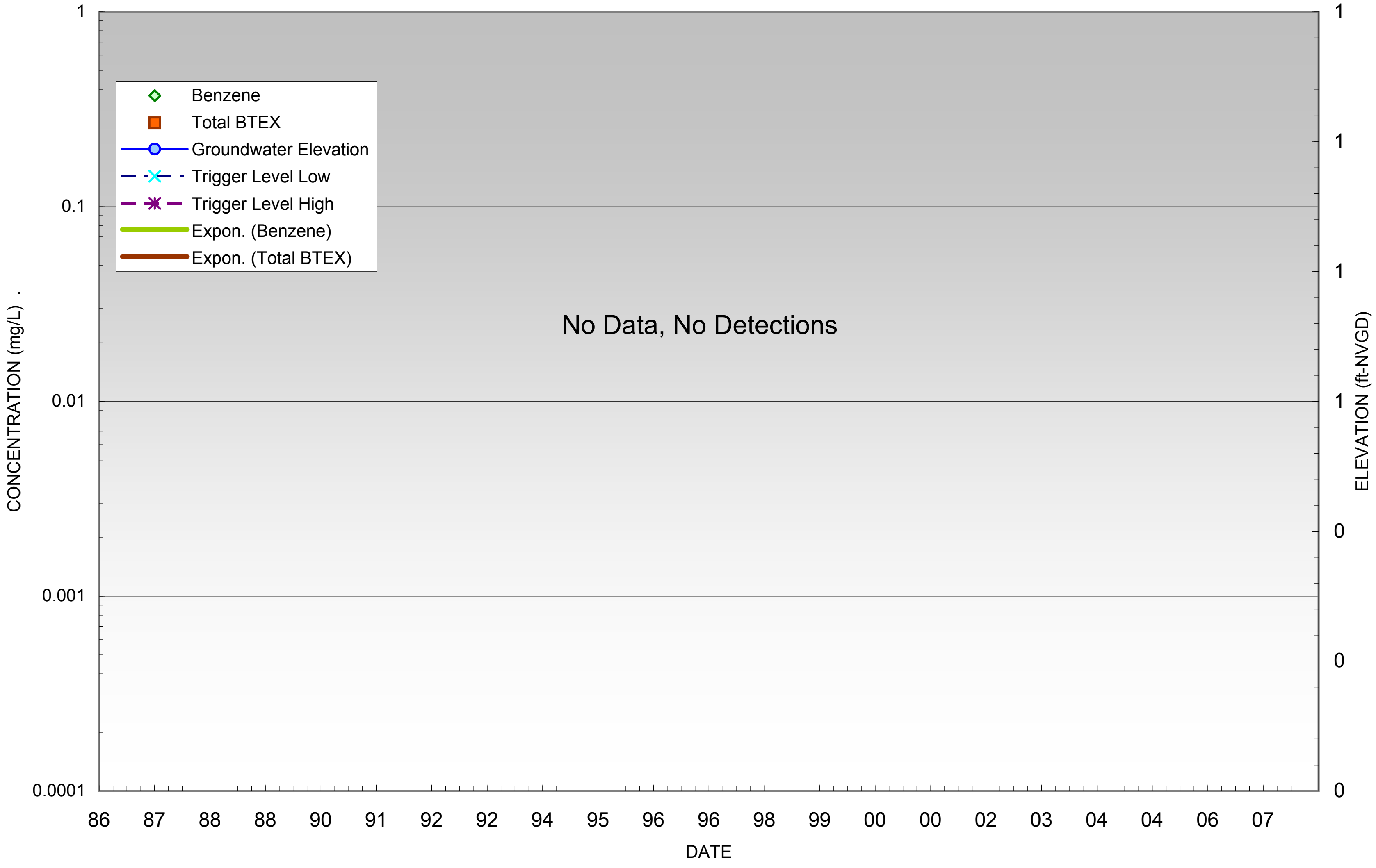

Figure B-18. MW-80 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

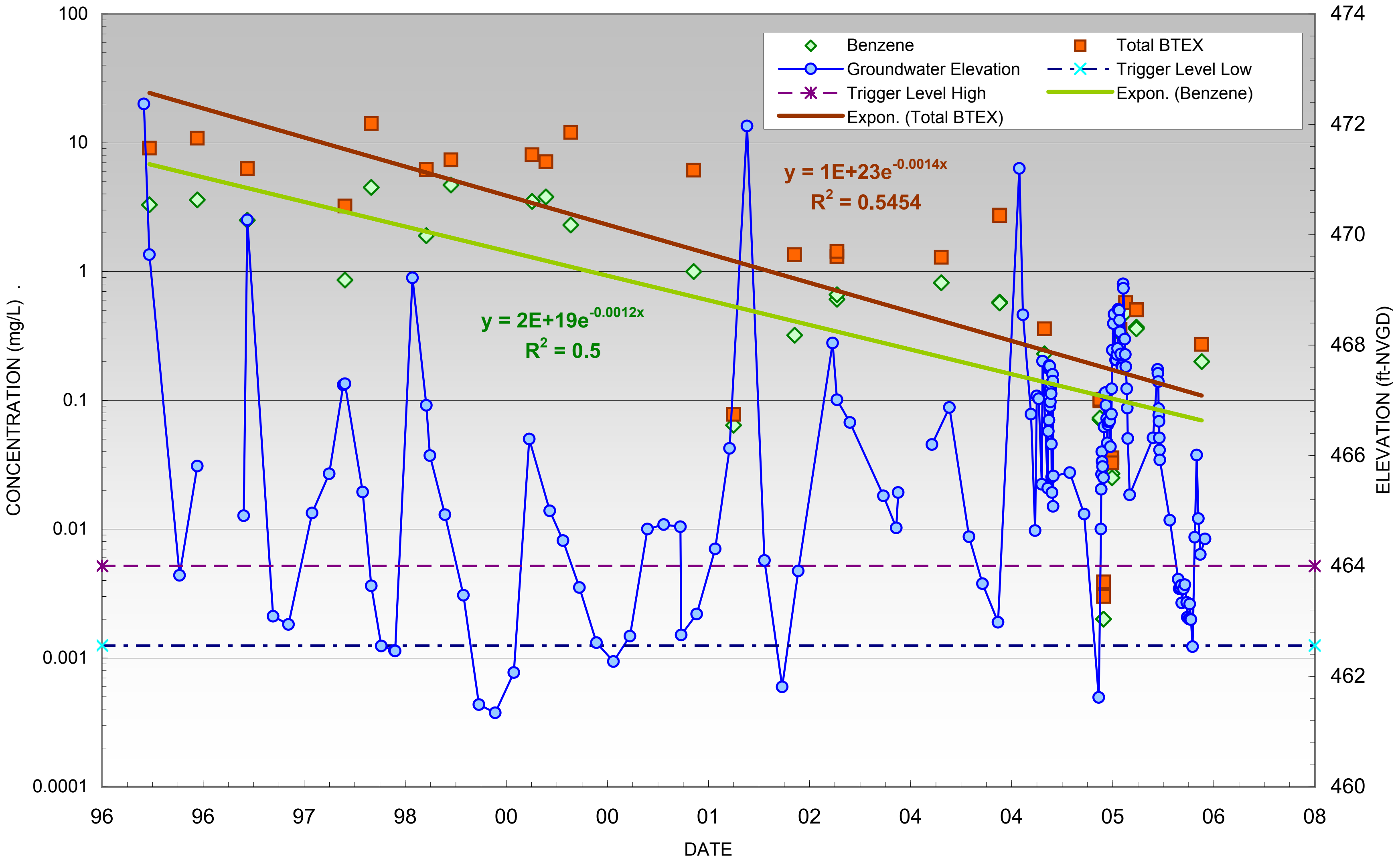

Figure B-19. MW-81S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

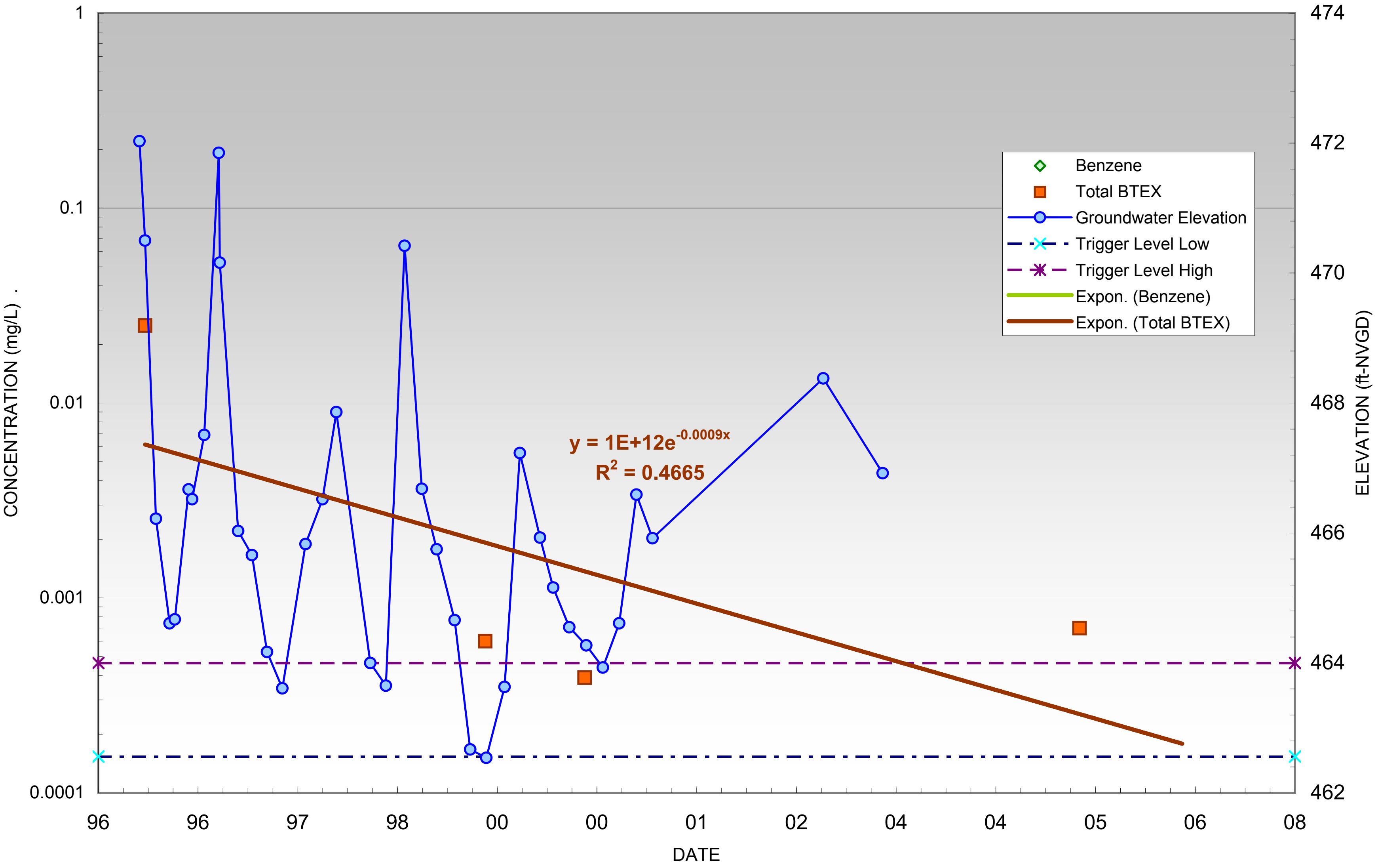

Figure B-20. MW-85D Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

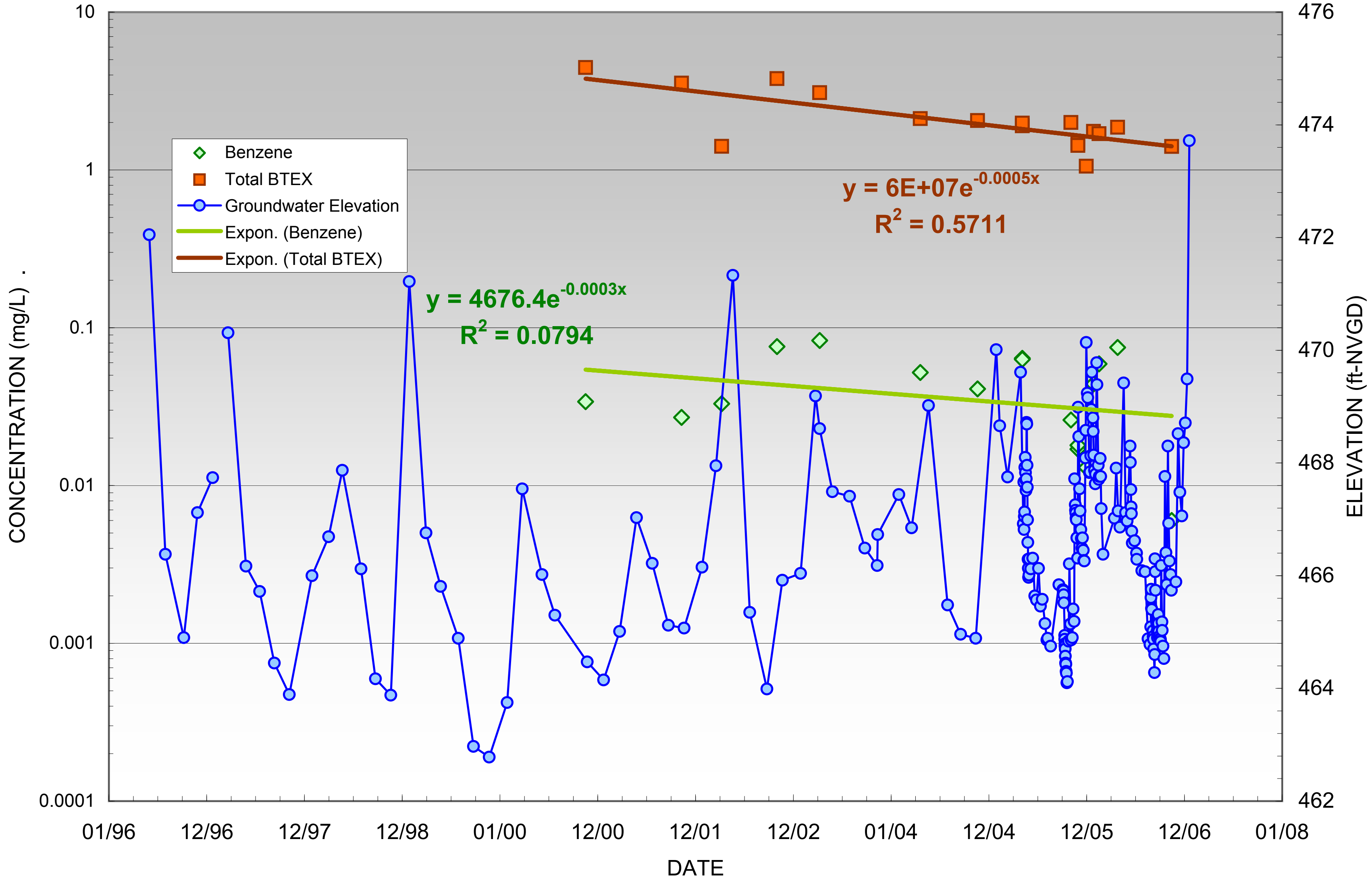

Figure B-21. MW-85S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

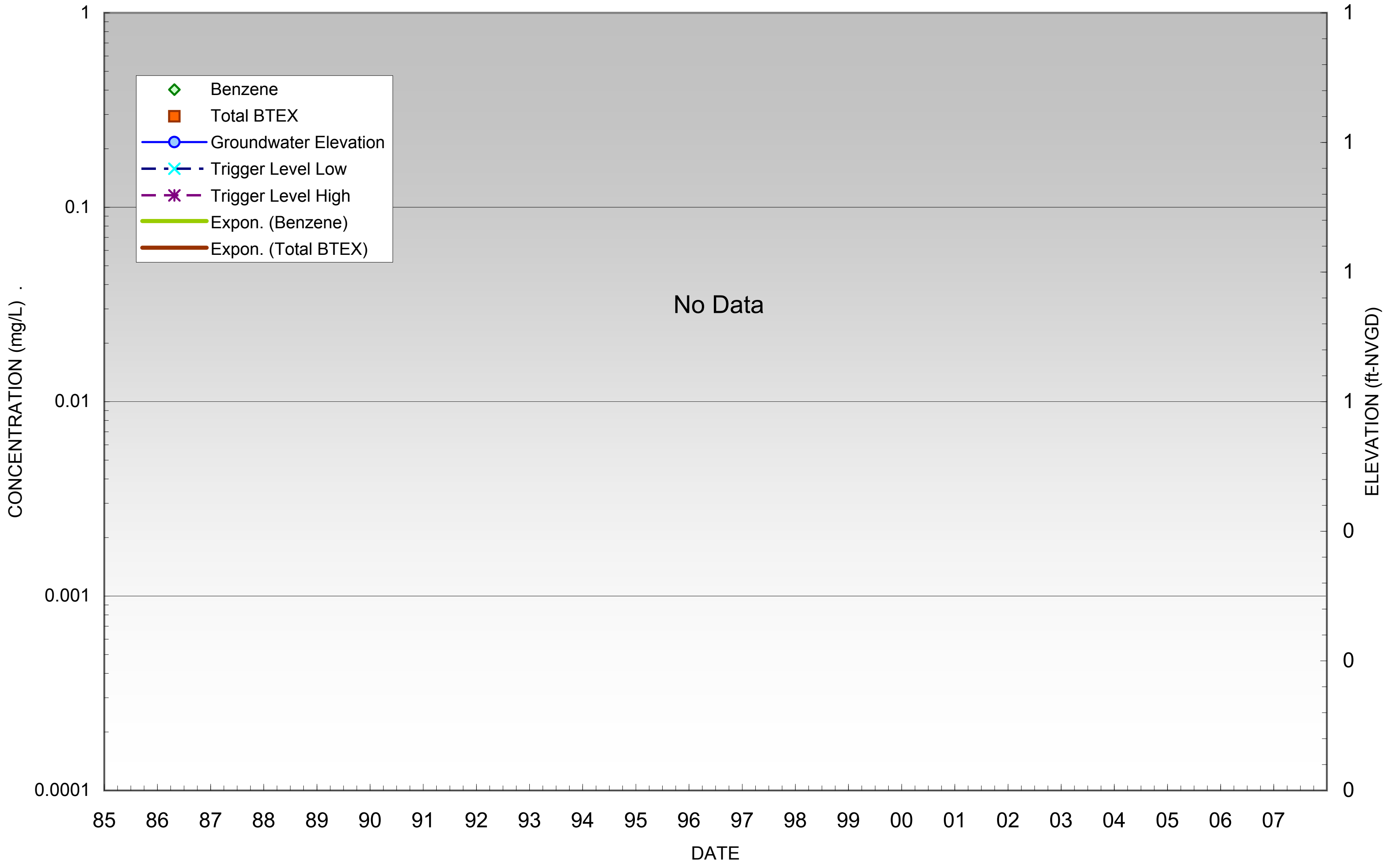

Figure B-22. MW-88 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

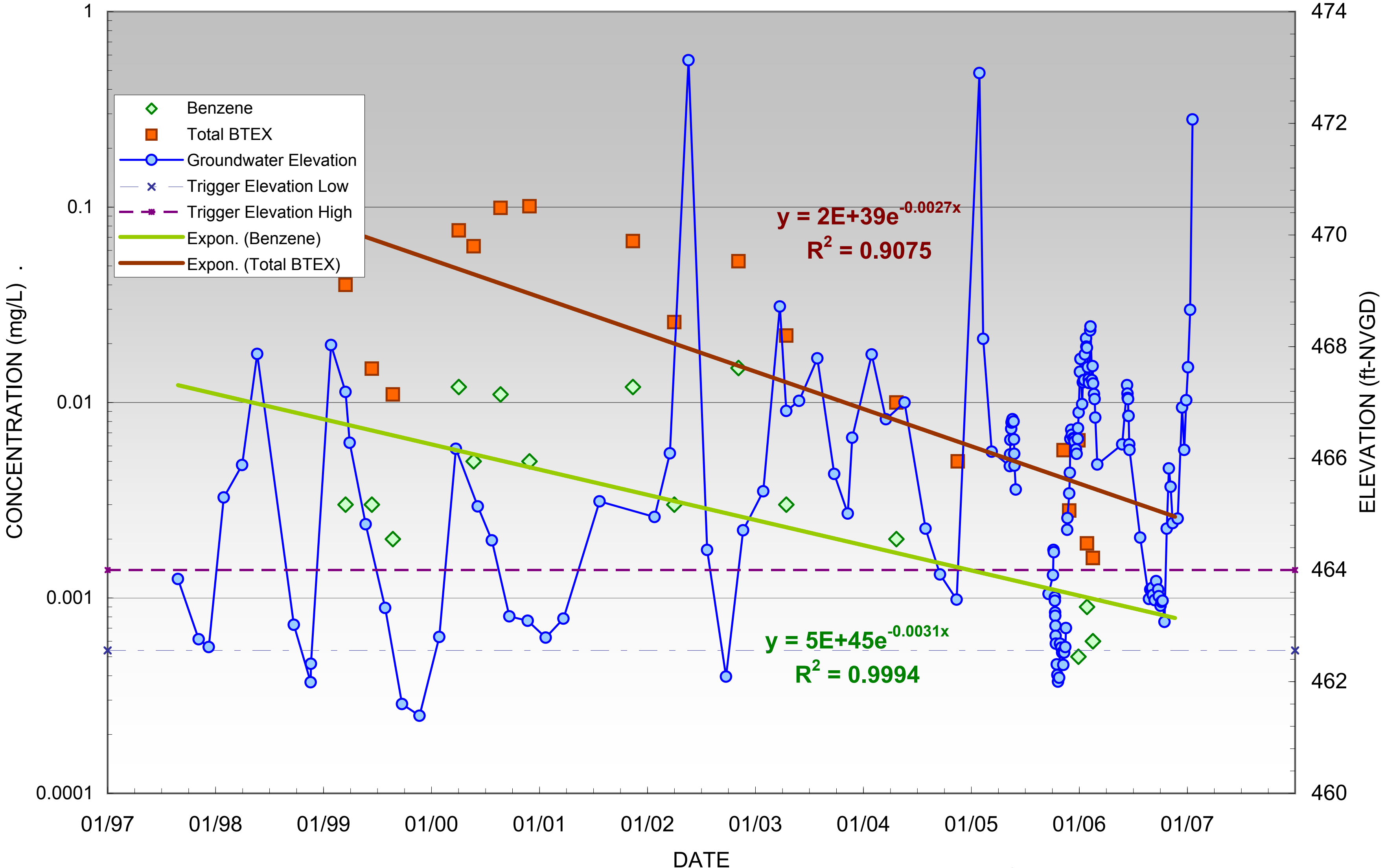

Figure B-23. MW-94S Dissolved-Phase Constituent Concentration vs. Time ($C=C_o*e^{-kt}$)

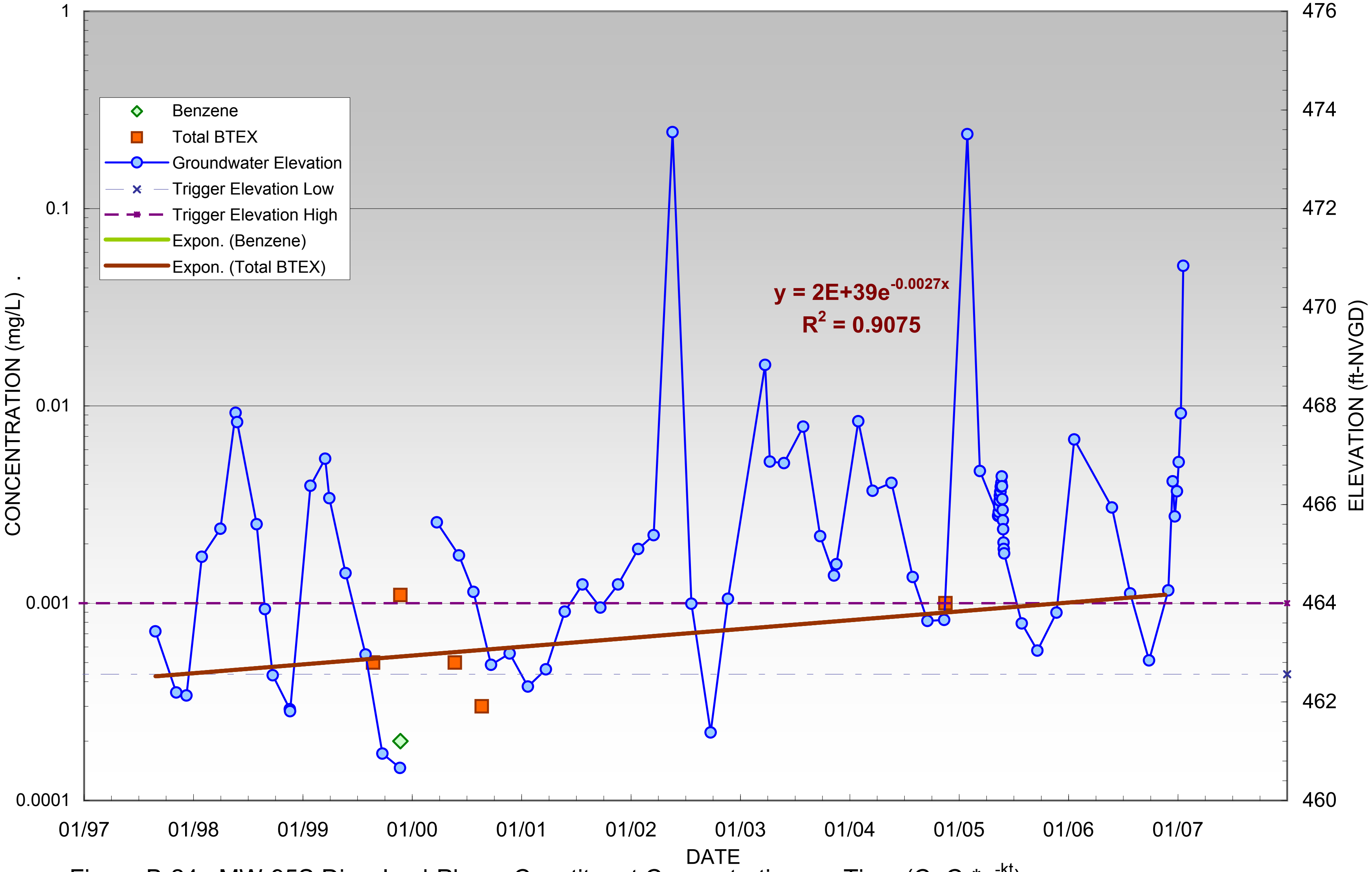

Figure B-24. MW-95S Dissolved-Phase Constituent Concentration vs. Time ($C=C_o*e^{-kt}$)

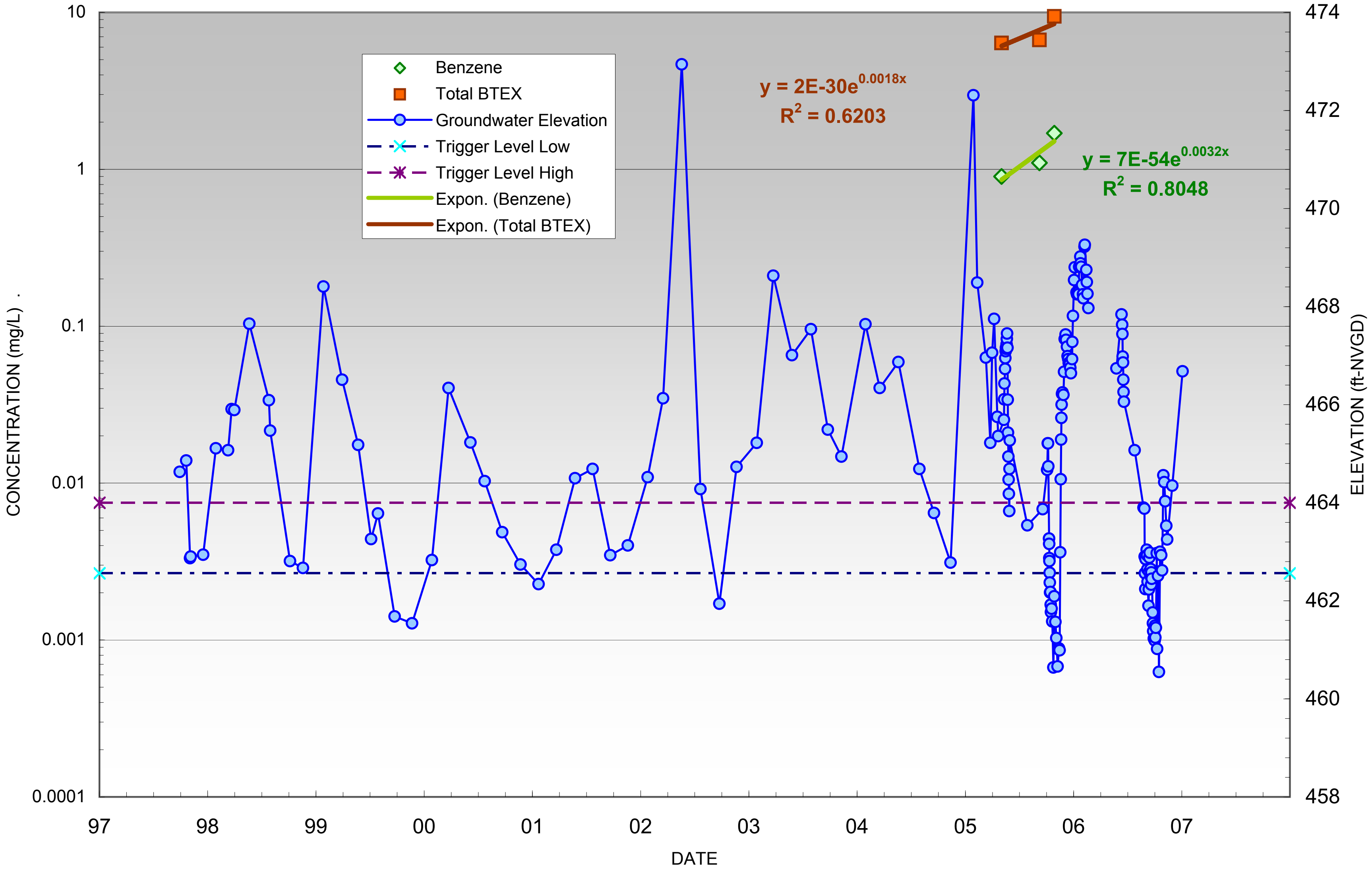

Figure B-25. MW-96S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

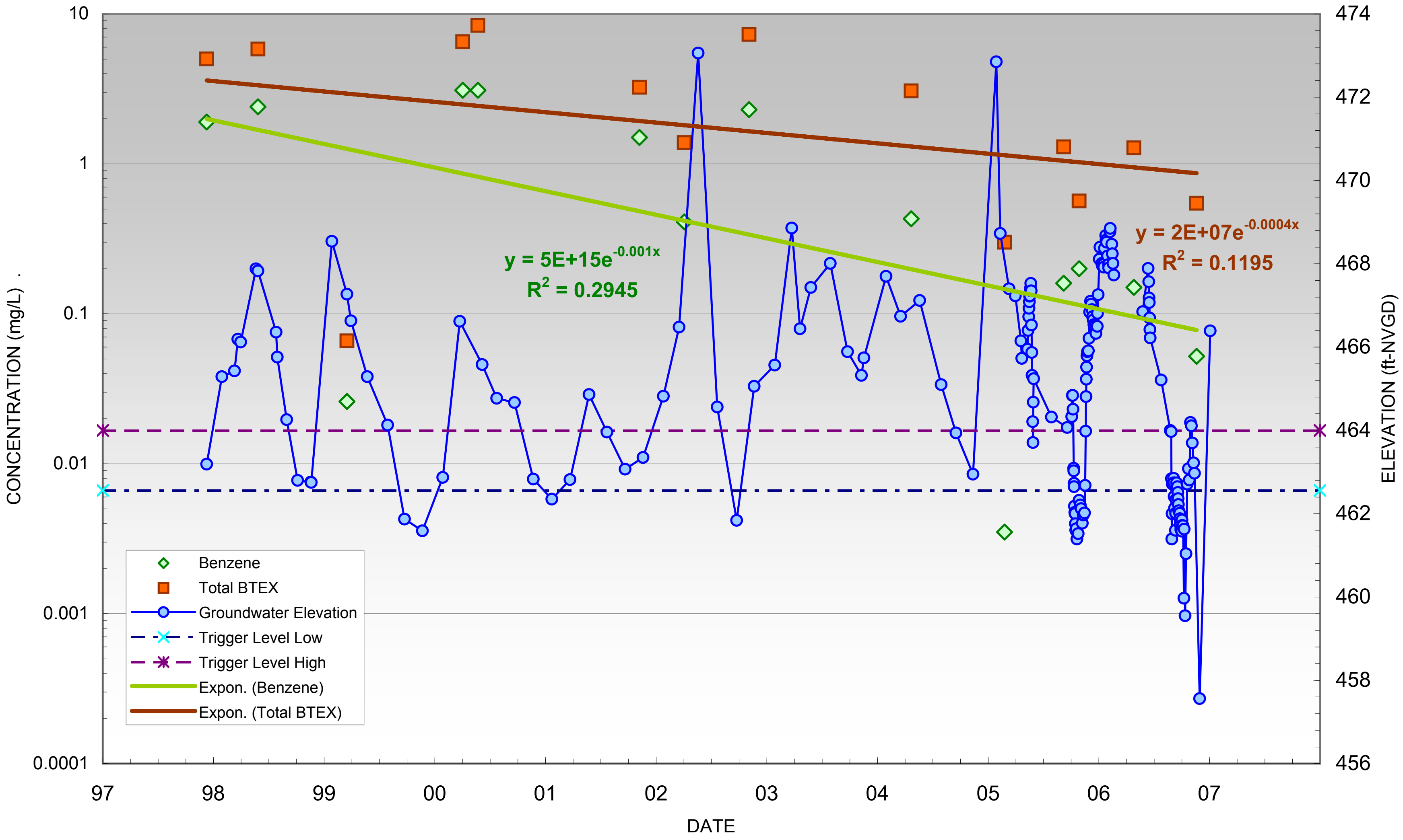

Figure B-26. MW-99S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

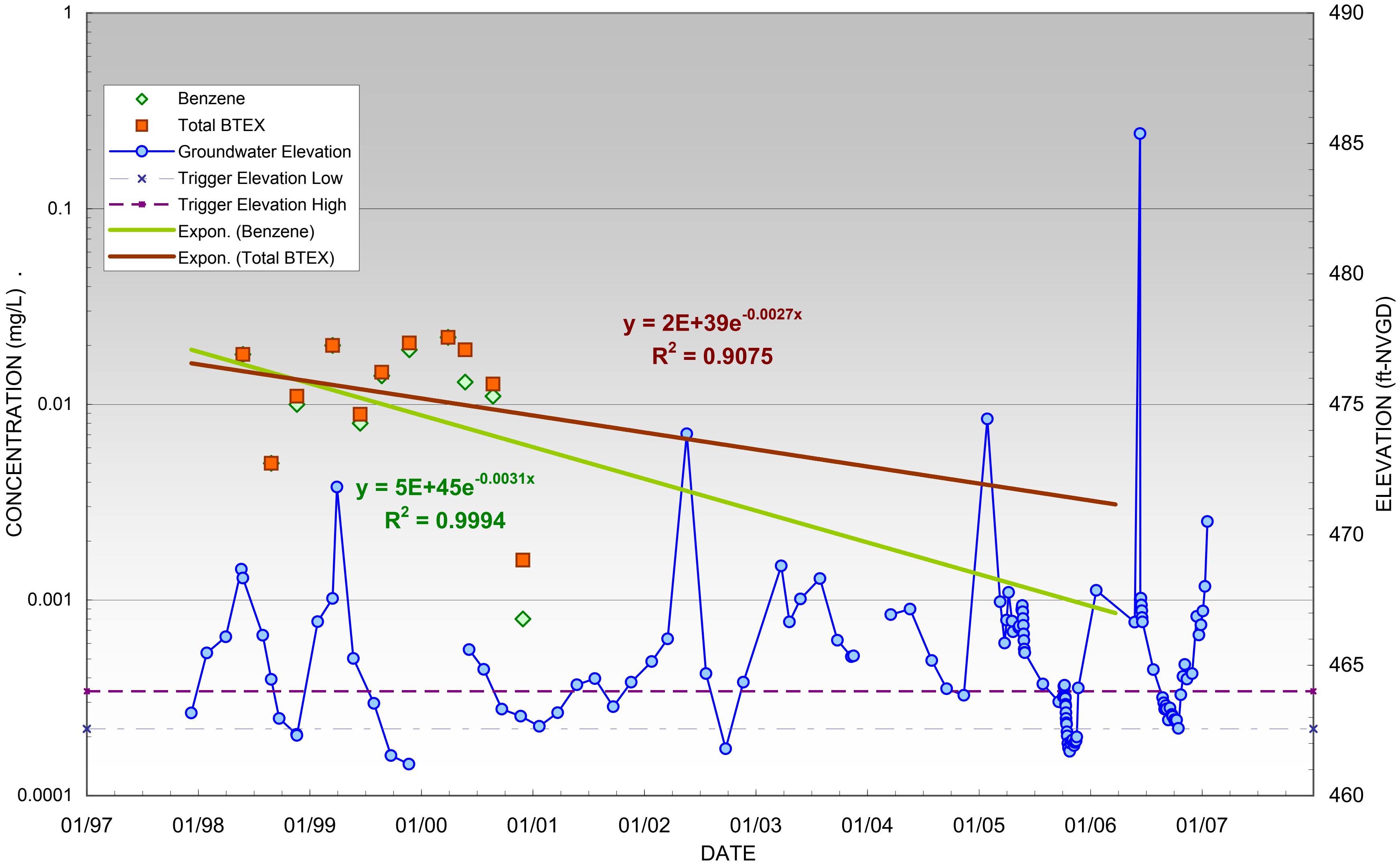

Figure B-27. MW-100S Dissolved-Phase Constituent Concentration vs. Time ($C=C_o*e^{-kt}$)

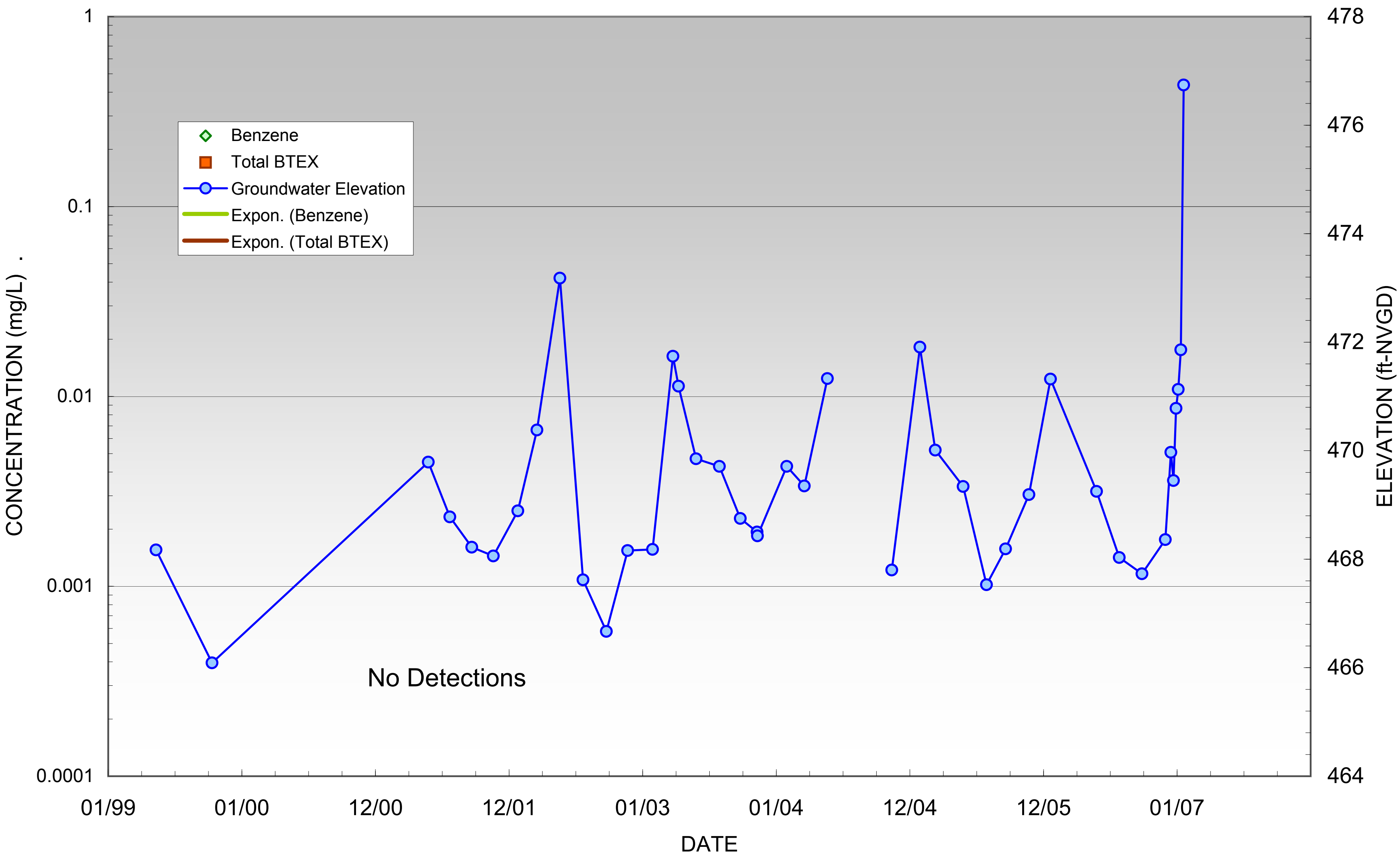

Figure B-28. MW-104S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

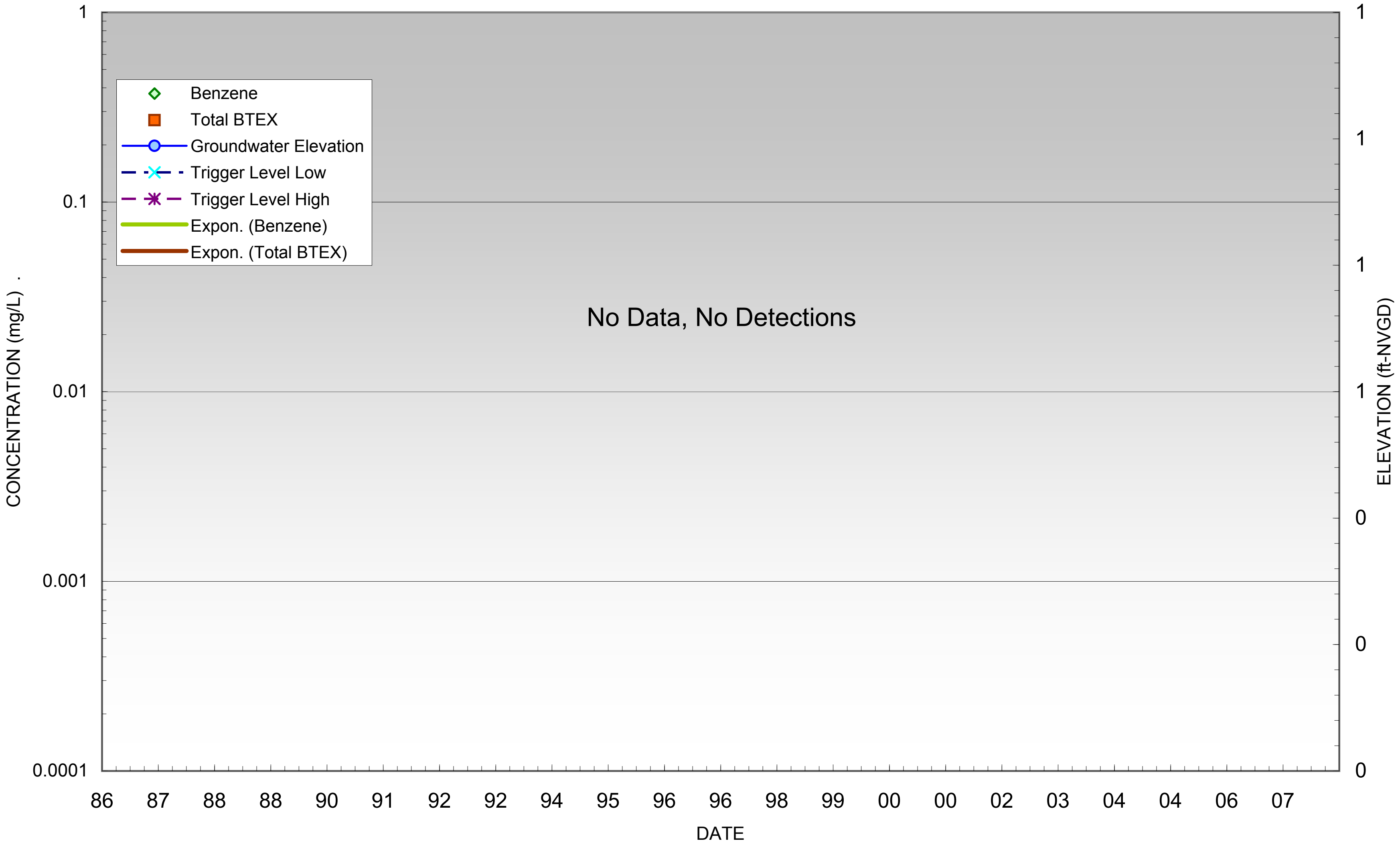

Figure B-29. MW-112 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

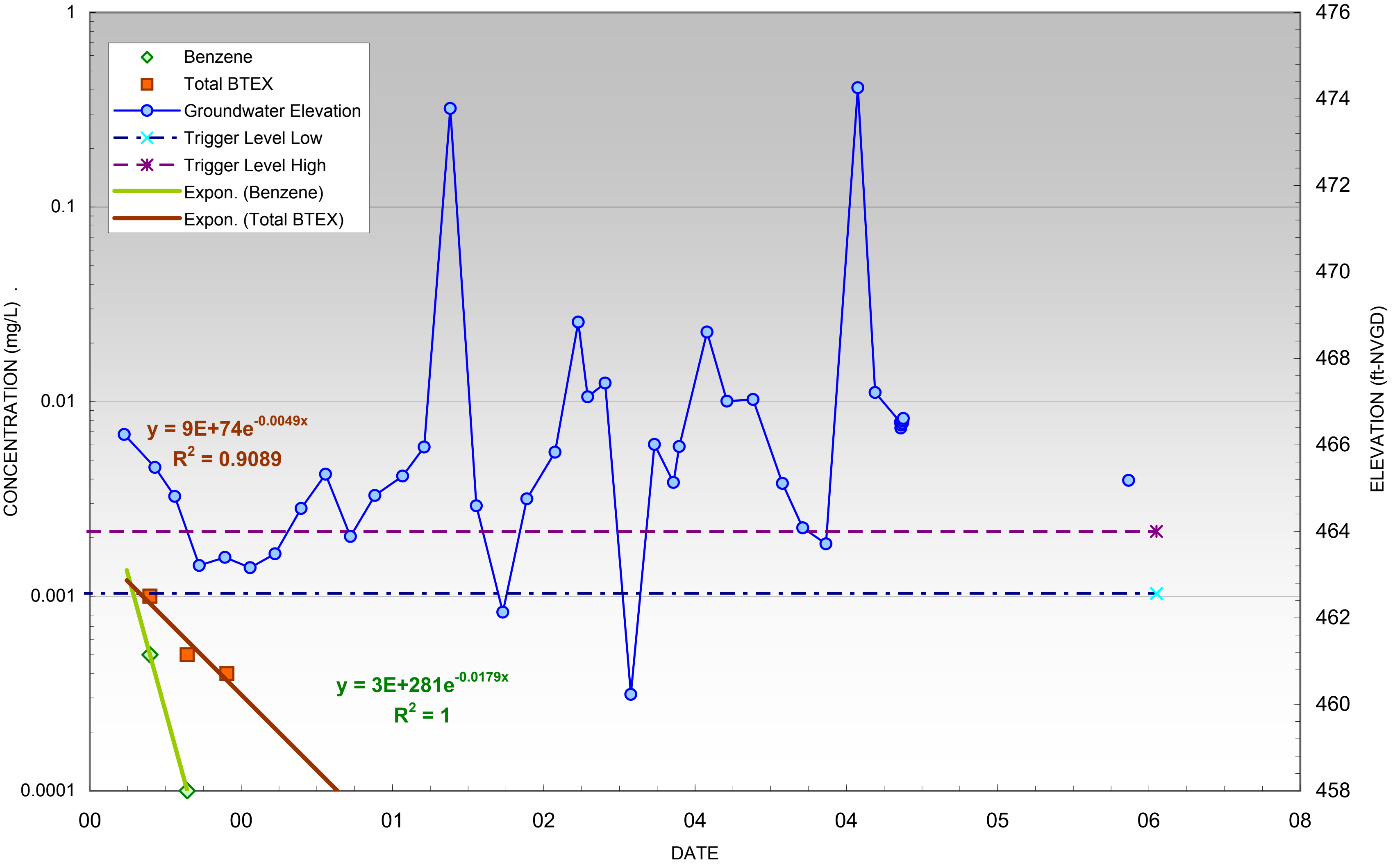

Figure B-30. MW-114 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

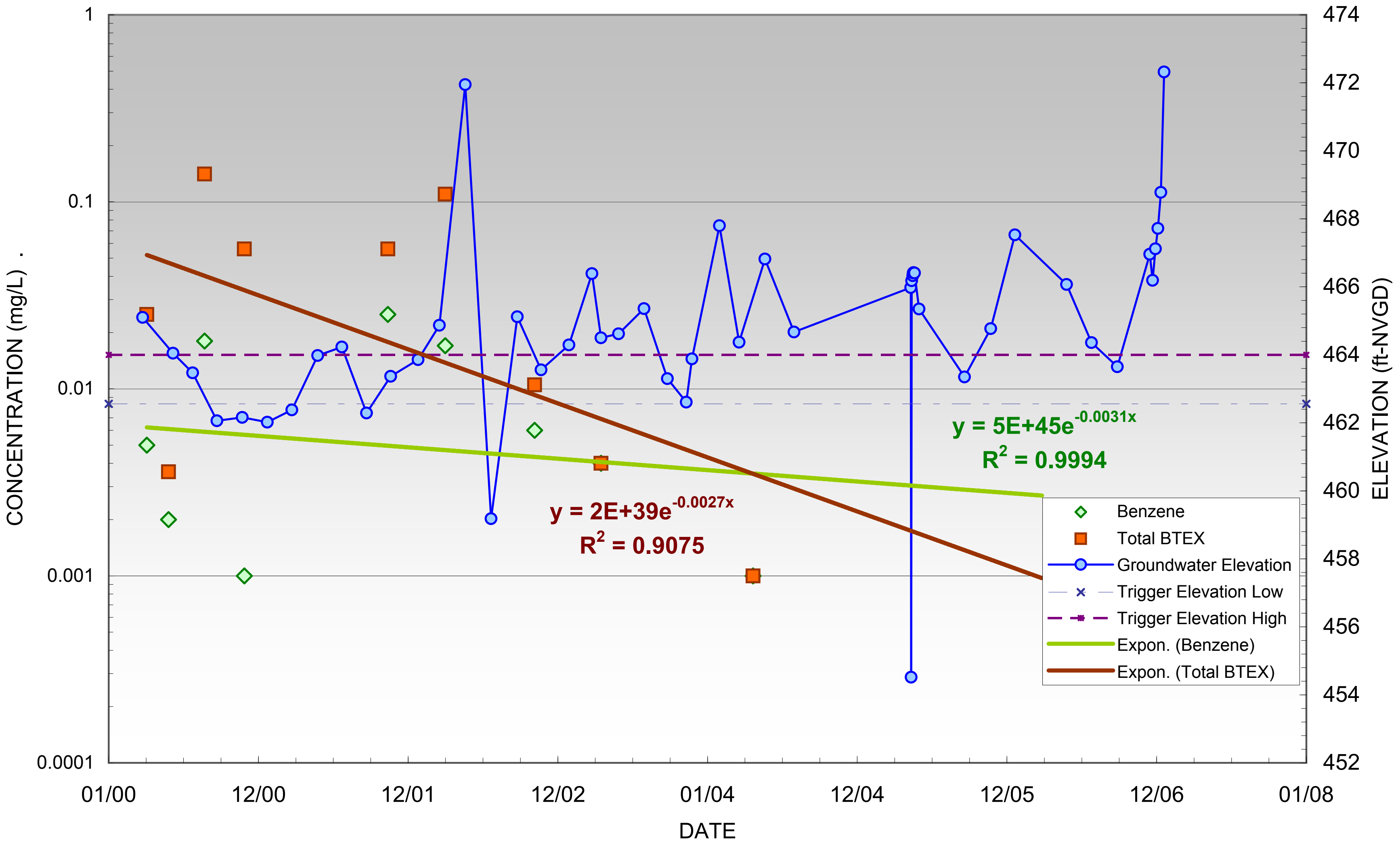

Figure B-31. MW-115S Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)

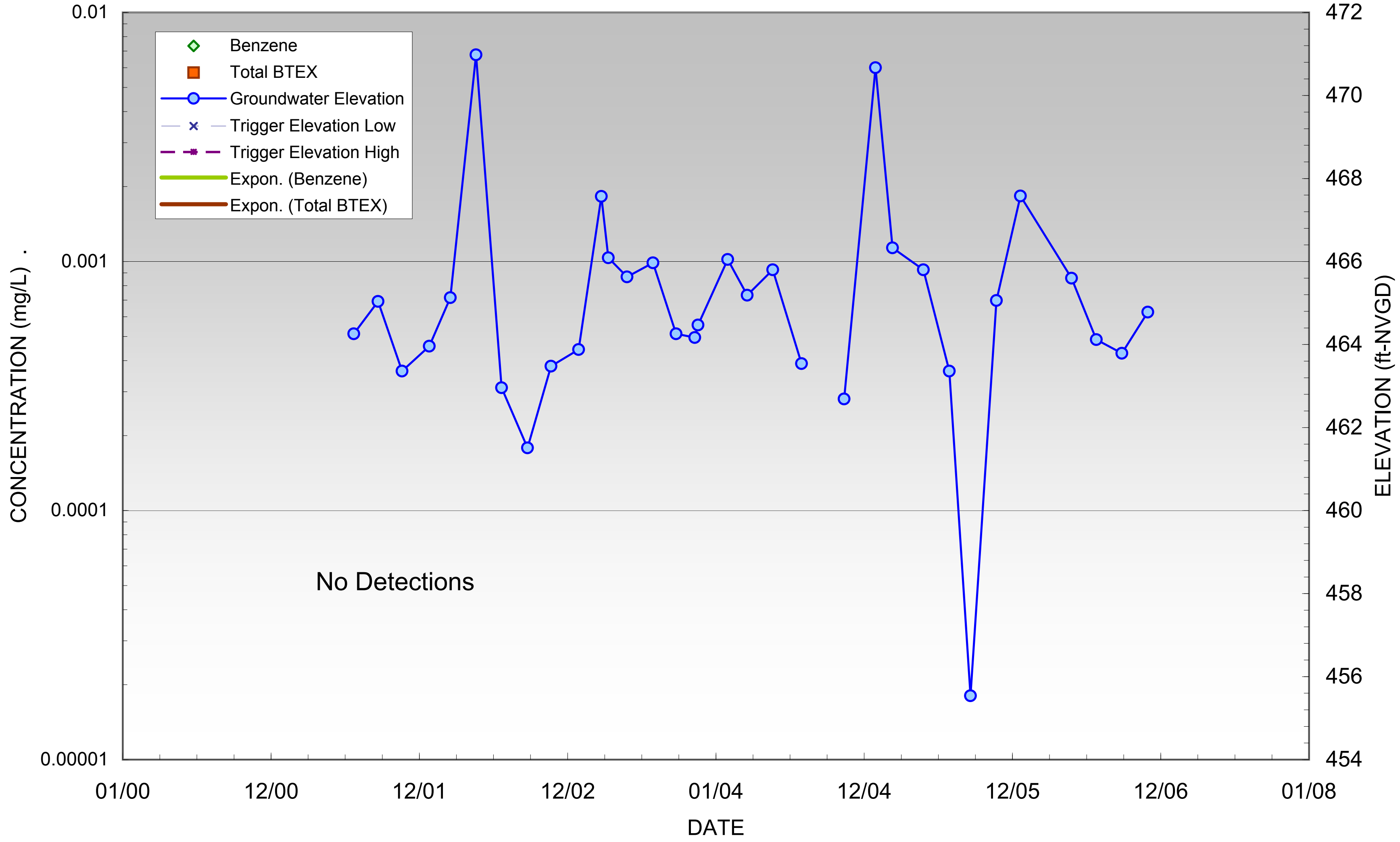

Figure B-32. MW-120 Dissolved-Phase Constituent Concentration vs. Time (C=Co*e-kt)