UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

June 24, 1986

OFFICE OF
THE ADMINISTRATOR

Honorable Lee M. Thomas
Administrator
U. S. Environmental Protection Agency
Washington, D. C. 20460

Dear Mr. Thomas:

The Environmental Engineering Committee of the Science Advisory Board has just completed its review of the draft "RCRA Groundwater Monitoring Technical Enforcement Guidance Document" (TEGD), prepared by the Office of Waste Program Enforcement (OWPE). We are pleased to forward the Committee's report for your review. In view of the extremely short deadlines requested for this review, we have already provided formal comments to the staff in the Office of Waste Programs Enforcement.

A comprehensive document for setting consistent standards for establishing and evaluating ground water monitoring efforts is badly needed, and the version of the draft document reviewed by the Committee is a good start toward achieving this goal. We continue to believe that the Agency needs to strongly emphasize that the TEGD is neither a regulation nor an "engineering handbook," and that flexibility, highly trained and experienced personnel, and professional judgement are needed by both EPA and those implementing ground water monitoring systems.

Much of the draft TEGD is technically sound. The Committee has made a number of recommendations for improvement, and acknowledges that the Office of Waste Program Enforcement has already made numerous changes which implement some of these recommendations. If other changes suggested are also made, the document should provide useful guidance to Federal and State personnel, as well as owner/operators, in the design and operation of ground water monitoring systems.

If you have questions about any of our findings or recommendations, we would be happy to provide further information or to meet with you to discuss them. We would appreciate a formal response to the conclusions and recommendations presented in this report.

Sincerely,

Raymond C. Loehr

Raymond C. Loehr, Chairman
Environmental Engineering Committee

Norton Nelson

Norton Nelson, Chairman
Science Advisory Board

cc: T. Yosie
G. Lucero
P. Cook
B. Johnson

SAB-EEC-86-007

REPORT

on the review of the

"RCRA GROUND-WATER MONITORING

TECHNICAL ENFORCEMENT GUIDANCE DOCUMENT"

by the

Environmental Engineering Committee
Science Advisory Board
U. S. Environmental Protection Agency

June, 1986

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SECTION I

PRINCIPAL FINDINGS AND RECOMMENDATIONS

The Science Advisory Board was asked by Mr. Gene A. Lucero, Director, Office of Waste Programs Enforcement (OWPE), on August 26, 1985, to review a draft document entitled "RCRA Ground Water Monitoring Technical Enforcement Guidance Document" (TEGD), which had been prepared by his staff. The document concerned the technical aspects of ground water monitoring at Resource Conservation and Recovery Act (RCRA) facilities. A Subcommittee of the Environmental Engineering Committee of the Science Advisory Board (SAB) was established to conduct the review, which has now been completed, except for review of Chapter 5 (Statistical Analysis of Detection Monitoring Data), which will be completed at a later date. The Committee appreciates the opportunity to review the document, and has concentrated on a number of technical issues highlighted for review by OWPE (see Appendix B), as well as some other issues raised by the Committee themselves.

A summary of the Committee's principal findings and recommendations follows. More detailed comments will be found in Section III.

General

A. The Committee recognizes that the document is the result of extensive technical thought and review of several previous drafts, and is a significant improvement over previous versions. However, some technical amendments remain to be made.

B. The Committee recommends that the TEGD be much more explicit in stating that it is a guidance document only, and requires informed judgement in its application and use.

In the public testimony which was a part of the Committee's review process, many individuals expressed the concern that the document would be used, particularly by persons with little or no experience in the design and operation of monitoring systems, to set specific requirements, such as number and location of monitoring wells, well materials and screen lengths, where such requirements could not be justified by the physical situation. It must be made very clear that the TEGD requires informed judgement in its application and use. This report proposes changes that should substantially reduce the likelihood of these kinds of problems.

C. Several examples in the TEGD require improvement if they are to serve the purpose intended.

Such graphic examples as those dealing with well screen length, placement of upgradient monitoring wells and well design and construction show details that may be inappropriate or misleading.

Characterization of Site Hydrogeology

D. The Committee recommends that the procedures specified for the design of detection monitoring systems be made more efficient, and that substantially more flexibility be encouraged in addressing the primary objective, that of determining the direction and magnitude of flow of potential pollutants.

In non-complex geology, the owner/operator would obtain most of the information needed to design a detection monitoring system using the procedures specified in the TEGD. Many guidelines however, such as well spacings, continuous sampling and the requirement for full Appendix VIII constituent analyses of potentially contaminated core samples should be re-evaluated in the light of increasing both the efficiency and cost-effectiveness of detection monitoring.

E. In addition to making the characterization and evaluation process more efficient, EPA should also elaborate and improve the discussion of a number of important factors which are inadequately addressed in the TEGD.

These factors include accuracy requirements for location surveys, bore-hole sealing, characterization of the underlying confining layer, the definition of "qualified geologist" and boring depth. Detailed discussions of these may be found in Section III.

F. A number of terms used in the TEGD need to be redefined to make them more specific, consistent with generally-accepted practice and consistent with the objective of protecting usable water supplies.

Definitions of terms such as bedrock, aquifer, uppermost aquifer, water table and hydraulic interconnection are not consistent with standard definitions.

Placement of Detection Monitoring Wells

G. The entire discussion in the TEGD related to detection well spacing should be revised to better reflect the purpose of the monitoring.

There should be a clearer distinction drawn between detection monitoring systems and assessment monitoring systems. Arbitrary well spacings should not be specified, but rather should be determined on the basis of site hydrogeological characteristics (as previously determined) and the requirement to determine the magnitude and direction of ground water flow. See Section III for one approach.

Monitoring Well Design and Construction

H. Guidance on well design and construction should further emphasize methods which minimize disturbance of the ground-water system and are appropriate for the hydrogeologic and chemical conditions.

Drilling: Emphasis should be placed upon the selection of drilling methods which (1) minimize disturbance of the geologic and hydrogeologic system and (2) present the least potential for introducing contamination.

Materials: Flourocarbon resins (such as Teflon, PFTE, FEP or PFA) or stainless steel 304 or 316 should be specified for use in the saturated zone when potentially sorbing organics are to be determined. In such cases, and where high potential for corrosion exists or is anticipated, fluorocarbon resins are preferable to stainless steel. PVC has utility when shown not to leach or absorb contaminants significantly.

Well Development: Well development and periodic redevelopment effort should be emphasized in addition to a performance standard.

I. EPA should allow substantially greater flexibility in the recommended length of well screens.

The maximum limitation of 10 feet on well screen length, particularly for detection monitoring where the primary purpose is to identify the presence of pollutants of concern, may not adequately accomodate all hydrogeologic situations which may be encountered in the field, and may, in fact, lead to the collection of misleading data. If the screen length is suitable given the hydrogeologic complexity, it should also be sufficient for water quality sampling.

Sampling and Analysis

J. Sampling protocols in the draft TEGD are substantially acceptable, but should be further tailored to hydrogeologic conditions and to the maintenance of sample integrity.

Purging: Purging requirements should be calculated based on an evaluation of the hydraulic performance of the well, and confirmed by pH, conductivity and temperature measurements.

Collection Equipment: Integrated sample withdrawal and purging equipment which minimizes sample disturbance is recommended. See Section III of this report for further details.

Statistical Analysis of Detection Monitoring Data

K. The Agency should use the AR t-test proposed in the draft TEGD in the short term, but must also acknowledge that there are many situations encountered in actual practice where the method may not yield accurate results.

The t-distribution model does not apply to the situation where sampled concentrations are drawn from a set of upgradient wells with different means, and then averaged. If the aquifer is not homogeneous with respect to concentration distributions (such as when stratification is present), the average of samples from these wells probably will not follow the Student's t-distribution. The same is true of a set of wells that have seasonal variations.

L. The Agency should institute a vigorous program of statistical analysis of data collected as the program proceeds to confirm the adequacy or inadequacy of the method proposed in the draft TEGD.

This analysis will allow the Agency to determine how much the distributions of the data deviate from the assumed Students-t, and to evaluate the implications of such deviations in terms of the robustness of the detection procedure.

M. The Agency should establish a group to devise a statistical test(s) that will satisfy regulatory needs and will, at the same time, be technically defensible over the wide range of situations encountered in actual practice.

The group should keep in mind that the goal of the statistical analysis is to detect leaks at RCRA facilities. Any test should be justified by reference to site specific factors, and these tests should be based on preselected values of Type I error (false positives), Type II error (false negatives), and the magnitude of the difference which defines the event that it is important to detect (the TEGD simply specifies that it must be "larger then background").

Assessment Monitoring

N. Greater emphasis should be placed on using a phased approach on required assessment wells, based on informed judgement about incoming sample analysis and hydrogeologic conditions, and local water use patterns.

Phased placement of additional wells should be utilized to spatially define the composite contamination plume. It is most important to define the spatial bounds of total contamination, having cataloged individual chemical constituents.

O. The specifications for the initial number of cluster wells are excessive. This Section should be rewritten to describe a general approach that contains the flexiblity to fit site-specific conditions.

The existing guidance recommendations call for seven well clusters with five wells per cluster. Such a configuration may or may not fit any given site. This degree of specificity in the guidance should not be employed.

P. The limitations of mathematical modeling to predict contaminant transport should be specified in terms of site hydrogeologic conditions.

The TEGD states, without reservation, that models can be used to predict hydraulic head and contaminant concentration at any point. A discussion should be added on model limitations, practical uses, and calibration needs.

SECTION II

INTRODUCTION

Background

On August 26, 1985, Mr. Gene A. Lucero, Director, Office of Waste Programs Enforcement, requested that the Science Advisory Board review a draft document, prepared by his staff, entitled "RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD)." In a subsequent memorandum (undated), Mr. Lucero furnished the document, together with related material, to the Committee, and provided a detailed, chapter-by-chapter list of issues on which he requested the SAB's review and advice. The SAB was further asked to concentrate on specific technical issues in the current version of the document, and not on whether or not the Agency had adopted the "best" regulatory approach.

The TEGD is intended to provide guidance on how to evaluate the design and operation of RCRA interim-status ground water monitoring systems. The intended audience includes facility owner/operators, permit writers, field inspectors, attorneys, and enforcement officials (engineers, hydrogeologists, statisticians), both within EPA and also in State organizations responsible for administering RCRA-related programs. The document provides guidance on the evaluation of:

A. Characterization of site hydrogeology (Chapter 1)

B. Placement of detection monitoring wells (Chapter 2)

C. Monitoring well design and construction (Chapter 3)

D. Sampling and analysis plans (Chapter 4)

E. Statistical analysis of detection monitoring data (Chapter 5)

F. Assessment monitoring plans (Chapter 6)

Appendices to the TEGD also provide details of the statistical methodology, together with some example applications, and descriptions of selected geophysical methods for sample analysis.

The Committee recognizes that the guidance was very difficult to write, and that it was impossible to describe every hydrogeologic/contamination situation which might face an enforcement official in view of the complexities typical at specific sites. The document attempts to balance the need for specific, detailed guidance with the reality that the compliance decision-making process in the ground water area is enormously complicated.

Committee Review Procedures

A Subcommittee of the Environmental Engineering Committee was formed to conduct the review. The Subcommittee consisted of nine individuals (see Roster, Appendix A). Two, Dr. Haun and Mr. Conway, were members of the Environmental Engineering Committee, and the rest were consultants specifically selected for the Subcommittee based on their expertise in the area of ground water monitoring, statistics, and environmental law. Mr. Conway and Dr. Cartwright were, in addition, members of an SAB Committee which recently reviewed the Agency's ground water research program. Subcommittee selections were based on recommendations from SAB staff, the Office of Waste Programs Enforcement, and outside experts in the field.

The Subcommittee held one open public meeting on October 3-4, 1985, in Washington, D.C. At that meeting, the Subcommittee was briefed on the contents of the TEGD by Agency staff, and heard testimony on the proposed guidance from a number of representatives of the waste management industry, state and local governments, consulting firms, and environmental groups. A list of commenters is included as Appendix C. The Subcommittee was also furnished extensive written testimony by both individuals testifying before the Subcommittee and others who were not able to attend the meeting. This written testimony is on file in the offices of the Science Advisory Board.

Other meetings of the Subcommittee, and subgroups thereof, were held on November 14-15, 1985 and December 4, 1985 to draft the final report. The completed report was submitted for approval to the the full Environmental Engineering Committee at its regular meeting on February 13-14, 1986. At that meeting, the Environmental Engineering Committee made a number of minor changes in the report, and also decided that the portions of the report dealing with statistical methods (Chapter 5 and Appendix B of the TEGD) needed further review. A Subcommittee, consisting of Dr. J. William Haun, Chairman, Dr. Charles O,Melia, Dr. Mitchell Small, Dr. Carl Silver and Dr. Charles Norwood, was appointed to conduct this review, and their report is attached as Appendix D.

While portions of this report were drafted by Mr. Harry C. Torno, Executive Secretary to the Environmental Engineering Committee, based on Subcommittee input, the report in its final form has been approved by, and represents the views of, the Environmental Engineering Committee as a whole.

SECTION III

REVIEW OF THE TECHNICAL ENFORCEMENT GUIDANCE DOCUMENT

This review provides detailed comments on a chapter-by-chapter basis, and supplements the more general comments and recommendations outlined in Section I.

Chapter 1 - Characterization of Site Hydrogeology

A. Optimum well spacing should be approached in a rational and efficient manner, rather than by grid sampling. A logical approach could be:

1. Prior to any drilling, regional geology and hydrogeology must be reviewed and a conceptual (three dimensional, physical) model of site hydrogeology devised.

2. Drilling then becomes an iterative process of seeking boring characteristics to confirm the model. The model is revised as each new bore-hole/well is drilled and further drilling is undertaken to test the revised model.

3. As the conceptual model becomes more refined, data from exploratory borings (hydrogeology) should begin to approximate model predictions. The site can be considered "characterized" at such a time as the geologic materials, ground water level, and ground water flow direction (in the different geologic units), can be accurately predicted before drilling.

It is critical that the quality of all hydrogeologic and chemical results be known and documented. The beginning of the QA/QC (quality assurance/quality control) program for the monitoring effort should be in the hydrogeologic characterization. The descriptions of the geologic materials, water levels, hydraulic conductivities and ground water gradients should conform to high professional reporting standards. Guidance by way of quantitative statements on the minimum acceptable levels of accuracy, precision and completeness should be provided in the document. The extent and confidence in the hydrogeologic characterization will therefore be driven by the complexity of the monitoring situation.

This approach will lead to a non-regular spacing of the exploratory borings. Relatively complex areas will have many boreholes, and uniform (simple) areas will have relatively few.

B. The TEGD should describe a procedure for the delineation of features such as bedding planes, foliation planes, joints, shear planes, shear zones, faults, and fault zones, and their associated secondary permeabilities as related to the transport of liquids. Again, integrating regional information and site-specific observations should be the key. The determination will often require special exploration activities, such as angle drilling, to determine the presence of vertical discontinuities.

C. Map scale (Pg. 1-3; Table 1-1) - The scale of the required geologic or soil map should not be held to 1" = 200 ft (1:2400), but should be of an "appropriate scale to identify properly the areal extent of the various geologic or engineering soil units, considering the size of the facility and complexity of the site geology".

D. Continuous sampling of earth materials at every boring location, as recommended in the draft TEGD (Page 1-8) to define adequately the subsurface conditions, may not be necessary. Sampling at 5- to 20-foot (on-center) intervals (depending on the vertical heterogeneity of the geologic substrata) in 50 to 75 percent of the borings (with continuous sampling in the remainder) should be adequate to define subsurface conditions.

E. The TEGD should include, in the list of possible investigatory techniques, the use of cone penetrometers for differentiating individual, unconsolidated substrata. This technique is gaining in acceptance with the engineering and regulated community, and could be used to obtain continuous depth information to augment boring data. A precaution, however, should be added that all boreholes should be sealed upon abandonment.

F. A competent field description of geologic units encountered in exploration, with limited laboratory analysis to confirm field observations, is generally sufficient. The requirement for petrographic analysis, bulk geochemical analysis, mineralogic analysis, and X-ray diffraction is unfounded, except in certain special cases.

G. Permeability

1. Unsaturated hydraulic conductivity values should be determined by appropriate laboratory methods for the major soil horizons. Pressure plate, one-step outflow, or column methods are recommended. Field determinations of saturated hydraulic conductivity are necessary to establish the validity of laboratory data. Pump tests are preferable, but impractical in low permeability layers.

2. The term "intrinsic permeability" and "permeability" should be replaced by "hydraulic conductivity." In those cases where floating hydrocarbons are known or could be a contaminant, then sieve (mechanical) analyses can be performed to augment the hydraulic conductivity measurements in predicting the ground water flow.

3. An impression is given, in the TEGD, that conducting a pumping test using a short screen in a thick aquifer would result in a hydraulic conductivity determination of the formation at the depth of the screen. This is not true. Partial penetration factors may give erroneous results.

A more accurate approach for determining the relative hydraulic conductivities of differing layers within a thick aquifer is to measure the overall aquifer transmissivity by a pumping test, then to assign relative hydraulic conductivities on the basis of grain size distribution. Other methods may also be used, but the implied method given by the TEGD may lead to erroneous conclusions.

We also suggest that the EPA require that all hydraulic conductivities be reported in cm/sec units, in order to achieve consistency.

H. The time and cost of a full Appendix VIII constituent analysis of potentially contaminated core samples (as recommended in Table 1-3 of the Draft TEGD) are not warranted, and seem excessive for a detection monitoring program. Appendix VIII constituent analyses are more properly conducted during a ground water quality assessment program.

I. For health and safety reasons, it may be necessary to collect subsurface soil samples and test for suspected contaminants. Care should be exercised to verify that OVA measurements are true and not artificially created by the operations at the ground surface.

J. An additional factor to consider in defining ground water flow paths (Page 1-20) is the effect of surface impoundments and other nearby surface water bodies on local ground water flow. Mounding below impoundments and manmade canals can be the most significant factors influencing the direction in which ground water contaminants migrate in shallow (nearsurface) aquifers. Also, the presence of discontinuities should be defined.

K. Additional factors which are inadequately addressed in the draft TEGD include:

1. Accuracy of locational (topographic) surveys. Ground water levels should be measured to an accuracy of 0.01 foot, in order to arrive at an accurate determination of flow direction. Accordingly, relative casing collar elevations must also be determined to a 0.01-foot accuracy.

2. Proper definition of the uppermost aquifer at the site. Substantial emphasis is placed on determination of the vertical component of flow. This factor is important in some cases and not in others. In all cases, the importance of vertical flow must be determined. This requires, at a minimum, two sets (clusters) of vertically-spaced piezometers. The exact number and depths are dependent on site characteristics. Once the potential importance of vertical flow has been identified, then the requirements for additional well clusters can be determined. For instance, if strong upward hydraulic gradients are encountered, no additional information may be required. However, if strong downward gradients are encountered, much additional information is needed on the distribution of heads and the characteristics of the confining layer.

3. Borehole Sealing. All borings made during site characterization (or at any other time) and not converted to piezometer installations or monitoring wells should be adequately sealed so as not to become an avenue for contaminant migration. All such wells to be abandoned should be plugged with materials that have the same or lower permeability than the formation (e.g. very low permeability seal is required in the low permeability confining beds, while less stringent sealing requirements should apply to a high-permeability aquifer).

4. Recommended addition to site characterization. The characterization of the underlying confining layer has not been adequately defined. In those situations where the underlying confining layer is relatively

uncharacterized, some of the borings should penetrate more than 10 feet into that layer, and should be planned to:

a. Determine the areal extent and thickness (if less than, say, 30 feet) of the lower confining layer,

b. Measure the hydrostatic pressure in any permeable layer encountered, and

c. Be grout-sealed through the confining layer in order to preclude migration of contaminants.

5. Definition of qualified geologist. The term Qualified Geologist should be replaced by qualified geologist, geotechnical engineer, or other qualified professional person with appropriate geotechnical experience. High quality borehole logs are essential to identify and fully to define all of the geologic and hydrogeologic factors that are critical to site characterization. The use of trained professionals is indicated on the basis of their ability to observe essential geologic features and because such individuals generally have a good understanding of the responsibilities inherent in professional field work as it relates to the design and long-term performance of waste management facilities. It is clear that not to specify the qualifications will be to invite the owner/operator to utilize the services of drillers or other unqualified individuals to produce the borehole logs that are used as the basis of the ground water monitoring program.

6. Depth of Borings. The statement that borings should penetrate 10 feet into bedrock is too specific. Borings should penetrate sufficiently deep into the underlying confining layer to define adequately its characteristics as a confining layer. This assessment should demonstrate an adequate understanding of such factors as the presence of weathering, core stones, glacial debris, and dissolution features.

Use of the term bedrock varies in the TEGD and is often inconsistent with normal geotechnical usage of the term. It is suggested that bedrock be replaced in illustrative examples by petrologic names of rock, but that such terms as weathered and fractured be retained in connection with bedrock descriptions. Bedrock is lithified geologic material (rock) or crystalline rock. The figures in the TEGD need to be reviewed for proper geologic usage. The TEGD seems to imply that bedrock is impermeable and then names other rock types which may be permeable.

L. The definition of aquifer and uppermost aquifer need to be more specific and should be consistent with the objective of protection of usable water supplies. These terms, and also mixer (referring to a partially soluble and/or miscible waste), should be added to the glossary (TEGD, Appendix G).

1. In some situations, the uppermost aquifer might extend hundreds or even thousands of feet into the earth, using the loose definition provided in the Draft TEGD. For instance, some slight degree of <u>hydraulic interconnection</u> or <u>hydraulic communication</u> (preferred by the Committee) between widely separated sand layers might be inferred without a more speci-

fic definition. In the Gulf Coast area, for example, coastal sedimentary deposits can alternate between sand and clay units to a depth of several thousand feet. Since, in a regional sense, some component of flow might exist between each adjacent sand unit, the uppermost aquifer might be considered thousands of feet thick. A more explicit definition of hydraulic interconnection should be provided.

2. The addition of the phrase "overlying or perched water-bearing zones" to the definition of uppermost aquifer substantially expands the concept of aquifer from that included in the original regulations by including any water-bearing zones above the aquifer regardless of their ability to yield water to a well, regardless of whether or not the zone is saturated, and regardless of the ability even to sample the overlying water. Included would be overlying clays and other tight formations that are of very low permeability. This definition of uppermost aquifer is much more expansive than the definition of aquifer and needs to be reconsidered.

3. The definition of uppermost aquifer provided in the draft TEGD (water table to lower confining layer) applies well to an unconfined, or "water-table," aquifer, but creates confusion when applied to a confined aquifer. The piezometric level in a confined aquifer is not necessarily the level of saturation in the overlying confining layer. Does the "uppermost aquifer" include that part of the overlying confining layer that is below the piezometric level in the underlying confined aquifer, or does it include that part of the overlying confining aquifer that is saturated? This issue is particularly relevant when there are other transmissive zones above the confined aquifer that do not underlie the waste management facility and which are not hydraulically connected to the confined aquifer.

4. One addition to the aquifer definition, that in many cases would restrict the zone of interest, is as follows:

> "If it can be demonstrated that a vertical upward component of flow exists in permeable layers underlying the uppermost permeable layer, and that the upward component will probably not be reversed by natural or man-caused influences, then the monitoring may be restricted to the uppermost, saturated, permeable layer."

Such a determination can be made by simply noting whether or not the static level(s) in the lower permeable zone are above the static levels in the uppermost zone. Such determination should be routinely required in order to assess the danger of downward migration of contaminants, and are a better evaluation factor than pumping tests held across an aquitard. Also, Figure 1.12 should be redrawn to show geologically realistic perched layers.

For the purposes of this Guidance, we offer the following definition of an aquifer.

> "An aquifer is a permeable and porous geologic unit that can transmit significant quantities of fluid under ordinary hydraulic gradients, and is capable of development as a source of water for human, industrial, agricultural or other beneficial use."

Chapter 2 - Placement of Detection Monitoring Wells

A. The horizontal spacing of monitoring wells needs further consideration. There should be a clear distinction made between detection monitoring systems and assessment monitoring systems, mainly in the interest of cost effectiveness. The purposes of detection is, simply, to assess the presence or absence of a contaminant. Assessment monitoring is used to determine the location and extent of contamination and possible methods of mitigation. The two monitoring systems need not make use of the same wells.

1. Monitoring well spacing - The purpose of site characterization work is to identify avenues and direction of ground water (contaminant) flow. No arbitrary spacing should be specified. Monitoring wells should be located in those areas where pollution migration is most likely to occur, based on the hydrogeological characterization of the site. Alternatives that should be allowed in lieu of large numbers of wells are:

a. Wells in zones of higher permeabilities.

b. Wells located only on the downgradient side (except, of course, for the required upgradient control wells).

c. Wells located further from the actual site (but still on the owner's property) that would intercept a dispersing plume.

The requirement that spacing be close around a double-lined facility is redundant, as there is a detection system between liners. Nearly all pollution will originate from point sources under waste sites, except for previously-developed unlined liquid-filled lagoons or from existing impoundment facilities.

2. Speculative wells - The text on page 2-16 of the Draft TEGD points out that a sufficiently detailed site characterization may reduce the need for "speculative wells" by identifying preferential flowpaths. Figures 2.3 and 2.4, however, show wells in all downgradient geologic strata, not just those that represent preferential flowpaths.

Additionally, Tables 2-1 and 2-2 do not include the extent of site hydrogeological characterization in the list of factors that influence the spacing and number of wells per cluster. More emphasis and more "credit" should be given for the use of sufficiently detailed site characterization in establishing the area location and depth of screening of wells. Some of the wells shown in the example are "speculative".

3. Minimum longitudinal distance - In certain instances, locating a well at the immediate edge of the waste management area (as recommended on pages 2 and 3 of the draft TEGD) is impractical. For example, pipe racks, powerlines, or underground piping often restrict drill rig access. Some guidance regarding the acceptable longitudinal distance from the waste management facility ought to be included in the TEGD. For instance, is a distance of 50 to 100 feet from the toe of a dike acceptable?

B. More flexibility in the length of the well screen should be allowed.

1. Well screen lengths should not be limited to a maximum of 10 feet, at least for detection monitoring. The objective of monitoring is to search for pollutants. If pollutants are discovered, then installation of depth-specific assessment monitoring wells and screens is appropriate. Aquifers commonly have zones of higher hydraulic conductivity which produce a large percentage of water to the well; these permeable zones will generally be the zones of dissolved contaminant transport which will be effectively sampled by long screens with minimal dilution. Sinkers and floaters can be detected by thief sampling much more economically than by well clusters.

2. Illustrations - Additional examples are needed to depict the thick clay, geologically-simple, and Cretaceous siltstone (Great Plains) regimes. Every effort should be made to eliminate extraneous monitoring wells in examples given, and to show why the remaining wells are effective. For example:

a. Fig. 2-11, TEGD - One fully-penetrating well should be sufficient, both in the upgradient and downgradient locations. Also, the piezometric surface should be redrawn to reflect the direction of flow.

b. Fig. 2-12, TEGD - In all probability, one well at each location, screened through the thickness of the sand and gravel layer would be sufficient. If the silt contains sandy layers, then a second well, screened through the silt layer, should also be required.

c. Fig. 2-13, TEGD - In this particular case, one well, screened through the entire saturated thickness, should be sufficient for the upgradient side. At the most, two downgradient wells should be used - one screening the upper half, and one screening the lower half of the porous sand. A well is not felt to be justified for the claystone. Again, the piezometric surface should be redrawn to reflect the flow direction indicated.

3. Placement of upgradient monitoring wells.

a. The number of background wells will be a function of hydrogeologic conditions at the site and the statistical requirement to measure variance, and usually more than two wells (and almost always more than one) will be necessary. In addition, upgradient wells should match downgradient wells with respect to formation screening for data to be amenable to comparison.

This section of the TEGD is written in such a way as to be biased toward the exceptional requirements, rather than toward the more common circumstances. The section should be rewritten to accomodate simple situations, and then progress to reasonable requirements for the more complicated situations.

b. As an illustration, see Figure 2-14, TEGD - Only if the potentiometric surface in the lower porous sand is lower than the piezometric surface in the upper gravelly sand should any monitoring wells be required in the lower sand. If the head is lower in the lower sand, then the upper half of that sand should be monitored. Also, if the thickness of the upper sand is greater than about 50 feet, or if the formation/unit is not homogeneous, then the upper and lower halves should be screened by separate wells.

In this illustration, the number of wells actually needed might be only one, under the most favorable circumstances, or three wells, under the worst circumstances. This is a good example of why illustrations must not only be carefully conceived, but must be thoroughly explained, in order for the concepts not to be misused.

Chapter 3 - Monitoring Well Design and Construction

A. Drilling Methods

1. Table 3-1, TEGD - Drilling methods should not be ranked numerically without some rationale. Air rotary drilling rated as 1 (one) is in conflict with both the need to keep foreign matter out of the monitoring zone and the statement on page 3-13 against air development techniques. A suggested ranking scheme could consist of appropriate versus nonappropriate techniques. An excellent reference for additional information on drilling methods is the NWWA/EPA "Manual of Ground Water Sampling Procedures."

NOTE: The use of decision trees can be very valuable in providing advice to evaluators of monitoring plans. For example the chart on page 3-14, Figure 3-3 of the TEGD is effective in communicating the need for careful handling of turbid samples though it contains several errors (a feedback loop should be included in the left branch, and "repurge" should actually be redevelop). Similar charts might be useful for other decisions.

2. Reasonable field alternatives to the use of a hollow stem auger for drilling in heaving sands should be included in the guidance for drilling methods. An example is the development of a positive head within the auger by filling the auger with water, thereby displacing the heaving sands when the knockout plug is removed.

3. A promising method for both characterization and monitoring well construction is the dual-wall drill stem air rotary. Formation sampling is excellent, the outer drill pipe provides a temporary casing, and monitoring well casing can be installed before the drill stem is withdrawn. These rigs are scarce at the present time, but this could change with demand.

4. Conditional statements concerning the use of air rotary drilling for monitoring wells (e.g., sloughing of sidewalls when the air pressure is removed and its inappropriate use when contaminated soil in the upper horizons is suspect) should be included. The exposure hazards to personnel of drilling through contaminated zones by air rotary methods should also be mentioned.

5. A statement regarding the potential for distributing a contaminant throughout the entire borehole if it is encountered during drilling operations (except with cable tool drilling) should be included and an appropriate response to this case included.

6. The use of bentonite may contribute to the long term TOC content of the ground water even with proper well development and purging. The use of bentonite should also be discouraged in situations where heavy metals may be found. These potential sources of chemical interference should be mentioned.

B. Monitoring Well Construction Materials

1. Statements concerning the appropriateness of well materials should include the statement that in all cases they are to be examined in terms of the anticipated lifetime of the monitoring program. The Committee recommends that fluorocarbon resins or stainless steel 304 or 316 be specified for use in the saturated zone when potentially sorbing organics are to be determined, or may be tested, during a 30-year period. In such cases, and where high corrosion potential exists or is anticipated, fluorocarbon resins are preferable to stainless steel (304 or 316). NSF-(National Sanitation Foundation) and ASTM-approved PVC for well casing may be appropriate if only trace metals or nonsorbing organics are the contaminants anticipated. As research demonstrates the appropriateness of other materials for screens or casing in the saturated or unsaturated zones, they may be acceptable. PVC, stainless steel or teflon are appropriate casing materials in the unsaturated zone.

2. Figure 3.1, TEGD - Suggest removing the 8"-10" dense phase sampling cup from the diagram. The cup at the bottom of the monitoring well will serve primarily to accumulate sediment and act as a source of persistent turbidity in the water samples.

3. Steam cleaning of a fluorocarbon resin casing/screen may not be necessary if it has already been washed with detergent, rinsed with methanol, and rinsed thoroughly with deionized water before packaging. Augers should be steam cleaned off-site if at all possible. The casing/screen should be enclosed in some type of protective wrap until the sections are actually lowered into the borehole, and should not be brought onto the site until this time.

4. Fluorocarbon resins, PVC and other plastic materials do not corrode in the strict sense of the definition. We suggest the use of the term corrosion for stainless steel and either weathering or deterioration when discussing plastics.

5. Distinguishing the difference in actual monitoring performance of stainless steel 304 and 316 would be difficult; either material should be appropriate if conditions call for stainless steel.

6. The terms vadose and unsaturated zone are used throughout the document. Vadose zone is recommended as the preferred terminology.

7. The reference to sodium bentonite as a recommended material seems overly specific and should be removed. The criteria for a proper seal should be one which is chemically compatible with the anticipated wastes and one to two orders of magnitude less permeable than the surrounding formation. Of the bentonite clays, calcium bentonite is less susceptible to metal and organic attack than sodium bentonite. Neat cement may also be an appropriate sealing material, although only calcium bentonite should be mixed with the cement, not sodium bentonite.

8. We recommend that uncontaminated water, rather than formation water, be used for mixing cement, mixing with bentonite, developing or any other use in construction of monitoring wells.

C. Well Development

1. Air development is quite useful and does not exert long term effects on subsurface conditions as long as proper purging and sampling procedures are followed. Despite frequent development, some wells may never provide turbidity-free (less than 5 NTU) samples. In these cases, some exception to the turbidity limitation should be allowed if repeated development does not improve the quality of the samples.

2. Some mention should be made of the need to evaluate the hydraulic properties of the well and the use of initial performance as a background level for annual redevelopment and continued maintenance.

D. Well Design

1. Placement of the sampling pump intake could properly be at the top of the screen, as well as midway in the screened interval, and actual conditions should override specific guidance. Pumps placed in the screen often cause turbulence which results in suspended solids in the sample and eventual plugging of screens.

2. The subcasing is an unusual suggestion, as there is little or no literature to support its use. This type of complicated construction is certain to encounter serious problems in installation, detection of malfunctions, and verification of performance or repair. If water level devices are to be lowered into the well, this entire string would probably have to be removed or some unconventional well design adopted.

E. Evaluation of existing wells - The field demonstration for existing and new wells will be extremely difficult to evaluate in practice. Differences in construction may or not manifest themselves during the field test. The results may lead to false conclusions in view of the normal variabilities inherent in water quality parameters or sampling which may be attributed to differences between old and new wells. Similarly, differences in well construction, development, etc., which can never be duplicated may also result in negative or positive biases due to causes other than well construction. We recommend that when such situations arise and when the wells are suspect that the wells be inactivated, sealed, and replaced.

<u>Chapter 4 - Sampling and Analysis</u>

A. Water Level Measurements

1. Water level measurements should be made to plus or minus 0.01 feet.

2. Recommend eliminating the use of an acoustical sounder as a water level measurement device as the resolution of such devices at less than 25 feet below the ground surface is generally very poor.

3. Where a dedicated pump is being used, then a permanently-installed pipe should be used as a guide for the water-level sounder.

4. A description of the type of manometer which would provide the resolution between aqueous and nonaqueous layers should be included. Electronic devices are also available for detection of conductance interfaces.

B. Well Evacuation

1. The removal or isolation of the stagnant water in the well should be encouraged. If the pump intake is placed at the top of the screen, well purging will be easier and more efficient. The owner/operator should establish the hydraulic and yield characteristics of the monitoring wells, calculate a purging requirement and then verify the purging process by measuring pH, conductance, and temperature in the field. This is the best way to get conductance and pH values for RCRA compliance. Both TOC and TOX have volatile fractions which should be acknowledged in the discussion of purging and sample collection.

2. Purging pumping rates should not be exceeded during sampling, or additional development will occur. The three-well-volume-ratio rule of thumb is not consistent with good practice. The purge volume should be calculated based on the hydraulic conductivity of the screened formation. Bailers are very poor devices for well purging, since continual mixing of the water column occurs during water collection. If any of these devices are deemed acceptable for purging, it will be difficult to get the regulated community to be more careful in the selection of sampling mechanisms. It is unclear as to how the water will "stabilize" within an hour or so after using a gas lift pump to purge a monitoring well.

C. Sample Withdrawal

1. Sampling monitoring wells and piezometers may be the source of a large part of the total error in the total sampling and analysis procedures. Good quality samples require both correct equipment and skill in using the equipment, and a basic understanding of the well sampling process. Bailers are poor sampling devices for volatiles and the bottom-draw models are tricky to handle adequately. Sample reproducibility is very poor in most field situations. The use of bailers for sampling should be carefully evaluated before allowing their use for sample collection. They should be discouraged where volatile organics are being determined.

2. The use of a steel chain should be mentioned in connection with the use of bailers. It is easy to clean, and more manageable than cable or wire under field conditions.

3. Regardless of whether a bladder pump or bailer is used, the use of procedures or equipment that minimize sample agitation and that reduce/eliminate contact with the atmosphere during sample transfer should be encouraged.

4. Cleaning of non-dedicated samplers and tubing for either inorganic or organic contaminants should begin with detergent/soap mixture and end with distilled water rinses before storing for the next use.

5. Bladder pumps do not provide a "continuous" sample, but rather provide a pulsating stream. They should therefore be operated carefully, so that the sample bottle is filled with either one complete "pulse" or as few pulses as possible by turning down the pressure on the compression cycle. This is possible with a careful operator and a low discharge rate.

6. A flow rate of 100 ml/minute for sample discharge is about the most rapid rate at which a 40 ml vial can be filled without undue agitation. This rate should apply to all samples where gases or volatile constitutents are of interest (e.g., pH, alkalinity, TOC, TOX, 601 and 602 organics, etc.). The sampling flow rate should not exceed the purge rate and the purge pumping rate should be below the flow rate used during well development. Otherwise, continued well development or well damage may occur.

7. Field electrode measurements of pH and conductance should be made before and after sample collection as a measure of purging efficiency and as a check on the stability of the water sampled over time.

D. Sample Preservation and Handling

1. Multiple transfers required by the use of bailers for sampling volatiles are not good practice. The transfer of samples from one container to another in the field should not be encouraged.

2. A trip blank for organics should be glass distilled, not deionized, water.

3. The sample blank should also be reported and more guidance should be given on the procedures for identifying sources of contamination. For example, methylene chloride will be virtually impossible to avoid in many cases.

4. Field logbooks should include documentation of the purging process (e.g., time started, initial water level, purge volume pumping rate, time finished, etc.).

5. Climatic conditions on the day of all sampling activites, including air temperature, should be reported.

E. Evaluation of the Quality of Ground Water Data

1. The LT (less than) detection limit values will vary somewhat with time as will the LOQ (limit of quantification) and LOD (limit of detection). That is, they should be established each day of analysis by the use of both procedural and field standards and reported with the data.

2. Extra digits carried through any computation provide an inaccurate impression of the quality of the data. The significant figures should reflect actual analytical precision.

3. Accuracy and precision determine significant figures, not vice versa. The discussion on Page 4-30 of the TEGD is, in addition, incorrect numerically. The precision of the range 65-73 $\pm$ 1 ug/L is about 1.5%, not 11%.

Chapter 5 - Statistical Analysis of Detection Monitoring Data

This Chapter was reviewed separately, and a report on this review is attached as Appendix D.

Chapter 6 - Assessment Monitoring

A. The specification of the initial number of wells required for assessment monitoring seems excessive. The investigation would be more efficient if it were accomplished in stages, with progressive well placements determined on knowledge gained. This comment, of course, does not recognize the implications of enforcement action should the owner/operator prove to be uncooperative with EPA Regional or State regulatory officials.

The guidance for establishing both the minimum number of initial well clusters (Section 6.5.2) and the minimum number of wells per cluster (Section 6.5.3) needs to be improved. The text recommends that seven well clusters be installed, with four inside the plume and three outside the plume. The text also recommends five wells per cluster, three within the plume and one each above and below the plume. These are initial wells, installed before the plume is defined. How can initial wells be specifically installed inside or outside of a plume before the plume is defined? Also, five wells per cluster is excessive in many situations (e.g., where the transmissive zone is less than twenty feet thick). The information gained from a five-well cluster may not be critical or even relevant to the design of a corrective action system (see also the discussion of imiscible compounds in the detection monitoring section).

B. The analytical effort should minimize the number of full Appendix VIII analyses. Given its high cost, "speculative" Appendix VIII constituent analysis should be avoided on all samples. Appendix VIII analysis seems appropriate on a few samples, with the plume then defined using tracer compounds.

C. The discussion on modeling in Section 6.4.3 of the Draft TEGD is too general and does not clarify either the practical uses or limitations of ground water models. The suggestion that models can be used to predict future events (page 6-11) is misleading and provides no additional precautions regarding the need for prior calibration and verification of any model (against geologic, hydrogeologic, and waste characterization data) before its use as a predictor.

APPENDIX A

U.S. ENVIRONMENTAL PROTECTION AGENCY
SCIENCE ADVISORY BOARD
ENVIRONMENTAL ENGINEERING COMMITTEE

GROUND WATER MONITORING GUIDANCE REVIEW SUBCOMMITTEE

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APPENDIX B

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

MEMORANDUM

SUBJECT: Science Advisory Board Review of the "Draft RCRA Ground-Water Monitoring Technical Enforcement Guidance Document"

FROM: Gene A. Lucero, Director
Office of Waste Programs Enforcement

TO: Addressees

Attached for your review is a copy of the Draft RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD). Also attached is a copy of the RCRA Ground-Water Monitoring Compliance Order Guidance (COG). Together, these documents provide comprehensive guidance on how to identify and rectify ground-water monitoring violations at RCRA facilities.

The purpose of the Science Advisory Board meeting on October 3-4 is to review technical issues in the draft TEGD. We have, however, included the COG in this package for background reading. The COG provides an overview of the RCRA ground-water monitoring regulations and explores the interrelationship of the Part 265, Part 270, and Part 264 regulations. It also describes the Agency's strategy for correcting ground-water monitoring violations at interim status land disposal facilities. I recommend that you read the COG since this document introduces the Agency's ground-water monitoring enforcement strategy and provides you with the policy and regulatory context that you need to conduct your review of the draft TEGD.

The draft TEGD provides guidance on how to evaluate the design and operation of RCRA interim status ground-water monitoring systems. The audience for the draft TEGD includes permit writers, field inspectors, attorneys and enforcement officials (engineers, hydrogeologists, statisticians). The TEGD provides guidance on how to evaluate:

° characterization of site hydrogeology (Chapter One);

° placement of detection monitoring wells (Chapter Two);

° monitoring well design and construction (Chapter Three);

° sampling and analysis plans (Chapter Four);

° statistical analysis of detection monitoring data (Chapter Five); and

° assessment monitoring plans (Chapter Six).

The draft TEGD represents the consensus views of an EPA workgroup made up of representatives from the Office of Waste Programs Enforcement, the Office of Solid Waste, the Office of Enforcement and Compliance Monitoring, the National Enforcement Investigations Center and EPA regions 3,5,6,8 and 9. Work on the draft TEGD began last fall after EPA completed a study on the compliance status of the regulated community in regards to the RCRA ground-water monitoring requirements. The study revealed serious problems. The level of noncompliance in the regulated community was alarmingly high. Confusion existed both within the regulated community and within EPA as to what constituted compliance. This confusion was contributing to a breakdown in our ability to efficiently issue permits to RCRA land disposal facilities.

The Office of Waste Programs Enforcement was given the job of writing enforcement guidance that would definitively describe how enforcement officials should apply the interim status ground-water monitoring regulations in compliance decisionmaking. As you can imagine, writing guidance of this type was very difficult. A "cookbook" which lays out every possible situation the enforcement official may encounter and describes how to make decisions in each situation was impossible to write. There are simply too many site specific situations enforcement official may encounter and too many variables which complicate decisionmaking. We wrote the draft TEGD very carefully to try to balance the need of the our enforcement program for specific, detailed guidance with the reality that compliance decisionmaking in the ground-water area is very complicated. In those areas where the enforcement official must consider numerous variables in decisionmaking, we have tried to identify all the important factors which may affect the decision and have tried, through example, to show how the enforcement official may consider individual variables. An example of this approach can be found in the discussion on the horizontal spacing between downgradient monitoring wells (2-5 to 2-15).

There are a number of technical issues on which we would like your review and advice. They are listed individually in an attachment with a brief synopsis which should aid you in your review. As you conduct your review I encourage you to keep in mind that this guidance was developed within the context of the RCRA interim status ground-water monitoring regulatory structure. This Science Advisory Board review should not be a forum on whether or not the Agency has adopted the "best" regulatory approach for interim status ground-water monitoring systems. Instead your review should focus on how we have dealt with specific technical issues in the document and how you feel we can improve the technical aspects of this document.

If you have questions regarding the draft TEGD please feel free to contact either Michael Barclay at (202) 475-9315 or Dr. Ken Jennings at (202) 475-9374.

addressees: Dr. Michael Barcelona
Dr. Keros Cartwright
Richard Conway
John Fryberger
Dr. Allen Hatheway
Dr. William Haun
James Krier
Robert Morrison
Dr. Carl Silver

attachments

1. Level of Site Hydrogeologic Investigation

Our objective in Chapter One was to describe the quality and quantity of hydrogeologic information needed by owner/operators - i.e. How much information is enough? What are appropriate techniques to collect information? Table 1-1 illustrates hydrogeologic investigatory techniques owner/operators may use to collect data as well as preferred presentation formats. We expect this chapter will be most useful to those enforcement officials who must order owner/operators to perform a hydrogeologic investigation (refer to phased order approach in COG).

If an owner/operator followed the approach described in this chapter for conducting a hydrogeologic investigation, will the investigation yield enough information for the owner/operator to design a detection monitoring system? Will it provide enough information to design an assessment monitoring program?

Can the approach this chapter describes for collecting information be made more efficient? What additional investigatory techniques might be useful in RCRA site investigations?

2. Definition of Uppermost Aquifer

The discussion beginning on page 1-33 describes how the enforcement official can decide if the owner/operator has correctly identified the uppermost aquifer beneath his site.

Do you feel the criteria we have established for identifying the uppermost aquifer (water table to confining layer and perched zones of saturation) adequately balances the need for specific guidance with the need for flexibility in enforcement decisionmaking?

Should we include additional guidance for conducting pump tests?

3. Horizontal Spacing Between Detection Monitoring Wells

Table 2-1 illustrates factors that enforcement officials may use to evaluate the spacing between detection monitoring wells. Detection monitoring wells must be located closely enough to assure that the ground-water monitoring system guarantees an acceptably high level of certainty that contaminant leakage will be immediately detected. The discussion beginning on page 2-5 describes how to use Table 2-1 in the context of an enforcement action.

We selected the 150' spacing as a point of departure for expanding or compressing well spacing. This number has been mentioned in early land disposal permit guidance and is used by EPA permit writers as a general rule of thumb for well spacing decisions. We feel that when site specific factors (Table 2-1) are applied in conjuction with the 150' rule of thumb that good decisionmaking regarding well spacing will result. Do you feel that this approach adequately balances the need for specific guidance with the need for flexibility in enforcement decisionmaking?

Are there additional factors that we should include in Table 2-1?

4. Well Construction Materials

Section 3.2.1 describes our preference for construction materials for RCRA monitoring wells. In those cases where the enforcement official will require the owner/operator to install wells as a condition of an order, we recommend that the enforcement official require the owner/operator to use teflon, stainless steel 316 or other proven chemically and physically stable materials for those portions of the well casing in the saturated zone. Other materials such as PVC may be used as construction materials in the unsaturated zone. Current research indicates that teflon and stainless steel 316 are more highly resistant to corrosion from chemical species likely to be encountered in RCRA monitoring and are less likely to interfere chemically with the quality of ground-water samples. The research results are not definitive however. Also, there are problems associated with constructing wells with teflon and with the long term structural viability of teflon wells (shearing of threads, deformation of screen slots).

Is it practical to recommend that RCRA wells be constructed of teflon given the engineering and structural problems associated with teflon?

The Agency currently does not have a program for testing materials to determine their suitability for use as well casing materials. Assume the Agency was interested in establishing criteria that manufacturers could use to test their products. How difficult would it be to establish such criteria? Could such criteria be developed quickly? Could the criteria be developed such that manufacturers could get quick turnaround on product testing?

The cost of stainless steel 316 and teflon is often cited as a factor which mitigates against their use as construction materials. Is the added cost of these materials to the overall monitoring program worth the added benefit they supply in terms of increased confidence in monitoring data?

Monitoring wells should be constructed of materials that will last 30 or more years. Also, monitoring wells should be constructed of materials that are chemically inert. Data available to us indicates that some materials commonly in use as construction materials will degrade upon exposure to chemical constituents such as those found in Appendix VIII. We do not, however, have extensive material testing data or definitive research findings regarding the longterm degradation one might expect various materials to experience as a result of exposure to different chemical compounds. Also, there is conflicting research regarding the adsorption and desorption properties of construction materials such as PVC. Should the Agency limit the type of materials that can be used in well construction (in the context of a compliance order) to those which we know to be chemically and structurally stable? Should we allow owner/operators to use construction materials which later research may prove to be structurally and/or chemically unstable?

5. Statistical Analysis - False Positives

The statistical analysis (i.e. student's t test) required by Part 265 yields a high rate of false positives - that is, an indication of contamination when none exists. We acknowledge this in the draft TEGD and have taken steps to mitigate problems associated with false positives. We have suggested an alternative statistical test which will reduce the incidence of false postives (the average replicate t test proposed by the Chemical Manufacturers Association). We have also recommended that owner/operators install more upgradient wells which will cut down on the likelihood of false positives. Finally, we have developed guidance on how owner/operators may prove or disprove false positives in the context of an assessment monitoring program (Section 6.3).

Do you have any recommendations as to how we can further reduce the incidence of false positives and at the same time avoid creating unacceptably high levels of false negatives?

6. Sampling and Analysis Plans

Chapter Four describes the type and amount of information owner/operators should include in their written sampling and analysis plans. This chapter more than any other chapter in the draft TEGD contains specific requirements we feel owner/operators should follow.

Have we included all the elements of sampling and analysis plans that you feel are necessary for the owner/operator to carry out an adequate sampling and analysis program (see section 4.1)? Are there other aspects of sampling and analysis programs that you feel we should include?

Would you suggest modification to any of the specific requirements related to sampling or analysis in this chapter?

7. Assessment Monitoring Plans

Chapter Six describes the type and amount of information owner/operators should include in their written assessment monitoring plans.

Have we included all the elements of assessment monitoring plans that you feel are necessary for the owner/operator to carry out a successful assessment monitoring program? What additional elements would you include?

We are interested in promoting the idea that owner/operators should use a variety of procedures and investigative tools in their assessment monitoring programs (see Section 6.4). Are there additional assessment methods other than those in Section 6.4 that we should have worked into the document?

Section 6.7 describes the type of analyses owner/operators should conduct in an assessment monitoring program. This section encourages owner/operators to consider conducting a sampling program concentrating on a limited set of parameters in the early phases of the assessment monitoring program and later expanding the sampling effort after the geometric dimensions of the plume(s) have been established. Should we provide more explicit guidance perhaps in the form of examples to illustrate this concept?

U. S. ENVIRONMENTAL PROTECTION AGENCY
SCIENCE ADVISORY BOARD
ENVIRONMENTAL ENGINEERING COMMITTEE

The following is a list of individuals who offered public comment on the draft of an Agency document entitled "RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) at a meeting on October 3-4, 1985.

Mr. Peter Vardy
Waste Management, Inc.

Mr. Swep Davis
Environmental Testing and Control

Dr. Jay Lehr
National Water Well Association

Mr. David Alexander
Envirosafe Services, Inc.

Ms. Sue Moreland
Association of State and Territorial
Solid Waste Management Officials

Mr. Tony Breard
CECOS International

Mr. David Mioduszewski
QED Environmental Systems, Inc.

Mr. Geoffrey Hunkin
Ground Water Sampling, Inc.

Ms. Linda Greer
Environmental Defense Fund

Dr. Charles Johnson
National Solid Wastes Management Association

Dr. Brian Meade
Consultant, duPont Corporation

Mr. James Gustin
Law Engineering Services

APPENDIX D

SAB-EEC-86-007

REPORT

on the review of the

"RCRA GROUND-WATER MONITORING

TECHNICAL ENFORCEMENT GUIDANCE DOCUMENT"

(SUPPLEMENT - Statistical Discussion)

by the

Environmental Engineering Committee
Science Advisory Board
U. S. Environmental Protection Agency

April, 1986

INTRODUCTION

In February, 1986, the Environmental Engineering Committee completed its review of the Office of Waste Programs Enforcement's draft "RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD).

At its regular meeting on February 13-14, 1986, the Environmental Engineering Committee decided that the portions of the report dealing with statistical methods (Chapter 5 and Appendix B of the TEGD) needed further review. A Subcommittee, consisting of Dr. J. William Haun, Chairman, Dr. Charles O'Melia, Dr. Mitchell Small, Dr. Carl Silver and Dr. Charles Norwood, was appointed, and this document is a report on their review.

In the introduction to Chapter Five of the TEGD, the Agency notes that RCRA facility owner/operators must implement a ground water monitoring program capable of determining if a facility has had a significant effect on the quality of the ground water, and states that this determination is based on the results of a statistical test.

The Committee has followed standard SAB review practice and concentrated on the scientific/technical aspects of the draft Guidance. The Committee recognizes that some of the following comments may encourage solutions not permitted by existing regulations, but we assume that the Agency's primary concern is to arrive at a technically acceptable method.

MAJOR ISSUES

The Committee recognizes the extreme difficulty in prescribing a single suitable test, given the wide variation in the hydrogeology of the sites, and in the data which have been collected. The Committee also believes that the Agency has done its best to prescribe a test which will meet existing interim status regulations (40 CFR Parts 264 and 265 - which require that a Student's t-test be used for this determination, but does not prescribe the specific test), and which recognizes many of the practical limitations on the data available.

It is unlikely, however, that any statistical test will meet, for most of the cases encountered in the field, the stated intention of the TEGD, which is to determine directly whether there has been a "significant increase in any ground water contamination indicator parameter in any well" (it is important to note that "significant" is defined as statistically larger than background).

One reason for this is that the Agency has not yet defined:

1. The magnitude of the difference which defines the event that it is important to detect (other than to state that it must be statistically larger than background); and

2. The probability with which that difference should be detected.

Statistical tests are characterized by the magnitude of the difference tested for, the false positive (Type I) error rate, and the false negative (Type II) error rate. The Agency discussion to date has focused primarily on the false positive rate and the concern that this not become too high for a facility. The magnitude of the difference tested for is by implication any positive difference whatsoever, given the manner in which the t-tests are currently formulated in the TEGD. It is not clear whether this is the result of thoughtful intent or simply the default condition. Finally, the allowable false negative rate is not addressed by the Agency, this being the important consideration from the perspective of protecting the public health (i.e., how likely is it that a leak will go undetected). All three parameters should be explicitly considered in the EPA formulation.

Another point that needs to be clarified in determining whether there has been a "significant increase" is the precise identification of the population with which the downgradient wells are being compared. Is it the distribution of concentrations at a single well, or should the baseline population variability incorporate the spatial and temporal variability which is inherent to the "upgradient" or more generally, the "no-leak-influence" condition. The general consensus is that the latter is what is intended. The implication of this is that the CABF t-test based on aliquot/replicate variability is inappropriate for use in the TEGD, because it fails to account for the inherent well-to-well and temporal variability of ground water quality. In addition, the high degree of correlation between replicate samples violates the assumption of independent sampling required in the t-test. The Agency has recognized this and intends to recommend that the CABF t-test be replaced by the AR t-test, which can incorporate upgradient spatial variability, and averages samples which are at least not obviously correlated to a high degree. The Agency has also been responsive to other apparent drawbacks in the draft TEGD, such as the need to use data transformations when concentration distributions deviate significantly from normality.

While the AR t-test does eliminate some of the difficulties associated with the CABF replicate t-test, there are limitations which still must be recognized. In particular, the underlying t-distribution model does not theoretically apply to the situation where sampled concentrations are being drawn from populations (i.e., different upgradient wells) with different means, and then averaged. Also, the AR t-test as currently formulated requires a single downgradient observation for comparison with the upgradient distribution (which, given the first argument may actually be a mixture of distributions). We consider each of these drawbacks in turn.

The AR-test is a physically appropriate model for the case where the groundwater aquifer (unaffected by a leak) is homogeneous in terms of concentration distributions. When inherent stratification is present, however, i.e., there are systematic differences in concentration distributions among wells, the average of samples from these wells may not, indeed most likely will not, follow the Student's t-distribution. One may conceptually skirt this issue by indicating that he is not interested in comparing downgradient wells to a single, uniform upgradient distribution, but rather to the average of the upgradient field. Nevertheless, the t-distribution no longer directly applies as before, and if the procedure is used, there is a clear need for secondary analysis of the ongoing RCRA data being collected to see how far the distributions do deviate from the assumed Students-t, and to evaluate the implications of this in terms of the robustness of the detection procedure.

The second problem involves the use of single (albeit, replicate averaged) downgradient observations to judge leak occurrence. This problem is difficult to address because we are interested in leaks even if they affect only one well (indeed, well-confined plumes are likely to do just that), and because we desire rapid detection and do not necessarily want to wait for evidence of contamination over a long-term period before triggering assessment monitoring. Two suggestions have been made for addressing this issue. The first is to average the downgradient observations. It is argued that the added sample size and associated increase in power would allow a greater ability to detect changes, even if they occur at only one of the downgradient wells. This procedure should be coupled with a check on the downgradient variance to ensure that a significant increase in one downgradient well is not being masked by random decreases in the others. The second suggestion (put forth by R.D. Gibbons, attached as Appendix A) is to abandon the t-test format and replace it with a tolerance interval test commonly used in quality control studies. This procedure would have the added advantage that it would eliminate the dependence on the t-distribution assumption for the upgradient mean, which as noted above, is questionable. The Agency should consider these recommendations as possibilities for alternative detection monitoring procedures.

ADDITIONAL CONSIDERATIONS

The application of the AR t-test with multiple upgradient wells averaged over the four quarterly first-year measurements allows proper consideration of spatial variability (between wells) and temporal variability (between seasons), so long as the temporal variations occur randomly. However, if seasonal variations occur deterministically, i.e., one or more of the four indicator parameters tend to be higher in one season and lower in another, then a bias is introduced in the test. False positives are more likely to be triggered during the season when background concentrations are high, and false negatives are more likely to occur during the season when background concentrations are low. Possible mechanisms for dealing with this problem include the use of more advanced Analysis of Covariance (ANCOVA) procedures, or the incorporation of seasonal adjustment factors in certain cases. The ANCOVA procedure would allow seasonality to be one of the dimensions of variations considered. The skill level required for field implementation of an ANCOVA would be high, though software is available. Seasonal adjustments could be considered by the EPA on a site-specific basis. Procedures should be developed by the Agency that would allow this in future regulations.

As part of the discussions of the Committee, some more general questions were raised as to whether the quarterly sampling protocol, using four indicator parameters, was really best for meeting the Agency's goal: identifying leaks at facilities. It was suggested that a broad review of the procedure be made. This could consider:

1. The appropriateness of the four chemical indicator parameters for detecting leaks. In particular, a more specific set of parameters (e.g., organic chemicals or heavy metals) may be appropriate on a site-specific basis.

2. The use of other hydrogeolical approaches for detecting leaks, such as tracer studies in conjunction with expert surveys.

RECOMMENDATIONS

1. The Agency should use the AR t-test method proposed in the TEGD in the short term. It should be explicitly acknowledged in the TEGD, however, that there are situations where the method may not yield accurate results, such as where seasonal variations occur, and examples should be provided. In these cases other statistical procedures, such as analysis of covariance (ANCOVA), may be appropriate.

2. The Agency should institute a vigorous program of secondary analysis (of data collected as the program proceeds) performed by skilled statistical analysts to confirm the adequacy or inadequacy of the proposed method.

3. The Agency should establish a group to attempt to solve the much greater overall problem of devising a statistical test that will satisfy regulatory needs as defined above, and will at the same time be technically defensible over the wide range of situations encountered in actual practice. This group should keep the following points in mind:

a. The goal of the statistical analysis should be to detect leaks from RCRA facilities.

b. Any test (statistical or not) should be justified by reference to site-specific factors. Those factors should define a physical system consistent with the assumptions required by the test selected.

c. Statistical tests should be based on preselected values of Type I error (false positives), Type II error (false negatives) and an environmentally significant difference. When these are specified, knowledge of variability on the site allows direct calculation of the number of wells required.

d. Lab bench (analytic) error should not be used to test whether two wells (or two regions) differ. Error components should include both temporal and spatial variation, where such variation is random. Where this variation is not random, the significant difference referred to in in c. above should be defined relative to the spatial and temporal variation appropriate to each site.

APPENDIX A
(to Statistical Supplement)

Petition:

A Methodology for the Statistical Evaluation of Groundwater Data

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The critical flaw associated with the CABF t-test is that it uses the aliquot or replicate sample as it's unit of observation. Since replicate samples of the same groundwater are almost perfectly correlated, the assumption of independent observations is violated, the degrees of freedom and sampling variability are incorrectly computed and the resulting test statistic has a false positve rate (i.e. type I error rate) that approaches unity. Statistics, such as, the AR t-test average the replicate samples and use a single number to represent the level of a compound at a particular well on a particular occassion. If the occassions are reasonably well separated (eg. quarterly measurements) the assumption of independence is tenable. However, unless we pool downgradient wells, (a practice that is doomed to failure), the use of any t-statistic is inappropriate, because we have no method of estimating downgradient variability and we must therefore assume that a single new downgradient observation represents a sample mean value. Clearly this in not the case. Our statistical problem is not one of comparing two mean values (i.e. obtained from a sample of upgradient wells and a sample of downgradient wells respectively) but rather a problem of determining the probability that a single new downgradient observation was drawn from an upgradient population distributed, with mean and variance that can be estimated from a sample of upgradient observations (which reflect both spatial and temporal variability). The only rigorous statistical solution to this problem is to construct tolerance intervals (see pp. 224ff. in Bowker A.H. and Lieberman G.J., Engineering Statistics, Englewood

Cliffs, N.J.: Prentice-Hall, 1959) around the upgradient mean value and compare each new downgradient observation to the upper bound of this interval (upper and lower bound in the case of pH). This statistical strategy, which is common in quality control studies where the integrity of a new manufactured product is determined by comparing one or more of its measureable characteristics to a historical sample of such products, has also been suggested by the TEGD in their Feb 6, 1986 response to the Science Advisory Board:

> Quality control techniques described by (Burr, 1976) may also be appropriate. Quality control techniques generally operate by using baseline measurements to establish tolerance limits which represent the bounds of acceptable performance based on future measurements.

We propose to use tolerance intervals for the analysis of all of our groundwater data. In the case of the four indicator parameters (TOC, TOX, pH and specific conductance), we will use tolerance intervals based on the normal distribution (specific details of this method are given in Appendix A). Briefly, the method simply requires that we multiply the upgradient standard deviation by a tabled value that depends only on the number of independent upgradient observations that we have (eg. 2 wells measured quarterly for 1 year produces 8 independent upgradient observations). The value produced by multiplying the upgradient standard deviation by the tabled value is then added to the upgradient mean. Any downgradient observation that exceeds this value is significant, otherwise it is considered to be within upgradient limits. Suitable transformation of the data (eg natural logarithm) is suggested to better approximate the assumed normality of this procedure (although it should be reasonably robust to minor departures from normality).

The previous methodology is not appropriate for data that exhibit truncated distributions due to detection limit problems. The 32 commonly measured volatile organic compounds all have detection limit problems and are therefore inappropriate for analysis using the tolerance interval described in Appendix A. A simple modification of this procedure in which the Poisson distribution is substituted for the normal distribution completely remedies this problem. The Poisson distribution which is the limiting form of the binomial distribution and has been used to describe rare event data such as mutation rates, is appropriate for the analysis of chemical data in which compounds are commonly found at levels at or below the detection limit or are measured at relatively few parts per billion. Unlike the normal distribution, the Poisson distribution yields unbiased estimates of the mean and variance despite severe truncation of the observed frequency distribution at the detection limit. We propose that all volatile organic compounds be statistically evaluated using the Poisson tolerance intervals. Complete details for the computation of both the fit of the Poisson distribution to an observed sample of upgradient data and estimation of the upper bound of the tolerance interval are given in Appendix B. As in the previous example, the significance of a new downgradient observation is determined by simply comparing it's value to the upper bound of the tolerance limit.

Appendix A

Gaussian Tolerance Limits for Individual Downgradient Observations

In groundwater management problems we are not interested in knowing the true value of a downgradient population mean, but rather, in estimating the highest likely downgradient value based on our knowledge of the upgradient population. Of course, if we knew the population values μ and σ, the areas of the normal curve would provide the required estimates. However, when only $\overline{x}$ and s are available from a sample of N independent upgradient observations, there are two kinds of uncertainty: the exact value of μ is unknown and σ may be greater or smaller than s. Fortunately, these combined uncertainties can be directly estimated and have been taken into account in extensive tabulations of a factor that can be used to compute limits within which a given percent of the population distribution from which the sample was drawn may be asserted to lie. Unlike a confidence limit, which predicts a minimum and maximum value of a parameter, tolerance intervals have to do with individual observations, such as the value of a specific parameter at a particular downgradient well on a certain occassion. The following table gives factors (K) for one-sided tolerance intervals.

Factors (K) for One-Sided Tolerance Limits*

	95%	99%
N	K	K
3	7.66	10.6
4	5.14	7.04
5	4.20	5.74
6	3.71	5.06
7	3.40	4.64
8	3.19	4.35
9	3.03	4.14
10	2.91	3.98
11	2.82	3.85
12	2.74	3.75
13	2.67	3.66
14	2.61	3.58
15	2.57	3.52
16	2.52	3.46

*Extracted from A.H. Bowker and G.J. Lieberman, <u>Engineering Statistics</u> (Englewood Cliffs, N.J.: Prentice-Hall,1959) Table 8.3

For an upgradient sample of size N, from which $\bar{x}$ and s are obtained (ie. the sample mean and standard deviation), the table gives the factor (K) which is used to compute the upper tolerance limit $\bar{x} + K(s)$. The resulting tolerance limit will include 95% or 99% of the observations and have a type 1 error rate of less than 5%. In this case N reflects the number of upgradient wells multiplied by the number of quarterly measurements; Hence, N=16 could be obtained by a single measurement of 16 upgradient wells, 4 wells measured quarterly for 1 year or 2 wells measured quarterly for two years. Each new downgradient observation is simply compared to this limit.

Appendix B

Poisson Tolerance Intervals for Rare Volatile Organic Compounds

A family of statistical models that is particularly well suited to "isolated" or rare event data are models that are based on the Poisson distribution. The Poisson distribution which is the limiting form of the binomial distribution (i.e. the distribution that describes the probability of the presence of an event when that probability is extremely small) has been effectively used to characterize rare event data such as mutation frequencies and radioactive count data. Using the Poisson distribution, we can therefore 1) test for the randomness of a process such as the occurrence of detectable levels of volatile organic compounds in upgradient wells, 2) develop interval estimates that will tell us how many parts per billion of a specific compound in a new downgradient observation are consistent with chance expectations and, 3) allow us to compare upgradient observations from different sites so that similar sites can be combined to enlarge our sample of upgradient or background observations and in turn increase the precision of our statistical estimates. In the following, the relevant hypotheses will be outlined and the appropriate statistical methods will be described.

Hypotheses and Questions of Interest

Question 1

Is the sampling distribution of the upgradient wells at a particular site for one or more volatile organic compounds consistent with expectations of a Poisson distribution?

If the answer to this question is yes, we can have confidence in assuming that the observations are independent and that the observed levels of these compounds are consistent with random sampling fluctuations. If the answer to this question is no, there is evidence for possible laboratory error or contamination of the upgradient well. Upgradient populations that do not fit a Poisson distribution are generally inappropriate for comparisons that will be described in this report and sources of laboratory error or contamination should be investigated.

To test hypothesis 1, we rely on the fact that based on the Poisson distribution, the probability of a sample with r parts per billion is

$$p(r) = \frac{u^{r}\, e^{-u}}{r!} \qquad r=0,1,2,\ldots \quad e=2.718 \qquad (1)$$

The term u in (1) is the mean of the Poisson distribution which is equal to

$$u = \sum_{i=1}^{N} fr \,/\, N \qquad (2)$$

where N is the total number of samples

f is the observed frequency of each response and

r is the number of parts per billion.

Based on these results, the expected number of samples with r parts per billion is

$$F = NP.$$

For the case of 0 parts per billion we therefore have

$$F_0 = Ne^{-u}$$

1 part per billion

$$F_1 = N\,ue^{-u}$$

2 parts per billion

$$F_2 = N\frac{u^2}{2}\,e^{-u}$$

3 parts per billion

$$F_3 = N\,\frac{u^3}{(2)(3)}\,e^{-u}$$

and 100 parts per billion

$$F_4 = N\,\frac{u^{100}}{100!}\,e^{-u}$$

To test if the observed counts are consistent with the expected counts, we compute the chi-square statistic

$$X^2 = \sum_{i=1}^{k} (f_i - F_i)^2 / F_i \qquad (3)$$

where k is the number of uniquely observed counts.

This chi-square statistic is distributed on k-2 degrees of freedom.

Question 2

Once we have obtained historical data on a population of upgradient wells, and have demonstrated that they fit a Poisson distribution, what is the probability that a new downgradient observation was drawn from the upgradient population?

This second question directly adresses the central issue of contamination. If a new downgradient observation falls within the 95% or 99% limits of the upgradient population the well should not be considered contaminated; however, if the new observation lies outside of this interval (i.e. higher than the upper bound) the well should be further examined for sources of contamination. Tolerance intervals for a Poisson distribution have a particularly simple form since the mean and variance of a Poisson distribution are identical. The 95% tolerance limit is therefore:

$$\lambda_{95\%} = u \pm 1.96\sqrt{u}$$

and the 99% tolerance interval is

$$\lambda_{99\%} = u \pm 2.58\sqrt{u}$$

In the present situation, we are only interested in increases in downgradient wells, therefore the one sided tolerance limit is given by

$$\lambda_{95\%} = u + 1.64\sqrt{u}$$

or

$$\lambda_{99\%} = u + 2.33\sqrt{u}$$

Example

Table 1, displays the observed and expected frequency distributions for each of the three datasets: 1) upgradient data from 6 facilities and 29 wells, 2) 82 field blanks and 3) 65 trip blanks. The tabled frequencies represent the combination of levels obtained from 32 volatile organic compounds.

Table 1

Observed and Expected Frequencies and Relevant Test Statistics

ppb	upgradient wells		field blanks		trip blanks	
	observed	expected	observed	expected	observed	expected
0 - 10	5016	5013.89	1983	1982.45	1770	1766.15
10 - 20	164	168.26	41	42.10	18	22.71
20 - 30	5	2.82	1	.45	0	.15
30 - 40	0	.03	0	.00	0	.00
40 - 50	0	.00	0	.00	0	.00
50 - 100	0	.00	0	.00	1	.00
100 - 500	0	.00	0	.00	0	.00
500 -	0	.00	0	.00	0	.00
X^2	1.72		0.01		0.66	
df	1		1		1	
p	ns		ns		ns	
upper bound tolerance limit	362 ppb		358 ppb		356 ppb	

hylene Chloride deleted

tection limit = 10 ppb (ie if all 31 compounds were not
tected we would expect 310 ppb)

The results displayed in Table 1 indicate the following.
st, all three datasets fit a Poisson distribution once
:hylene chloride is deleted (ie. the chi-square statistic for
e null hypothesis that the Poisson distribution fits these
oserved data was not significant indicating that the null
ypothesis could not be rejected).

Second, given a detection limit of 10 ppb, we would expect 310 ppb if all 31 compounds (ie. 32 - methylene chloride) were at or below the detection limit. The upper bounds of the tolerance limits were 362 ppb for upgradient wells, 358 ppb for field blanks and 356 ppb for trip blanks. These findings indicate that for all 31 compounds considered simultaneously, new downgradient samples may exceed the detection limit (ie. 310 ppb) by 52 ppb for each well at each sampling period in which all 31 compounds are measured. For example, 30 compounds may be at or below the detection limit and a single compound may exist at 62 ppb. Alternatively, 29 compounds may be at or below the detection limit and 2 compounds may exist at 31 ppb each. Conversely, if all 31 compounds exhibit 12 ppb each, this would produce a total of 372 ppb which would exceed the upper bound of the tolerance limit and be rejected. Inspection of tolerance limits for upgradient wells, field blanks and trip blanks revealed virtually identical results.

*
Methylene Chloride deleted

**
Detection limit = 10 ppb (ie if all 31 compounds were not detected we would expect 310 ppb)

The results displayed in Table 1 indicate the following. First, all three datasets fit a Poisson distribution once methylene chloride is deleted (ie. the chi-square statistic for the null hypothesis that the Poisson distribution fits these observed data was not significant indicating that the null hypothesis could not be rejected).

Second, given a detection limit of 10 ppb, we would expect 310 ppb if all 31 compounds (ie. 32 - methylene chloride) were at or below the detection limit. The upper bounds of the tolerance limits were 362 ppb for upgradient wells, 358 ppb for field blanks and 356 ppb for trip blanks. These findings indicate that for all 31 compounds considered simultaneously, new downgradient samples may exceed the detection limit (ie. 310 ppb) by 52 ppb for each well at each sampling period in which all 31 compounds are measured. For example, 30 compounds may be at or below the detection limit and a single compound may exist at 62 ppb. Alternatively, 29 compounds may be at or below the detection limit and 2 compounds may exist at 31 ppb each. Conversely, if all 31 compounds exhibit 12 ppb each, this would produce a total of 372 ppb which would exceed the upper bound of the tolerance limit and be rejected. Inspection of tolerance limits for upgradient wells, field blanks and trip blanks revealed virtually identical results.