Method 541: Determination of 1-Butanol, 1,4-Dioxane, 2-Methoxyethanol and 2-Propen-1-ol in Drinking Water by Solid Phase Extraction and Gas Chromatography/Mass Spectrometry

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1 Scope and application

Method 541 is a gas chromatography (GC) method for the determination of 1-butanol, 1,4-dioxane, 2-methoxyethanol, and 2-propen-1-ol in finished drinking water. Method 541 requires detection using mass spectrometry (MS) in selected ion monitoring (SIM) to provide selectivity for the method analytes. This method is intended for use by analysts skilled in the performance of solid phase extractions, the operation of GC/MS instrumentation and in the interpretation of the associated data.

1.1 Analyte List

Analyte	Chemical Abstracts Services Registry Number (CASRN)
1-butanol	71-36-3
1,4-dioxane	123-91-1
2-methoxyethanol	109-86-4
2-propen-1-ol (allyl alcohol)	107-18-6

1.2 Supporting Data

Precision and accuracy data have been generated for the detection of the method analytes in reagent water and finished drinking water from both ground water and surface water sources (Sect. 17, Tables 5–7 and Sect. 17, Tables 9–11). Single-laboratory Lowest Concentration Minimum Reporting Levels (LCMRL) (Sect. 3.11) for the analytes in this method are presented in Section 17, Table 4 and Table 8. Laboratories using this method are not required to determine LCMRLs, but they must demonstrate that the Minimum Reporting Level (MRL) (Sect. 3.12) for each analyte meets the requirements described in Section 9.2.4.

1.3 Method Flexibility

The laboratory is permitted to select GC columns, inlets, and GC conditions different from those utilized to develop the method. However, the basic chromatographic elements of the method must be retained. At a minimum, the internal standards and surrogate analytes specified in the method must be used. Changes may not be made to sample collection and preservation (Sect. 8), the quality control (QC) requirements (Sect. 9), or the extraction procedure (Sect. 11). Method modifications should be considered only to improve method performance. In all cases where method modifications are proposed, the analyst must perform the procedures outlined in the Initial Demonstration of Capability (IDC, Sect. 9.2), verify that all QC acceptance criteria in this method (Sect. 9.3) are met, and verify method performance in representative sample matrixes (Sect. 9.4).

2 Summary of the Method

Samples (0.05 L) are collected in amber, glass bottles containing the method preservatives, sodium sulfite (dechlorination) and sodium bisulfate (pH adjustment). In the laboratory, two surrogate analytes are added. The method and surrogate analytes are isolated from water using solid phase extraction (SPE). The SPE cartridges are dried to remove adsorbed water and eluted with 2 mL of 5% methanol in dichloromethane. Extracts are analyzed, without further concentration, by GC/MS in the SIM mode of detection. The method analytes are identified by comparing the retention times and ion abundance ratios to reference retention times and ion abundance ratios obtained from calibration standards acquired under identical GC/MS conditions. The concentrations of 1-butanol, 1,4-dioxane,

2-methoxyethanol, and 2-propen-1-ol are calculated using the integrated peak area and the internal standard technique.

3 Definitions

3.1 Analysis Batch

A set of samples that is analyzed on the same instrument during a 24 hour period that begins and ends with the analysis of the appropriate Continuing Calibration Check (CCC) standards. Additional CCCs may be required depending on the length of the Analysis Batch and the number of field samples.

3.2 Calibration Standard

A solution of the method analytes, surrogate analytes, and internal standards prepared from the Primary Dilution Standards. The calibration standards are used to calibrate the instrument response with respect to analyte concentration.

3.3 Continuing Calibration Check (CCC)

A calibration standard that is analyzed periodically to verify the accuracy of the existing calibration.

3.4 Extraction Batch

A set of up to 20 field samples (not including QC samples) extracted together using the same lot of solid phase extraction devices, solvents, surrogate solution, and fortifying solutions.

3.5 Field Duplicates (FD)

Separate samples collected at the same time, shipped and stored under identical conditions. Method precision, including the contribution from sample collection procedures, is estimated from the analysis of Field Duplicates. Field Duplicates are used to prepare Laboratory Fortified Sample Matrix and Laboratory Fortified Sample Matrix Duplicate QC samples. For the purposes of this method, Field Duplicates are necessary to conduct repeat analyses if the original field sample is lost, or to conduct repeat analyses in the case of QC failures associated with the analysis of the original field sample.

3.6 Internal Standard (IS)

A pure compound that is added to all standard solutions and extracts in a known amount and used to measure the relative response of method analytes that are components of the same solution. The IS should respond to instrument conditions and sample matrix in a similar manner as the method analytes, and have no potential to be present in the samples.

3.7 Laboratory Fortified Blank (LFB)

An aliquot of reagent water, containing method preservatives, to which known quantities of the method analytes are added. The LFB is used during the IDC to verify method performance for precision and accuracy. The LFB is also a required QC element with each Extraction Batch. The results of the LFB verify method performance in the absence of sample matrix.

3.8 Laboratory Fortified Sample Matrix (LFSM)

An aliquot of a field sample to which known quantities of the method analytes are added. The purpose of the LSFM is to determine whether the sample matrix contributes bias to the analytical results. For this method, separate field samples are required for preparing fortified matrix so that sampling error is included in the accuracy estimate.

3.9 Laboratory Fortified Sample Matrix Duplicate (LFSMD)

A Field Duplicate of the sample used to prepare the LFSM that is fortified and analyzed identically to the LFSM. The LFSMD is used instead of the Field Duplicate to assess method precision when the method analytes are rarely found at concentrations greater than the MRL.

3.10 Laboratory Reagent Blank (LRB)

An aliquot of reagent water that contains the preservatives and surrogate analytes. An LRB is included in each Extraction Batch to determine if the method analytes or other interferences are introduced from the laboratory environment, the reagents, glassware, or extraction apparatus.

3.11 Lowest Concentration Minimum Reporting Level (LCMRL)

The single-laboratory LCMRL is the lowest spiking concentration such that the probability of spike recovery in the 50% to 150% range is at least 99%.[1,2]

3.12 Minimum Reporting Level (MRL)

The minimum concentration that can be reported by a laboratory as a quantified value for a method analyte following analysis. For each method analyte, this concentration must meet the criteria defined in Section 9.2.4 and must be greater than or equal to the concentration of the lowest calibration standard.

3.13 Primary Dilution Standard (PDS)

A solution that contains compounds prepared from stock standards. PDS solutions are diluted to prepare calibration standards and sample fortification solutions, and are used to fortify QC samples.

3.14 Quality Control Sample (QCS)

A solution containing the method analytes at a known concentration that is obtained from a source external to the laboratory and different from the source of calibration standards. The purpose of the QCS is to verify the accuracy of the primary calibration standards.

3.15 Reagent Water

Purified water that does not contain any measurable quantity of the method analytes or interfering compounds at, or above, one-third of the MRL.

3.16 Safety Data Sheets

Written information provided by vendors concerning a chemical's toxicity, health hazards, physical properties, fire and reactivity data, storage instructions, spill response procedures, and handling precautions.

3.17 Selected Ion Monitoring (SIM)

A GC/MS technique where only one or a few ions are monitored instead of scanning over a selected mass range. When used with gas chromatography, the set of ions monitored is usually changed periodically throughout the chromatographic run to correlate with the characteristic ions of the analyte, surrogates, and internal standards as they elute from the chromatographic column.

3.18 Stock Standard Solution

A concentrated standard solution that is prepared in the laboratory using assayed reference materials or that is purchased from a commercial source with a certificate of analysis.

3.19 Surrogate Analyte

A pure compound, chemically similar to the method analytes, that is unlikely to be found in any sample. The surrogate is added to each sample in a known amount before extraction. Surrogates are quantitated using the same procedures as other sample components. Because surrogates are present in every sample, they provide a means of assessing method performance for each sample extraction.

4 Interferences

4.1 Glassware, Reagents and Equipment

Method interferences may be caused by contaminants in solvents, reagents (including reagent water), sample bottles and caps, and other sample processing hardware. All laboratory reagents and equipment must be routinely demonstrated to be free from interferences under the conditions of the analysis. This may be accomplished by analyzing LRBs as described in Section 9.3.1.

4.2 Matrix Interferences

Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source depending upon the nature of the water. Matrix components may directly interfere by producing a signal at or near the retention time of an analyte peak. Matrix components may also suppress or enhance the signal of the method analytes. (Suppression and enhancement effects occur within the GC inlet when co-eluting contaminants influence the transmission efficiency of an analyte to the column.) Humic and fulvic material in environmental samples may be co-extracted during SPE and can cause enhancement and suppression. Total organic carbon (TOC) is an indicator of the humic content of a sample if such information is available. The analysis of Laboratory Fortified Sample Matrix provides evidence for the presence (or absence) of matrix effects.

4.3 Extraction Cartridges

Solid phase extraction cartridges may be a source of interferences. The analysis of LRBs provides important information regarding the presence or absence of such interferences. Each brand and lot of SPE devices should be monitored to ensure that contamination does not preclude analyte identification and quantitation. It is recommended to keep SPE cartridges sealed while in storage in order to prevent contamination of SPE sorbent.

4.4 Matrix Effects in the Presence of Water

During method development studies, matrix enhancement, matrix suppression, and retention time shifts were observed when analyzing extracts containing residual water from the extraction procedure. These effects are eliminated by drying SPE cartridges prior to solvent elution and by adding a desiccant to the organic extract. It is important to follow all of the steps in the extraction procedure (Sect. 11) related to water management.

4.4.1 Nitrogen-drying Manifold

A drying manifold designed for SPE cartridges is required for this method. A rotameter or other appropriate flow measurement device must be placed in the delivery line to the nitrogen-drying manifold to ensure that the volume of gas passing through the SPE cartridges is consistent for each Extraction Batch.

4.4.2 Optimizing the Cartridge Drying Step

The laboratory is required to optimize the nitrogen volume for each SPE format prior to conducting the method (during the IDC). The gas volumes recommended in Section 9.1.4 are good starting parameters. The authors verified these values for each extraction format across multiple lots of cartridges.

4.5 Analyte Extraction Efficiency

Overall extraction efficiency for 2-propen-1-ol is lower than the other analytes. Typical recovery for 2-propen-1-ol can be expected to fall in the 80 to 90% range. Typical recovery for 1-butanol and 2-methoxyethanol can be expected to fall in the 80 to 100% range. 1,4-Dioxane is routinely recovered near 100%.

4.6 Extraction Flow Rate

During method development, the authors observed low analyte recovery for some extractions when the flow rate during loading of the SPE cartridges exceeded 10 mL/min. For this reason, a loading rate of 5 mL/min is recommended for this method.

4.7 QC Compounds

Depending on the source and purity, labeled analogs used as internal standards and surrogates may contain a small percentage of the corresponding native analyte. Such a contribution may be significant when attempting to determine MRLs.

5 Safety

5.1 Chemicals

Each chemical should be treated as a potential health hazard and exposure to these chemicals should be minimized. Each laboratory is responsible for maintaining an awareness of OSHA regulations regarding safe handling of chemicals used in this method. A reference file of safety data sheets should be made available to all personnel involved in the chemical analysis.

5.2 Sodium Bisulfate

Sodium bisulfate is used as a sample preservative to inhibit microbial growth. Sodium bisulfate is highly acidic and should be used with appropriate caution.

5.3 Dichloromethane

The primary hazard when conducting the procedures in this method is exposure to dichloromethane. This solvent is a possible human carcinogen, volatilizes readily with vapors heavier than air, and quickly permeates many types of common laboratory gloves. Handle this material with appropriate protection for the eyes, skin, and respiratory system. Always perform extractions and prepare standard solutions in a laboratory fume hood.

6 Equipment and Supplies

References to specific brands and catalog numbers are included as examples only and do not imply endorsement of the products. Such reference does not preclude the use of other vendors or suppliers.

6.1 Sample Containers

Amber glass bottles or vials fitted with polytetrafluoroethylene (PTFE) lined screw caps.

6.2 Vials

Various sizes of amber glass vials with PTFE-lined screw caps for storing standard solutions. Amber or clear glass, 2 mL autosampler vials with PTFE-faced septa.

6.3 Micro Syringes

Suggested sizes include 5, 10, 25, 50, 100, 250 and 1000 microliters.

6.4 Volumetric Pipettes

Class A.

6.5 Analytical Balance

Capable of weighing to the nearest 0.0001 gram.

6.6 Compressed Gas: Helium

Ultra-high-purity; for use as the GC carrier. Alternate carrier gases, such as hydrogen (99.999% or better) may be used if the QC criteria in Sect. 9 are met. Instrument manufacturers should be consulted prior to any GC carrier gas conversion.

6.7 Compressed Gas: Nitrogen

Ultra-high-purity; for drying SPE cartridges.

6.8 Compressed Gas: Air

Ultra-high-purity; for drying SPE cartridges.

6.9 Disposable Pasteur Pipettes

Five and three-fourths inch borosilicate glass, used to transfer samples to autosampler vials (Fisher Cat. No. 13-678-20B or equivalent).

6.10 Volumetric Flasks

Class A, suggested sizes include 2, 5, and 10 mL for preparation of primary dilution standards and calibration standards [Pyrex Brand Cat. No. 5640-2 (2 mL), 5640-5 (5 mL), and 5640-10 (10 mL)]. The 2 mL size is used to receive the sample eluate during the elution step in the extraction procedure.

6.11 Solid Phase Extraction Apparatus for Cartridges

6.11.1 UCT EU-541 SPE Cartridge

UCT, Inc., (Bristol, PA) EU-541 activated carbon (Cat. No. EU541163), 600 mg, 3 mL cartridge; requires tube adaptor (Supelco Cat. No. 57020-U, UCT Cat. No. AD0000AS, or equivalent) to attach sample reservoir to cartridge and to attach cartridge to the drying manifold.

6.11.2 Waters AC-2 SPE Cartridge

Waters Corporation (Milford, MA) AC-2 activated carbon (Cat. No. JJAN20229), 400 mg, reversible cartridge; requires 3 mL solvent reservoir (Supelco Cat. No. 57241 or equivalent).

6.11.3 Vacuum Extraction Manifold

Equipped with flow and vacuum control [Supelco Cat. No. 57030-U, UCT Cat. No. VMF016GL (the later requires UCT Cat. No. VMF02116 control valves), or equivalent systems]. Automated devices designed for use with SPE cartridges may be used; however, all extraction and elution steps must be the same as in the manual procedure. Extraction and elution steps may not be changed or omitted to accommodate the use of an automated system.

6.11.4 Sample Delivery System

Polypropylene sample reservoirs (60 mL Restek Cat. No. 26015, 75 mL UCT Cat. No. RFV0075P, or equivalent) which attach to the cartridge, are recommended.

6.11.5 Extract Collection Tubes

Two mL volumetric flasks (Pyrex Brand Cat. No. 5640-2 or equivalent) suitable for collection of eluate from the SPE cartridges.

6.12 Laboratory Vacuum System

Sufficient capacity to maintain a vacuum of approximately 20 inches of mercury.

6.13 Drying Manifold for SPE Cartridges

Manifold with flow control valve (Supelco Visidry™ Drying Attachment, Cat. No. 57100-U, or equivalent).

6.14 Flow Meter for Drying Manifold

Rotameter, 0–30 liters/min [Organomation Associates, Inc., (Berlin, MA) Cat. No. NA-1421 or equivalent]. Install the rotameter between the gas supply and the drying manifold. See Section 17, Figure 1, for additional guidance.

6.15 Gas Chromatograph/Mass Spectrometer (GC/MS)

Analytical system complete with temperature programmable GC suitable for use with capillary columns and all required accessories including gas supply, liquid autosampler and data system. Table 3 in Section 17 lists retention times observed for method analytes using the column and analytical conditions described below.

6.15.1 Column

30 m x 0.25 mm i.d. polyethylene glycol (PEG; commonly called WAX), bonded-phase fused silica column, 0.50 µm film thickness. Helium carrier gas: 0.9 mL/min in constant flow mode. Oven temperature program: 30 °C (5 min), 10 °C/min to 110 °C (0 min), 25 °C/min to 200 °C (6 min hold).

6.15.2 GC Inlet

Split/splitless injector operated in pulsed splitless mode (200 °C; 10-psig pulse pressure) with a 30 second split delay. The injection volume was one microliter.

6.15.3 Inlet Liner for Split/Splitless Inlet

Single-gooseneck splitless liner, 4 mm deactivated glass with deactivated glass wool.

6.15.4 GC/MS Interface

The interface should allow the capillary column or transfer line exit to be placed within a few millimeters of the ion source. Other interfaces are acceptable as long as the system has adequate sensitivity and QC performance criteria are met.

6.15.5 Mass Spectrometer (MS)

Any type of MS may be used that is capable of SIM or selected ion storage (SIS) mode (i.e., quadrupole and ion trap) with electron impact ionization at 70 eV. The instrument must be operated in SIM mode (or SIS) for enhanced sensitivity and selectivity. The minimum scan range capability of the MS must be *m/z* 35 to 260, and it must produce a full scan mass spectrum that meets all criteria in Table 1 when a solution containing one ng, or less, of bromofluorobenzene (BFB) is injected into the GC/MS.

6.15.6 Data System

An interfaced data system is required to acquire, store and output GC/MS data. The computer software must have the capability of processing stored data by recognizing a chromatographic peak within a given retention time window. The software must be able to construct a linear regression or quadratic regression calibration curve and calculate analyte concentrations using the internal standard technique.

7 Reagents and Standards

Reagent grade or better chemicals must be used. Unless otherwise indicated, all reagents must conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society (ACS), where such specifications are available. Other grades may be used if the reagent is demonstrated to be free of analytes and interferences and all requirements of the IDC are met when using these reagents.

7.1 Methanol

CH_3OH, CASRN 67-56-1, purge-and-trap-grade (Honeywell, Burdick & Jackson brand, Cat. No. 232 or equivalent). No other grades of methanol are permitted for this method.

7.2 Dichloromethane

DCM, CASRN 75-09-02, pesticide residue grade or equivalent. Use DCM to prepare the elution solvent: 5% methanol in DCM.

7.3 Sodium Sulfate, Anhydrous

Na_2SO_4, CASRN 7757-82-6, conditioned at 400 °C for at least four hours in a muffle furnace. An "ACS grade, suitable for pesticide residue analysis" of granular, 10–60 mesh, anhydrous Na_2SO_4 is recommended (Fisher Scientific Cat. No. S415 or equivalent).

7.4 Sample Preservation Reagents

These preservatives are solids and may be added to the sample bottle before shipment to the field.

7.4.1 Sodium Sulfite

Na_2SO_3, CASRN 7757-83-7, reduces residual chlorine at the time of sample collection.

7.4.2 Sodium Bisulfate

$NaHSO_4$, CASRN 7681-38-1, reduces sample pH to inhibit microbial growth and prevent analyte degradation.

7.5 Stock Standard Solutions

Vendor certified solutions of the method analytes, the internal standards, and the surrogate analytes are recommended. Users may prepare stock standards starting with the neat liquid if not available as certified solutions or sufficient concentration, following the guidance provided in this section. Useful concentrations for stock standards are typically in the range of 1000–2000 µg/mL.

7.5.1 Internal Standard Stocks

This method requires two internal standards: 1,4-dioxane-d_8 (CASRN 17647-74-4) and chlorobenzene-d_5 (CASRN 3114-55-4). Obtain the internal standards as certified mixtures in methanol.

7.5.2 Surrogate Analyte Stock Standards

This method requires two surrogate standards: 1-butanol-d_{10} (CASRN 34193-38-9) and 2-propen-1-ol-d_6 (CASRN 1173018-56-8). Prepare a mixture of 1-butanol-d_{10} and 2-propen-1-ol-d_6 in purge-and-trap-grade methanol. During method development, 1-butanol-d_{10} was obtained as the neat compound from

CDN Isotopes (Pointe-Claire, Quebec, Canada, Cat. No. D-1181). During method development, 2-propen-1-ol-d_6 was obtained as the neat compound from Sigma-Aldrich (Cat. No. 614629).

7.5.3 Method Analyte Stock Standard Solutions

Obtain the analytes listed in Section 1.1 as certified mixes in methanol, or as neat standards if desired.

7.5.4 Preparation Instructions for Analytes Obtained as Neat Compounds

Prepare the stock standards individually at 2000 µg/mL. Using an analytical balance, obtain a tare weight for a vial containing 20 mL of purge-and-trap-grade methanol. To achieve 2.0 mg/L nominal concentrations, calculate the volume of the liquid analyte corresponding to 40 mg. Measure this volume with a 100 µL syringe and inject the entire quantity under the surface of the methanol. Subtract the tare weight from the final weight to calculate the exact solution concentration. When a compound's purity is assayed to be 96 percent or greater, the weight can be used without correction to calculate the concentration of the stock standard.

7.5.5 Storage of Stock Standards

Experience indicates that the most likely cause of standard deterioration for this method is solvent evaporation. After opening sealed ampoules, store commercial mixes in glass vials with Teflon closures at –10 °C or lower temperature. Stock standard solutions prepared in-house are estimated to be stable for at least one year if stored at –10 °C. Store these stocks in the vials in which they were prepared. Laboratories should use appropriate QC practices to determine when stock standards need to be replaced. Expiration dates of commercially available mixtures provided by the vendor can be used to estimate shelf life of stock solutions if evaporation of the solvent is prevented.

7.6 Primary Dilution Standards (PDS)

Prepare Primary Dilution Standards by combining and diluting appropriate volumes of the stock standards with purge-and-trap-grade methanol. Store the PDS solutions in glass vials with Teflon-lined septa at –10 °C or lower temperature. During method development, PDS solutions were demonstrated to be stable for at least one year; however, laboratories should use appropriate QC practices to determine when PDS standards need to be replaced. The PDS concentrations appearing in this section were used during method development, and are intended to be examples only.

7.6.1 Internal Standard Primary Dilution Standard

Prepare the internal standard PDS at 50 µg/mL in methanol from the internal standard stock. The authors added 10 µL to each 2 mL extract and calibration standard to achieve a concentration of 0.25 µg/mL.

7.6.2 Surrogate Analyte Primary Dilution Standard

Prepare the surrogate standard PDS at 50 µg/mL in methanol from the surrogate standard stock. The authors added 10 µL to each 0.050 L sample to achieve a concentration of 10 µg/L.

7.6.3 Method Analyte Primary Dilution Standard

The analyte PDS is used to prepare the calibration standards and to fortify LFB, LFSM and LFSMD QC samples with the method analytes. Select nominal analyte concentrations for the PDS such that between 5 and 25 µL of the PDS is used to fortify samples and prepare standard solutions. More than one PDS concentration may be necessary to meet this requirement. The analyte PDS is prepared by combining appropriate volumes of the analyte stock standard solutions in purge-and-trap-grade methanol. During method development, three PDS solutions were used. The concentrations of these solutions are listed in the table in Section 7.7.2.

7.7 Calibration Standards

Prepare a series of calibration standards of at least six levels by diluting the analyte PDS into 5% methanol in DCM. The lowest calibration standard must be at, or below, the concentration representing the MRL in the aqueous sample for each analyte. Using the internal standard and surrogate PDS solutions, add a constant amount of each internal standard and surrogate to each calibration standard. The concentration of the surrogate analytes should match the concentration of the surrogates in sample extracts, assuming 100% recovery through the extraction process. The calibration standards may also be used as CCCs.

7.7.1 Example Calibration Scheme

The dilution scheme for calibration standards used to collect method performance data (Section 13) is presented in Section 7.7.2. The right-most column gives the aqueous concentration of method analytes achieved by fortifying the same quantity of PDS solution into a 0.050 L aqueous sample, e.g., when preparing fortified field samples. Ten microliters of the internal standard PDS (50 µg/mL) were added to each calibration standard resulting in a concentration of 0.25 µg/mL. Ten microliters of the surrogate PDS (50 µg/mL) were added to each calibration standard resulting in a concentration of 0.25 µg/mL in the calibration standard (10 µg/L aqueous sample equivalent).

7.7.2 Dilution Scheme for Calibration Standards

CAL[a] Level	Analyte PDS (µg/mL)	PDS Volume (µL)	Final Std. Volume 5% methanol:DCM (mL)	CAL Std.[c,d] (µg/mL)	Aqueous Equivalent 0.050 L Sample (µg/L)
0.5 x MRL	1,4-dioxane (0.40) Alcohols, 2-ME[a] (2.0)	25	2.0	0.0050 0.025	0.20 1.0
Std. #1, MRL[b]	1,4-dioxane (4.0) Alcohols, 2-ME (20)	5.0	2.0	0.010 0.050	0.40 2.0
2	1,4-dioxane (4.0) Alcohols, 2-ME (20)	10	2.0	0.020 0.10	0.80 4.0
3	1,4-dioxane (4.0) Alcohols, 2-ME (20)	20	2.0	0.040 0.20	1.6 8.0
4	1,4-dioxane (40) Alcohols, 2-ME (200)	5.0	2.0	0.10 0.50	4.0 20
5	1,4-dioxane (40) Alcohols, 2-ME (200)	10	2.0	0.20 1.0	8.0 40
6	1,4-dioxane (40)	20	2.0	0.40	16

a. CAL = calibration standard; alcohols = 1-butanol, 2-propen-1-ol; 2-ME = 2-methoxyethanol.
b. During method development, the MRL was confirmed at this level.
c. Ten µL internal standard PDS (50 µg/mL) added to each calibration standard results in a concentration of 0.25 µg/mL.
d. Ten µL surrogate PDS (50 µg/mL) added to each calibration standard results in a concentration of 0.25 µg/mL in the CAL standard (10 µg/L aqueous sample equivalent).

7.7.3 Storage of Calibration Standards

The stability of calibration standards was evaluated during method development at concentrations within the calibration range. The calibration standards are stable for at least 6 months when stored in autosampler vials with PTFE-faced silicone septa at –10 °C.

7.7.4 GC/MS Tune Check Solution

BFB, 1 µg/mL, CASRN 460-00-4. Prepare in a solvent mixture identical to the extract solvent composition.

8 Sample Collection, Preservation, and Storage

8.1 Sample Bottles

Prior to shipment to the field, add sodium sulfite and sodium bisulfate to each sample bottle: 2.5 mg of sodium sulfite and 50 mg of sodium bisulfate. Cap the vials tightly to avoid spillage of the preservation reagents. The final concentrations of sodium sulfite and sodium bisulfate in the sample are 50 mg/L and 1000 mg/L, respectively, for a 50 mL sample. Do not dilute these salts in water. The preservatives must be added in the solid form.

8.2 Sample Collection

Open the tap and allow the system to flush for approximately 5 minutes. Using a graduated cylinder, fill each bottle with exactly 50 mL of sample. Invert the bottle several times to mix the sample with the preservatives. Rinse the graduated cylinder several times with the subsequent sample before filling the next bottle.

8.3 QC Samples

Collect additional field samples to fulfill QC requirements for Field Duplicates, LFSMs, and LFSMDs. For this method, all QC samples are prepared using duplicate samples collected in the field, i.e., not split samples prepared in the laboratory.

8.4 Sample Shipment and Storage

Samples must be chilled during shipment and must not exceed 10 °C during the first 48 hours after collection. In the laboratory, samples must be stored at, or below, 6 °C and protected from light.

8.5 Verification upon Receipt

Samples must be confirmed to be at, or below, 10 °C when they are received at the laboratory. When samples are returned to the laboratory, use a pH meter to periodically verify that sample pH is less than 3 for each drinking water source. For each water source, analyze one sample using common assays for residual chlorine, e.g., N,N diethyl-p-phenylenediamine (DPD)-colorimetric technique. Residual chlorine should not be present in preserved water samples.

8.6 Sample Holding Time

Analyze samples as soon as possible. Samples must be analyzed within 28 days of collection.

8.7 Storage of Extracts

Store the 2 mL extracts obtained from the SPE procedure in a freezer at, or below, –10 °C.

8.8 Extract Holding Time

Extracts must be analyzed within 28 days after sample extraction.

9 Quality Control

QC requirements include the IDC and ongoing QC requirements. This section describes each QC parameter, its required frequency, and the performance criteria that must be met in order to satisfy EPA quality objectives. The QC criteria discussed in the following sections are summarized in Section 17, Table 14 and Table 15. These QC requirements are considered the minimum acceptable QC program. Laboratories are encouraged to institute additional QC practices to meet their specific needs. Calibrate the GC/MS system following the steps in Section 10 prior to optimizing the SPE cartridge drying parameters and conducting the IDC.

9.1 Optimizing SPE Cartridge Drying Parameters

For this method, the SPE cartridge drying parameters must be optimized for each extraction format. The goal is to produce dry extracts for GC analysis and to conserve compressed gas required by this method. The WAX column is very sensitive to water in the extracts and retention time shifts will occur if residual water is not completely removed. In addition, the authors observed suppression and enhancement of analyte response when residual water was present in the extracts.

9.1.1 Prepare for the Test

Review the extraction procedure in Section 11. Pay particular attention to the steps for drying the AC-2 cartridges (Sect. 11.2.5) and the UCT EU-541 cartridges (Sect. 11.3.5) after sample loading. Proper drying technique results in a clear, single-layer extract after elution: no cloudiness or separate water layer. In addition, retention times observed during extract analysis should match those observed for calibration standards. Perform the following experiment to identify the optimum volume for nitrogen drying. Purified air (zero air) may be used in place of nitrogen; however, vacuum drying is not permitted.

9.1.2 Condition SPE Test Cartridges

Load two SPE cartridges onto the extraction manifold and condition with the following exception: aspirate the reagent water in the final conditioning step for ~30 seconds and then close the manifold valve. [For the Waters AC-2 format, remove the wet 3 mL reservoirs and replace them with dry reservoirs.] Add 150 µL of methanol (Waters AC-2) or 200 µL of methanol (UCT EU-541) to each reservoir and aspirate at full vacuum for ~30 seconds.

9.1.3 Dry the Cartridges

Set up the drying manifold, but do not attach it to the extraction lid. Install the rotameter between the nitrogen regulator and the control valve on the drying manifold (Figure 1). Place the cartridges on the drying manifold in the load direction. Start the nitrogen flow at between 2 and 5 L/min per cartridge (total flow measured on the rotameter divided by the number of cartridges); start a timer and dry for 5 minutes. For the first one to two minutes, water is expelled from the bottom of the cartridges. With continued flow, the sorbent visibly lightens in shade. While the cartridges are drying, dry the manifold valves used during the conditioning step with methanol followed by vacuum aspiration (Sect. 11.2.5.3). Do not omit this step: the valves hold a significant quantity of water.

9.1.4 Flow Rate and Volumes used during Method Development

A rotameter is sensitive to pressure drop across the device and the flow rate observed may not be accurate. The authors recorded a true flow rate of 5.0 liters/min per cartridge as measured by a mass flow meter when the rotameter indicated a flow rate of 2 L/min (nitrogen delivery pressure of 80 psig). For example, when drying five cartridges, the mass flow meter read 25 liters/min while the rotameter read 10 liters/min. As measured with a mass flow meter, the optimized nitrogen volumes were as

follows: Waters AC-2 (5 L/min x 5 minutes = 25 liters per sample) and UCT EU-541 (5 L/min x 8 minutes = 40 liters per sample. Because the rotameter is used to repeat the total flow optimized in these steps, accuracy is not required.

9.1.5 Elute the Test Cartridges

Replace the cartridges on the manifold in their original positions and elute with 2 mL of 5% methanol in DCM following the procedure in Sect. 11.4. The extracts should be clear without a discernible water layer. If the extracts are wet, repeat the experiment and incrementally increase the nitrogen flow or time until a volume is reached that results in a clear, single-layer extract. Save these extracts for Step 9.1.7.

9.1.6 Estimate the Minimum Required Nitrogen Volume

If the extracts contain no visible water after the first trial, repeat the experiment and incrementally decrease the nitrogen volume. Determine the minimum volume of nitrogen that results in single-layer extracts. Save these extracts for Step 9.1.7.

9.1.7 Analyze and Evaluate the Extracts

Fortify the extracts with analytes, internal standards, and surrogates and bring to volume (2 mL) with elution solvent. Ensure that the sodium sulfate desiccant is properly conditioned. Dry the extracts with sodium sulfate per Section 11.6. Analyze the extracts. The retention times should match those observed for calibration standards. If retention time shifts occur, increase the nitrogen volume and repeat the experiment until the problem is resolved.

9.1.8 Select a Volume above the Minimum

The authors determined empirically that up to six times the minimum volume necessary to eliminate retention time shifts could be applied without adverse effects on method performance. However, excessive drying (beyond this limit) decreased analyte recovery during the solvent elution step. 2-Propen-1-ol is the most sensitive analyte to over drying. The authors recommend adding a few minutes to the drying time representing the optimized nitrogen volume to ensure retention time shifts do not occur if operating conditions vary slightly, e.g., different lots of SPE media. Use the rotameter to ensure that the optimized nitrogen volume is applied to all subsequent sample extractions.

9.2 Initial Demonstration of Capability (IDC)

The IDC must be successfully performed prior to analyzing field samples. The IDC must be repeated if changes are made to analytical parameters not previously validated during the IDC, for example, selection of alternate quantitation ions, extending the calibration range, or changing the internal standard assignment of an analyte. Prior to conducting the IDC, the analyst must meet the calibration requirements outlined in Section 10. The same calibration range used during the IDC must be used for the analysis of field samples.

9.2.1 Demonstration of Low System Background

Analyze an LRB immediately after injecting the highest calibration standard in the selected calibration range. Confirm that the blank is free from contamination as defined in Section 9.3.1.

9.2.2 Demonstration of Precision

Prepare, extract and analyze five replicate LFBs in a valid Extraction Batch (five replicate LFBs and an LRB). Fortify the LFBs near the midpoint of the initial calibration curve. The method preservatives must be added to the samples as described in Section 8.1. The percent relative standard deviation (%RSD) of the concentrations of the replicate analyses must be less than, or equal to, 20% for all method analytes.

$$\%RSD = \frac{Standard\ Deviation\ of\ Measured\ Concentrations}{Mean\ Concentration} \times 100$$

9.2.3 Demonstration of Accuracy

Using the same set of replicate data generated for Section 9.2.2, calculate the average percent recovery. The average percent recovery for each analyte must be within plus or minus 30% of the true value.

$$Average\ \%\ Recovery = \frac{Average\ Measured\ Concentration}{Fortified\ Concentration} \times 100$$

9.2.4 Minimum Reporting Level (MRL) Confirmation

Establish a target concentration for the MRL based on the intended use of the method. Analyze an initial calibration following the procedures in Section 10. The lowest calibration standard used to establish the initial calibration (as well as the low-level CCC) must be at, or below, the concentration representing the MRL. Establishing the MRL concentration too low may cause repeated failure of ongoing QC requirements. Confirm the MRL following the procedure outlined below.

9.2.4.1 Prepare and Analyze MRL Samples

Fortify, extract and analyze seven replicate LFBs at, or below, the proposed MRL concentration. The LFBs must contain the method preservatives as specified in Section 8.1.

9.2.4.2 Calculate MRL Statistics

Calculate the mean and standard deviation for each analyte in these replicates. Determine the Half Range for the Prediction Interval of Results (HR_{PIR}) using the following equation:

$$HR_{PIR} = 3.963S$$

Where,
S is the standard deviation and 3.963 is a constant value for seven replicates.[1]

Calculate the Upper and Lower Limits for the Prediction Interval of Results ($PIR = Mean \pm HR_{PIR}$) as shown below.

$$Upper\ PIR\ Limit = \frac{Mean + HR_{PIR}}{Fortified\ Concentration} \times 100$$

$$Lower\ PIR\ Limit = \frac{Mean - HR_{PIR}}{Fortified\ Concentration} \times 100$$

9.2.4.3 MRL Acceptance Criteria

The MRL is confirmed if the *Upper PIR Limit* is less than, or equal to, 150%; and the *Lower PIR Limit* is greater than, or equal to, 50%. If these criteria are not met, the MRL has been set too low and must be confirmed again at a higher concentration.

NOTE: These equations are only valid for seven replicate samples.

9.2.5 Quality Control Sample (QCS)

Analyze a Quality Control Sample (Sect. 9.3.10) to confirm the accuracy of the primary calibration standards.

9.3 Ongoing QC Requirements

This section describes the ongoing QC elements that must be included when processing and analyzing field samples.

9.3.1 Laboratory Reagent Blank (LRB)

Analyze an LRB with each Extraction Batch. The LRB must contain the method preservatives and the surrogate analytes at the same concentration used to fortify field samples. Background from method analytes or contaminants that interfere with the measurement of method analytes must be less than one-third the MRL. If method analytes are detected in the LRB at concentrations equal to, or greater than this level, then all data for the problem analyte(s) must be considered invalid for all samples that yielded a positive result. Subtracting blank values from sample results is not permitted.

9.3.1.1 Estimating Background Concentrations

Although quantitative data below the MRL may not be accurate enough for data reporting, such data are useful in determining the magnitude of background interference. Therefore, the analyte concentrations in the LRB may be estimated by extrapolation when results are below the MRL.

9.3.1.2 Influence of Background on Selection of MRLs

It is important to evaluate background values of analytes that commonly occur in LRBs. The MRL should be set at a value greater than three times the mean concentration observed in replicate LRBs. If LRB values are highly variable, setting the MRL to a value greater than the mean LRB concentration plus three times the standard deviation may provide a more realistic MRL.

9.3.1.3 Evaluation of Background when Analytes Exceed the Calibration Range

After analysis of a sample in which method analytes exceed the calibration range, one or more LRBs must be analyzed (to detect potential carryover) until the system meets the LRB acceptance criteria. If this occurs during an automated sequence, examine the results of samples analyzed following the sample that exceeded the calibration range. If the analytes that exceeded the calibration range in the previous sample are detected at, or above, the MRL, these samples are invalid. If the affected analytes do not exceed the MRL, these subsequent samples may be reported.

9.3.2 Continuing Calibration Check (CCC)

Analyze CCC standards at the beginning of each Analysis Batch, after every tenth field sample, and at the end of the Analysis Batch. See Section 10.3 for concentration requirements and acceptance criteria for CCCs.

9.3.3 Laboratory Fortified Blank

An LFB is required with each Extraction Batch. The concentration of the LFB must be rotated between low, medium, and high concentrations from batch to batch. The low concentration LFB must be within a factor of two times the MRL. The high concentration LFB must be near the high end of the calibration range established during the initial calibration. Results of the low-level LFB analyses must be within 50% of the true value for each analyte. Results of the medium and high-level LFB analyses must be within plus or minus 30% of the true value for each analyte. If the LFB results do not meet these criteria, then all data for the problem analytes must be considered invalid for all samples in the Extraction Batch.

9.3.4 BFB MS Tune Check

A complete description of the MS Tune Check is found in Sect. 10.1.1. Perform the MS Tune Check in full scan mode. The acceptance criteria for the MS Tune Check are summarized in Section 17, Table 1. The

MS Tune Check must be performed each time a major change is made to the mass spectrometer and prior to establishing or re-establishing an initial calibration. Daily BFB analysis is not required.

9.3.5 Internal Standards (IS)

The analyst must monitor the peak areas of the internal standards (1,4-dioxane-d_8 and chlorobenzene-d_5) in all injections of the Analysis Batch. The internal standard responses (as indicated by peak areas) in any chromatographic run must not deviate by more than plus or minus 50% from the average areas measured during the initial calibration. In addition, the peak areas must not deviate by more than plus or minus 30% from the responses in the most recent CCC. If an IS area for a sample does not meet these criteria, check the corresponding IS area of the most recent CCC and proceed as follows.

9.3.5.1 Corrective Action for Failed Internal Standards in Samples

If the IS criterion is met in the CCC but not the sample, reanalyze the extract in a subsequent Analysis Batch. If the IS area fails to meet the acceptance criteria in the repeat analysis, but passes in the most recent CCC, extraction of the sample may need to be repeated provided the sample is still within the holding time. If re-extraction is not possible, qualify the original sample results as "suspect–IS response." Qualify only those analytes referenced to the failed internal standard.

9.3.5.2 Corrective Action for Failed Internal Standards in CCCs

If both the original field sample and the CCC fail the IS area criterion, take corrective action (e.g., Sect. 10.4). After servicing the instrument, re-inject the extract in a subsequent Analysis Batch. If the IS area fails to meet the acceptance criteria in the repeat analysis, but passes in the most recent CCC, extraction of the sample may need to be repeated provided the sample is still within the holding time. If re-extraction is not possible, qualify the original sample results as "suspect–IS response." Qualify only those analytes referenced to the failed internal standard.

9.3.6 Surrogate Recovery

The surrogate analytes are fortified into the aqueous portion of field samples and QC samples prior to extraction. Calculate the percent recovery for each surrogate. Recovery must be in the range of 70 to 130%.

$$\%\ Recovery = \left(\frac{Calculated\ Surrogate\ Concentration}{Fortified\ Concentration\ of\ Surrogate}\right) \times 100$$

9.3.6.1 Corrective Action for Failed Surrogates

If a surrogate fails to meet the recovery criterion, evaluate the recovery of the surrogate in the CCCs, the integrity of the calibration solutions, and take corrective action such as recalibration and servicing the GC/MS system. Analyze the failed extract in a subsequent Analysis Batch. If the repeat analysis meets the surrogate recovery criterion, report only data for the reanalyzed extract. If the repeat analysis fails the 70 to 130% recovery criterion after corrective action, extraction of the sample must be repeated provided a sample is available and still within the holding time. If the re-extracted sample also fails the recovery criterion, or if a duplicate field sample is not available, qualify all data for that sample as "suspect–surrogate recovery."

9.3.7 Laboratory Fortified Sample Matrix (LFSM)

Within each Extraction Batch, analyze a minimum of one LFSM. The background concentrations of the analytes in the sample matrix must be determined in a separate field sample and subtracted from the measured values in the LFSM. If various sample matrixes are analyzed regularly, for example, drinking

water processed from ground water and surface water sources; collect performance data for each source.

9.3.7.1 Prepare the LFSM

Prepare the LFSM by fortifying a Field Duplicate with an appropriate amount of the analyte PDS (Sect. 7.6.3) and surrogate PDS (Sect. 7.6.2). Generally, select a spiking concentration that is greater than or equal to the native concentration for most analytes. Selecting a duplicate aliquot of a sample that has already been analyzed aids in the selection of an appropriate spiking level. If this is not possible, use historical data when selecting a fortifying concentration.

9.3.7.2 Calculate the Percent Recovery

Calculate the percent recovery (%R) using the equation:

$$\%R = \frac{(A - B)}{C} \times 100$$

Where,
A = measured concentration in the fortified sample,
B = measured concentration in the unfortified sample, and
C = fortification concentration.

In order to obtain meaningful percent recovery results, correct the measured values in the LFSM and LFSMD for the native levels in the unfortified samples, even if the native values are less than the MRL.

9.3.7.3 Evaluate Analyte Recovery

Recoveries for analytes fortified at concentrations near or at the MRL (within a factor of two times the MRL concentration) must be within plus or minus 50% of the true value. Recoveries for analytes fortified at all other concentrations must be within plus or minus 30% of the true value. If the accuracy for any analyte falls outside the designated range, and the laboratory performance for that analyte is shown to be in control in the CCCs and in the LFB, the recovery is judged matrix biased. Report the result for the corresponding analyte in the unfortified sample as "suspect–matrix."

9.3.8 Field Duplicate or Laboratory Fortified Sample Matrix Duplicate (FD or LFSMD)

Within each Extraction Batch, analyze a minimum of one Field Duplicate or one Laboratory Fortified Sample Matrix Duplicate. If the method analytes are not routinely observed in field samples, analyze an LFSMD rather than an FD.

9.3.8.1 Calculate the RPD for Field Duplicates

Calculate the relative percent difference (RPD) for duplicate measurements (FD1 and FD2) using the equation:

$$RPD = \frac{|\mathrm{FD}_1 - \mathrm{FD}_2|}{(\mathrm{FD}_1 + \mathrm{FD}_2)/2} \times 100$$

9.3.8.2 Acceptance Criterion for Field Duplicates

RPDs for Field Duplicates must be plus or minus 30% for each analyte. Greater variability may be observed when Field Duplicates have analyte concentrations that are near or at the MRL (within a factor of two times the MRL concentration). At these concentrations, Field Duplicates must have RPDs that are plus or minus 50%. If the RPD of an analyte falls outside the designated range, and the laboratory performance for the analyte is shown to be in control in the CCC and in the LFB, the precision is judged

matrix influenced. Report the result for the corresponding analyte in the unfortified sample as "suspect–matrix."

9.3.8.3 Calculate the RPD for the LFSM and LFSMD

If an LFSMD is analyzed instead of a Field Duplicate, calculate the RPD using the equation:

$$RPD = \frac{|LFSMD - LFSM|}{(LFSMD + LFSM)/2} \times 100$$

9.3.8.4 Acceptance Criterion for Fortified Matrix

RPDs for duplicate LFSMs must be plus or minus 30% for each analyte. Greater variability may be observed when the matrix is fortified at analyte concentrations near or at the MRL (within a factor of two times the MRL concentration). LFSMs at these concentrations must have RPDs that are plus or minus 50%. If the RPD of an analyte falls outside the designated range, and the laboratory performance for the analyte is shown to be in control in the CCC and in the LFB, the precision is judged matrix influenced. Report the result for the corresponding analyte in the unfortified sample as "suspect–matrix."

9.3.9 Retention Time Shifts

If QC failures are associated with retention time shifts in a sample, residual water in the extract may be the cause of the failed QC. In this case, re-extract the sample and increase the time devoted to drying the SPE cartridge with nitrogen.

9.3.10 Quality Control Sample (QCS)

A QCS (as defined in Sect. 3.14) must be analyzed during the IDC, and then at least quarterly thereafter. Prepare the QCS in the elution solvent near the midpoint of the calibration range. The acceptance criterion for the QCS is plus or minus 20% of the true value. If the accuracy for any analyte fails the recovery criterion, prepare fresh standard dilutions and repeat the QCS evaluation.

9.4 Method Modification QC Requirements

The analyst is permitted to modify the GC injection technique, GC column and conditions, and MS conditions. Any proposed method modifications must retain the basic chromatographic elements of this method (Sect. 2). Examples of method modifications include alternate GC column phases, MS conditions, quantitation ions, and additional QC analytes proposed for use with the method. The following are required after a method modification.

9.4.1 Repeat the IDC

Establish an acceptable initial calibration (Sect. 10.2) using the modified conditions. Repeat the procedures of the IDC (Sect. 9.2).

9.4.2 Document Performance in Representative Sample Matrixes

The analyst is also required to evaluate and document method performance for the proposed modifications in real matrixes that span the range of waters that the laboratory analyzes. This additional step is required because modifications that perform acceptably in the IDC, which is conducted in reagent water, could fail ongoing method QC requirements in real matrixes. This is particularly important for methods subject to matrix effects, such as GC/MS-based methods. For example, a laboratory may routinely analyze drinking water from municipal treatment plants that process ground water, surface water, or a blend of surface and ground water. In this case, the method modification requirement could be accomplished by assessing precision (Sect. 9.2.2) and accuracy (Sect. 9.2.3) in a surface water with

moderate to high total organic carbon (e.g., 2 mg/L or greater) and a hard ground water (e.g., 250 mg/L as calcium carbonate ($CaCO_3$) equivalent, or greater).

9.4.3 Monitor Performance of the Modified Method

The results of Section 9.4.1 and Section 9.4.2 must be appropriately documented by the analyst and independently assessed by the laboratory's QA officer prior to analyzing field samples. When implementing method modifications, it is the responsibility of the laboratory to review the results of ongoing QC, and in particular, the results associated with LFSM, duplicate samples, CCCs, and the internal standard area counts. If repeated failures are noted, the modification must be abandoned.

10 Calibration and Standardization

Demonstration and documentation of acceptable mass spectrometer tune and initial calibration is required before performing the IDC and prior to analyzing field samples. The MS Tune Check and initial calibration must be repeated each time a major instrument modification is made, or maintenance is performed.

10.1 GC/MS Optimization

Any type of MS may be used as described in Sect. 6.15.5. Data presented in Section 17 were obtained in the SIM mode using a quadrupole mass analyzer. Operation of the MS in selected ion monitoring mode enhances sensitivity; however, less qualitative data are obtained for the method analytes and any potential interferences. Because of this, and because the selected ions for the compounds of interest are low masses that are likely to occur more frequently in interferences than most higher mass ions, the analyst should also rely on chromatographic resolution to reduce the possibility of false positives. It is recommended to use a GC column that is at least 30 m in length, with sufficient capacity to separate the least retained analytes from the extraction solvent, and that provides adequate separation of the compounds of interest from possible interferences.

10.1.1 MS Tune and MS Tune Check

Calibrate the mass and abundance scales of the MS using calibration compounds and procedures recommended by the manufacturer with any modifications necessary to meet tuning requirements. Introduce BFB (Sect. 7.7.4) into the GC/MS system. Acquire a mass spectrum using a scan range of *m/z* 35–260. Use a single spectrum at the apex of the BFB peak, an average spectrum of the three highest points of the peak, or an average spectrum across the entire peak to evaluate the performance of the system. Appropriate background subtraction is allowed; however, the background scans must be chosen from the baseline prior to, or after, elution of the BFB peak. If the BFB mass spectrum does not meet all criteria in Section 17, Table 1, the MS must be re-tuned to meet these criteria before proceeding with the initial calibration.

10.1.2 GC Conditions

Establish GC operating conditions appropriate for the GC column dimensions by optimizing the inlet conditions and temperature program. GC conditions used during method development are summarized in Section 17, Table 2. Tailing peak profiles are expected for 1-butanol, 2-propen-1-ol and, especially, 2-methoxyethanol. However, the column and inlet conditions chosen should not cause peaks to split or broaden. The authors obtained acceptable results for this method as illustrated by the profiles in the reconstructed ion chromatogram (Sect. 17, Figure 2) and in the extracted ion current profiles (EICPs) (Sect. 17, Figure 3). Optimize chromatographic resolution such that a unique quantitation ion is available

for each analyte that is free from interference due to an identical fragment ion in any co-eluting (or overlapping) peaks.

10.1.3 SIM MS Conditions

Choose one primary quantitation ion and at least one confirmation ion. If possible, select a second confirmation ion. Additional ions may be monitored that demonstrate a unique fragment in the mass spectrum. Verify that the primary ion is free from interference due to an identical fragment ion in any overlapping peaks. If the chromatogram is divided into SIM windows (also termed segments or periods), the laboratory must ensure that each method analyte elutes entirely within the assigned window during each Analysis Batch. Make this observation by viewing the mass chromatogram of the quantitation ion for each analyte in the CCCs analyzed during an Analysis Batch. The entire Analysis Batch is invalid if one or more analyte peaks drift outside of designated SIM windows in any CCC.

10.1.4 Suggested Ions and Dwell Times

Section 17, Table 3 lists ions used for quantitation and confirmation during method development. Set the dwell time for each ion to acquire at least seven to 10 scans across each chromatographic peak. SIM windows and dwell times used to collect method performance data are included in Table 3.

10.2 Initial Calibration

An initial calibration requires optimizing GC/MS conditions and confirming that the instrument meets the BFB tune check criteria (Section 10.1.1). Calibration must be performed using peak areas and the internal standard technique. Calibration using peak heights and external standard calibration are not permitted.

10.2.1 Calibration Standards

Prepare a set of at least six calibration standards as described in Section 7.7. The lowest concentration of the calibration standards must be at, or below, the MRL. The MRL must be confirmed using the procedure outlined in Section 9.2.4 after establishing the initial calibration. Additionally, field samples must be quantified using a calibration curve that spans the same concentration range used to collect the IDC data, e.g., analysts are not permitted to use a restricted calibration range to meet the IDC criteria and then use a larger dynamic range during analysis of field samples.

10.2.2 Calibration Curve

Calibrate the GC/MS system using peak areas and the internal standard technique. Fit the calibration points with either a linear or a quadratic regression (response vs. concentration). Weighting may be used. The GC/MS instrument used during method development was calibrated using quadratic curves with no weighting. Because the surrogate analytes are added at a single concentration level to the calibration standards, calibrate for each surrogate using an average response factor. Suggested internal standard assignments and quantitation ions for each method analyte are presented in Section 17, Table 3.

10.2.3 Calibration Acceptance Criteria

Evaluate the initial calibration by calculating the concentration of each analyte as an unknown against its regression equation. For calibration levels that are less than or equal to the MRL, the result for each analyte should be within plus or minus 50% of the true value. All other calibration points should calculate to be within plus or minus 30% of their true value. If these criteria cannot be met, the analyst could have difficulty meeting ongoing QC criteria. In this case, corrective action is recommended such as reanalyzing the calibration standards, restricting the range of calibration, or performing instrument

maintenance. If the cause for failure to meet the criteria is due to contamination or standard degradation, prepare fresh calibration standards and repeat the initial calibration.

10.3 Continuing Calibration Checks (CCCs)

Analyze a CCC to verify the initial calibration at the beginning of each Analysis Batch, after every tenth field sample, and at the end of each Analysis Batch. The beginning CCC for each Analysis Batch must be at, or below, the MRL. This CCC verifies instrument sensitivity prior to the analysis of samples. Alternate subsequent CCCs between the remaining calibration levels. Verify that the CCC meets the following criteria.

10.3.1 Internal Standard Responses

The absolute area of the quantitation ion for each internal standard (1,4-dioxane-d_8 and chlorobenzene-d_5) must be within plus or minus 50% from the average area measured during the initial calibration. If these limits are exceeded, corrective action is necessary (Sect. 10.4).

10.3.2 Surrogate Analytes

The calculated concentration of the surrogate analytes must be within plus or minus 30% of the true value. If the surrogate analytes fail this criterion, corrective action is necessary (Sect. 10.4).

10.3.3 Method Analytes

Calculate the concentration of each method analyte in the CCC. Each analyte fortified at a level less than or equal to the MRL must calculate to be within plus or minus 50% of the true value. The calculated concentration of the method analytes in CCCs fortified at all other levels must be within plus or minus 30%. If these limits are exceeded, then all data for the failed analytes must be considered invalid. Any field samples analyzed since the last acceptable CCC that are still within holding time must be reanalyzed after an acceptable calibration has been restored.

10.4 Corrective Action

Failure to meet calibration performance criteria requires corrective action. Acceptable method performance may be restored simply by servicing the GC injection port and clipping the column. Following this and other minor corrective action, check the calibration with a mid-level CCC and a CCC at the MRL, or recalibrate according to Section 10.2. If internal standard and calibration failures persist, maintenance may be required, such as servicing the MS system and replacing the GC column. These latter measures constitute major maintenance, and the analyst must return to the initial calibration step (Sect. 10.2) and verify sensitivity by analyzing a CCC at, or below, the MRL.

11 Procedure

This section describes the procedures for sample preparation and analysis. Important aspects of this analytical procedure include proper sample collection and storage (Sect. 8), ensuring that the instrument is properly calibrated (Sect. 10), and that all required QC elements are included (Sect. 9.3). For this method, the volume of nitrogen required to dry SPE cartridges must be determined prior to conducting this procedure. Refer to Section 9.1 for guidance on determining this volume.

11.1 Sample Preparation

All field and QC samples must contain the preservatives listed in Section 8.1, including the LRB and LFB.

11.1.1 QC Samples

With each Extraction Batch (Sect. 3.4), include one LRB, one LFB, and one LFSM. One FD, or one LFSMD, is required. Refer to Section 9.3 for the frequency of QC elements. Fortify the LFB, LFSM, and LFSMD, with an appropriate volume of analyte PDS (Sect. 7.6.3).

11.1.2 Surrogate Analytes

Add an aliquot of the surrogate PDS (Sect. 7.6.2) to each sample. Cap and mix the samples. For method development work, a 10 µL aliquot of the 50 µg/mL surrogate PDS was added to 0.050 L in the original sample bottle for a final concentration of 10 µg/L.

11.2 Extraction Procedure Using Waters AC-2 SPE Format

11.2.1 Set up the Extraction Manifold

Place extraction cartridges on the SPE vacuum manifold and attach 3 mL polypropylene reservoirs. Establish a vacuum between –8 and –5 psig.

11.2.2 Cartridge Cleaning

Add 3 mL of 5% methanol in DCM to each reservoir and draw enough solvent through the cartridge to soak the sorbent. Allow the sorbent to soak for approximately one minute. Draw the remaining solvent to waste until the cartridge is dry. Repeat this step with 2 mL of purge-and-trap-grade methanol.

11.2.3 Cartridge Conditioning

11.2.3.1 Condition with Methanol

Add approximately 2 mL of methanol to the reservoir and draw enough solvent through the cartridge to soak the sorbent. Allow the sorbent to soak for approximately one minute. Draw the solvent through the cartridge; aspirate, but do not allow the sorbent to dry completely. It is not necessary to leave a solvent layer above the sorbent bed.

11.2.3.2 Condition with Water

Fill the 3 mL reservoir completely with reagent water. Draw the water through the cartridge, but do not allow the sorbent to dry completely. It is not necessary to leave a water layer above the sorbent bed. Remove the 3 mL reservoir. The AC-2 cartridges are now ready for sample loading.

11.2.4 Sample Loading

Attach 60 mL reservoirs to the SPE cartridges. Load samples at a flow rate of 5 mL/min or less using a vacuum between –8 and –5 psig. Approximate this rate by ensuring that individual drops are observed exiting the delivery tubes and by timing this step. Rinse the empty sample bottles with 5 mL of reagent water and add the rinse to the reservoir. After the sample passes completely through the cartridge, aspirate for approximately 30 seconds; close the manifold valve. After all samples are loaded, remove the 60 mL reservoirs and increase the vacuum to approximately 20 psig in preparation for the drying steps.

11.2.5 Cartridge Drying

The drying steps are very important. Precisely repeat the procedure optimized during the IDC.

11.2.5.1 Methanol Rinse Step

Attach a clean, dry 3 mL reservoir to each cartridge. Add 150 µL of methanol to each reservoir. Aspirate at full vacuum for approximately 30 seconds. Remove the reservoirs and set aside for later use during the elution step.

11.2.5.2 Nitrogen Purge Step

Transfer the cartridges to the drying manifold. Do not attach the drying manifold to the lid of the extraction manifold. Dry with high-purity nitrogen or zero air using the flow rate and duration optimized during the IDC. Use the rotameter to monitor the flow rate.

11.2.5.3 Drying Manifold Valves

Remove residual water from the manifold valves while the cartridges are drying. Open the valves and transfer a few milliliters of methanol to the top of each valve. Pull air through the valves under full vacuum. Do not omit this step. The manifold valves and delivery tubes hold enough water to cause retention time shifts when analyzing the final extract.

11.3 Extraction Procedure using UCT EU-541 SPE Format

11.3.1 Set Up the Extraction Manifold

Place extraction cartridges on the SPE vacuum manifold. Establish a vacuum between –8 and –5 psig.

11.3.2 Cartridge Cleaning

Fill each cartridge with 5% methanol in DCM and draw enough solvent through the cartridge to soak the sorbent. Allow the sorbent to soak for approximately one minute. Draw the remaining solvent to waste until the cartridge is dry. Repeat this step with 2 mL of purge-and-trap-grade methanol.

11.3.3 Cartridge Conditioning

11.3.3.1 Condition with Methanol

Add approximately 2 mL of methanol to each SPE cartridge and draw enough solvent through to soak the sorbent. Allow the sorbent to soak for approximately one minute. Draw the solvent through the cartridge; aspirate, but do not allow the sorbent to dry completely. It is not necessary to leave a solvent layer above the sorbent bed.

11.3.3.2 Condition with Water

Fill each cartridge completely with reagent water. Draw the water through the cartridge, but do not allow the sorbent to dry completely. Repeat this step a second time, but leave one to two mL of water above the sorbent bed.

11.3.4 Sample Loading

Attach 60 mL reservoirs to the SPE cartridges using a tube adaptor (Sect. 6.11.1). Load samples at a flow rate of 5 mL/min or less using a vacuum between –8 and –5 psig. Approximate this rate by ensuring that individual drops are observed exiting the delivery tubes and by timing this step. Rinse the empty sample bottles with 5 mL of reagent water and add the rinse to the reservoir. After the sample passes completely through the cartridge, aspirate for approximately 30 seconds; close the manifold valve. After all samples are loaded, remove the 60 mL reservoirs and increase the vacuum to approximately 20 psig in preparation for the drying steps.

11.3.5 Cartridge Drying

The drying steps are very important. Precisely repeat the procedure optimized during the IDC.

11.3.5.1 Methanol Rinse Step

Add 200 µL of methanol to the SPE cartridge with intent to rinse residual water droplets from the walls of the cartridge. Any remaining water on the walls will be eliminated during the nitrogen-drying step. Aspirate at full vacuum for approximately 30 seconds.

11.3.5.2 Nitrogen Purge Step

Transfer the cartridges to the drying manifold. Do not attach the drying manifold to the lid of the extraction manifold. Dry with high-purity nitrogen or zero air using the flow rate and duration optimized during the IDC. Use the rotameter to monitor the flow rate.

11.3.5.3 Drying Manifold Valves

Remove residual water from the manifold valves while the cartridges are drying. Open the valves and transfer a few milliliters of methanol to the top of each valve. Pull air through the valves under full vacuum. Do not omit this step. The manifold valves and delivery tubes hold enough water to cause retention time shifts when analyzing the final extract.

11.4 Cartridge Elution

When all valves are dry, release the vacuum on the extraction manifold and place 2 mL volumetric tubes under each sample position. Return the dried cartridges to the same position on the manifold used during sample loading. (Attach a dry, 3 mL reservoir to each Waters AC-2 cartridge. It is not necessary to reverse the cartridges.) Measure approximately 2.3 mL of elution solvent and add this volume to each reservoir. Soak each cartridge for 1 minute then elute in a slow, dropwise manner. Aspirate each cartridge completely. The extracts should not have a visible water layer. Typically, approximately 1.8 mL of elution solvent is recovered.

11.5 Internal Standard Addition

Add an aliquot of the internal standard PDS (Sect. 7.6.1) to each extract. For method development work, a 10 µL aliquot of the 50 µg/mL internal standard PDS was added to each 2 mL extract for a final concentration of 0.25 µg/mL. Bring each extract to volume with the 5% methanol in DCM elution solvent.

11.6 Extract Drying

Add approximately 2 cm^3 of sodium sulfate directly to the 2 mL volumetric tube. Estimate this volume of salt by filling the 2 mL volumetric until the solid level reaches just under or at the 2 mL mark. The liquid level will rise close to the ground glass section of the volumetric, but should not overflow. Stopper securely and vortex for 10 seconds. Allow the desiccant to remain in contact with the solvent for 15 minutes. Using a disposable pipette, transfer the supernatant to a 2 mL autosampler vial. (Condition the sodium sulfate at 400 °C for four hours just prior to use with this method. Repeat the conditioning process at least once per month and more frequently in humid weather.)

11.7 Analysis of Sample Extracts

Establish GC/MS operating conditions per the guidance in Section 10.1. Analyze an archived, unfortified extract to condition the GC inlet and column. This step is optional; however, the authors believe it is an expedient means of "conditioning" the analytical system, especially after maintenance or an extended period of disuse. Establish a valid initial calibration following the procedures in Section 10.2 or confirm that the existing calibration is still valid by analyzing a low-level CCC. If establishing an initial calibration for the first time, complete the IDC prior to analyzing field samples. Analyze field and QC samples in a properly sequenced Analysis Batch as described in Section 11.8.

11.8 The Analysis Batch

An Analysis Batch is a sequence of samples that is analyzed on the same instrument during a 24 hour period that begins and ends with the analysis of CCCs. The Analysis Batch must not have more than 20

field samples. QC samples, such as the LRB, LFB, FD, LFSM, and LFSMD, are not counted as part of the 20-sample limit. The purpose of the field sample limit is to ensure that a low-level CCC and an LRB are repeated on a regular and frequent basis. Analytical conditions for the Analysis Batch must be the same as those applied during calibration.

11.8.1 Initial CCC

After a valid calibration is established, begin every Analysis Batch by analyzing a low-level CCC at, or below, the MRL. The calculated concentration of the method analytes in this CCC must be within plus or minus 50% of the true value. The calculated concentration of the surrogate analytes must be within plus or minus 30%. The initial CCC must pass the plus or minus 50% internal standard area criterion (Sect. 10.3.1). The initial CCC confirms that the calibration curve is valid.

11.8.2 Field and QC Samples

After the initial CCC, continue the Analysis Batch by analyzing an LRB, followed by field and QC samples.

11.8.3 CCC Frequency

Analyze a mid- or high-level CCC after every tenth field sample. QC samples, such as the LRB, LFB, FD, LFSM, and LFSMD, are not counted when determining the required frequency of CCCs.

11.8.4 Final CCC

The last injection of the Analysis Batch must be a mid- or high-level CCC. The acquisition start time of the final CCC must be within 24 hours of the acquisition start time of the low-level CCC at the beginning of the Analysis Batch. More than one Analysis Batch within a 24 hour period is permitted. An Analysis Batch may contain field and QC samples from multiple extraction batches.

11.8.5 Initial Calibration Frequency

A full calibration curve is not required before starting a new Analysis Batch. A previous calibration can be confirmed by running an initial, low-level CCC followed by an LRB. If a new calibration curve is analyzed, an Analysis Batch run immediately thereafter must begin with a low-level CCC and an LRB.

12 Data Analysis and Calculations

12.1 Establish Retention Time Windows

Select an appropriate retention time window for each analyte to identify them in QC and field sample chromatograms. Base this assignment on measurements of actual retention time variation for each compound in standard solutions analyzed on the GC/MS over the course of time. The suggested variation is plus or minus three times the standard deviation of the retention time for each compound for a series of injections. The injections from the initial calibration and from the IDC may be used to calculate the retention time window. However, the experience of the analyst should weigh heavily on the determination of an appropriate range.

12.2 Identify Analytes by Retention Time

Initially, identify each analyte by comparison of its retention time with that of the corresponding analyte peak in a recent initial calibration standard or CCC. Use the same software settings established during the calibration procedure and the predetermined retention time windows.

12.3 Confirm Analyte Identifications

Examine the SIM spectrum for each analyte. Use appropriate background subtraction to remove ions contributed by co-eluting matrix components. For each analyte identified by retention time, at least one

confirmation ion must be present. The abundance of the confirmation ions relative to the quantitation ion should agree within an absolute 20 percent of the relative abundance in the spectrum taken from a recent calibration standard. For example, if an ion has a relative abundance of 30 percent in the calibration standard, its abundance in the sample spectrum should be in the range of 10 to 50 percent. Only confirmation ions that exhibit greater than 30% relative abundance to the quantitation ion in the mass spectrum of the calibration standard must meet this criterion. Knowledge of sample history and the experience of the analyst are important factors that may aid analyte confirmation.

12.4 Compound Quantitation

Calculate analyte concentrations using the multipoint calibration. Report only those values that fall between the MRL and the highest calibration standard. Calculations should be rounded to an appropriate number of significant figures, typically two, but not more than three. Do not base quantitation of samples on response factors calculated from CCCs.

12.5 Data Review

Prior to reporting data, the chromatograms must be reviewed for incorrect peak identification or improper integration. Prior to reporting data, the laboratory is responsible for verifying that QC requirements have been met and that any appropriate qualifier is assigned.

12.6 Exceeding the Calibration Range

The analyst must not extrapolate beyond the established calibration range. If an analyte result exceeds the range of the initial calibration curve, dilute the extract with elution solvent containing the required concentration of internal standards. Re-inject the diluted sample. Incorporate the dilution factor into final concentration calculations. The resulting data must be annotated as a dilution, and the reported MRLs must reflect the dilution factor. Report surrogate recoveries observed in the undiluted sample.

13 Method Performance

13.1 Precision, Accuracy, and LCMRL Results

Tables for these data are presented in Section 17. LCMRLs are presented for each of two SPE formats: Waters AC-2, 400 mg cartridges (Table 4) and UCT EU-541, 600 mg cartridges (Table 8). For each of these formats, single-laboratory precision and accuracy data are presented for three water matrixes: reagent water (Waters AC-2: Table 5 and UCT EU-541: Table 9), finished ground water (Waters AC-2: Table 6 and UCT EU-541: Table 10), and finished surface water (Waters AC-2: Table 7 and UCT EU 541: Table 11). Figure 4 and Figure 5 are reconstructed ion chromatograms of extracts (Waters AC-2 format) obtained from drinking water using the GC/MS conditions employed during method development.

13.2 Analyte Stability Study

Chlorinated (finished) surface water samples were inoculated with diluted, microbial-rich water from an ambient source, and fortified with 0.80 µg/L of 1,4-dioxane and 4.0 µg/L of 2-propen-1-ol, 1-butanol and 2-methoxyethanol. These samples were preserved and stored as required in this method. The percent change from the initial analyzed concentration observed after 7, 14, 21, and 28 days is presented in Section 17, Table 12.

13.3 Extract Storage Stability

Extract storage stability studies were conducted on extracts obtained from chlorinated surface water fortified with the method analytes (Sect. 13.2). The percent change from the initial analyzed concentration observed after 7, 14, 21, and 28 days storage is presented in Section 17, Table 13.

14 Pollution Prevention

For information about pollution prevention applicable to laboratory operations described in this method, consult: Less is Better, Guide to Minimizing Waste in Laboratories, a web-based resource available from the American Chemical Society at www.acs.org.

15 Waste Management

The Agency requires that laboratory waste management practices be consistent with all applicable rules and regulations, and that laboratories protect the air, water, and land by minimizing and controlling all releases from fume hoods and bench operations. In addition, compliance is required with any sewage discharge permits and regulations, particularly the hazardous waste identification rules and land disposal restrictions.

16 References

1. US EPA Document # 815-R-05-006, "Statistical Protocol for the Determination of the Single-Laboratory Lowest Concentration Minimum Reporting Level (LCMRL) and Validation of Laboratory Performance at or Below the Minimum Reporting Level (MRL)", Office of Water, November 2004.
2. US EPA Document # EPA 815-R-11-001 , "Technical Basis for the Lowest Concentration Minimum Reporting Level (LCMRL) Calculator", Office of Water, December 2010.

17 Tables, Figures, and Method performance Data

Table 1. 4-Bromofluorobenzene (BFB) Mass Intensity Criteria

m/z	**Required Intensity (relative abundance)**
95	Base peak, 100% relative abundance
96	5 to 9% of *m/z* 95
173	Less than 2% of *m/z* 174
174	Greater than 50% of *m/z* 95
175	5 to 9% of *m/z* 174
176	Greater than 95% but less than 105% of *m/z* 174
177	5 to 10% of *m/z* 176

Table 2. Gas Chromatography/Mass Spectrometry (GC/MS) Conditions

Parameter	**Conditions**[a]
Column	Phenomenex (Torrance, CA) ZB-WAX *plus*: 30 meter, 0.25 mm i.d., 0.5 µm film thickness (d_f)
Inlet liner	4-mm i.d., single-gooseneck, deactivated glass with deactivated glass wool
Inlet conditions	200 °C, pulsed splitless injection mode: 10 psig until 0.5 minutes, purge flow (split) on at 0.5 minutes @ 100 mL/min
Injection volume	1 µL using a 10 µL syringe
Column flow rate	0.9 mL/min in constant flow mode, helium carrier gas
GC temperature program	30 °C for 0.5 min, 10 °C/min to 110 °C, hold 0 min, 25 °C/min to 200 °C, hold 6 min
Solvent delay	9.8 min before activating filaments in the electron impact source
MS source temperature	230 °C
MS quadrupole temperature	150 °C
GC/MS interface	Direct, 200 °C

a. The chromatograms presented in Figures 2–5 were obtained under these conditions.

Table 3. Retention Times, Quantitation Ions, and Internal Standard Assignments[a]

Analyte	SIM Window (minutes)	RT[b]	Q-Ion[c]	Confirmation Ions[c]	IS[c] Reference
Filament delay	9.8				
Internal standard (IS): 1,4-dioxane-d_8	9.8 – 10.6	10.29	96	64, 46	---
1,4-dioxane	9.8 – 10.6	10.31	88	87, 58, 57	1,4-dioxane-d_8
Surrogate: 2-propen-1-ol-d_6	10.6 – 12.1	11.16	61[d]	63, 46	chlorobenzene-d_5
2-propen-1-ol	10.6 – 12.1	11.26	57	58, 55, 39	chlorobenzene-d_5
Surrogate: 1-butanol-d_{10}	10.6 – 12.1	11.71	64	63, 50, 46	chlorobenzene-d_5
1-butanol	10.6 – 12.1	11.87	56	55, 43, 41	chlorobenzene-d_5
2-methoxyethanol	12.1 – 22.5	12.50	45	76, 47, 58	chlorobenzene-d_5
Internal standard: chlorobenzene-d_5	12.1 – 22.5	13.14	117	76, 119	---

a. These quantitation ions are appropriate for the column used to generate method performance data. See Figures 2–5 for reconstructed ion chromatograms (RICs) and extracted ion current profiles (EICPs) obtained during collection of the method performance data.
b. RT = retention time observed using Phenomenex Zebron ZB-WAX *plus* column.
c. Dwell times vary between 20 and 40 ms.
d. This mass corresponds to $C_3D_4HO^{+\cdot}$ rather than the expected fragment, $C_3D_5O^{+\cdot}$, *m/z* 62.

Table 4. LCMRL Results for the Waters AC-2 SPE Format[a]

Analyte	LCMRL Fortification Levels (µg/L)	Calculated LCMRL (µg/L)
1,4-dioxane	0.0, 0.040, 0.070, 0.10, 0.20, 0.30, 0.40, 0.50	0.074
2-propen-1-ol	0.0, 0.20, 0.35, 0.50, 1.0, 1.5, 2.0, 2.5	0.30
1-butanol	0.0, 0.20, 0.35, 0.50, 1.0, 1.5, 2.0, 2.5	0.44
2-methoxyethanol	0.0, 0.20, 0.35, 0.50, 1.5, 1.0, 2.0, 2.5	0.37

a. LCMRL = lowest concentration minimum reporting limit; SPE = solid phase extraction.

Table 5. Precision and Accuracy Data for Reagent Water: Waters AC-2 SPE Format[a]

Analyte	Fortification (µg/L)[b]	Mean %R[c] (*n*=7)	%RSD[c]	Fortification (µg/L)	Mean %R (*n*=5)	%RSD
1,4-dioxane	0.40	102	3.9	8.0	96.8	2.0
2-propen-1-ol	2.0	88.1	4.4	40	90.8	1.1
1-butanol	2.0	97.0	2.6	40	92.2	1.8
2-methoxyethanol	2.0	93.3	3.0	40	92.4	1.6
Surrogate: 2-propen-1-ol-d_6	10	92.6	3.3	10	92.2	0.94
Surrogate: 1-butanol-d_{10}	10	95.5	2.3	10	92.7	1.1

a. SPE = solid phase extraction.
b. The MRL was confirmed at these concentrations during collection of the method performance data.
c. %R = percent recovery; %RSD = percent relative standard deviation.

Table 6. Precision and Accuracy Data for Ground Water: Waters AC-2 SPE Format[a]

Analyte	Fortification (µg/L)[b]	Mean %R[c,d] (*n*=5)	%RSD[d]	Fortification (µg/L)	Mean %R[c] (*n*=5)	%RSD
1,4-dioxane	0.40	104	3.0	8.0	98.5	2.2
2-propen-1-ol	2.0	93.0	2.7	40	92.5	2.4
1-butanol	2.0	86.4	1.8	40	92.3	2.0
2-methoxyethanol	2.0	83.3	1.2	40	92.8	2.0
Surrogate: 2-propen-1-ol-d_6	10	93.5	2.3	10	93.1	1.5
Surrogate: 1-butanol-d_{10}	10	95.1	1.7	10	92.7	1.7

a. Ground water physical parameters: pH = 7.8; total hardness = 337 mg/L (as $CaCO_3$); free chlorine = 0.60 mg/L, total chlorine = 0.86 mg/L; SPE = solid phase extraction.
b. The MRL was confirmed at these concentrations during collection of the method performance data.
c. Recoveries corrected for native levels in the unfortified matrix.
d. %R = percent recovery; %RSD = percent relative standard deviation.

Table 7. Precision and Accuracy Data for Surface Water: Waters AC-2 SPE Format[a]

Analyte	Fortification (µg/L)[b]	Mean %R[c,d] (*n*=5)	%RSD[d]	Fortification (µg/L)	Mean %R[c] (*n*=5)	%RSD
1,4-dioxane	0.40	94.1	3.2	8.0	93.0	4.3
2-propen-1-ol	2.0	87.6	1.2	40	89.1	3.7
1-butanol	2.0	79.0	3.1	40	87.7	3.4
2-methoxyethanol	2.0	86.6	2.8	40	89.2	3.8
Surrogate: 2-propen-1-ol-d_6	10	88.0	1.2	10	88.9	2.9
Surrogate: 1-butanol-d_{10}	10	87.5	2.4	10	88.6	2.8

a. Surface water physical parameters: pH = 7.3; total organic carbon (TOC) = 2.28 mg/L; free chlorine = 1.06 mg/L, total chlorine = 1.51 mg/L; SPE = solid phase extraction.
b. The MRL was confirmed at these concentrations during collection of the method performance data.
c. Recoveries corrected for native levels in the unfortified matrix.
d. %R = percent recovery; %RSD = percent relative standard deviation.

Table 8. LCMRL Results for the UCT EU-541 SPE Format[a]

Analyte	LCMRL Fortification Levels (µg/L)	Calculated LCMRL (µg/L)
1,4-dioxane	0, 0.048, 0.070, 0.10, 0.20, 0.30, 0.40, 0.48	0.090
2-propen-1-ol	0, 0.16, 0.24, 0.35, 0.50, 1.0, 1.5, 2.0, 2.4	0.17
1-butanol	0, 0.24, 0.35, 0.50, 1.0, 1.5, 2.0, 2.4	0.61
2-methoxyethanol	0, 0.24, 0.35, 0.50, 1.0, 1.5, 2.0, 2.4	0.30

a. LCMRL = lowest concentration minimum reporting limit; SPE = solid phase extraction.

Table 9. Precision and Accuracy Data for Reagent Water: UCT EU-541 SPE Format[a]

Analyte	Fortification (µg/L)[b]	Mean %R[c] (*n*=5)	%RSD[c]	Fortification (µg/L)	Mean %R (*n*=5)	%RSD
1,4-dioxane	0.40	96.2	3.7	8.0	93.7	2.3
2-propen-1-ol	2.0	84.3	5.7	40	86.7	4.2
1-butanol	2.0	97.1	0.84	40	91.8	1.9
2-methoxyethanol	2.0	86.2	8.2	40	86.4	3.4
Surrogate: 2-propen-1-ol-d_6	10	84.4	6.7	10	87.4	2.9
Surrogate: 1-butanol-d_{10}	10	90.1	1.8	10	92.3	1.6

a. SPE = solid phase extraction.
b. The MRL was confirmed at these concentrations during collection of the method performance data.
c. %R = percent recovery; %RSD = percent relative standard deviation.

Table 10. Precision and Accuracy Data for Ground Water: UCT EU-541 SPE Format[a]

Analyte	Fortification (µg/L)[b]	Mean %R[c,d] (*n*=5)	%RSD[d]	Fortification (µg/L)	Mean %R[c] (*n*=5)	%RSD
1,4-dioxane	0.40	102	2.7	8.0	96.3	4.9
2-propen-1-ol	2.0	84.7	0.83	40	83.9	0.96
1-butanol	2.0	82.0	1.2	40	89.4	2.4
2-methoxyethanol	2.0	87.4	1.3	40	82.7	1.5
Surrogate: 2-propen-1-ol-d_6	10	84.3	2.0	10	82.9	2.0
Surrogate: 1-butanol-d_{10}	10	90.1	1.1	10	89.4	2.5

a. Ground water physical parameters: pH = 7.8; total hardness = 337 mg/L (as $CaCO_3$); free chlorine = 0.60 mg/L, total chlorine = 0.86 mg/L; SPE = solid phase extraction.
b. The MRL was confirmed at these concentrations during collection of the method performance data.
c. Recoveries corrected for native levels in the unfortified matrix.
d. %R = percent recovery; %RSD = percent relative standard deviation.

Table 11. Precision and Accuracy Data for Surface Water: UCT EU-541 SPE Format[a]

Analyte	Fortification (µg/L)[b]	Mean %R[c,d] (*n*=5)	%RSD[d]	Fortification (µg/L)	Mean %R[c] (*n*=5)	%RSD
1,4-dioxane	0.40	96.3	3.1	8.0	101	5.0
2-propen-1-ol	2.0	92.2	3.1	40	88.1	1.0
1-butanol	2.0	84.2	5.5	40	89.7	2.1
2-methoxyethanol	2.0	93.7	1.8	40	85.7	1.2
Surrogate: 2-propen-1-ol-d_6	10	90.4	1.9	10	86.2	1.4
Surrogate: 1-butanol-d_{10}	10	92.4	2.3	10	90.2	1.6

a. Surface water physical parameters: pH = 7.3; total organic carbon (TOC) = 2.28 mg/L; free chlorine = 1.06 mg/L, total chlorine = 1.51 mg/L; SPE = solid phase extraction.

b. The MRL was confirmed at these concentrations during collection of the method performance data.

c. Recoveries corrected for native levels in the unfortified matrix.

d. %R = percent recovery; %RSD = percent relative standard deviation.

Table 12. Aqueous[a] Sample Holding Time Data (*n*=4)

Analyte	Fortified Conc. (µg/L)	Day Zero Mean (µg/L)	Day Zero %RSD	Day 7 %Change[b]	Day 7 %RSD	Day 14 %Change	Day 14 %RSD	Day 21 %Change	Day 21 %RSD	Day 28 %Change	Day 28 %RSD
1,4-dioxane	0.80	0.78	4.6	0.19	3.7	-1.8	2.7	-2.6	4.2	-0.59	6.0
2-propen-1-ol	4.0	3.5	3.2	0.53	2.0	-3.2	1.8	-3.7	2.2	-2.4	3.5
1-butanol	4.0	3.6	2.6	-1.5	2.2	-8.1	2.2	-6.8	4.2	-4.8	4.2
2-methoxyethanol	4.0	3.4	3.5	-1.2	2.6	-2.0	2.0	-0.47	3.7	0.24	2.8

a. Finished water from a surface water source. Physical parameters: pH = 7.3; total organic carbon (TOC) = 2.28 mg/L; free chlorine = 1.06 mg/L, total chlorine = 1.51 mg/L.

b. %Change = percent change from Day Zero calculated as follows: (Day X mean concentration – Day Zero mean concentration) / Day Zero mean concentration * 100%, where X is the analysis day.

Table 13. Holding Time Data for Sample Extracts (*n*=4)

Analyte	Fortified Conc. (µg/L)	Day Zero Mean (µg/L)	Day Zero %RSD	Day 7 %Change[a]	Day 7 %RSD	Day 14 %Change	Day 14 %RSD	Day 21 %Change	Day 21 %RSD	Day 28 %Change	Day 28 %RSD
1,4-dioxane	0.80	0.76	2.7	2.5	5.9	7.5	8.4	1.9	4.9	1.7	6.6
2-propen-1-ol	4.0	3.4	1.8	2.3	2.3	1.4	2.9	0.35	2.4	3.1	2.6
1-butanol	4.0	3.4	2.2	1.7	2.4	0.42	1.6	1.9	2.4	2.5	2.6
2-methoxyethanol	4.0	3.4	2.0	2.8	2.7	1.1	1.2	2.5	2.6	2.9	2.6

a. %Change = percent change from Day Zero calculated as follows: (Day X mean concentration – Day Zero mean concentration) / Day Zero mean concentration * 100%, where X is the analysis day.

Table 14. Initial Demonstration of Capability (IDC) Quality Control Requirements

Method Reference	Requirement	Specification and Frequency	Acceptance Criteria
Section 9.1	Optimize SPE cartridge drying parameters	For each extraction format	Extract must be visibly dry. Retention times must match those observed for calibration standards.
Section 9.2.1	Demonstration of low system background	Analyze a Laboratory Reagent Blank after the high calibration standard during the IDC calibration.	Demonstrate that all method analytes are less than one-third of the Minimum Reporting Level (MRL).
Section 9.2.2	Demonstration of precision	Extract and analyze 5 replicate Laboratory Fortified Blanks (LFBs) near the mid-range concentration.	Percent relative standard deviation must be ≤20%.
Section 9.2.3	Demonstration of accuracy	Calculate mean recovery for replicates used in Section 9.2.2.	Mean recovery within ±30% of the true value.
Section 9.2.4	MRL confirmation	Fortify and analyze 7 replicate LFBs at the proposed MRL concentration. Confirm that the Upper Prediction Interval of Results (PIR) and Lower PIR meet the recovery criteria.	Upper PIR ≤150% Lower PIR ≥50%
Section 9.2.5	Quality Control Sample (QCS)	Analyze mid-level QCS.	Results must be within ±20% of the true value.

Table 15. Ongoing Quality Control Requirements

Method Reference	Requirement	Specification and Frequency	Acceptance Criteria
Section 10.1.1	Bromofluorobenzene (BFB) Tune Check	1µg/mL in elution solvent in full scan mode with each initial calibration, or after major mass spectrometer service.	Table 1, Section 17
Section 10.2	Initial calibration	Use the internal standard calibration technique to generate a linear or quadratic calibration curve. Use at least 6 standard concentrations. Evaluate the calibration curve as described in Section 10.2.3.	When each calibration standard is calculated as an unknown using the calibration curve, the lowest level standard should be within ±50% of the true value. All other points should be within ±30% of the true value.
Section 9.3.1	Laboratory Reagent Blank (LRB)	Include one LRB with each Extraction Batch. Analyze one LRB with each Analysis Batch.	Demonstrate that all method analytes are below one-third the Minimum Reporting Level (MRL), and that possible interference from reagents and glassware do not prevent identification and quantitation of method analytes.

Method Reference	Requirement	Specification and Frequency	Acceptance Criteria
Section 9.3.3	Laboratory Fortified Blank	Include one LFB with each Extraction Batch.	For analytes fortified at concentrations ≤2 x the MRL, the result must be within ±50% of the true value; ±30% of the true value if fortified at concentrations greater than 2 x the MRL.
Section 10.3	Continuing Calibration Check (CCC)	Verify initial calibration by analyzing a low-level CCC at the beginning of each Analysis Batch. Subsequent CCCs are required after every tenth field sample and to complete the batch.	The lowest level CCC must be within ±50% of the true value. All other points must be within ±30% of the true value.
Section 9.3.5	Internal standards (IS)	Internal standards are added to all standards and sample extracts.	Peak area counts for each IS must be within ±30% of the area in the most recent CCC, and ±50% of the average peak area in the initial calibration.
Section 9.3.6	Surrogate analytes	Surrogates are added to all field samples and QC samples prior to extraction.	70% to 130% recovery
Section 9.3.7	Laboratory Fortified Sample Matrix (LFSM)	Include one LFSM per Extraction Batch. Fortify the LFSM with method analytes at a concentration close to but greater than the native concentrations (if known).	For analytes fortified at concentrations ≤2 x the MRL, the result must be within ±50% of the true value; ±30% of the true value if fortified at concentrations greater than 2 x the MRL.
Section 9.3.8	Laboratory Fortified Sample Matrix Duplicate (LFSMD) or Field Duplicate (FD)	Include at least one LFSMD or FD with each Extraction Batch.	For LFSMDs or FDs, relative percent differences must be ≤30% (≤50% if concentration ≤2 x the MRL).
Section 9.3.9	QC failures associated with retention time shifts	Evaluate retention times for analytes, surrogates, and internal standards failing QC criteria.	Retention times of the method analytes must be within the windows determined using dry calibration standards (Sect. 12.1). SPE drying procedures must be optimized for each extraction format (Sect. 9.1).
Section 9.3.10	Quality Control Sample (QCS)	Analyze a QCS at least quarterly.	Results must be ±20% of the true value.

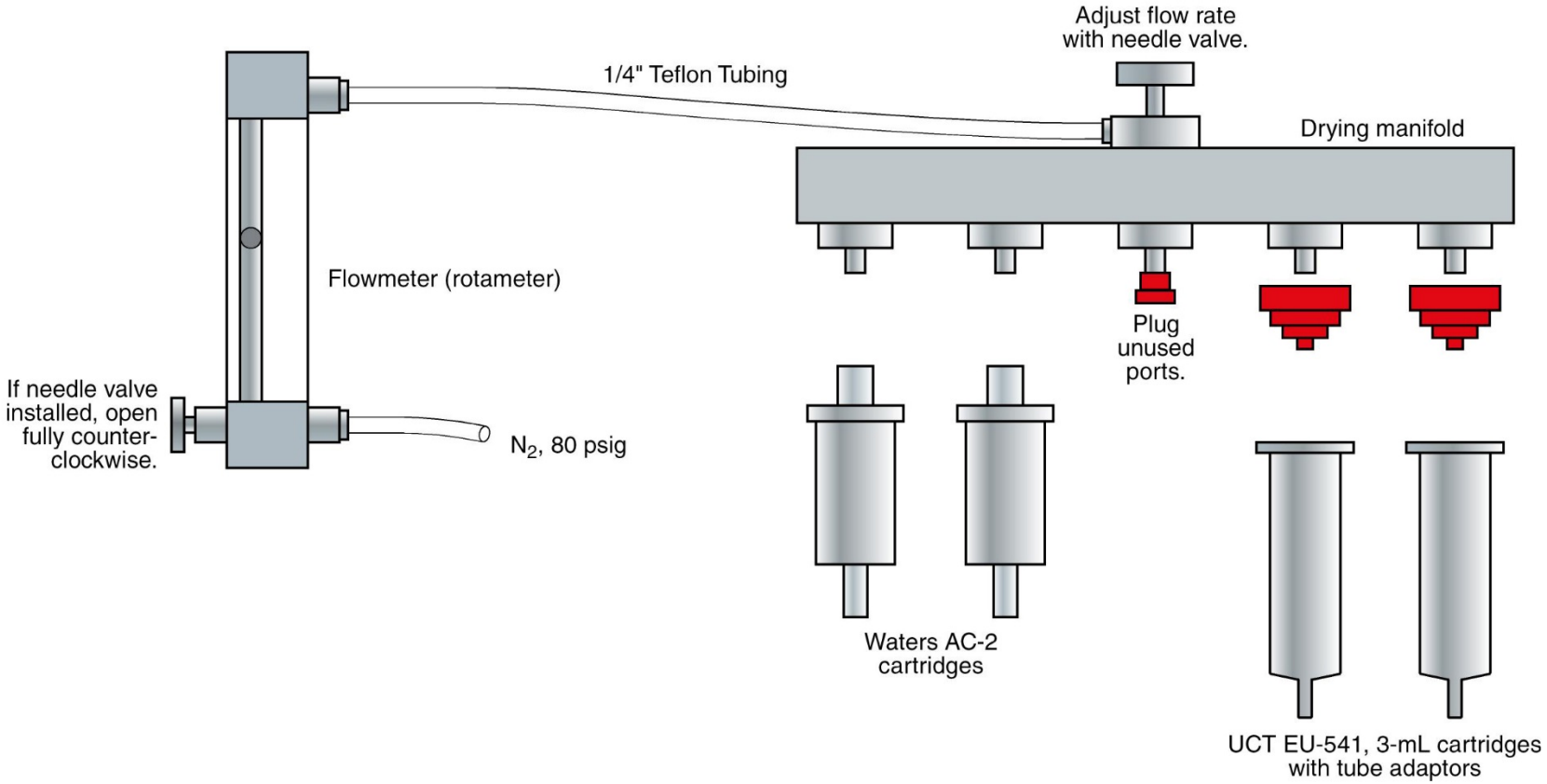

Figure 1. Drying apparatus and proper placement of rotameter in flow path

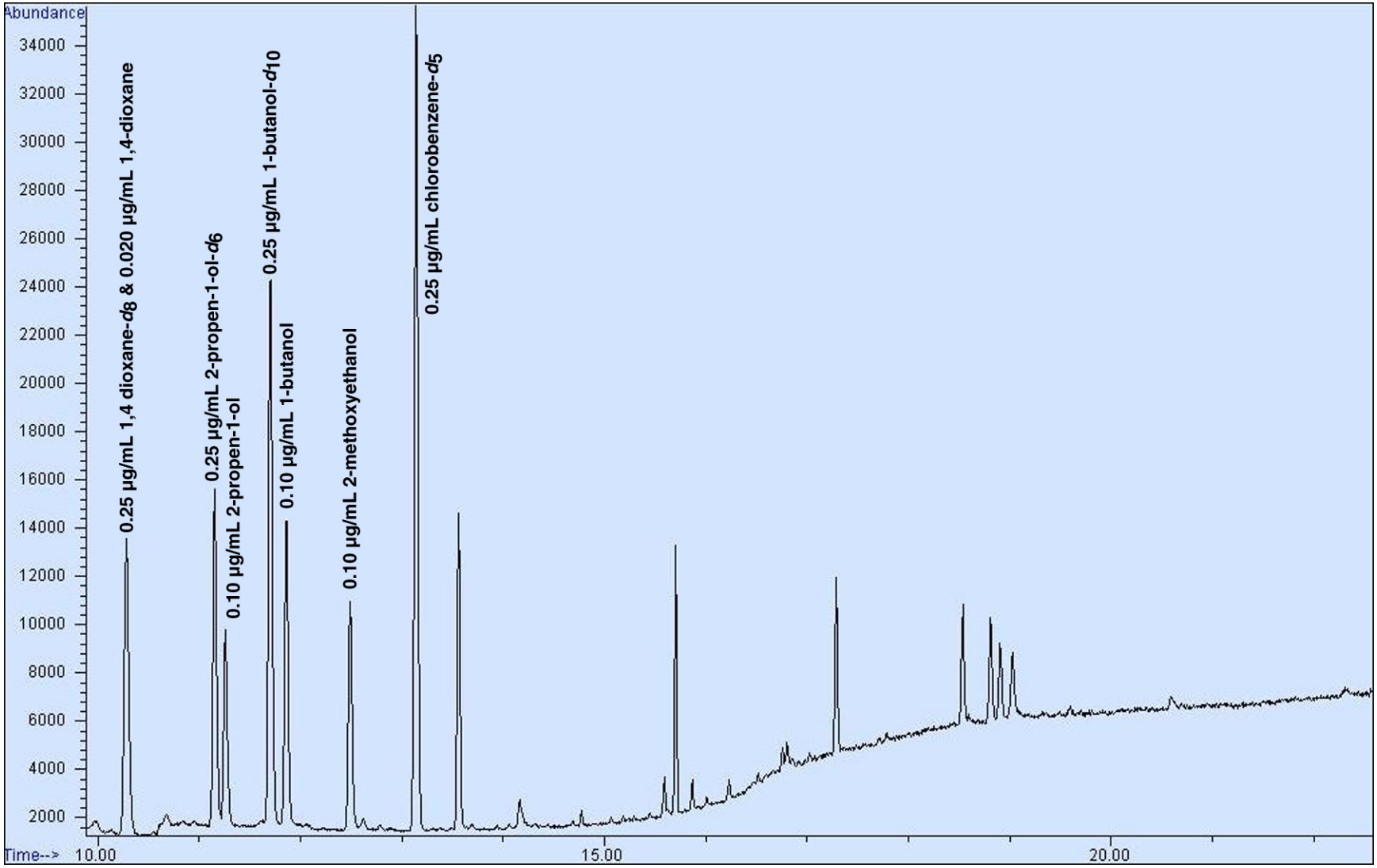

Figure 2. Reconstructed ion chromatogram (RIC), SIM mode, for calibration standard

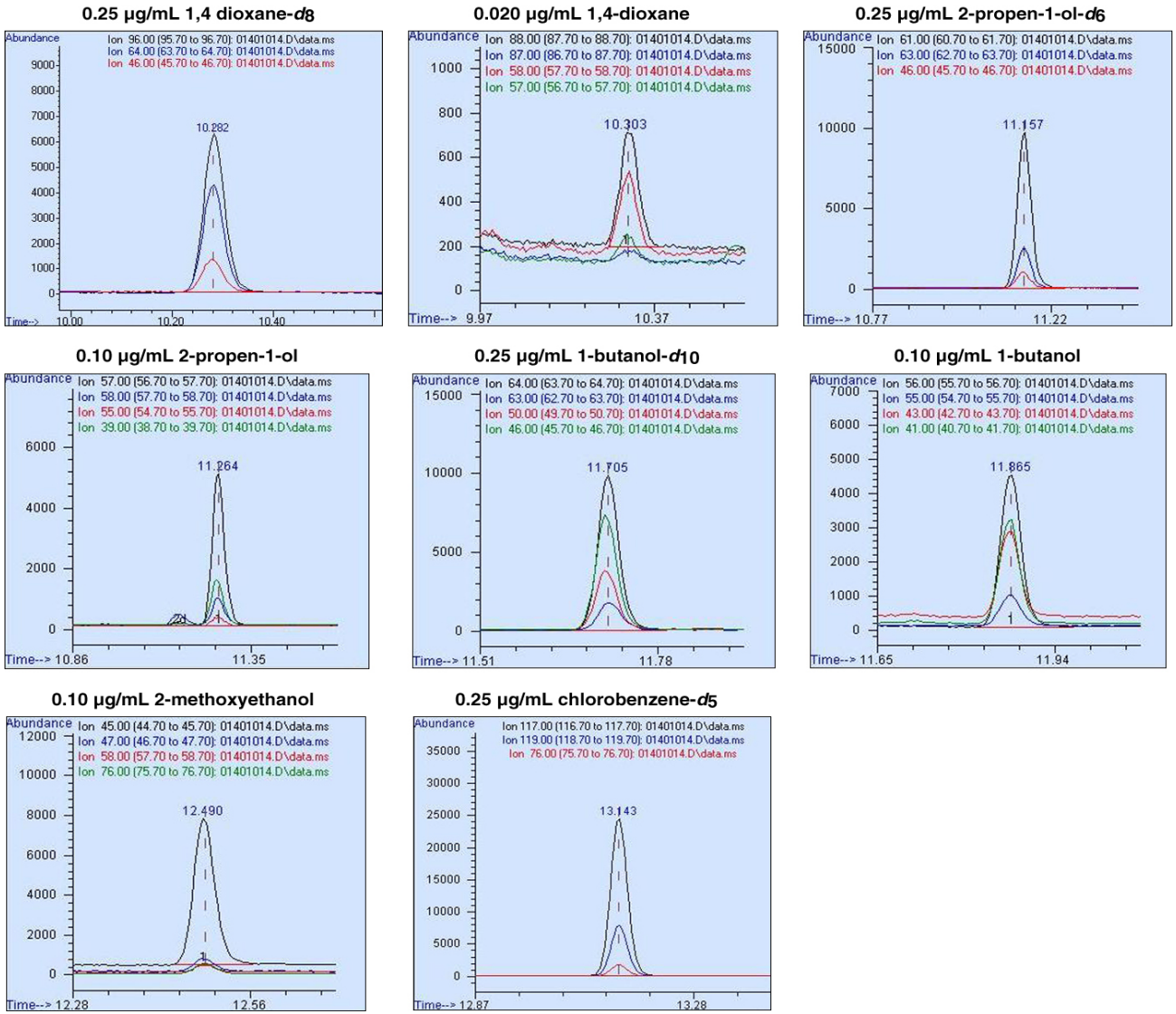

Figure 3. Extracted ion current profiles for calibration standard; concentrations as listed

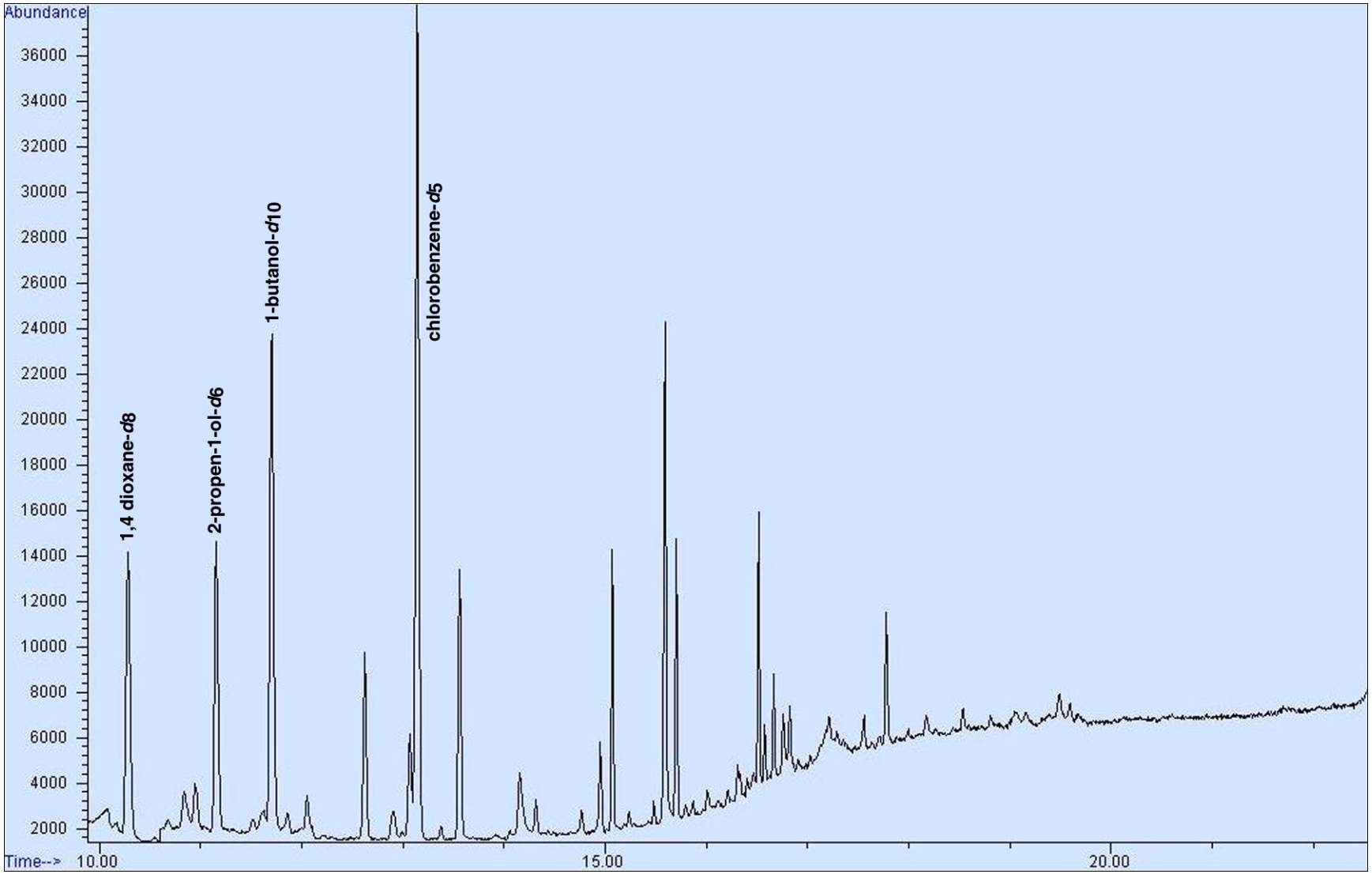

Figure 4. RIC, SIM mode, for unfortified drinking water from a surface water source

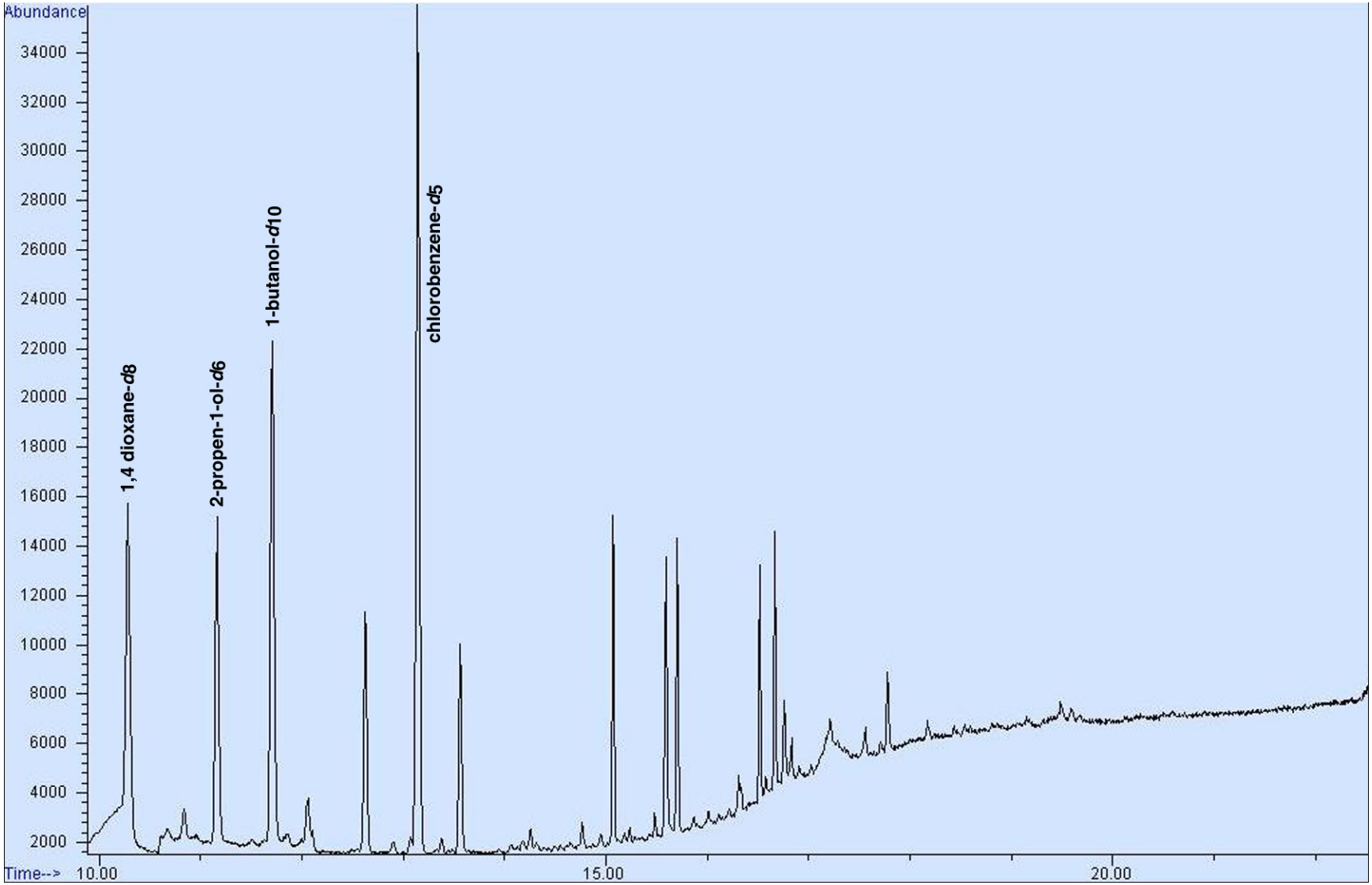

Figure 5. RIC, SIM mode, for unfortified drinking water from a ground water source