# ♦EPA **Ground Water Sampling --**

A Workshop Summary

Dallas, Texas

November 30 - December 2, 1993

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**Robert S. Kerr Environmental Research Laboratory**
**Office of Research and Development**
**U.S. Environmental Protection Agency**
**Ada, OK  74820**

# Notice

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# Foreword

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

The Robert S. Kerr Environmental Research Laboratory is the Agency's center of expertise for investigation of the soil and subsurface environment. Personnel at the laboratory are responsible for management of research programs to: (a) determine the fate, transport and transformation rates of pollutants in the soil, the unsaturated and the saturated zones of the subsurface environment; (b) define the processes to be used in characterizing the soil and subsurface environment as a receptor of pollutants; (c) develop techniques for predicting the effect of pollutants on ground water, soil, and indigenous organisms; and (d) define and demonstrate the applicability and limitations of using natural processes, indigenous to the soil and subsurface environment, for the protection of this resource; and (e) provide technical assistance to characterize and remediate contaminated soils and ground water.

The dissemination, review and implementation of new environmental research findings is essential in providing the background information required for practitioners and policy makers working in the areas of environmental protection and restoration. This information is critically needed in the area of ground-water sampling, where recent improvements in technology have far outpaced our ability to evaluate and incorporate new methods into sampling protocols and technical guidance documents.

The primary objective of this workshop was to provide a forum for the presentation and discussion of recent research findings on ground-water sampling for researchers, practitioners, regulators and policy makers. Secondary objectives were: to improve communication and the transfer of information between these diverse groups, encourage consistency in ground-water sampling programs where appropriate, and identify research and technology transfer needs. Participants included representatives of universities, private industry, environmental consultants, the U.S. Environmental Protection Agency, the U.S. Geological Survey, the Department of Energy, and several state environmental agencies.

Clinton W. Hall
Director
Robert S. Kerr Environmental
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**Appendices**

# I.   Executive Summary

Monitoring purposes have evolved in the past decade reflecting an increasing emphasis on assessment and remedial action performance over detection monitoring. The recognition of many potential contamination sources as well as the regulatory inclusion of a large number of sites in need of investigation have spurred this evolution in practice. New more efficient methods and tools for hydrogeochemical characterization have been developed which can make site investigations more reliable and cost-effective. Improved field screening techniques, geophysical, portable analytical, and computerized hydrologic data acquisition systems, lighter drilling and boring tools, multi-level samplers, and hydraulic "push" technologies are some of the tools which may be applied to subsurface studies. Professional practices and standards for all monitoring have lagged behind methodological research and development. Regulatory acceptance of new tools and methods has been slow in general. However change is inevitable and, if properly implemented, could lead to more uniformly reliable and less expensive investigations. Improved training and certification of hydrogeologic professionals could also aid in this regard. Decreased reliance on wells as primary data collection points follows on the recognition that many inorganic and most organic contaminants have an appreciable fraction of their mass associated with subsurface solids. Also, wells designed for detection and assessment monitoring purposes frequently become obsolete when vadose or saturated zone remedial action has begun. It may be anticipated that as the familiarity with and supporting documentation for more effective methods grow, more stringent standards of professional practice will evolve as well. In summary, the state of current monitoring practice is steadily changing to more reliable, cost-effective techniques which should improve the spatial coverage, accuracy and precision of data collection efforts.

The primary objective of this workshop was to provide a forum for the presentation and discussion of recent research findings on ground water sampling in the context of continuing advances in environmental monitoring technologies and changing environmental regulatory requirements. Participants included researchers, practitioners, regulators and policy makers from governmental and non-governmental sectors. Secondary objectives of the workshop were: to improve communication and the transfer of information between these diverse groups, encourage consistencey in ground water sampling programs where appropriate, and identify research and technology transfer needs.

## Ground-Water Monitoring Goals and Objectives

One of the most important steps in the design and implementation of a ground-water monitoring program involves defining the data, analyses, and information required to meet the monitoring program objectives. Common examples of monitoring objectives may include leak detection at hazardous and solid waste land disposal facilities, hazardous waste site assessments, corrective action evaluations, and ground-water resource evaluations. In a broad sense, monitoring objectives define the data or information that the investigator needs to support decisions or conclusions. Monitoring objectives are developed to satisfy regulatory requirements, support resource assessments and research goals, and support the development of site conceptual models.

In defining monitoring objectives, data quality objectives (DQOS) are used to specify the type and quality of data required to support decisions. DQOS describe the overall level of uncertainty that a decision-maker is willing to accept in results derived from environmental data. This uncertainty is used to specify the quality of the measurement data required, usually in terms of objectives for accuracy, precision, bias, representativeness, comparability, and completeness. DQOS are defined prior to the initiation of the field and laboratory work. Also, DQOS are communicated to field and laboratory personnel performing the work to make informed decisions during the course of the project to attain those DQOS. The procedures used to characterize the hydrogeology of a site, to design and construct a monitoring network, to collect and analyze environmental samples, and to evaluate analytical results should ensure that the data are of the type and quality necessary to meet the objectives of the monitoring program.

The development and refinement of a site conceptual model underlies all ground-water monitoring programs. A conceptual model is an understanding of the hydrogeologic characteristics of a site, and of how the hydrogeologic characteristics (e.g., geology and geochemistry of the site and the distribution of contaminant migration pathways) are integrated into a hydrogeologic system that contains interacting and dynamic components. Development of a site conceptual model is an iterative process. After a ground-water monitoring system has been installed and numerous ground-water samples have been collected, the conceptual model for a site may be further refined, depending on the DQOS.

## Design and Installation of Subsurface Sampling Points

The design and installation of sampling points for subsurface investigations and monitoring have undergone substantial change since the days when wells of one type or another were the dominant data collection platforms. A variety of gas, solid and liquid sampling techniques are in use for field screening and to improve spatial coverage of subsurface conditions, particularly for volatile organic contaminants. These techniques may effectively substitute for permanent sampling installations. They can be employed during drilling or in conjunction with various "push" technologies which rely on hydraulic or percussion advancement principles.

The utilization of soil gas probes, piston-coring devices, and "drill-tool" water sampling devices (e.g.," Hydropunch", screened augers/pumps, etc.) during drilling has led to an improved ability to identify hydrostratigraphic units and zones of contamination. In these instances, the location, design, construction and performance of short-screened (i.e., <2m), narrow diameter monitoring wells or multi-level samplers can enable more focused and reliable hydrogeochemical data collection. Fewer drill holes and less disturbance of subsurface conditions result from the use of these emerging techniques which also reduce the time and cost involved in monitoring efforts.

Wells are traditionally installed to address one or more of the following objectives: regulatory monitoring; water level measurement; hydraulic conductivity estimation; or to measure or evaluate some other hydrogeochemical site characteristic. Generally speaking, wells are designed to yield enough water for sample collection for regulatory purposes; however, this is not always practical in low water-yielding formations. Conventional monitoring well designs are generally inadequate in these types of formation and alternative designs are needed together with sampling methodologies which do not introduce unwanted artifacts in the collected samples.

## Well Purging and Sampling

Traditional approaches to purging and sampling ground water are undergoing significant reevaluation. The most common method involves purging a well at a high pumping rate or bailing, until a fixed number of casing volumes (usually 3-5) is evacuated, followed by sample collection. This approach has raised concerns about the representativeness of samples collected using these methods, especially if the sampling objectives include monitoring of contaminants. Concerns include entrainment of immobile particles and the possible need to filter samples to remove those artifacts, costs of pumping and disposing of large volumes of contaminated water, and uncertainties in interpreting the source of the sampled water. Many of the

Workshop participants recommended a method which is referred to as low-flow (with minimal-drawdown) purging and sampling. The principal differences between this and more traditional approaches centers on the rate of pumping and the criteria for deciding that purging is complete. The newer method calls for slow flow rates for purging and sampling in order to minimize chemical and hydrological disturbance in and around the well. Furthermore, the completion of purging is gauged on site-specific criteria (stabilization of water quality parameters) rather than on a fixed number of well volumes pumped. Conceptually, formation water flowing through the screened section of the well is purged and then sampled no faster than it enters the well bore under natural hydrological flow conditions. The criteria for the appropriate rate for purging and sampling is hydrological: pumping rates should produce no net (or at least minimal) drawdown of the water table. Under these conditions, low-flow sampling removes water from only the screened zone and stabilization of water quality indicator parameters can be used as a criteria for deciding when formation water has been accessed and sampling can begin. The ideal endpoint would be stabilization of the concentration of a contaminant (or other species of interest); however, some indicator parameters may be correlated with different classes of contaminants (e.g., dissolved oxygen with volatile organics, and turbidity with metals). A conservative approach was recommended which included the use of dissolved oxygen and specific conductance for volatile contaminants, turbidity and specific conductance for metals (and metalloids) and hydrophobic organics, and perhaps also the use of oxidation-reduction (redox) potentials for both cases.

There are several advantages to the low-flow, minimal drawdown method, including the following:

- *More Representative Samples* — Minimal disturbance of the sampling point and reduced stress on the formation results in low turbidity samples which are representative of the "mobile" load of contaminants (dissolved and colloidassociated) present in the formation. By minimizing "artifactual" turbidity, this method also reduces the need for filtration of samples and the costs of analyses of filtered and unfiltered samples.

- *Waste minimization*— The volume of purge water required to access formation water is much less than for more traditional purging methods because low-flow sampling conditions remove water from only the screened zone. This minimizes the volume of water that will require waste disposal at contaminated sites.

- *Spatial Resolution in Sampling* —A fundamental benefit of the decreased purge volume is that a

smaller volume of the aquifer is sampled. This represents a significant improvement in our ability to detect and resolve contaminant distributions, which may vary greatly over small distances in three-dimensional space. In fractured clay or rock, for example, most of the water comes from the fractures. Because the fracture porosity is so small, the sampling process may draw in water from a very large volume of the deposit. This could greatly dilute the concentration of contaminants in the sample. Analogous flow problems can occur in granular aquifers due to vertical heterogeneities in hydraulic conductivity in typically layered sediments.

Switching to the low-flow sampling method met with some resistance on the part of sampling practitioners because of potential problems with data comparison and interpretation of temporal trends due to differences in sample collection methods. There was also concern that increased time may be required for purging and sampling at slow flow rates, and additional equipment may be needed. It was also questioned whether the method was practical in tight or low water-yielding formations where monitoring wells are often urged to dryness. However, recognizing the disadvantages, the advantages of the low-flow sampling method in providing a higher quality sample that more closely represents the mobile dissolved and colloidal components in the formation suggest that this is the direction in which the state of professional practice must proceed. In the case of low water-yielding formations, extension of the low-flow method to more "passive" sampling is proposed for further study as an alternative to current practices in such geologic settings.

## Colloidal Transport and Ground-Water Sampling

Recognition of the potential role of colloids in facilitating contaminant transport has heightened awareness of the need to obtain ground-water samples that are representative of naturally mobile colloids. Carefully collected field evidence shows that commonly-used sampling protocols (bailing, rapid pumping) produce ground-water samples in which colloids have been artificially entrained. That is, bailed and rapidly pumped samples often contain substantial turbidity that is not representative of conditions within the subsurface. In practice, the suspended particles causing this turbidity have been removed from the samples by filtering in the field. Usually, membrane filters with 0.45 m pores have been used to remove turbidity despite biases introduced by their use. The consensus of the workshop endorsed low-flow sampling techniques (described above) which make it possible to obtain ground-water samples that are relatively free of turbidity, without resorting to filtering, by withdrawing water at relatively slow rates which induce little or no drawdown of the water level in a monitoring

well. The use of the term "low-stress" sampling in place of low-flow was proposed to emphasize the importance of minimizing disturbance or stress to the subsurface system. Concern about the potential effect of colloid-facilitated transport is limited to certain classes of low-volubility, surface-reactive contaminants, including radionuclides (e.g., Pu, Am, U, Co, Sr, Cs), heavy metal cations (Cu, Pb), inorganic contaminants typically in anionic form (Cr(VI), As), as well as high molecular weight organic compounds (polychlorinated biphenyls, polycyclic aromatic hydrocarbons). For other contaminants, such as low molecular weight, non-surface-reactive contaminants (e.g., volatile organic compounds), the significance of colloids can be deemed insignificant, based on published partitioning values. Further research is needed to clearly identify what types of subsurface environments pose the greatest risk for this mode of contaminant transport.

## Filtration and Sample Handling

The decision to collect filtered or unfiltered ground-water samples should be based on ground-water monitoring and data quality objectives. Field filtration should not necessarily be the default choice. Consideration must be given to what the application of field filtration is attempting to accomplish, and filtration should not be used as a corrective measure for poor sampling practices. To estimate truly dissolved concentrations of elemental species, the smaller the filter pore size the better, with 0.1 pm generally the most practical for field usage. Dissolved concentrations of elemental species are required for geochemical modeling purposes and other determinations (e.g., alkalinity). In-line field filtration is considered the most desirable approach to minimize sample handling, sample exposure to the atmosphere, and facilitate the expeditious transfer of the water sample to the sample container. For assessment of colloidal mobility, samples must not be filtered. This places more importance on the manner in which samples are collected and the efforts taken to exclude non-mobile or artifactual suspended particles from the sample. Compatibility of unfiltered samples with the eventual analytical method imposed on the sample must be considered. Unfiltered samples collected to evaluate the "mobile" contaminant loading (i.e., dissolved + colloidal) and having high turbidity must undergo digestion prior to analysis. This issue requires special attention in the site-specific sampling plan.

Sample transfer from the sampling device to the sample container should be accomplished with as little disturbance as possible. This operation is relatively straightforward with low-flow sampling techniques, however is problematic using bailers. The excessive volume of sample required for different regulatory programs was also seen as a major impediment to improving our ability to collect

"representative" samples, particularly in low water-yielding formations. Wells in these geologic settings may recharge at extremely slow rates, requiring hours of sampling time to fulfill regulatory sample volume requirements. In many cases, current analytical requirements for sample volumes are considerably less than "regulatory" requirements which are based on outdated analytical methods and instrumentation. Advantages of reduced sample volume requirements are: lower sample container filling time at lower flow rates, lower bottle costs, lower shipping costs, and reduction of liquid wastes back at the laboratory.

**Documentation and Technology Transfer**

Despite the fact that more focused, real-time hydrogeochemical data collection has been enabled by recent technological advances, the growth of the knowledge base and improvements in field sampling practice are seriously lagging. Additional and better documentation is required at virtually every step of the sampling process. This will permit better interpretation of the collected data and more assurance that data quality objectives are being met. Improvements in technology transfer from the research community to the user communities is also needed. Training and perhaps certification of field sampling personnel should be encouraged and efforts should be expanded in this area by state and federal regulatory agencies.

_Summary edited by Robert W. Puls, Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency and written by Michael J. Barcelona, University of Michigan, John E McCarthy, Oak Ridge National Laboratory, and James R. Brown and Robert W. Puls, U.S. Environmental Protection Agency._

# II.   Agenda

| | | |
|---|---|---|
| 7:30 - 8:00 a.m. | General Introduction | Robert W. Puls |
| 8:00 - 8:30 a.m. | A Federal Perspective on the Acquisition of Representative Ground Water Samples: A Historical Review | James R. Brown and Andrew L. Teplitzky |
| 8:30 - 9:00 a.m. | Sampling Program Purpose and Design Considerations | Michael J. Barcelona |
| 9:00 - 9:30 a.m. | The Relationship of Monitoring Well Design, Construction, and Development to Turbidity in Wells, and Related Implications for Ground Water Sampling | David M. Nielsen |
| 9:30 -10:00 a.m. | Use of Low-Flow or Passive Techniques for Sampling Ground Water | Robert W. Puls |
| 10:15 - 10:45 a.m. | Sampling Colloids and Colloid-Associated Contaminants in Ground Water | Debera A. Backhus, J. N. Ryan, D.M. Groher, J.K. MacFarlane, and P.M. Gschwend |
| 10:45 - 11:15 a.m. | Need for Practical Approaches to Conduct Multilevel Sampling | Gary A. Robbins |
| 11:15 - 12:45 p.m. | Effects of Well Design and Time of Pumping on Concentrations of Volatile Organic Compounds in Ground Water Samples | Jacob Gibs and Thomas E. Reilly |
| 11:45 a.m. | Lunch | |
| 1:00 -1:30 p.m. | Common Sampling and Analytical Procedures Viewed in the Context of Data Quality Needs | William R. Mabey and Nancy Barnes |
| 1:30 - 2:00 p.m. | Considerations in Selecting Filtered or Unfiltered Samples for Analyses of Metals in Ground Water Samples | Dennis E. Reece |
| 2:00 - 2:30 p.m. | A Study of the Impact of Monitoring Well Purging and Filtering Techniques on Metals Concentrations in Ground Water Samples from the Auburn Road Landfill Site in Londondery, N.H. | Carol A. White |
| 2:30 - 3:00 p.m. | Ground Water Sampling of Fractured Clay and Rock | Larry McKay, Kent Novakowski, and John McCarthy |
| 3:30 - 4:00 p.m. | Evaluation of Field-Filtration Variables for Representative Samples of Trace Metals in Ground Water | Karl F. Pohlmann, Gary A. Icopini, and Charlita G. Rosal |
| 4:00 - 4:30 p.m. | Monitoring Well Sampling—You Can't Always Get What You Want, But Can You Get What You Need? | Jack Connelly |

| 4:30 - 5:00 p.m. | Abstract of Statistical Comparison of Metal Concentrations in Filtered and Unfiltered Ground Water Samples | Robert Gibbons and Martin Sara |
| --- | --- | --- |
| 5:30 - 7:30 p.m. | Poster Session | |

**WEDNESDAY, DECEMBER 1, 1993**

| 8:00 - 11:30 a.m. | Small Group Discussions |
| --- | --- |

Monitoring Goals and Objectives
Well Design, Construction, and Development
Well Purging and Sampling
Turbidity and Colloid Transport
Sample Handling and Analysis

| 11:30 a.m. | Lunch |
| --- | --- |

| 1:30 - 5:00 p.m. | Small Group Discussions |
| --- | --- |

Monitoring Goals and Objectives
Well Design, Construction, and Development
Well Purging and Sampling
Turbidity and Colloid Transport
Sample Handling and Analysis

**THURSDAY, DECEMBER 2, 1993**

| 8:00 - 11:00 a.m. | Reports from Small Group Discussions | Michael J. Barcelona, Linda Aller, Robert W. Puls, Joseph N. Ryan, and Karl Pohlmann |
| --- | --- | --- |
| 11:00 - Noon | Wrap-Up | Robert W. Puls |

# III. Extended Abstracts

The following extended abstracts are provided for the oral presentations made by invited speakers on the first day of the Workshop.  Speakers were selected by the Steering Committee and the topics were intended to provide some foundation for subsequent discussions which occurred both formally and informally during the balance of the Workshop.  The first day's presentations covered a wide range of sampling-related topics from a diverse group of individuals active in ground-water sampling.  It should be noted that the abstracts were not part of the formal peer-review process which the remainder of this document underwent, and represent opinions or personal points of view in many cases.  As a result, some presentations are in conflict with others.  An attempt was purposely made to provide a forum for the exchange of conflicting views and data on the first day, and thus stimulate discussions for the remainder of the Workshop.

# A REVIEW OF FEDERAL REGULATIONS AND GUIDANCE FOR GROUND-WATER SAMPLING

## James R. Brown and Andrew L. Teplitzky

Several Federal regulations mandate the collection and analysis of ground-water samples to protect ground-water resources and to determine the anthropogenic impacts on ground-water quality: The Resource Conservation and Recovery Act (RCRA); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); the Toxic Substances Control Act (TSCA); and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Annually, these regulations result in the collection of hundreds of thousands of ground-water samples. Some of the regulations use general performance standards for ground-water sample collection requirements. Other regulations require specific procedures for the collection of ground-water samples.

The RCRA program regulates, in part, owners and operators of municipal solid waste landfills (MSWLFs), hazardous waste management facilities, and underground storage tanks. Ground-water monitoring regulations at RCRA MSWLFs prohibit the filtration of ground-water samples. RCRA hazardous waste ground-water monitoring regulations and underground storage tank standards do not specify whether the samples should be filtered or not. Implementation of specific sampling protocols for hazardous waste disposal facilities and underground storage tanks is done at the State or EPA Region level, mainly through technical guidance documents. EPA's ground-water sampling guidance for hazardous waste disposal facilities is found in the *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD)* (USEPA, 1986), and *RCRA Ground-Water Monitoring: Draft Technical Guidance (GWM)* (USEPA, 1992).

The TEGD recommends:

1) the use of sampling equipment and procedures that minimize sample agitation and reduce or eliminate contact with the atmosphere;

2) that low-yielding wells be purged at a rate that does not cause recharge water to be excessively agitated; and

3) that sampling rates for volatile organic compounds not exceed 100 milliliters per minute.

The TEGD also recommends that samples collected for the analysis of organic compounds not be filtered. However, samples collected for the analysis of metals should be split into two portions: one portion should be filtered and analyzed for dissolved metals, and one portion should not be filtered and analyzed for total metals.

GWM recommends the use of low rate purging and sampling procedures, discourages the use of bailers, and generally does not recommend the filtration of ground-water samples used for leak detection purposes.

The CERCLA program (commonly referred to as "Superfund") regulates the remediation of uncontrolled and abandoned hazardous waste sites. The regulations specify only general performance standards for collecting ground-water samples. Several guidance documents, however, prescribe ground-water sampling procedures for various sampling objectives.

*A Compendium of Superfund Field Operations Methods* (USEPA, 1987), recommends that the sampling protocol be dictated by the study objectives. The Compendium states that if the study objective is to assess the migration mechanisms in conjunction with migration pathways, then it is necessary to know the concentration of dissolved and total constituents.

The *Risk Assessment Guidance for Superfund* (USEPA, 1989), notes that data from filtered and unfiltered ground-water samples are useful for evaluating chemical migration in ground water, and that a comparison between these samples can provide important information on the form in which a chemical exists in ground water. The *Risk Assessment Guidance* also specifies the use of data from unfiltered samples for estimating exposure concentrations.

A Superfund Ground-Water Issue Paper entitled, "Ground-Water Sampling for Metals Analysis," (Puls and Barcelona, 1989), also makes several ground-water sampling recommendations for the Superfund program. The paper recommends:

1) the collection of unfiltered samples to determine a conservative estimate of contaminant loading in an aquifer;

2) the use of small pore-size filters (<0.45 micron) to determine the concentration of dissolved metals;

3) the use of low-rate purging and sampling procedures (e.g., 100 milliliters per minute); and

4) that bailers not be used to collect ground-water samples.

Ground-water samples are also collected under provisions of the Toxic Substances Control Act (TSCA). TSCA requires that materials containing concentrations of polychlorinated biphenyls in excess of 50 parts per million must be disposed of in a landfill with a ground-water monitoring network. The TSCA regulations (40 CFR § 761.75(b)(6)(ii) and (iii)) outline general performance standards for ground-water sampling methods, but do not address specifically whether ground-water samples should be filtered or unfiltered.

Under § 3(c)(2)(B) of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), EPA may require pesticide registrants to submit monitoring data from ground-water studies to support the registration of pesticide products. These studies are performed when residues of the pesticide have been detected in ground water or when EPA suspects that the pesticide will leach to ground water based on a review of the environmental fate data. FIFRA's *Draft Guidance for Ground-Water Monitoring Studies* (USEPA, 1988) recommends the filtration of ground-water samples; however, this practice is being re-evaluated and revised FIFRA guidance may change the sampling recommendation.

State implementation of the Federal RCRA ground-water sampling requirements exhibits varying practices across the nation. Information submitted to EPA by State environmental agencies on ground-water sampling procedures at MSWLFs and hazardous waste management facilities reveals a non-uniform approach to the acquisition of representative ground-water samples. During the summer of 1993, all 50 States submitted publically available information about ground-water sampling policies and regulations to EPA. The data show that in both the municipal solid waste and hazardous waste programs:

1) some States allow the filtration of ground-water samples;

2) some States do not allow the filtration of ground-water samples;

3) some States require or recommend the collection of both filtered and non-filtered ground-water samples; and

4) some States allow either filtered or non-filtered ground-water samples.

Figures 1 and 2 exhibit the distribution of these ground-water sampling practices throughout the United States for the municipal solid waste and hazardous waste programs respectively. The figures do not suggest any apparent regional trends in sampling practices used by the various State agencies. A comparison of these sampling practices to a generalized hydrogeologic map of the United States also fails to depict any deliberate consistency in sampling practices within a distinct ground-water region (Figure 3). Overall, that data show that ground-water sampling practices lack consistency within EPA Regions, within ground-water regions of the U.S., among States, and between the municipal solid waste and hazardous waste programs within States.

As made evident by this brief review of various Federal environmental regulations requiring ground-water monitoring, sampling requirements vary: some regulations allow the filtration of ground-water samples and others do not. Some Federal regulations are not specific with regard to how the samples should be collected, relying instead upon guidance from State environmental agencies to develop the sampling protocol. A general survey of these State sampling policies and regulations shows no apparent consistency with respect to regulatory objectives or hydrogeologic setting. Therefore, a need exits to develop uniform ground-water sampling guidance that considers the objectives of the ground-water monitoring regulatory programs and incorporates site-specific hydrogeologic information.
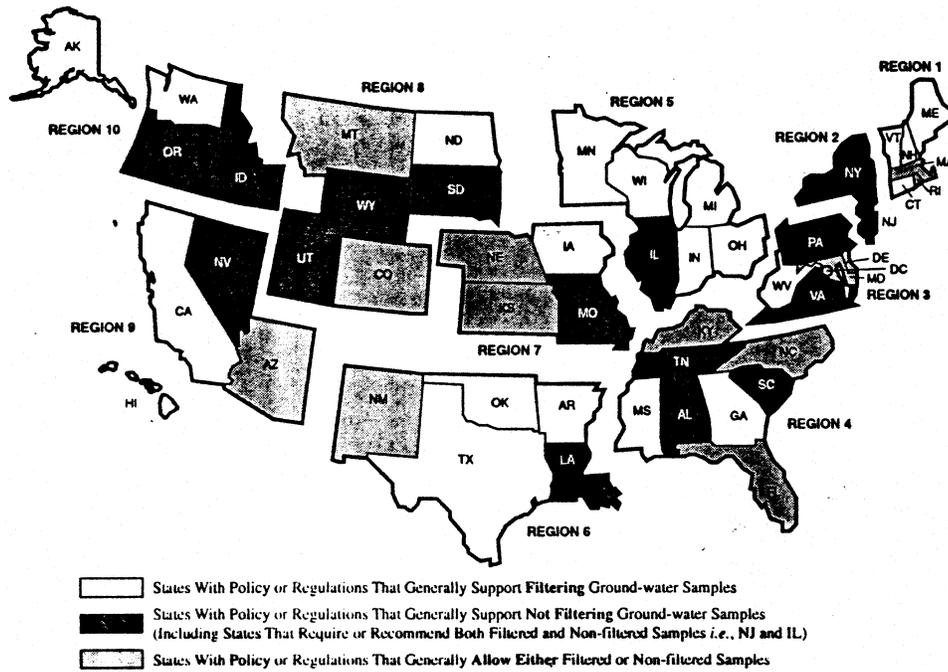
**Figure 1. Ground-Water Sampling at Municipal Solid Waste Landfills.**
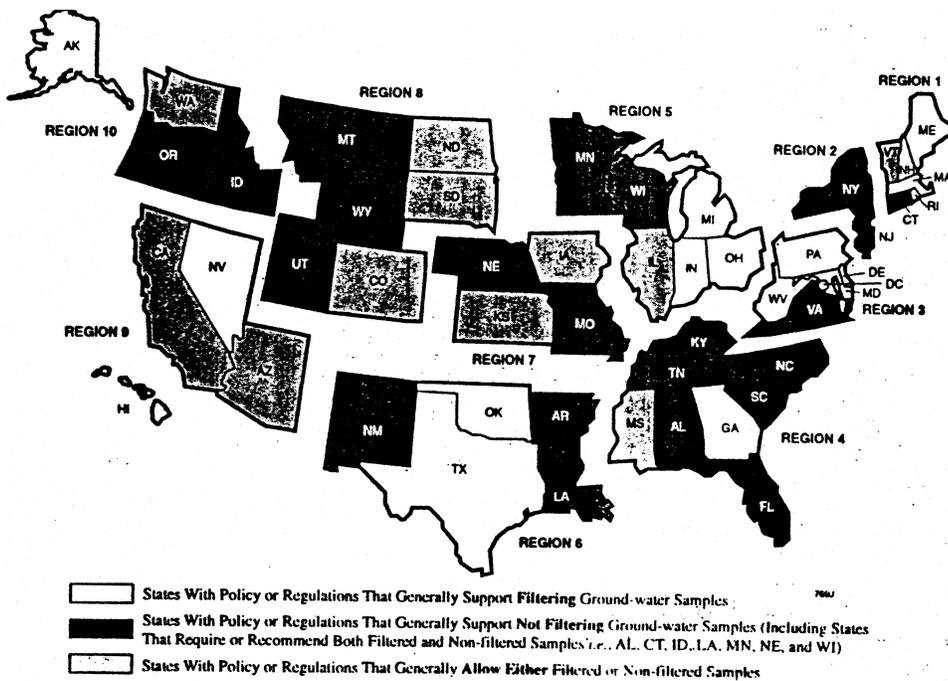


**Figure 2. Ground-Water Sampling at Hazardous Waste Sites.**
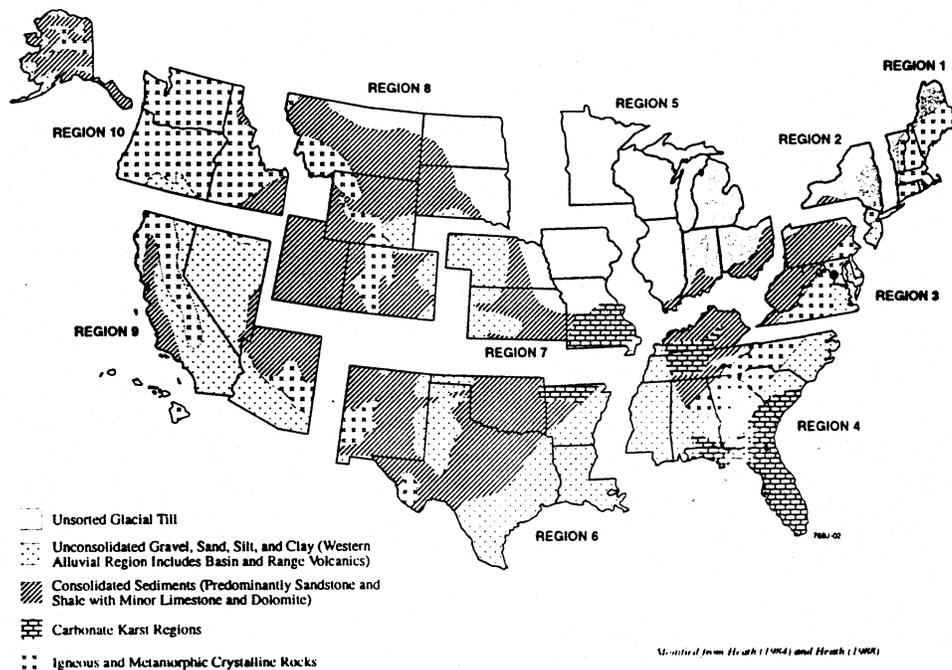
**Figure 3. Generalized Hydrogeologic Map of the United States.**

### References

Federal Insecticide, Fungicide, and Rodenticide Act, 7 U.S.C. § 3(c)(2)(B).

Ground-water Monitoring Requirements for Landfill Disposal of PCBs, 40 CFR § 761.75(b)(6)(ii) and (iii), (1992).

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# SAMPLING PROGRAM PURPOSE AND DESIGN CONSIDERATIONS

## Michael J. Barcelona

Ground-water and subsurface monitoring programs have diverse purposes and objectives which inevitably change as detective efforts evolve into assessments and from there to remedial-action performance evaluations. Common objectives to many subsurface site characterization and monitoring programs allow us to approach network designs from a basic set of criteria for representativeness, accuracy, precision, specifity, and sensitivity.

Detective monitoring programs have as their main objectives: the characterization of the site and placement of sampling points so as to permit detection of indicator parameters (e.g. TOC, pH, conductance, metals or volatile organic compounds (VOC's) etc. Assessment monitoring efforts would follow detection of releases and seek to determine the specific extent and magnitude of contaminant distributions. In turn, programs planned to support the design and implementation of remedial actions increase in detail to the point where real differences in contaminant mass removal may be determined over time. Fundamental to all of these purposes are the following objectives[1]:

1.  Avoidance of gross errors[2] (i.e. false negative data collection due to poor sampling techniques, choice of location or focusing on symptoms rather than media where the bulk of the contaminant mass resides),

2.  Minimization of costs in dollars, time and human resources by avoidance of redundancy in data collection, while providing a basis for detecting real trends[3], and,

3.  Complete data collection of both hydrogeologic parameters and chemical concentrations sufficient to permit decision-making at a known level of confidence.

In all of these efforts, representativeness, accuracy, precision, specificity and sensitivity are of value to the monitoring effort. Good professional standards of practice apply and it is time that these standards are applied to both field and laboratory techniques.

### Representativeness

Though representativeness in sampling is often parroted back in plans and reports, there exists a substantial gap between what is commonly practiced and what we can identify as standards for professional practice from the scientific literature. In simplest terms, representativeness stems from the purposes of the investigation recognizing that purposes change (as does the dollar value of the data) and all sites merit some level of specific detective and site characterization effort. This comes from a recognition that the basic geologic descriptions and a consistent hydrogeo-chemical framework which constitute a conceptual model of a site have lasting value for the future.

Natural variability in background and "impacted" hydrogeochemical conditions provides limits on the distributions of chemical concentrations and aquifer properties. These can be described in statistical terms. Representativeness, therefore, implies that the sampled population reflects at least some properties of the total population. Values which lie beyond these limits will require some explanation. The site's unique characteristics will determine the extent to which the statistical distributions of critical parameters (e.g. major hydro-stratigraphic units, hydraulic conductivity, transmissivity, background and contaminant concentrations) must be known. Clearly, presuming that the site has been characterized to a degree that it would pass peer review could establish if in fact good professional practice had been performed. It is at this point that the basis for a thorough monitoring effort may address major deficiencies within program constraints.

The literature has shown numerous examples of deficiencies which can and should be remedied in routine monitoring efforts[3,4,5]. Progress has been in a number of operational areas which deserve more in-depth consideration in ongoing efforts.

### Focus on the Media

A focus on the correct medium (i.e. solid associated contaminants, rather than symptoms in soil gas or water) for the major mass of contaminants is essential to <u>accurate</u> monitoring efforts. Table 1 shows data which reflects the dominant nature of solid-associated volatile organic contaminant mass. This has also been observed by many groups. Here, the guidance from the Agency with regard to monitoring practice (e.g. bulk solid sampling without preservation) is at odds with good professional performance. If in fact, the correct medium is left under-represented with respect to chemical data collection, it is often the case that

redundant well completions rather than in-depth hydrogeologic data collection and interpretation may have been made. The major liability here is that though some information exists for the major contaminants, both background conditions and critical design parameters for remedial action are lacking. The major pitfalls here are:

1. Overly rigid work plans which do not permit needed exploratory field screening or borehole/solid sampling for hydrogeochemical parameters in background and contaminated zones,

2. The use of known biased procedures in water (e.g. bailer sampling for VOC's) or solids (e.g. bulk jar sampling) without sufficient allowances for mineralogic, site specific contaminant sorption/desorption parameters, or hydraulic conductivity determinations.

In addition, whether by dint of tradition or the "parrot-syndrome" (i.e. parroting back the format and detail of earlier studies) monitoring efforts may fail to provide sufficient hydrogeologic data and its integration with the chemical data to suit the reasonable long-term interests of the monitoring work[6,7]. From this perspective, it may be irrelevant that precise, specific or sensitive analytical determinations have been made since the focus of the investigation may have been off the mark. It is far more important that high quality decisions have been made in the field. It true quality is the key (and why has this become less of a value?), the quality of decision making can only be assured if active peer-review at the planning stage becomes a part of the overall field program.

## Critical Considerations For Improving Professional Practice

What is vitally important here in the judgement of good professional practice? From the literature we can glean the following:

1. Implement consistent field screening techniques for both chemical and hydrogeologic parameters with careful lab confirmation of a percentage of the total samples [8,9];

2. Minimize planned well completions where they will afford the most long-term information term and collect sufficient background data for meaningful comparison;

3. Recognize that field sampling can often be the most significant source of error. Avoid the use of "different" well design, purging and sampling techniques across the site so that chemical concentration comparisons are in fact statistically comparable, (this also means rejection of biased purging and sampling techniques (i.e. the bailer); and,

4. Permit sufficient time and flexibility in the program's directions to avoid "dead-end" data collection which wastes time, human resources and dollars to no useful end[10,11].

The foregoing discussion stresses the value of a balanced approach to site characterization and monitoring, which

Table 1.    Relative Masses (μg) of TCA in ground water and aquifer solids for a representative 1 liter aquifer element.[25]

| Well | Ground Water | MeOH Preserved Solid | Bulk Jar, 4°C Solid | % Total TCA in Solid |
|------|------|------|------|------|
| 15 | 13.5 | 21.0 | - | 60 |
| 31 | 85.7 | 516.0 | 52 | 86 |
| 32 | 11.1 | 30.9 | - | 74 |
| 37 | 83.7 | 239 | - | 74 |

(-)    denotes no detectable levels of TCA in bulk jar sample by static headspace gas chromatography-Hall electrolytic conductivity detection (7 day holding time)   (Barcelona, M. J. and D. M. Shaw, 1992 unpublished data).

values completeness in the data collection effort. Refinement of the hydrogeochemical dataset via an evolutionary, DQO-driven investigative effort will serve both the regulated and regulating communities' goals most closely[5]. We must reject the use of poor practices and educate the entire community that these sites will not simply go away. They may yield eventually to a well-founded, documented monitoring approach based on geologic and hydrogeologic fact.

Table 2 contains an example of results of a controlled data collection effort by using dedicated bladder pumps and consistent purging and sampling procedures from a large network for VOC's in ground water. Here the magnitude of natural variability (what we are trying to evaluate) far outweighs the errors from analytical or sampling procedures. In addition, the use of dedicated devices has been shown to minimize costs associated with network operation[12].

Many other examples of controlled data collection can be pointed out from the literature to aid future monitoring network designs[13]. These approaches have the merit of lower cost as well as a focus on the correct media for decision-making purposes.

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**Table 2.** Overall Mean, Relative Standard Deviation and Percentage of Total Variance Attributable to Laboratory or Field (Sampling) Error, and Natural Variability (November 1990-September 1992)

| *Overall* | *Relative Mean* | *(Std. Dev.)* | *Percent of Total Variability* | | |
|---|---|---|---|---|---|
| | | | *Lab* | *Field* | *Natural* |
| *VOC* | *($\mu$g/L)* | *%* | *%* | *%* | *%* |
| 111 TCA | 119.5 | (36%) | 1.29 | 3.26 | 95.45 |
| TCE | 29.8 | (43%) | 1.95 | 12.75 | 85.30 |
| c12DCE | 45.2 | (32%) | 1.69 | 4.72 | 93.59 |
| 11DCA | 44.3 | (28%) | 1.02 | 5.22 | 93.76 |
| 11DCE | 16.3 | (31%) | 3.61 | 4.15 | 92.24 |

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# THE RELATIONSHIP OF MONITORING WELL DESIGN, CONSTRUCTION AND DEVELOPMENT TO TURBIDITY IN WELLS, AND RELATED IMPLICATIONS FOR GROUND-WATER SAMPLING

## David M. Nielsen

A strong correlation exists between improper ground-water monitoring well design, construction and development and high levels of turbidity in ground-water samples. This correlation is independent of the type of geologic material in which the wells are installed. Research conducted by the author, prior to the compilation of two recently approved ASTM standards (D-5092, Standard Practice for Design and Installation of Ground-Water Monitoring Wells in Aquifers; D-5342, Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers) indicates that proper well design, construction and development can alleviate turbidity problems in most unconsolidated formation materials (sands and gravels). However, the same research demonstrated that current well design, construction and development practices are not sufficiently advanced to limit turbidity in monitoring wells installed in predominantly fine-grained unconsolidated formation materials (silts and clays).

Work conducted on this subject by others (Paul et al., 1988) has demonstrated th vigorous development of wells installed in fine-grained glacial till actually aggravates turbidity problems and that standard well design practices, even when supplemented by additional controls on sediment production, failed to ameliorate turbidity problems. Additional research is required to develop suitable well design, construction and development guidelines applicable to predominantly finegrained formation materials. This is particularly critical in waste disposal facilities, at which monitoring wells are or well be required by regulation, are purposely sited in areas where these geologic materials prevail.

Recently proposed regulatory restrictions on ground-water sample filtration appear to be founded primarily on the premise that proper monitoring well design construction and development practices can alleviate sample turbidity problems in all wells. Current research demonstrates other wise. Though proper well design, construction and development are important steps toward eliminating sedimentladen ground-water samples in some hydrogeologic settings, these measures will not suffice in all situations. Field filtration of ground-water samples intended for metals analysis, while not a suitable substitute for proper well design and construction in coarse-grained formation materials, is necessary to ensure comparability of analytical data from wells installed in predominantly fine-graine formation materials. To disallow field filtration of samples from these wells is to fail to recognize the limitations of current well design technology.

# USE OF LOW-FLOW OR PASSIVE SAMPLING TECHNIQUES FOR SAMPLING GROUND WATER

## Robert W. Puls

### Introduction

It is generally accepted that monitoring wells must be purged to access formation water to obtain "representative" ground water quality samples. Historically anywhere from 3 to 5 well casing volumes have been removed prior to sample collection to evacuate the standing well water and access the adjacent formation water. However, a common result of such purging practice is highly turbid samples from excessive downhole disturbance to the sampling zone. This disturbance includes the following: mixing of stagnant casing water with water which resides in the screened interval and the formation; aeration; degassing; and excessive turbidity due to high pump rates or the continual plunger action of bailers. The excessive turbidity created can impact estimations for both "dissolved" and "total" metals determinations, and cause other artifacts which may adversely affect sample quality. An alternative purging strategy has been proposed using pumps which permit much lower flow rates (< 1 liter/min) and placement within the screened interval of the monitoring well. The advantages of this approach include less disturbance to the sampling zone, increased spatial resolution of sampling points (i.e., sample smaller portion of the aquifer), less variability, less purge time (and volume), and low-turbidity samples. The overall objective is a more passive approach to sample extraction with the ideal being to match the intake velocity with the natural ground water flow velocity (i.e. negligible drawdown during purging). The volume of water extracted to access formation water is generally independent of well size and capacity and dependent upon well construction, development, hydrogeologic variability and pump flow rate. This is particularly evident where dedicated sampling systems are employed. A detailed understanding of the hydrogeochemistry of the sampling zone, particularly with respect to aquifer heterogeneities, is important in both the design of the sampling system and the interpretation of the resultant sampling data for site assessment and remedial evaluation purposes.

Required purge volume or purge duration is evaluated through continuous monitoring of water quality parameters (WQPs) such as dissolved oxygen, specific conductance, oxidation-reduction (redox) potential and turbidity to determine the presence of formation water. Research has shown (Puls et al. 1992; Backhus et al. 1993; Barcelona et al. 1994) that purging at these lower rates with various types of pumps (peristaltics, low-speed submersibles, and bladder pumps) does indeed produce low turbidity and generally high quality samples. A perceived disadvantage of such strategies however is the additional time required to purge the wells. In general however, this same research has shown that the volumes required to access formation water are less than 2 casing volumes and in deeper wells are actually only fractions of a casing volume, suggesting that the purge volume is independent of well size or casing volume. This previous research was conducted exclusively with portable sampling systems. Studies which have utilized a downhole camera during the purging process (Puls and Powell, 1992; Kearl et al. 1992) have suggested that the installation of the sampling devices themselves causes the most disturbance to the sampling point. If installation of the sampling system can be avoided through the use of dedicated sampling systems, then this could greatly reduce the time required to obtain representative formation samples and also greatly reduce the volume of water brought to the surface.

This study was conducted to evaluate the use of low-flow purging methods in dedicated sampling installations in routine monitoring wells. Stabilization of water quality indicator parameters, together with time series sampling of contaminants and water chemistry was employed to evaluate the purge volume required to access formation water.

### Study Site

The field site is located at the U.S. Coast Guard (USCG) Support Center near Elizabeth City, North Carolina, about 100 km south of Norfolk, Virginia and 60 km inland from the Outer Banks of North Carolina. The base is located on the southern bank of the Pasquotank River, about 5 km southeast of Elizabeth City. The topography of the site is essentially flat and between two and three meters above sea level. The river has a width of approximately 3.2 km along the USCG base's northern boundary and a depth about 3 meters. A chrome plating shop, located within an aircraft hangar on the base, had been in use for more than 30 years, and had discharged acidic chromium wastes through a hole in the concrete floor into the soils immediately below the shop's foundation and the underlying aquifer (Puls et al. 1994).

The site geology consists of typical Atlantic coastal plain sediments characterized by complex and variable sequences of surficial sands, silts and clays. In the vicinity of the plating shop, the surface soils are silty clays. These overlie a thin sandy clay layer at about 1.5 m, which overlie a sequence of sands and silty fine sands. In some locations, a dense gray clay layer substitutes for the sandy clay layer at 1.5 m. Fine to medium sands dominate from 4 to 20 m. A dense gray clay unit (Yorktown Confining Unit) persists at a depth of 20 m. This depth is slightly variable and dips gently from north to south.

## Materials and Methods

### Monitoring Wells and Sampling Pumps

Eight different monitoring wells at the site were used in the study. With the exception of two of the wells, these were all 5 cm (2 in.) diameter schedule 40 polyvinylchloride (PVC) wells with 0.25 mm (0.01 in) slotted screens. Other characteristics of the sampled wells used in the study are listed in Table 1. The wells ranged in depth from 4.6 to 15.2 meters below ground surface. System volume (Table 1) refers to the volume of water in the tubing and the water quality parameter measurement device (QED PurgeSaver). Well volume (Table 1) refers to the water in the monitoring well itself which varied somewhat over time due to fluctuations in the water table level. Two of the wells (MW 25, MW 31) were installed without casing. For these two wells, a permanently dedicated PVC bladder pump (QED Inc.) and a permanently dedicated variable-speed submersible pump (Redi-Flo 2, MP1; Grundfos Inc.) were encased in 0.25 mm (0.01 in.) slotted screens, sealed and connected with 0.63 cm (0.25 in.) teflon-lined polyethylene tubing. These units were lowered inside 7 cm (2.75 in.) hollow-stem augers to the desired depth and the formation was allowed to collapse in around the units. For the caseless Grundfos, a sandpack was used inside the screen, whereas for the caseless QED pump glass beads were used as the packing or filter material. These systems are referred to as permanently dedicated, because they cannot be removed for servicing. The same type pumps (Grundfos Redi-Flo2 and QED bladder) and tubing were used in the traditional monitoring wells as well.

### Purging and Sampling Procedures

The pumps (except for the permanently installed pumps) were set with the pump intake at approximately mid-screen. Following installation (April, 1992), most of the pumps remained in place throughout the study (April, 1992 - June, 1993). Data was first collected in August, 1992, and then again in February, March, and June of 1993. The sampling procedures described in previous publications (Puls et al. 1992; Puls and Powell, 1992) were generally followed, except all purge water was collected in sequential 500 ml increments for analysis of volatile organics

(trichloroethylene [TCE], dichloroethylene [DCE], and vinyl chloride), major cations and metals, anions, and chromium. Water levels were measured and recorded prior to purging and monitored continuously while purging to minimize drawdown (<0.1 m). Flow rates ranged from 0.22-0.55 L/min. A flow-through cell with data logger (QED PurgeSaver) was used to continuously monitor pH, temperature, dissolved oxygen (DO), and specific conductance. Purging and continuous sampling continued beyond equilibration of water quality indicator parameters to a maximum of 21 liters. Equilibration was defined as three successive readings within ±10% for DO and turbidity, ±3% for specific conductance, and ±0.05 for pH. At the flow rates utilized, these readings were taken every three minutes. Equilibration criteria were based on evaluation of preliminary plotted WQP data and equipment accuracy. Temperature was recorded but not used for stabilization.

## Results and Discussion

Purging results in terms of water quality parameter (WQP) equilibration and contaminant concentration (CC) equilibration are shown in Table 1. WQP and CC equilibration volumes were independent of well depth or well volumes. WQP equilibration volumes ranged from 4 to 10 L, while CC equilibration volumes ranged from 2.5 to 7.5 L. The two dedicated permanent wells (MW 23, 31) had some of the lowest CC equilibration volumes as might be expected due to the minimal stagnant well water above the pump (0.64-0.81 L in buried pump tubing). MW 22, the deepest well, had the smallest CC equilibration volume for all wells used in the study, while the largest CC equilibration volume was for the shallowest well (MW 2).

The equilibration trends for the WQP's were similar for all wells in the study. Specific conductance increased slightly and equilibrated prior to dissolved oxygen and turbidity. Dissolved oxygen decreased and equilibrated after specific conductance and prior to turbidity. Turbidity followed a generally exponential decline. Contaminant concentration equilibration volumes were less than or equal to WQP equilibration volumes. Differences in initial and final equilibration contaminant concentrations were generally less than 20% for TCE, c-DCE, vinyl chloride and chromium.

Using a spherical conceptual model for the aquifer volume sampled, CC equilibration was achieved within a 13-16.5 cm radius (assuming a porosity of 0.38). Alternatively, if casing volume is defined by only the water within the screened interval of the well where the pumps are located, CC equilibration was attained between 1.1-2.4 screened interval casing volumes (SICV) for the dedicated pumps in the 5 cm monitoring wells.

## Summary and Conclusions

An alternative conceptual model is proposed which considers the evacuation of only a portion of the screened interval volume rather than the entire casing volume. Depending upon well depth and the analytes of interest, various types of pumps may be used with the pump intake located within the screened interval and at the desired sampling depth. Significant reductions in purge volume have been attained using dedicated systems, and thorough economic analyses may show this to be a cost-effective alternative for routinely-sampled monitoring wells.

While this strategy works most effectively where well screens are short (<1.5 m) and located within a relatively homogeneous geologic zone, they may also be effective in longer screened intervals and where geologic heterogeneities may exist. This remains to be tested. The utility of these techniques has not been explored in open boreholes in fractured rock. Proper well construction and well development and complete documentation of all sampling activities becomes increasingly important where such strategies are employed. A detailed understanding of the hydrologic and geologic variability of the system is essential in establishing sampling points and designing the overall sampling program.

## Disclaimer

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**Table 1.** Characteristics of wells used in the study and water quality parameter and contaminant concentration equilibration data, U.S. Coast Guard Support Center, Elizabeth City, NC.

| Well | Depth[1] | Screen[2] | Device[3] | WQPEV[4] | CCEV[5] | SystemVol.[6] | Well Vol.[7] |
|------|------|------|------|------|------|------|------|
| 2 | 4.6 | 1.5 | CS | 7.5 | 7.5 | 0.6 | 5.6 |
| 13 | 4.6 | 1.5 | CS | 7.0 | 4.5 | 0.6 | 5.6 |
| 13 | 4.6 | 1.5 | CS | 7.0 | 7.0 | 0.6 | 5.6 |
| 14 | 6.1 | 1.5 | BL | 10.0 | 4.5 | 0.9 | 8.7 |
| 15 | 4.6 | 1.5 | BL | 6.0 | 5.5 | 0.8 | 5.6 |
| 16 | 4.6 | 1.5 | CS | 4.0 | 3.5 | 0.8 | 5.6 |
| 22 | 15.2 | 3.1 | CS | 7.5 | 2.5 | 1.3 | 27.2 |
| 23 | 7.1 | 0.9 | BLp | 7.5 | 3.5 | 0.8 | 0.5 |
| 31 | 4.9 | 0.5 | CSp | 6.5 | 3.5 | 0.6 | 0.3 |

[1] Depth = well depth in m,
[2] Screen = screen length in m,
[3] CS = low-speed centrifugal submersible pump, BL = bladder pump, CSp = permanently buried low-speed centrifugal submersible pump, BLp = permanently buried bladder pump.
[4] WQPEV = water quality parameter equilibration volume in liters,
[5] CCEV = contaminant concentration equilibration volume in liters,
[6] System volume = volume (in liters) of tubing and flow-through cell,
[7] Well volume = volume (in liters) of water in well casing and well screen.

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# SAMPLING COLLOIDS AND COLLOID-ASSOCIATED CONTAMINANTS IN GROUND WATER

**D.A. Backhus, J.N. Ryan, D.M. Groher, J.K. MacFarlane and P.M. Gschwend**

Groundwater monitoring wells are used to obtain general information about groundwater quality and specific information about concentrations and speciation of mobile contaminants in the vicinity of a well. This information is used to determine whether a given facility is currently in compliance with regulations. In addition, data from monitoring wells can be used to provide clues to as to the processes affecting contaminant fate in the subsurface, allowing development of models for accurate predictions of spacial and temporal contaminant distributions. These predictions allow for assessment of risks under various scenarios and evaluation of alternative remediation strategies. It is crucial that samples obtained from monitoring wells accurately reflect *in situ* mobile contaminant concentrations, as the cost of a bad decision based on inaccurate data can be great.

In the past, it was generally assumed that contaminants existed in the saturated zone either as associated with the aquifer material and therefore immobile or dissolved in and moving with the groundwater. Hence, when a turbid groundwater samples was obtained from a monitoring well it was assumed that the turbidity was an artifact of well construction, preparation, or sampling procedures. Filtration was and continues to be used to remove the particles causing this presumed artifact turbidity. In recent years, we have come to realize that in some subsurface systems, turbidity causing materials may actually be present in an aquifer as mobile colloidal species (see review by McCarthy and Zachara, 1989). Filtration of groundwater samples from these aquifers may remove both mobile colloids and artifact particles. If the mobile colloids are inherently hazardous (e.g., pathogenic bacteria, asbestos particles, precipitates of radioactive materials or toxic metals) or if significant quantities of contaminants sorb onto these mobile colloids, then it is important that samples analyzed to determine compliance, assess risks, and develop models include these, as well as, dissolved contaminant species. Removal of these mobile colloids from groundwater samples could lead to underestimation of contaminant concentrations and mobility, affecting determinations of both compliance and current risks. Failure to account for colloid- associated contaminants in

predictive models used for decision making could lead to serious errors in setting clean-up priorities and in designing cost effective remediation strategies.

Examination of the role of colloid-associated contaminants in subsurface systems requires an ability to distinguish between artifact particles and mobile colloids in groundwater samples. We have designed and tested a groundwater sampling system which avoids inclusion of artifact colloids/particles in samples and minimizes losses of mobile colloids and changes in colloid character during sample collection and storage (Backhus et al., 1993). This sampling system **(Figure 1)** incorporates slow prolonged pumping using a positive-displacement pump with a low sample contact surface area constructed of stainless steel and teflon (model SP-202, Fultz, Inc., Lewistown, PA). The pumping rate is controlled by a variable voltage AC-DC converter powered by a generator, allowing minimum steady pumping rates of about 100 mL/min to be maintained at most wells. An inflatable packer or packers are used to isolate the sampling zone. Groundwater from this sampling zone is pumped to the surface through a continuous piece of polypropylene (0.64 cm id) or aluminum (0.48 cm id) tubing. At the surface, groundwater flows directly into a flow-through monitoring cell to allow measurement of water chemistry parameters (pH, Eh, dissolved oxygen (DO), temperature, and specific conductance) during well purging. In addition, samples are obtained periodically during well purging to monitor turbidity. These samples are collected by overfilling and tightly capping a cuvette or vial and examined by using a submicron particle analyzer or turbidity meter. Once the well is deemed sufficiently purged, unfiltered groundwater samples for geochemistry and colloid analyses are collected in glass bottles designed to allow closure without inclusion of head space; therefore, they minimize the exchange of gases between the sample and the atmosphere during storage. Prior to sampling, these bottles are filled with argon. Samples are collected by inserting the sampling tube to the bottom of the bottle and overfilling the bottle (by at least half of its volume). Samples for specific contaminant analyses are collected in a similar manner in suitable sampling vessels (e.g., 40 mL glass vials or 4 L bottles). Additional groundwater colloid
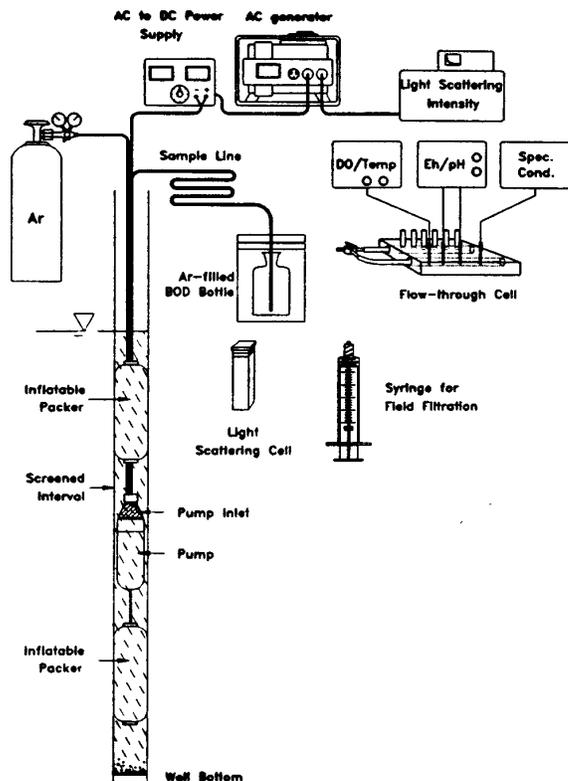
**Figure 1.  Sampling setup for collection of ground water from monitoring wells when colloids or colloid associated chemicals may be of importance.**

samples are collected by joining the end of the sampling tube to a 5 mL plastic syringe tip and allowing the plunger to be displaced backwards to rinse and then fill the syringe. The filled syringe is connected to a filter holder containing a 15 or 30 nm pore size Nuclepore polycarbonate membrane filter.  The sample is forced through the filter by pressure from weights (0.8 kg/cm2), then rinsed with 5 mL of distilled, deionized water, and placed in a covered petri plate in a desiccator to dry.

Samples collected as indicted above should provide accurate information about *in situ* groundwater geochemistry, mobile colloid concentrations, and total mobile contaminant loads, as well as, the characteristics of mobile colloids (e.g., size, morphology, and elemental composition from scanning electron microscopy/energy dispersive x-ray analysis of colloids caught on field filters).  This sampling scheme (1) minimizes collection of artifact particles sheared from aquifer materials by using slow pumping rates; (2) avoids precipitation of artifact colloids and changes in the character of mobile colloid by using flow-through sampling methods and sample storage in DO bottles which minimize changes in groundwater chemistry as the sample is brought to the

surface and sealed; (3) assures that prior to sampling, the well is sufficiently purged of artifact particles which may have been introduced during construction or formed due to atmospheric exposure via the well casing; and (4) minimizes losses of mobile colloids by avoiding filtration of ground-water samples.

Groundwater samples have been collected from numerous sites across the United States using this careful sampling scheme (Gschwend and Reynolds, 1987; Backhus and Gschwend, 1990; Gschwend et al., 1990; Ryan and Gschwend, 1990; Groher, 1990).  Collectively, the results of these studies provide information both about groundwater sampling and about the existence of mobile colloids in the subsurface.  Regarding sampling, similar results were found at most wells when groundwater turbidity was examined as a function of time or volume of water removed from the well.  Initially high turbidity level, decreased to a stable level after several hours of slow pumping (e.g., **Figure 2**). At "background"wells, turbidity levels approached those observed for distilled water blanks (e.g., **Figure 2**).  At contaminated wells (within a contaminant plume or where geochemistry was altered due to natural processes), turbidity
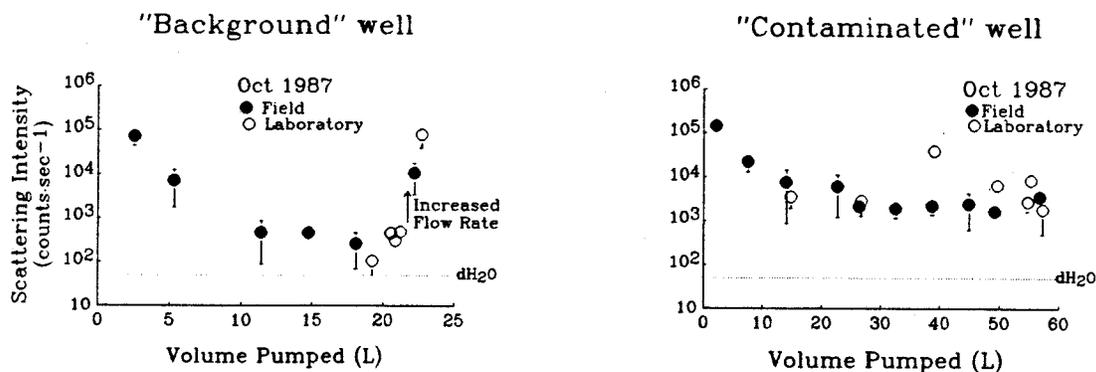
**Figure 2. Turbidity timecourses from wells at the Delaware Site.**

levels stabilized at significantly higher levels (e.g., **Figure 2**) indicating that mobile colloids may be present. When the timecourses of other monitored parameters were compared with turbidity, some parameters ($O_2$, pH, Eh) were generally found to stabilize before turbidity ($O_2$ vs turbidity in **Figure 3**). At some sites, a few parameters did not reach a stable level during well purging and sampling (e.g., total nonvolatile organic carbon, TOC and specific conductance, **Figure 3**). At the one site where we monitored contaminant concentrations as well as water chemistry parameters and turbidity, the timecourse for lower solubility contaminants (Pyrene, Chrysene, and Benzo (a) anthracene) were found to closely mimic the turbidity timecourse (**Figure 3**). Little variation was seen from the more soluble and more abundant contaminant naphthalene. These data suggest that turbidity may provide a better indication of required well purging times than other typically monitored parameters for the less soluble, possibly colloid-associated contaminants.

At a few sites, the effect of pumping rate on turbidity was examined. Turbidity initially increased with pumping rate (**Figure 2 and Figure 4**), but then decreased to a stable level again after pumping at the higher rate for a while (**Figure 4**). The stable level eventually achieved at the higher rate was not always the same as that observed at the slow rate ("Background" vs Contaminated well **Figure 4**). At the "Background" well, the stable turbidity level was higher at the increased flow rate, while at the contaminated well, the same stable turbidity level was reached at both pumping rates. Finally, comparison of bailed and slowly pumped groundwater samples indicate that the method chosen effects the results obtained (**Figure 4**). At the New York site, bailed samples contained 10 - 100 times greater colloid concentrations, and up to 750 times greater polycyclic aromatic hydrocarbon concentrations than were

detected in slowly pumped samples. The results of our sampling experiences indicate that both the parameter used to judge the adequacy of purging efforts prior to sampling and the sampling method (pumping rate, and pumping vs bailing) may effect geochemistry parameters and contaminant and colloid concentrations observed in groundwater samples.

Regarding the existence of mobile colloids in aquifers, at each of the sites where stable turbidity levels in Contaminated wells were significantly greater than levels found in "Background" wells, colloid size characteristics (size, composition, surface charge, stability) and groundwater geochemistry were examined to assess whether colloids collected in the samples were likely to be natural *in situ* colloids. Based on alteration of the regional geochemical conditions by the "contaminated" plume and expected colloid solubilities and surface charges, explanations have been surmised for the presence of mobile colloids at several of the sites sampled. At the Massachusetts, it is hypothesized that the changes in groundwater chemistry due to the influence of the plume of secondarily treated sewage lead to precipitation of colloids (Gschwend and Reynolds, 1987). At the New Jersey, Delaware (Ryan and Gschwend, 1990), and Nevada sites (Gschwend et al., 1990) it is hypothesized that changes in groundwater chemistry lead to dissolution of secondary mineral phases (iron oxyhydroxides or calcium carbonates) which had cemented colloidal material to the aquifer solids and consequently mobilization of colloidal material.

Results obtained at numerous sites using the careful groundwater sampling protocol described above indicate that mobile colloids do exist in the subsurface. However, there is insufficient information available, at this point, to
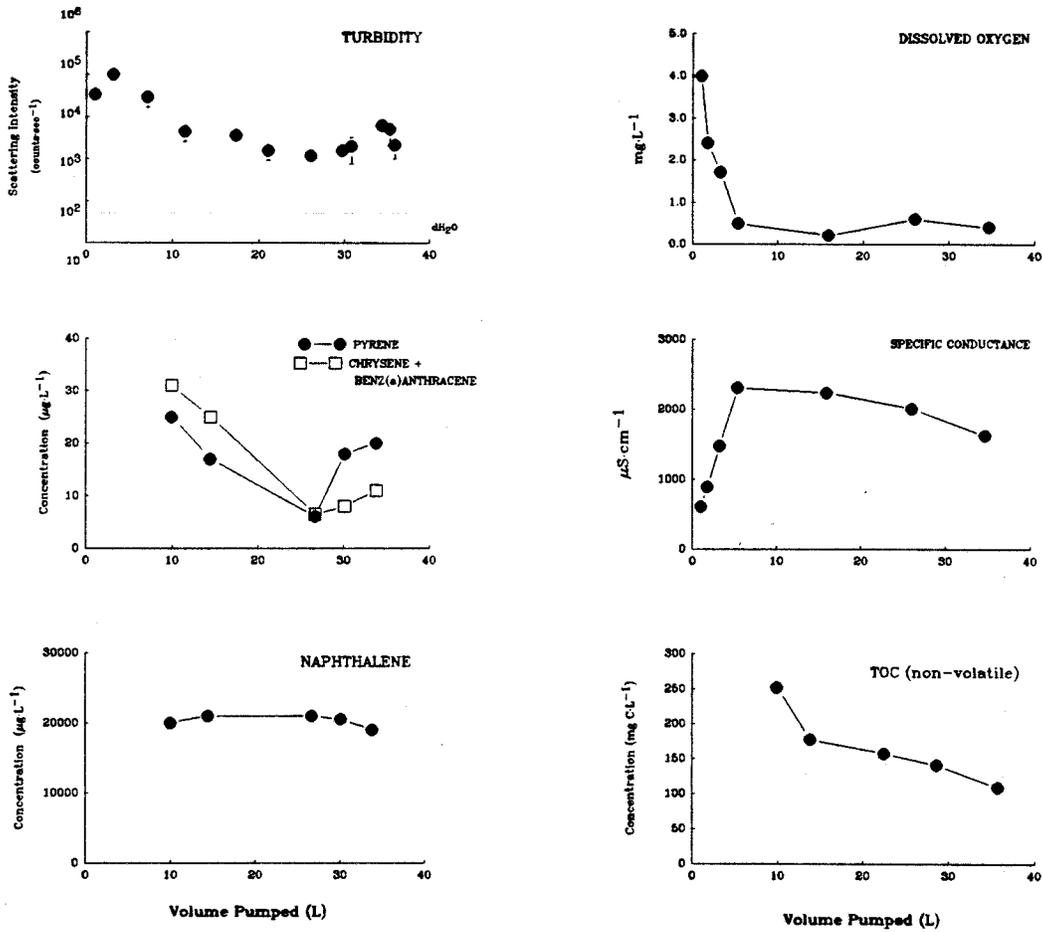
**Figure 3.** Monitored parameter timecourses from well D at the Connecticut Site.
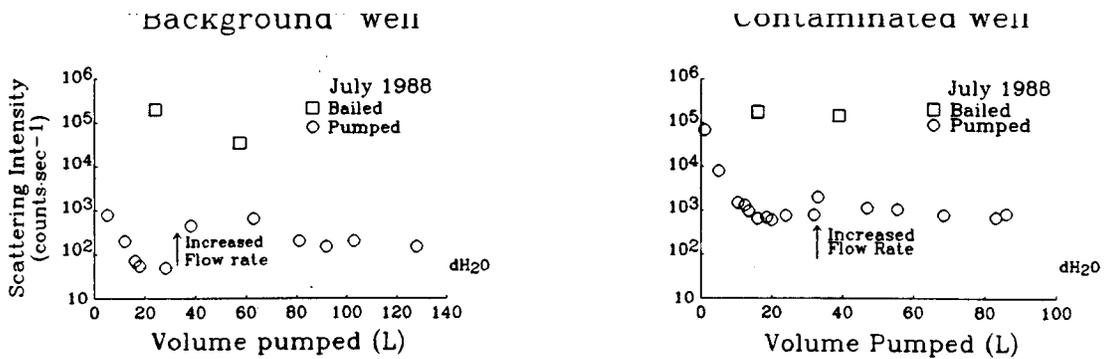


**Figure 4.** The effect of pumping rate and sampling method on observed turbidity, NY site.

judge the wide spread significance of mobile colloids. There is sufficient information to warrant continued examination of the role of mobile colloidal materials in the transport of subsurface contaminants. Examination of the role of colloids requires careful sampling methods which incorporate: slow prolonged pumping, monitoring turbidity during purging, maintaining *in situ* groundwater chemistry conditions throughout sampling and storage, avoiding filtration of samples which are used to assess colloid concentration and total mobile loads of contaminants, and collection of auxiliary data to confirm findings regarding the existence of mobile colloids. If no evidence supporting the existence of colloids and colloid-associated contaminants is found at a given site, then more practical sampling schemes may be instituted with comparable results.

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# NEED FOR PRACTICAL APPROACHES TO CONDUCT MULTILEVEL SAMPLING

## Gary A. Robbins

Robbins (1989), Robbins and Martin-Hayden (1991) and Martin-Hayden et al. (1991) have shown that vertical mass averaging in typical monitoring well results in water quality samples that ate influenced by well screen length, vertical concentration gradients, vertical variations in formation and backfill hydraulic conductivity, the amount of water removed for purging, and water levels achieved in a well during purging and when sampling. Because of vertical mass averaging, samples taken from wells can be highly misleading in terms of the absolute and relative abundances of water quality contituents. This in turn can lead to gross misinterpretations of contaminant distributions, transport properties, and physical, chemical and biological conditions and processes that influence overall water quality. It follows that efforts directed at obtaining representative samples from typical monitoring wells are futile. Mass averaging during well purging and sampling will result in a well-biased and non-representative sample irrespective of sampling method.

It should be kept in mind that monitoring wells were not designed to provide representative samples. They are simply an outgrowth of combining geotechnical engineering practice (i.e., the availability of hollow stem augers), everyday water well practice (i.e., constructing wells with casing and screens), and public health practice (i.e., collection of samples for standard laboratory analysis). That is, on a historical basis, monitoring well were not developed in consideration of the three-dimensional nature of groundwater flow and quality.

It is suggested here that research efforts be refocused on developing practical approaches for conducting multilevel sampling. Multilevel sampling issues requiring resolution include: methods for constructing multilevel sampling nests in hollow stem auger holes, methods for ground water sampling using direct push technologies, methods for collecting water quality samples during drilling, testing seals between samplers, defining the vertical spacing between samplers and their intake lengths, preventing intake clogging in fine grain formations, and sampling contituents exhibiting high vertical gradients. When dealing with non-aqueous phase liquids (NAPL), methods are needed for sampling mobile and residual NAPLs, and avoidance of cross contamination when samplers are constructed through zones of NAPL.

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# Effects of Well Design and Time of Pumping on Concentrations of Volatile Organic Compounds in Ground-Water Samples

**Jacob Gibs and Thomas E. Reilly**

Because a water sample collected from a well is an integration of water from different depths along the well screen, concentrations of analytes measured in the sample can be biased if analyte concentrations are not uniform along the length of the well screen. The concentration in the sample is a function of variations in well-screen inflow rate and analyte concentration with depth. These relations were investigated at a site with gasoline-contaminated groundwater in Galloway Township, Atlantic County, New Jersey. Numerical simulation of the integration of water along the well screen at this site and in a hypothetical system was used to determine the total mass of selected volatile organic compounds entering the screen by assuming a layered porous medium in which each layer is characterized by uniform hydraulic conductivity and chemical concentration.

A well screen with seven short screened intervals was designed and installed at two locations at the Galloway Township site. Independent samples were collected from the seven screened zones at each location. The sample concentrations from each screened zone were flow-rate weighted and integrated to simulate a sample concentration from a 5-foot-long, 2.375-inch-outside-diameter conventional wire-wound screen. The integrated volatile organic compound concentration was as little as 28 percent of the maximum concentration observed in samples from the multiscreened well.

Numerical simulation of the integration of water along the well screen at this site and in hypothetical heterogeneous ground-water systems also was used to investigate the temporal variation in water quality. Concentrations of constituents that are not uniformly distributed along the screened interval of the well can vary during purging and continued pumping after purging as a result of vertical variations in flow rate in the vicinity of the well screen. This variation in water quality with time also can be affected by well design characteristics, such as the use of a filter pack and screen length. Results of numerical simulations of flow associated with a hypothetical well design show that at a constant pumping rate the percentage of total flow into the screened zone at the ends of the screen that is derived from increases in vertical flow as screen length decreases or when a filter pack is used. Thus, a water sample collected from a well in which the screen length is short or a filter pack is used represents water from a vertical interval in the aquifer that is larger than the actual length of the well screen.

# COMMON SAMPLING AND ANALYTICAL PROCEDURES VIEWED IN THE CONTEXT OF DATA QUALITY NEEDS

## William R. Mabey and Nancy Barnes

The practice of sampling in the monitoring and investigation of groundwater quality has experienced significant advances in knowledge in the last decade. While some of the methods now in use were adapted from the water supply industry, many other methods reflect modifications that resulted from the recognition of shortcomings of some methods in obtaining water samples that provide reliable chemical data. Research has been vital in recognizing these shortcomings and developing better methods as well as increasing our knowledge of groundwater chemistry, hydrogeology, and remedial technologies. However, incorporating these changes as acceptable professional methods has been sometimes slow because of the precedence of existing data with the older methods, costs of equipment and training field personnel, and the lack of familiarity and the uncertainties with the newer methods.

Recognizing that groundwater data are collected for specific applications, it is appropriate to depart from historical precedence, policy, or preoccupations regarding uncertainties, and rather focus on the methods as they provide quality data. Quality data can be defined as those data that are fully described so that they may be intelligently used (Campbell and Mabey, 1985). This definition is consistent with the Data Quality Objectives (DQO) as set forth in USEPA guidance. In this DQO context, data are evaluated according to the criteria of accuracy, representativeness, comparability, completeness and precision. Clearly, data must have known qualities so that the data user can decide whether the data can be applied to the intended application.

The DQO objectives listed above are well-established in the evaluation of analytical chemical data. The accuracy and precision attainable for these data are measureable using stated procedures. The data validation process according to the Contract Laboratory Program (CLP) provide the basis for expression of the quality of analytical data, and where any qualifications on the data are valuably discussed in a summary report format. A review of the analytical procedures and CLP criteria shows that negative bias (that is, lower concentrations than actually present) is reasonably inherent in many methods because of losses during sample handling and analyses. While a complete discussion of analytical data quality is not the purpose of this paper, it is important to recognize that data acceptable in the CLP program may have losses of over 50% for some semi-volatile organic chemicals (Guide to Environmental Analytical Methods, 1992).

Appropriately, there is increasing concern for the quality of data from groundwater monitoring and investigation programs because of the way in which wells are constructed, developed, purged, and sampled (Puls and Powell, 1992). An evaluation of some procedures now in common use shows that the accuracy of resulting data should be of concern. In particular, some negative bias is often likely because of losses as a result of some groundwater purging and sampling procedures. As with other measurements, good precision (that is, repeatability) can be a misleading if accuracy is not also attained. It should also be recognized that databases can have the effect that the very qualities that contribute to a measured value can be lost, and data from the database then are inappropriate for comparison purposes.

It is ironic that the implementation of new sampling methods can be viewed as a "conflict" between the DQO criteria of comparability and representativeness. While the established methods have merits of familiarity and established use, research and other experience is showing that some methods may not give representative samples based on what can be shown or is reasonably of concern based on the newly gained scientific knowledge. However, attempts to develop methods that produce data more representative of our understanding of groundwater conditions are hampered by reasons presented in the opening paragraph. Often overlooked is the realization that some known bias in data may be acceptable for particular applications, and that having the most accurate or representative value may not be necessary.

One area where research has revealed a negative bias in metals data because of sampling practices is in the filtration of groundwater samples. Previously, turbid water samples were often filtered, usually with a 0.45 micron filter, to remove particulate materials from the water sample. The rationale was that the turbidity was an artifact of well

construction and sampling, and filtering provided a true dissolved concentration of analytes in the groundwater sample. However, when research and some field observations observed that colloidal material was mobile in some saturated zone systems, filtration was discouraged to avoid removing the collodial material (Puls and Barcelona, 1989). Thus, to remove a negative bias in metals concentrations, the sampling procedure has changed to possibly provide a positive bias in the data. As an alternative procedure, the low flow rate purging and sampling of a monitoring well has been employed to achieve low turbidity and more representative groundwater samples (Puls and Powell, 1992).

Several field sampling efforts by Montgomery Watson have attempted to evaluate the significance of sample turbidity on the concentrations of metals in groundwater samples. In one project in California, wells previously installed in another investigation study were found to have significant turbidity and high metals concentrations. These wells were purged at rates as low as 0.5 gallons/minute using a bladder pump until the temperature, electrical conductivity (EC) and turbidity parameters stabilized. Typically, turbidity was the last parameter to stabilize according to DQO criteria, and the times for stabilization ranged from one to seven hours, with purge volumes ranging from 15 to 365 gallons (15 to 40 casing volumes). The wells were then sampled first using the bladder pump, and then using a bailer. For each sampling procedure a water sample was filtered using a 0.45 micron filter so as to provide a comparison of the effect of filtration. Sampling with the bailer provided turbid samples (>200 NTU) and the bailed, unfiltered water samples typically showed two-fold higher concentrations of metals present (including barium, chromium, copper, zinc, etc) than the unfiltered water collected with a bladder pump (NTU values of 4 and 5) . However, the metal concentrations of the bailed, filtered samples were generally comparable to those of the filtered and unfiltered samples collected with the bladder pump (generally less than 10% difference) These data then provide empirical evidence that filtration can produce representative groundwater samples for some monitoring wells at this site. It is also of note that for several monitoring wells the iron concentrations in the filtered water samples collected with the pump were higher than the concentrations in the filtered, bailed water samples, a result that is rationalized by the aeration of the bailed sample, the subsequent oxidation of ferrous (iron) to the ferric state, and removal of the solid ferric oxide/hydroxide by filtration.

At another site, a Montgomery Watson sampling team collected groundwater samples over a several month period with varying pumping rates to develop an understanding of the metals concentrations as a function of turbidty. The total suspended solids (TSS) was also determined by the laboratory as a quantitative measure of the particulate

content of the samples. A log/log plot of TSS against the field-measured turbidity showed a roughly linear relationship. Plots of TSS against the concentrations of several metals also showed the expected relationship of higher concentrations at higher TSS values. This relationship was most notable for lead; however, when the lead concentrations were divided by the iron or aluminum concentrations the resulting ratios were roughly independent of the TSS values. If it is accepted that the iron and aluminum values are associated with their natural abundances in soils, it is also reasonable that the lead concentrations observed are also associated with the natural abundance of soil constituents. Such a normalization approach also has shown value in explaining high metal concentrations in water samples at other sites.

Measures to improve the quality of sampling data clearly are needed. The improvements may include improved sampling procedures or obtaining additional information to support the measured numbers. For example, measurement of redox potentials or other groundwater chemistry parameters are useful support the presence of reduction products such as vinyl chloride. Because of the time and equipment costs of the low flow rate purge/sample collection procedure, it also seems reasonable that empirical evidence of the comparability of the sample with that of a filtered water sample may be the basis for planning a monitoring program, where water samples may be filtered during three events in a quarterly monitoring program while using the low flow rate purge/sample collection procedure once a year as a quality assurance measure.

While procedures to document measurement performance have been developed for analytical data quality purposes, such general procedures are difficult to implement for some field sampling efforts because of the various sampling methods and the differing hydrogeologic conditions encountered. However, the quality of data would be substantially improved if a more formal documentation process for reporting well installation, development, purging and sampling were applied, with any limitations or crucial observations being reported and discussed in the text of the report. This information is critical for future sampling and evaluation of groundwater data where the qualities of the water samples should be compared before the analytical data are compared.

Finally, research observations or experience at unique sites needs to be put in the appropriate context rather than being put in general procedures that are incorporated in all applications. For example, calculations indicate that the contribution of a chemical sorbed on colloidal material to the total measured concentration of a chemical in a groundwater sample is likely to be negligible unless a large amount of collodial material is present, the chemicals of concern are detectable at very low concentrations, or they

are highly sorbed.  Such an understanding is important for collecting quality data in a cost effective sampling program.

In conclusion, it is important to recognize the qualities of the groundwater samples for the correct use of the data.  The selection of sampling procedures should be made with regard to the uses of the data and limitations of the data, and this information needs to be documented for data users adn for planning future sampling efforts.

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# CONSIDERATIONS IN SELECTING FILTERED OR UNFILTERED SAMPLES FOR ANALYSES OF METALS IN GROUNDWATER SAMPLES

## Dennis E. Reece

A basic problem in establishing uniform groundwater sampling procedures is that procedures that efficiently provide representative samples for an intended use at one site may not for others. The decision to use filtered or unfiltered samples for metals can depend on a number of site specific factors including:

- intended use of the data
- monitor well construction and conditions
- aquifer properties
- data quality objectives process (the data to be collected and the associated procedures should be developed to specifically make decisions or answer questions for making decisions)

Analysis of unfiltered samples containing suspended solids associated with well installation or sampling can result in high metal concentrations which are not representative of metal concentrations in the groundwater. Alternately, if metal contaminants are present in the form of mobile colloids, analysis of filtered samples may not identify the colloidal fraction of the contamination.

The intended use for the data to be collected is important. For detection monitoring the main concern is with consistently identifying the concentrations of mobile constituents present in the groundwater with adequate reproduceability to allow determination of whether the data indicate increases relative to site background conditions. Determining the mobile concentrations of constituents is often of primary concern during assessments and corrective actions. Determining total (dissolved and solid phase) concentrations present in a well is usually of prime concern for use of the data in human health risk assessment or for evaluating suitability of a well for use as a drinking water supply.

Well construction and development practices and aquifer properties influence the potential for significant well siltation and for potential presence of contaminants in mobile colloidal form.

The Data Quality Objectives process can be used on a site specific basis to select sampling procedures which are appropriate for the specific data uses and site conditions. There is considerable variability in the experience and technical knowledge among those involved in groundwater sampling. Complex sampling requirements are often not implemented appropriately. Cost of the procedures can also be an important factor in how well the sampling procedures are implemented. Selection of procedures for collecting suitable groundwater samples should consider the complexity and cost of implementation, and should be practical for a wide range of site conditions rather than ideal conditions. Required procedures should be implementable and enforceable.

The selection of filtered or unfiltered samples should be considered relative to two contradictory issues which may be present at a site: siltation of monitor wells and possible presence of contaminants in mobile colloidal form.

The severity of these problems is usually controlled by:

- well construction
- well development
- aquifer properties
- sampling procedures

Siltation is a widespread problem which can have drastic impacts on results for metals when unfiltered samples are analysed. It is an easily identifiable problem and is sometimes more easily addressed than the issue of whether mobile colloids are present. Siltation is often greatest in fine-grained low yield zones such as thin silty or clayey intervals which are often required to be monitored. If the sampling conditions result in high solids content or nonreproduceable solids content in samples, analysis of unfiltered samples for metals may result in useless data.

Siltation problems can often be mitigated at the well by proper selection of procedures for well design and construction, well development and sample collection. However, experience indicates that these are not always effective or practical for mitigating siltation.

Siltation problems (for metals analysis) may also be mitigated by sample pretreatment such as decanting, centrifuging, macrofiltration, microfiltration or analysis for both filtered and unfiltered samples. These methods, however, have limitations and pose a risk of introducing

contamination during pretreatment or of removing mobile colloidal material actually present in the groundwater, thus reducing the representativeness of the sample.

The issue of possible presence of mobile contaminants in colloidal form is a less easily identifiable problem. Relative to siltation, significant colloidal transport of contaminants is probably a much less widespread problem. The impacts on monitoring data are also probably less severe for most sites. Transport of contaminants in colloidal form may be of more concern in high yield aquifers than in low yield aquifers. Geochemical conditions in the aquifer matrix may also be a controlling factor in the potential importance of colloidal transport.

Colloidal material present in water samples may result from either artificial means related to well construction and sampling or from transport of colloidal material in the groundwater. Proper well design, construction, development and sampling procedures can reduce the artificial sources. Microfiltration of the samples may eliminate from the sample both undesired artificially introduced colloids and mobile colloids actually present in the groundwater. Analysis of unfiltered samples will include colloidal material, if any is present, but will provide representative data only if siltation does not result in artificially high suspended solids content.

Groundwater data from three sites were examined to illustrate the range of impact of siltation on metal results when unfiltered samples are analyzed for metals.

Site 1 is a landfill site at which waste had not yet been placed and at which there was no previous development or use of the site. Four quarters of background monitoring had been completed on unfiltered samples. The monitoring system included five monitor well pairs. Each pair included a monitor well completed in a shallow clayey unit and a second monitor well completed in a deeper sand unit. The wells were reportedly sampled using nondedicated peristaltic or bladder pumps. Turbidity values for the samples indicated relatively high and variable suspended solids content in the shallow monitor wells in the clay unit. Mean turbidity values for these wells varied from <100 to 7,000 ntu. Values for four of the sand unit wells were much lower and less variable. Mean turbidity values for these wells ranged from 15 to 25 ntu. One of the sand unit wells exhibited higher turbidity values which were suspected to have resulted from well construction or development procedures. The high turbidity of the shallow clay unit wells resulted in high and variable concentrations of some metals for the unfiltered samples (in particular arsenic, beryllium, cobalt, copper, nickel, chromium and zinc). Relatively high correlations were observed between turbidity values and metal concentrations for the shallow

clayey unit wells. Metal concentrations were highly variable from quarter to quarter for each shallow clayey unit well and among different wells due to variability of suspended solids content. Analysis of the unfiltered samples limited usefulness of intrawell or interwell statistical comparison tests. Total dissolved solids values, by contrast with turbidity values, were relatively constant from quarter to quarter indicating that dissolved concentrations were relatively constant. Further evaluation of the data did not indicate that contamination was present at the site.

Site 2 was a site at which monitor wells were completed in a relatively thick high yield sand and gravel aquifer. Twenty-one wells were sampled using high yield dedicated pumps. Both filtered (0.45 micron) and unfiltered samples were collected and analyzed for thirteen metals. Turbidity was low for all samples. Comparison of the results did not indicate that filtering the samples lowered the concentrations of metals.

Groundwater samples were collected at Site 3 from soil borings using downhole tools without installation of monitor wells. Sampling conditions at this site approximated a worst case condition with respect to siltation. All samples were very turbid and contained very high suspended solids content. Comparison of results of analyses for 23 metals for filtered (0.45 micron) and unfiltered samples indicated markedly higher concentrations in the unfiltered samples for all 23 metals except selenium and thallium.

# A STUDY OF THE IMPACT OF MONITORING WELL PURGING AND FILTERING TECHNIQUES ON METALS CONCENTRATIONS IN GROUNDWATER SAMPLES FROM THE AUBURN ROAD LANDFILL SITE IN LONDONDERRY, N.H.

## Carol White

### Introduction

A study of the impact of various sampling techniques on metals concentrations, in particular iron and arsenic, was conducted as part of a larger remedial investigation at the Auburn Road Landfill Site in Londonderry, N.H. A major objective of the remedial investigation was the development of a detailed understanding of the site geochemistry. Collection of samples representative of the in-situ groundwater chemistry was essential to the success of the study. At the suggestion of EPA, a low flow-rate purging and sampling method was employed to collect groundwater samples from monitoring wells at the site.

### Site Description

The Auburn Road Landfill Site is a Superfund site located in southeastern New Hampshire in the Town of Londonderry. Municipal and industrial wastes were disposed in three separate landfills at the site. Contaminants present in the groundwater at the site as a result of these disposal activities include low levels several organic compounds: 2-butanone, trichloroethane, tetrachloroethane, benzene and toluene, and arsenic. The site consists of glacial outwash sands overlying moderately fractured metamorphic bedrock. Over 150 monitoring wells have been installed at the site vicinity. The majority of the wells are constructed of 2-inch diameter polyvinylchloride screen and riser; screen lengths generally range from 1 to 15 feet in length.

### Sampling Methods

Prior to sample collection, all monitoring wells were purged using either a peristaltic pump with dedicated tubing, or a bladder pump. Where possible, dedicated tubing was installed in each monitoring to mid-screen level several days or weeks prior to sampling. This enabled the purging to be conducted with minimal disturbance of the water column. In general, purging rates ranged from 0.2 to 0.3 l/min. During purging a flow-through cell equipped with pH, Eh, specific conductance, dissolved oxygen and temperature sensors was used to obtain in-line measurements. An turbidimeter with a separate in-line flow-through cell was utilized for turbidity measurements. Purging was considered complete when turbidity measurements had stabilized (± 10%). Initially, during the 1991 sampling program, a minimum 2.5 well volumes were purged prior to sampling. After a few sampling rounds it became clear that generaly the in-line measurements stabilized within one well volume or less, and the minimal well volume criteria was dropped. All field measurements, purging volumes and other pertinent sample data were recorded for each well during the sampling episode.

### Results and Discussion

#### *Low-flow Purge Rate: Filtered vs. Unfiltered Samples*

In 1991, the low-flow rate sampling methodology was used to collect groundwater samples from 52 of the existing monitoring wells at the site. Both filtered and unfiltered samples were collected for iron and arsenic analysis. Pre-washed, disposable 0.45 micron filters were used to collect the filtered groundwater samples from the pump discharge. As shown on Figure 1, samples collected from wells included in this study showed an excellent correlation between filtered and unfiltered arsenic concentrations. Filtered and unfiltered iron concentrations were also well correlated, except near the method detection limits.

#### *Low-flow Rate Unfiltered vs. High-flow Rate Filtered Samples*

In 1992, a comparison of the unfiltered samples collected at a low-flow purge rate (0.2 to 0.3 l/min) versus filtered samples collected at a high-flow purge rate (≥ 0.5 l/min) was conducted. A comparison of the sample results for iron and arsenic are presented on Figure 2. In all cases, the filtered samples obtained with high-flow rate method yielded higher iron and arsenic concentrations than the unfiltered, low-flow rate samples. These data suggest that the high-flow rate sampling method may in fact mobilize particles that can pass through a 0.45 micron filter resulting in elevated metals concentrations. These results also suggest
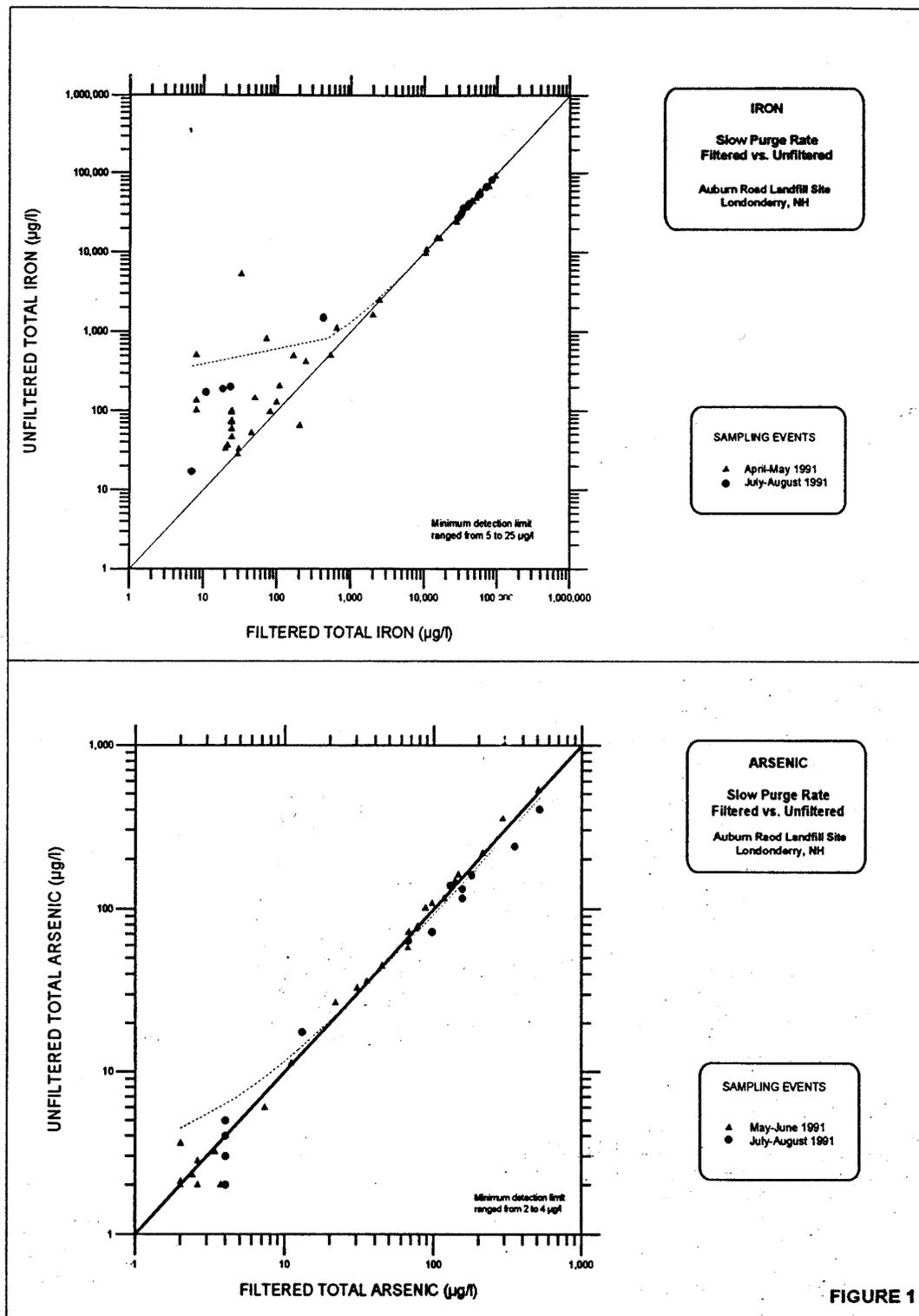
**Figure 1. Correlations between filtered and unfiltered iron (top) and arsenic (bottom).**

**IRON**
Auburn Road Landfill Site
Londonderry, NH

CONCENTRATION (ppb)

Filtered, Slow Purge, May '91
Unfiltered, Slow Purge, May '91

Filtered, Fast Purge, Dec. 1992
Unfiltered, Slow Purge, Dec 1992

**ARSENIC**
Auburn Road Landfill Site
Londonderry, NH

CONCENTRATION (ppb)

Filtered, Slow Purge, May '91
Unfiltered, Slow Purge, May '91

Filtered, Fast Purge, Dec. 1992
Unfiltered, Slow Purge, Dec 1992

FIGURE 2

49
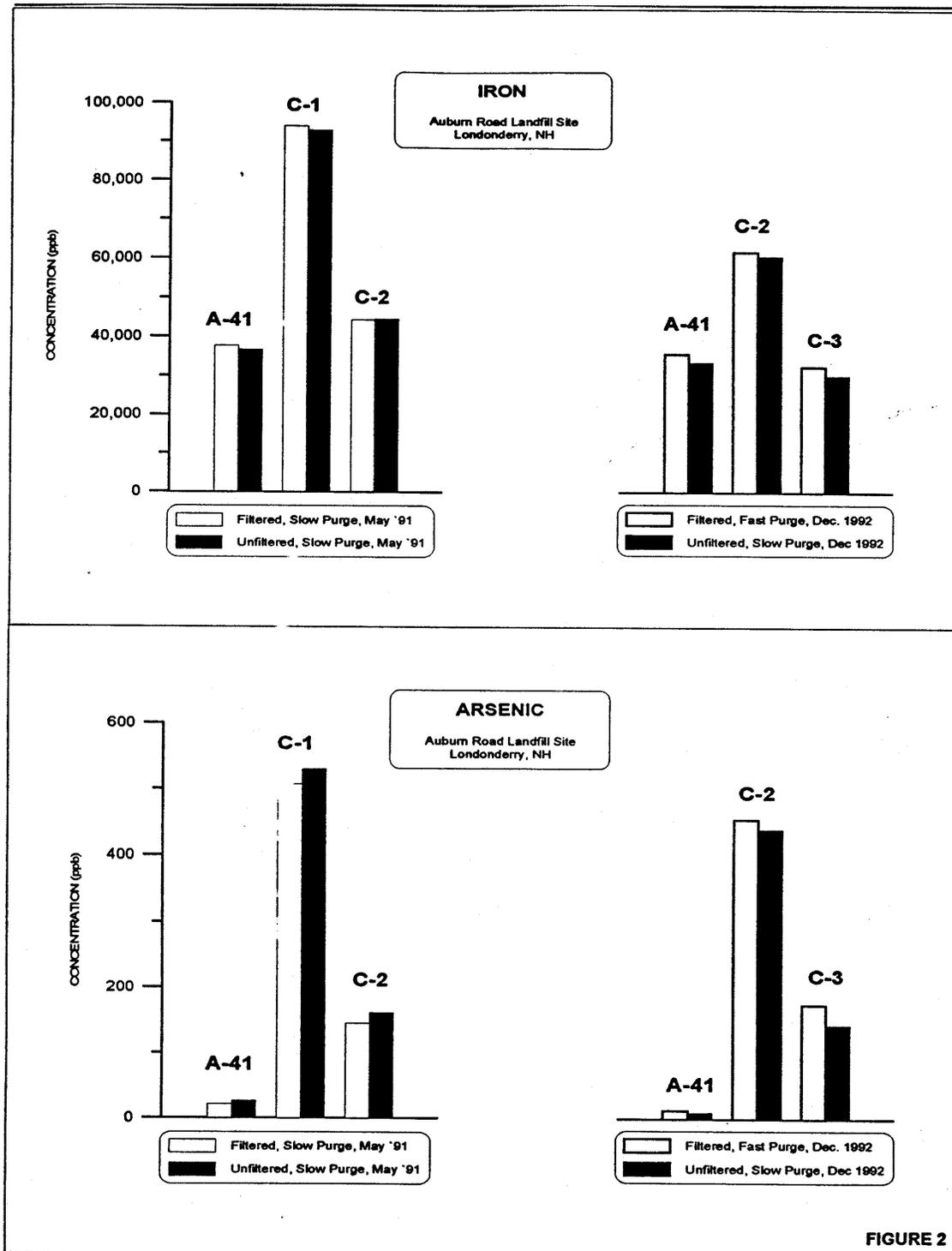
Figure 2.  Comparison of filtered vs. unfiltered, slow purge and filtered, fast purge unfiltered, slow purge in different wells for iron (top) and arsenic (bottom).

that the data obtained with the low-flow rate sampling method are more representative of the in-situ ground water chemistry.

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# GROUNDWATER SAMPLING IN FRACTURED CLAY AND ROCK

**Larry D. McKay, Kent Novakowski, and John F. McCarthy**

### Introduction

Deposits of fractured clay and rock are widespread and many contaminated sites are located in such materials. Groundwater flow and contaminant migration in these materials are controlled by different factors than in granular media and sampling/monitoring programs must reflect these differences if they are to be effective.

### Hydraulic Properties of Fractured Media

In a fractured porous medium, flow is largely controlled by the distribution, orientation, length and aperture of fractures or joints. In many materials flow through the blocks of "matrix" between the fractures is much less than through the fractures. Measurements of hydraulic conductivity are largely dependent on how many hydraulically-conductive fractures are intersected by the measurement zone (typically in a borehole). As a result, measured values can vary greatly and often depend on the length and orientation of the measurement zone. Not all fractures are hydraulically-conductive and at some sites investigators have found that a few large aperture fractures may dominate an entire flow system. One of the most critical parameters governing flow, aperture, cannot be directly measured and is almost always inferred from hydraulic or solute transport data, usually using the "cubic law" (Snow, 1970). Hence there is always a large degree of uncertainty associated with fracture aperture values. The fracture porosity of a deposit generally represents only a small fraction ($10^{-2}$ to $10^{-5}$) of the total volume of a deposit and is often much less than the intergranular porosity of the deposit (<0.01 to 0.7).

### Case Study - Borehole Flow Meter Survey at Oak Ridge Reservation

Recent borehole flow meter surveys at the Oak Ridge Reservation in Tennessee (Will, et al., 1992) illustrate some of the problems encountered in fractured media. Based on drilling records, core samples and geophysical/downhole-camera surveys of a 405 foot deep borehole, CH-9, it appeared that the shales at this site were highly fractured with typical fracture spacings of a few inches to a few feet. However, an electromagnetic flow meter survey under ambient conditions (no pumping) indicated that flow was restricted to two narrow zones at 135 and 330 foot depth. Flow was found to enter the deeper zone, then flow up the

well bore and exit into the shallow fracture zone with a flow rate of up to 0.2 gpm or about 700 gal per day. This presents several potential problems: possible mixing of contaminated and uncontaminated waters; and if you don't have a flow meter and the well is to be completed with a multilevel sampler to prevent uphole flow, how do you decide where to put the sampling zones?

### Contaminant Transport in Fractured Porous Media

The transport of contaminants through fractured p.m. is highly dependent on the physical properties of the contaminants with solutes, colloids and immiscible phase liquids behaving in radically different manners. Solute transport is strongly influenced by matrix diffusion, which is the transfer of solute mass from the zone of rapid flow within the fractures into the relatively immobile pore water in the blocks of matrix between fractures. Recent field experiments (McKay et al., 1993) and model simulations (ex: Sudicky & McLaren, 1992) have shown that matrix diffusion is sufficient to retard migration of a non-reactive solute by several orders of magnitude or more relative to fracture flow velocities in fractured high porosity sediments. Although we expect to see the greatest retardation in high porosity clays and shales recent experiments (Birgersson & Neretieks, 1990) indicate that this can be significant even in granitic rock.

Colloidal contaminants, because of their larger diameters, are not as strongly influenced by matrix diffusion and can actually migrate faster than non-reactive solutes (McKay et al., 1993). Immiscible phase contaminants, particularly DNAPL's (dense non-aqueous phase liquids) are also not strongly influenced by matrix diffusion and can move rapidly downwards through fracture systems with movement controlled by the density and viscosity/interfacial tension properties of the fluid, and the size of fracture apertures (or openings). The residual DNAPL, which coats the fracture walls, may then be slowly dissolved and transported away by the flowing groundwater or may diffuse directly into the matrix pore water (Keuper & McWhorter, 1991).

### Implications for Groundwater Monitoring

Some common problems which are expected in fractured media include:

- contaminant plumes which are very irregular in shape and relative concentration (due to variations in the distribution of hydraulically-conductive fractures),
- difficulty in distinguishing which fractures are contributing to flow in a borehole and hence difficult to determine where the contaminants are coming from.
- potential for ambient flow along the borehole, resulting in mixing or (even worse) spreading of contaminants into previously uncontaminated zones
- problems with sample dilution due to large volume of sampling interval in conventional boreholes/wells (Novakowski, 1992).
- purging prior to sampling may draw in water from a large volume of the deposit (because of the very low fracture porosity) and this water may not be representative of what was initially in the fractures and is likely not in equilibrium with pore water in the matrix adjacent to the fractures. For example a 10 litre water sample taken from a well in a rock with a fracture porosity of $10^{-4}$ could draw water from up to 100 m$^3$ of the rock.

## Improvement of Monitoring and Sampling Methods

Monitoring and sampling methods should be evaluated on a site-specific basis with respect to both the properties of the fractured media and to the type of contaminant. Possible improvements for existing wells could include:

- use of downhole methods including flow meter logs, temp. logs and conductivity logs to identify location of hydraulically-conductive fracture zones.
- installation of packers or seals to minimize borehole storage volumes and to prevent flow along the borehole
- sampling using minimal purging

New monitoring programs could include

- angled or horizontal boreholes to increase the probability of intersecting vertical fractures (where needed)
- use of monitoring wells designed to minimize storage volume and prevent flow along the borehole (examples: Westbay system, Waterloo multi-level)
- sampling of matrix pore water directly from core samples. In clays a variety of methods have been developed including: leaching with de-mineralized water, squeezing out pore water in high pressure cells, displacement with toluene, and finally direct measurement of vapour phase contaminants in small holes drilled into the core sample.
- measurement of contaminant concentrations along streams to identify specific fracture discharge zones (Clapp et al., 1992)

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# EVALUATION OF FIELD-FILTRATION VARIABLES FOR REPRESENTATIVE SAMPLES OF TRACE METALS IN GROUND WATER

**Karl F. Pohlmann , Gary A. Icopini and Charlita G. Rosal**

## Abstract

Selected ground-water sampling and field-filtration methods were evaluated to determine their effects on trace metal concentrations in ground-water samples. The study focused on conditions where traditional approaches may produce samples with high particle concentrations and concomitant elevated metals concentrations. These samples are often filtered to remove suspended particles before laboratory chemical analysis; however, filtration may also remove colloidal particles that may be important to the transport of trace metals. Two filtration variables were evaluated in this study: (1) collecting samples without filtration, and (2) filtering samples with 0.45-µm pore size filters. Samples were collected with a bailer, a submersible pump at a "low" rate of 0.3 L/min, and a submersible pump at a "moderate" rate of 1.0 L/min. Pump discharge rates were controlled by pump speed rather than by flow restrictors or valves.

The results showed that some sampling methods entrained large quantities of particles greater than 0.45 µm in size. The quantities and sizes of these particles suggested that they were not mobile in ground water under natural flow conditions but were primarily artifacts of well construction, development, and purging. Analysis of unfiltered samples containing high concentrations of these artifactual particles and associated metals resulted in metal concentrations that were often orders-of-magnitude higher than in corresponding 0.45-µm-filtered samples. This effect was most consistent and pronounced in bailed samples, because operation of the bailer caused the greatest agitation in the sampling zone. The use of pumps at low to moderate rates resulted in minimal concentration differences between unfiltered and 0.45-µm-filtered samples in all but the most turbid wells, and reflected the entrainment of only minor amounts of artifactual particles larger than 0.45 µm in size. The three sample collection methods produced similar results when samples from less turbid wells were filtered, however, the pumping methods produced the most consistent overall results. Little variation was evident between filtered and unfiltered pumped samples, reflecting minimal agitation in the sampling zone and sample during purging and sample collection. Use of submersible pumps at low speeds may reduce the uncertainty in results when collecting samples of inorganic ground-water constituents that have the potential to associate with particles in ground water.

## Introduction

Ground-water samples are commonly field-filtered to remove sediments mobilized during well construction and sampling because inclusion of these particles may bias analytical determinations, leading to elevated and erroneous concentrations of mobile contaminants (Puls et al., 1991; Backhus et al., 1993). However, indiscriminant field filtration using 0.45-µm filters ignores the presence of colloidal particles in ground water that may exist between the extremes of solutes and sediments. The small size of colloids facilitates their mobility in certain ground-water systems and provides them with high ratios of surface area to mass, which increases their relative sorptive capabilities (McDowell-Boyer et al., 1986). The association of metals with colloids has been shown to provide a potentially important mechanism for transport of these metals in ground water (McCarthy and Zachara, 1989).

Routine filtration of ground-water samples may have particularly important implications for metal determinations when metals are associated with particles larger than the filter pore size and/or when turbid samples are collected. Turbid samples may result when bailers or submersible pumps operated at moderate to high discharge rates (greater than 1 L/min) are used in inadequately designed, constructed, or developed wells, or wells completed in formations containing fine-grained sediments. Collecting samples at rates that approach natural ground-water advective flow velocities may minimize disturbance in the sampling zone, reduce entrainment of normally immobile species, and thereby alleviate the need to filter samples. This approach to sampling has been advocated by several researchers, with maximum suggested pumping rates of 100 to 300 mL/min (Ryan and Gschwend, 1990; Puls et al., 1990; Backhus et al., 1993).

The U.S. Environmental Protection Agency (EPA) is interested in the implications of field-filtration on metal

concentrations in ground-water samples. This paper summarizes some of the results of a field study addressing this issue (the work presented here is fully described in Pohlmann et al., 1994). The objectives of the study were to (1) evaluate the impacts on trace-metal concentrations of filtration with 0.45-μm pore size filters versus not filtering; and (2) investigate the effects of interactions between field filtration and other sampling variables including sampling device, pumping rate, and well turbidity. The study focused on sampling in conventional standpipe monitoring wells under conditions where traditional approaches to sampling may produce turbid samples. Three field sites were visited: an active municipal solid waste landfill in Wisconsin, a closed solid waste landfill in Washington, and a site contaminated by industrial waste in Nevada.

## Methods and Materials

The monitoring wells sampled in this study were constructed of polyvinyl chloride, and were 5.1 cm in diameter, with the exception of one 10.2 cm diameter well. The top of the well screens ranged from 2 to 19 m below ground surface, with well screen lengths of 0.6 to 6.0 m. The static water level ranged from 1 to 14 m below ground surface. Volumes of water within the well screens ranged from 1.2 to 50 L.

The results of three sample collection methods will be described in this paper. The first method used a dual check valve bailer with a volume of approximately 0.4 L. Samples were transferred from the bailer directly to sample bottles for unfiltered samples or to a filtration vessel for filtered samples. Compressed nitrogen gas was used to drive the samples through either membrane filters or disposable cartridge filters. The second sampling method was a submersible centrifugal pump (CP) operated at an appropriate speed to produce a flow rate at the surface of approximately 300 mL/min. Filtration was conducted on-line with disposable cartridge filters. The third method was a bladder pump (BP) operated at an appropriate speed and pressure to produce a flow rate at the surface of approximately 1 L/min. Filtration was conducted in the same manner as for the centrifugal pump. The pumps and bailer were positioned to collect samples from about 0.6 m below the top of the well screen.

Measurements of turbidity, dissolved oxygen (DO), temperature, electrical conductivity (EC), and pH of the pump discharge were made on-line, while measurements of these parameters for the bailer discharge were made off-line. Stabilization of these parameters provided an indication of equilibrium between incoming ground water, the action of the sampler, and stagnant water in the well; thereby suggesting that purging was complete. The relative values of these parameters also provided a means for comparing the sampling methods with respect to their ability to minimize

disturbance in the sampling zone. Estimates of particle size distribution were determined gravimetrically by serial ultrafiltration using microfilters of 5.0 μm, 0.4 μm, 0.1 μm, and 0.03 μm pore size.

## Results and Discussion

The relative disturbance in the sampling zone caused by a sampling method was most evident in the field measurements of turbidity and DO, particularly under low well-yield conditions. When the discharge rate exceeded the well yield, the increasing hydraulic gradient between the formation and the well mobilized large quantities of particles, thereby elevating turbidity values. Continued removal of water from the well dewatered the filter pack, leading to gravity drainage of pore water and sediments and continually increasing turbidity values. Bailer turbidity values were further elevated by the surging action of the bailer which mobilized large quantities of particles in the well. Elevated DO values of the bailer and BP at 1 L/min in low-yield wells reflect the formation of a large air-water interface which increased the potential for oxygenation of incoming ground water as the filter pack was dewatered. The bailer caused additional aeration of the samples as a result of the increased exposure to the atmosphere during sample collection and transfer. The lower discharge rate of 0.3 L/min, which was generally closer to the well yield, resulted in less variability and more representative values of turbidity and DO, as well as lower purge volumes.

Somewhat less variable results were observed between sampling methods in wells where the purging and sampling rate did not exceed the well yield. Under these conditions, hydraulic gradients into the well were minimal, the filter pack was not dewatered, and turbidity was generally lower. The two pumping methods produced similar values of most field measurements, while the surging action of the bailer produced turbidity values that were approximately two orders of magnitude higher than those produced by the pumps. Likewise, DO values in bailed samples were elevated with respect to the pumped values, an artifact of the bailing process. As a result, the pumps produced equilibrium DO and turbidity conditions with relatively low purge volumes, while the bailer produced high values of these parameters and did not reach equilibrium after greater purge volumes.

In almost every case, samples collected by bailer contained higher particle concentrations than those collected by the pumps, with the greatest differences occurring at the most turbid wells. Furthermore, the size distribution of particles in most bailed samples was highly skewed toward larger particles, with over 96 percent larger than 0.45 μm, and generally over 93 percent larger than 5.0 μm. The quantities and sizes of these particles suggest that they were not mobile in ground water under natural flow conditions but

were primarily the artifacts of well construction, development, and purging and were mobilized by agitation in the sampling zone caused by bailing. The particle size distribution in samples pumped from the most turbid wells (the low-yield wells) were also skewed toward larger particles, but total particle concentrations were much lower than in the bailed samples. In the less turbid (high-yield) wells, total particle concentrations in pumped samples were orders-of-magnitude lower than in bailed samples, reflecting the lower degree of agitation caused by the pumping methods. Also, particle sizes in the pumped samples were generally more uniformly distributed; approximately 50 percent of the particles were larger than 0.45 μm.

Differences in metal concentrations between filtered and unfiltered samples were most evident in low-yield and highly turbid wells, particularly when the samples were collected by bailer. In fact, several metals present in unfiltered bailed samples were below detection levels in the corresponding filtered samples. The large differences in concentration between filtered and unfiltered bailed samples reflect the association of metals with the high concentrations of artifactual particles entrained during bailing. For example, iron in the sampling zone likely existed as iron hydroxide particles, particles containing elemental iron, and ferrous iron sorbed to particle surfaces. Removal of the majority of particles during filtration therefore greatly reduced iron concentrations in the filtered samples. Other metals likely existed as aqueous species sorbed to particle surfaces, or as elemental components of particles originating as aquifer solids, and their concentrations were similarly reduced by filtration. Additionally, ferrous iron may have oxidized and precipitated during bailing, transfer, and filtering of the samples, and then removed during filtration. Finally, the formation of a thick filter cake during filtration of bailed samples likely reduced the effective pore size of the filter membrane, thereby blocking passage of some particles smaller than 0.45 μm; this would further reduce the concentrations of associated metals in the sample.

Trace metal concentrations in unfiltered samples pumped from low-yield and highly turbid wells were generally lower than in unfiltered samples bailed from the same wells. This reflects the lower degree of agitation associated with pumping and, as a result, the lower artifactual particle concentrations. Removal of the larger particles in the pumped samples did, however, cause filtered samples to contain lower metal concentrations than unfiltered samples, though the differences in concentration were much lower than in bailed samples. Unfiltered metal concentrations in samples pumped at 1 L/min were often slightly higher than in samples pumped at 0.3 L/min, but the concentrations in the filtered samples from both pumps were essentially the same. Furthermore, metal concentrations in filtered pumped samples did not differ significantly from those in filtered bailed samples.

In less turbid and high-yield wells, unfiltered bailed samples usually contained the highest metal concentrations of all samples, but the differences between these concentrations and concentrations in filtered samples were much smaller than for low-yield and turbid wells. Several metals showed only slight differences between filtered and unfiltered results in bailed samples. These results reflect the lower proportion of artifactual particles removed during filtration as compared to the low-yield and turbid wells, but also are related to metal speciation at each well. Differences between filtered and unfiltered pumped samples were minimal, and the concentrations were essentially the same as those in the filtered bailed samples, despite the variability in proportion of particles smaller than 0.45 μm. This suggests that many metals existed primarily as dissolved species and/or were associated with particles smaller than 0.45 μm in the less turbid and high-yield wells included in this study.

**Conclusions**

The effects of field filtration on trace metal concentrations were most evident when a bailer was used to sample low-yield and/or turbid wells. Concentrations in unfiltered bailed samples were up to several orders-of-magnitude higher than in filtered bailed, filtered pumped, and unfiltered pumped samples. Elevated metal concentrations in unfiltered bailed samples reflected the entrainment of large quantities of normally immobile artifactual particles and their associated matrix metals, and unknown quantities of contaminant metals. Pumping at low to moderate rates in low-yield and/or turbid wells resulted in less agitation in the sampling zone, lower particle concentrations, and reduced effects of field filtration on metal concentrations.

The effects of field filtration were the least evident in high-yield wells and/or wells having lower turbidity. Samples bailed from these wells exhibited much smaller differences between unfiltered and 0.45-μm-filtered samples. However, bailing clearly mobilized artifactual particles that caused elevated metal concentrations in most unfiltered bailed samples. In contrast, samples pumped from these wells exhibited virtually no differences between unfiltered and filtered samples, reflecting the minimal entrainment of artifactual particles larger than 0.45 μm during sampling at low to moderate pumping rates. Concentrations in filtered samples bailed from high-yield wells and/or from wells having lower turbidity were generally equivalent to concentrations in pumped samples. This reflects the removal of larger, normally immobile artifactual particles and associated metals from the bailed samples.

Although the three sample-collection methods generally produced similar results when samples from less turbid wells were filtered, the pumping methods produced the most consistent overall results. Most metals showed little variation between filtered and unfiltered pumped samples,

reflecting the minimal agitation in the sampling zone and sample during purging and sample collection. Use of submersible pumps at low speeds may reduce the uncertainty in results when collecting samples of inorganic ground-water constituents that have the potential to associate with particles in ground water.

**Notice**

The U.S. EPA, through its Office of Research and Development (ORD), prepared this extended abstract for a workshop presentation and proceedings. It does not necessarily reflect the views of the EPA or ORD.

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# MONITORING WELL SAMPLING - YOU CAN'T ALWAYS GET WHAT YOU WANT BUT CAN YOU GET WHAT YOU NEED?

## Jack Connelly

### Introduction

In 1985, Wisconsin was one of the first states to develop guidelines for installing monitoring wells, and in 1990 we became the only state to develop comprehensive rules for monitoring well installation and development. Wisconsin's monitoring well installation rule includes many requirements to ensure that the water produced from a monitoring well is representative of groundwater. Wisconsin also recognized the need for consistent sampling procedures, so in 1987 we developed Groundwater Sampling Procedures Guidelines that we require landfill owners and consultants to follow. We are proud of both our sampling procedures guidelines and our monitoring well installation rule, and these documents are in demand by many states' researchers and regulators. The guidelines require field filtering of groundwater samples collected for inorganic analysis. This requirement is based upon our 15+ years of infield sampling experience and the geology of our state. Therefore, when the final Subtitle D criteria were published, we were shocked that EPA had banned the use of field filtering. We were especially surprised that such a rigid policy would be included in an otherwise flexible rule.

We surveyed those sampling Wisconsin landfills to investigate the impact of changing our sampling requirements. The results from 305 respondents (see Appendix I for complete results) show that:

1. 80 percent of the samplers use a bailer to purge their wells,
2. 89 percent use a bailer to retrieve samples from the wells,
3. over 55 percent of the sampled wells are turbid.

Many of the landfill monitoring wells in Wisconsin are turbid because we encourage locating landfills in fine-grained soils to limit contaminant migration. Wells screened in tight soils often do not clear up during development, and if bailed samples are not filtered, metals results are erroneously high, variable and misleading. Table 1 lists results from an upgradient unimpacted well at a foundry landfill. We typically see very high metals values in unfiltered samples ("Bailer Unfiltered" results) that also vary from one sampling period to the next. The variability

and elevated metals results are caused by well turbidity, not by groundwater contamination. Columns C and D in Table 1 more accurately represent groundwater quality. Many such sites with turbid wells would be required to perform Assessment Monitoring under Subtitle D because of falsely elevated metals values.

The impact of banning field filtering in Wisconsin would be significant. Wisconsin has 15 to 20 years of data based on filtered samples. We have detected contamination and taken action at many sites relying primarily on this method. To determine which sites to investigate we do not rely on unfiltered turbid samples that produce falsely elevated metals values but instead rely on VOCs and trends in non-metallic inorganic parameters.

**Table 1. Metals Concentrations ($\mu$g/L) from Unimpacted Well at Foundry Site**

|  | A<br>MCL | B<br>Bailer<br>Unfiltered | C<br>Bailer<br>Filtered | D<br>Low Flow<br>Unfiltered |
|---|---|---|---|---|
| Arsenic | 50 | 120 | <2 | <1 |
| Cadmium | 5 | 9.2 | <0.5 | 0.29 |
| Chromium | 100 | 450 | <2 | 1.2 |
| Lead | 15 | 320 | <5 | <1 |

Recent advances in monitoring technology have produced the relatively new low-flow pumping technique (LFPT), improving the quality of unfiltered samples, and recent experience shows that the LFPT for purging and sampling can produce reliable samples. After review of the articles referenced in the Subtitle D criteria as background to this issue, we agree that colloidal material may indeed move through some aquifers. Since contaminants may be adsorbed on colloids, the filtering of groundwater samples

could remove one source of contamination.  However, as illustrated in the data from columns C and D of Table 1, the significance of the colloidal source is unclear.  Few studies have actually compared results from contaminated samples that have been bailed and filtered with results from samples collected using the LFPT.  The evidence from these studies, discussed below, has been mixed and inconclusive.  In addition, there has not been a study of the practicality of using the LFPT.

**Is Low-Flow Pumping Practical?**

EPA contracted with the Desert Research Institute (DRI) to study the filtering issue for a year.  Wisconsin's Outagamie County Landfill was one of three sites DRI chose.  DRI collected both filtered and unfiltered samples using the LFPT one week after the County collected samples using a bailer and field filtering.  All three types of sampling results were similar for metals.  We were impressed with the LFPT's ability to minimize turbulence and aeration.  The LFPT produced "clear" samples from wells that had produced highly turbid samples when bailed the previous week.

We made the following additional observations about the LFPT:

1.  There is a significant amount of bulky equipment required:  a heavy reel, 100 feet of hose and electrical cable, a regulator, a 60-90 pound generator (or battery or nitrogen tank depending on pump type), meters for measuring conductivity, DO, pH, temperature and turbidity and a flow through cell. (Many Wisconsin wells cannot be reached by vehicle.)

2.  It is time-consuming to transport and set-up the equipment, purge the well and collect the sample. (An average of **two wells** were sampled **per day**.)

3.  The pump sometimes had difficulties pumping at very low rates.

4.  The equipment would be very difficult to operate in Wisconsin type winter conditions (e.g. if the pump turned off, water remaining in the tubing would freeze in a matter of minutes).

5.  Low-flow pumping could not be used in wells that could be purged dry. (Many monitoring wells in Wisconsin can be purged dry.)

One of our biggest practical concerns with the LFPT is the amount of time required to sample wells.  A typical Wisconsin landfill remaining open under Subtitle D would have 50 monitoring wells.  It would take samplers 1 week to sample such a site using a bailer and field filtering, while it would take 3-5 weeks to sample the site using the LFPT.  An ideal set-up for sampling would be a dedicated low-flow pump because there would be less equipment to transport and freezing would be less likely since the tubing is in the well, not exposed to the air and less time would be needed for decontamination.  However, it is not realistic to expect that most landfill owners will install a dedicated pump system in each of its monitoring wells immediately to comply with the Subtitle D criteria.  As part of our survey of groundwater samplers we asked them what type of dedicated sampling equipment they were using.  Seventy-six percent of the samplers did not use any type of dedicated system, 16% used dedicated bailers and only 8% used dedicated pumps.  Although dedicated pumps have been available for a number of years, most landfill owners in Wisconsin are not choosing to use them.

We evaluated the LFPT at facilities with high levels of metals, such as plating companies.  At the Riverside Plating Company a consultant sampled several monitoring wells using a bailer and collected both a filtered and unfiltered sample from each well.  We sampled the same wells using the LFPT during the month following the consultant's sampling.  We experienced a number of problems during this sampling.  We had hoped to sample 3 to 4 wells in a day but found our rate of sampling to be similar to DRI's - a maximum of 2-3 wells per day.  The pump would shut off unexpectedly while purging some of the wells.  It had to be restarted at a high rate which created added turbulence and increased the purging time.  It took approximately 45 minutes to set up and calibrate the equipment prior to sampling each well and slightly less time to take down the equipment following sampling.  Purging and sampling, excluding set up and take down time, took anywhere from 1-4 hours for each well.

**How Do Results Compare?**

To date, the metals results comparing bailing and field filtering to low-flow pumping have been inconclusive.  Table 1 represents data collected at an unimpacted well in Wisconsin where metals are high only in bailed and unfiltered samples due to turbidity.  The bailing and field filtering and low- flow pumping produced very similar results indicating no metals contamination.  Researchers sampling for arsenic using the two methods found somewhat lower values using bailing and field filtering than low-flow pumping (Puls et al. 1992 and Puls and Powell 1992), but the values were close enough that under our enforcement standards and procedures, we would have taken the same enforcement action using the results from either method.  Chromium results have varied depending on the level of contamination.  Table 1 illustrates similar results at low levels of contamination.  Table 2, representing preliminary results from Wisconsin's study, illustrates

**Table 2. Chromium Concentrations (μg/L) at Two Impacted Wells - Riverside Plating Co.**

| | Well P-3 | | | Well P-4 | | |
|---|---|---|---|---|---|---|
| | *Bailer Unfiltered* | *Bailer Filtered* | *Low Flow Unfiltered* | *Bailer Unfiltered* | *Bailer Filtered* | *Low Flow Unfiltered* |
| Chromium | 77 | 20 | 14 | 340 | 470 | 292 |

similar results for the two methods at medium levels of chromium contamination (see Well P-3) and exaggerated levels of contamination using bailing and field filtering at high levels of chromium contamination (see Well P-4). Puls et al. (1992) also found exaggerated levels of chromium when using the bailing and field filtering method. However, in a separate study Paul and Puls (1993) found "very little difference" in chromium concentrations between the bailer and low-flow pumps at high levels of chromium contamination.

**Conclusion**

Wisconsin has over 9,000 landfill monitoring wells, of which over 85 percent are bailed and over 50 percent produce turbid samples. If turbid samples collected from these wells are not filtered, the results will be erroneously high for metals and these erroneously high values will force many landfill owners into Assessment Monitoring under Subtitle D.

A logical alternative to bailing is the low-flow pumping technique, which can produce clear samples without filtering in many circumstances. However, before requiring landfills and others to use this technique two critical questions need resolution:

1. Does bailing and field filtering produce significantly different results from low-flow pumping? (The results of the comparison to date have been preliminary and inconclusive.)

2. Can the low-flow pumping technique be implemented practically? (The evidence indicates it would be difficult to implement in the field but more evidence should be gathered.)

We propose postponing the ban on field filtering while EPA and the states gather additional evidence to answer these two questions. What risk is involved in postponing the ban? Very little, if any, at municipal solid waste landfills. Our experience has been that metals rarely migrate beyond 100 feet of our landfills. We have found that more mobile constituents such as VOCs and chloride are far better indicators of contaminant releases from landfills than are metals.

In Wisconsin we have used results from our current techniques of bailing and field-filtering for inorganics and bailing without filtering for VOCs to require groundwater investigations at 100 landfills and implement remedial action at over 50 of these landfills. We believe that our monitoring and remediation programs would not be significantly improved by adding requirements for low-flow pumping.

We suggest that EPA use some of the flexibility used throughout Subtitle D, at least while we gather additional data to answer the two questions posed above. We recommend that EPA:

1. Lift the ban on field filtering until more research is completed.

2. Collect additional metals data from individual wells using both bailing and field filtering and low-flow pumping.

3. Determine whether there is a significant difference between the metals values using the two techniques.

4. Evaluate ways to improve bailing and field filtering if there are significant differences between the two techniques.

5. Evaluate the practicality of the low-flow pumping

technique, especially for sites in northern climates, in fine grained soils where wells can be purged dry and sites with a large number of monitoring wells.

No matter which sampling technique seems best scientifically, if it can't be implemented, it serves no purpose. Returning to the title of my presentation, you can't always get what you want. What all of us would love to have is the ideal, perfect sampling technique. But if you try sometime, and balance the ideal with what works in the field, you just might find, you get what you need.

**References**

Paul, C.J. and R.W. Puls. 1993. Comparison of Ground-Water Sampling Devices Based On Equilibration of Water Quality Indicator Parameters. EPA/600/A-93/005, 13 pp.

Puls, R.W. and R.M. Powell. 1992. FOCUS PAPER: Acquisition of Representative Ground Water Quality Samples for Metals. Ground Water Monitoring Review, v. 12, no. 3, pp. 167-176.

Puls, R.W., D.A. Clark, B. Bledsoe, R.M. Powell and C.J. Paul. 1992. Metals in Ground Water: Sampling Artifacts and Reproducibility. Hazardous Waste and Hazardous Materials, v. 9, no. 2, pp. 149-162.

## RESULTS OF WISCONSIN'S GROUNDWATER SAMPLING PROCEDURES SURVEY

This survey was sent on October 13, 1993 to those sampling groundwater at 470 Wisconsin landfills, of which 305 had replied at the time the results were compiled.

1.    At about how many of the following types of Wisconsin landfills do you  collect groundwater samples? (e.g., if you sample at 2 municipal and 3 demolition landfills, fill in 2 in front of "Municipal Solid Waste" and 3 in front of "Demolition")

|  |  |  |  |
|---|---|---|---|
| _58%_ | Municipal Solid Waste | _8%_ | Demolition |
| _29%_ | Industrial | _5%_ | Other |

2.     Of the above landfills, about how many are

|  |  |  |  |
|---|---|---|---|
| _31%_ | Active (taking waste) | _54%_ | Closed |

3.    At about how many landfills do you use the following equipment to purge the     wells?    (e.g., if you use a bailer at 3 landfills and a bladder pump at 2landfills, fill in 3 in front of "Bailer' and 2 in front of "Bladder Pump")

|  |  |  |  |
|---|---|---|---|
| _80%_ | Bailer | _0.2%_ | Gas Displacement Pump |
| _12%_ | Bladder Pump | _1.6%_ | Air Lift Pump |
| _0.2%_ | Centrifugal Pump | _0.9%_ | Peristaltic Pump |
| _9%_ | Submersible Pump | _1.6%_ | Suction Lift Pump |
| _0.9%_ | Others (list brand name of pump if unsure of type) | | _____ |

4.    About how many well volumes do you remove from the well when purging wells which you cannot purge dry?

        _3.7_     number of well volumes purged

5.    About how much time elapses between the time you finish purging a well which recharges rapidly and the time that you sample it?

                                                                    (Circle One)
        None, we have no such well ..................................................8.7%

        less than 30 minutes ............................................................60%

        30 to 60 minutes .....................................................................6%

        1 to 2 hours ..........................................................................3.3%

        2 to 4 hour ...........................................................................1.1%

        4 to 6 hours ..........................................................................0.0%

6 to 12 hours ..................................................................... *1.1%*

12 to 24 hours ................................................................... *11%*

25 to 48 hours .................................................................. *4.3%*

49 to 72 hours .................................................................. *0.0%*

6.      At about how many landfills do you use the following equipment to retrieve the samples from the well?

   _40%_  Bailer                                          _6%_    Submersible Pump

   _49%_  Bailer with Bottom                              _.0%_   Gas Displacement Pump
          Emptying Device
   _11%_  Bladder Pump                                    _0.7%_  Peristaltic Pump

   _1.6%_ Centrifugal Pump                                _0.9%_  Suction Lift Pump

   _0.9%_ Others (List brand name of pump if unsure of type)

7.      About what percent of all monitoring wells that you sample produce turbid water (i.e., water is not clear)?

       _18%_  < 25%        _21%_  25-50%        _27%_  51-75%        _34%_  >75%

8.       Do you filter samples for inorganics?              _84%_  Yes            _14%_    No
   (e.g., alkalinity, hardness)

   If Yes, is filtering done in        _66%_  Field

                                       _18%_  Lab

9.      Do you filter samples for metals?                   _88%_  Yes            _12%_    No

   If Yes, is filtering done in        _71%_  Field

                                       _17%_  Lab

10.     If field filtering, do you use:    _68%_  A transfer container

                                           _25%_  An in line filter system

11.     About how long is it, on the average, between the time you take a sample and the time that it is filtered?

                                                      (Circle One)
                0 minutes (in line filtering).......................................... *18%*

                Less than 15 minutes. .................................................. *45%*

                15 to 60 minutes ......................................................... *16%*

                1 to 2 hours ............................................................... *6.5%*

2 to 3 hours .................................................... *3.3%*

More than 3 hours ...................................... *11%*

12.     About how many landfills that you sample have dedicated sampling equipment?

       *16%*  Landfills with dedicated bailers (separate bailers for each well)

       *7.6%*  Landfills with dedicated pump system (separate pump for each well)

13.     Do you use distilled water (also includes deionized and reagent grade water) to rinse equipment between wells?

       *95%*  Yes                             *5%*  No

If Yes, where is it usually obtained?

       *22%*  Grocery store

       *59%*  Laboratory

       *14%*  Other (please specify) *most often: Culligan, or office purification equipment*

If No, what do you use?

       *"River water" or "Just dry it off"  were notable responses*
       Used to rinse equipment

The figures that follow graphically illustrate the answers to several of the sampling questions asked in the survey.

## How long is it between the time you take a sample, and when it is filtered?
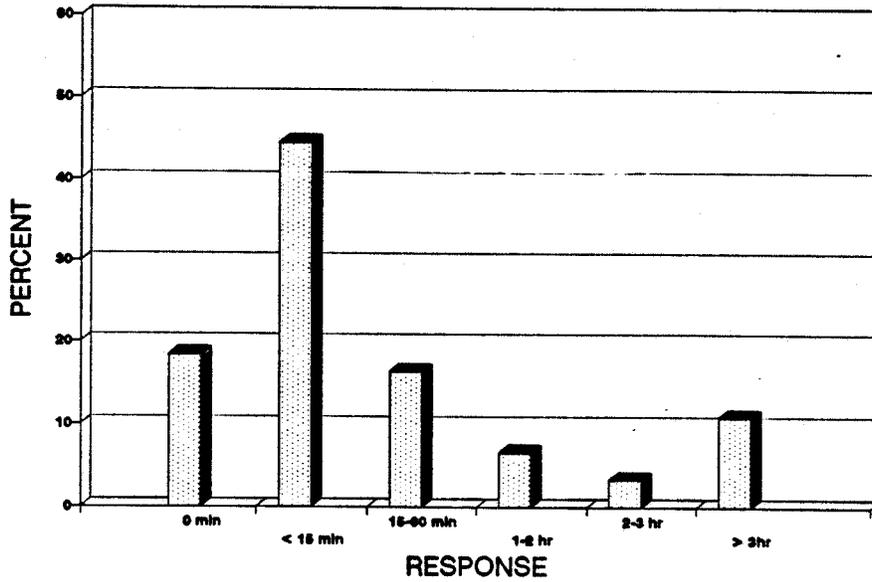


## Do you filter for inorganics and/or metals? If so, where?
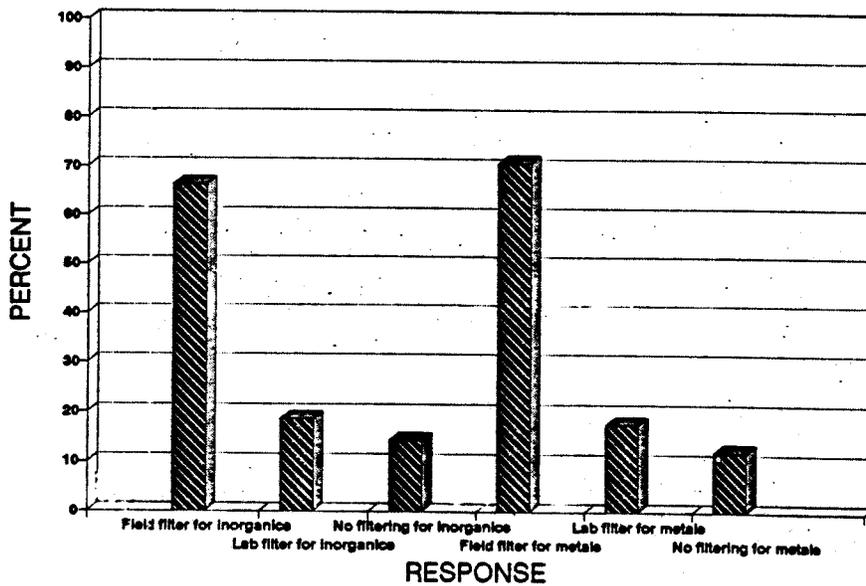
## About what percent of monitoring wells that you sample produce turbid water?
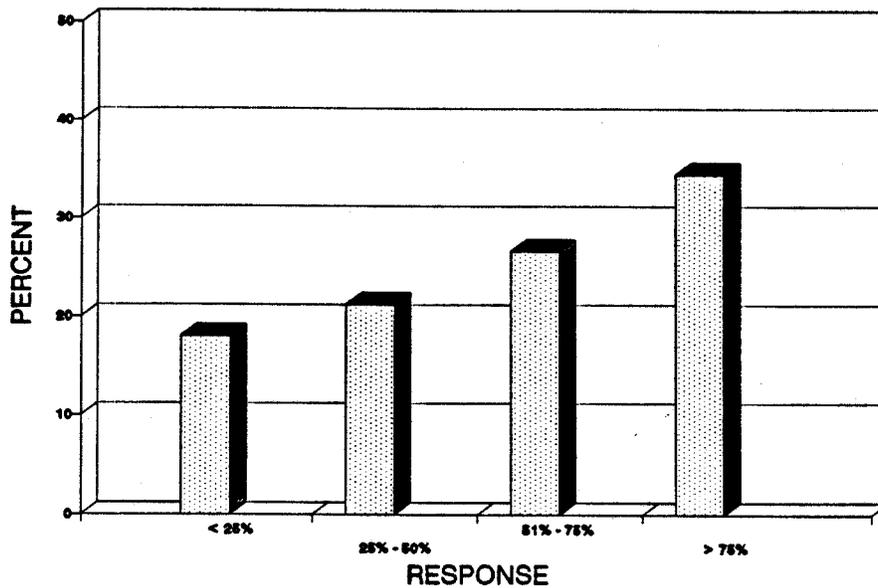


## Summary of dedicated sampling devices.
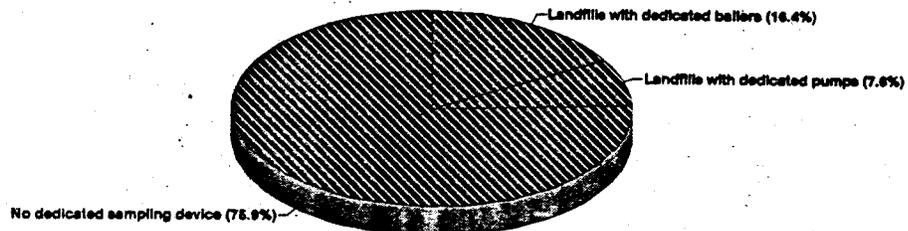
# How long is it between the time you take a sample, and when it is filtered?
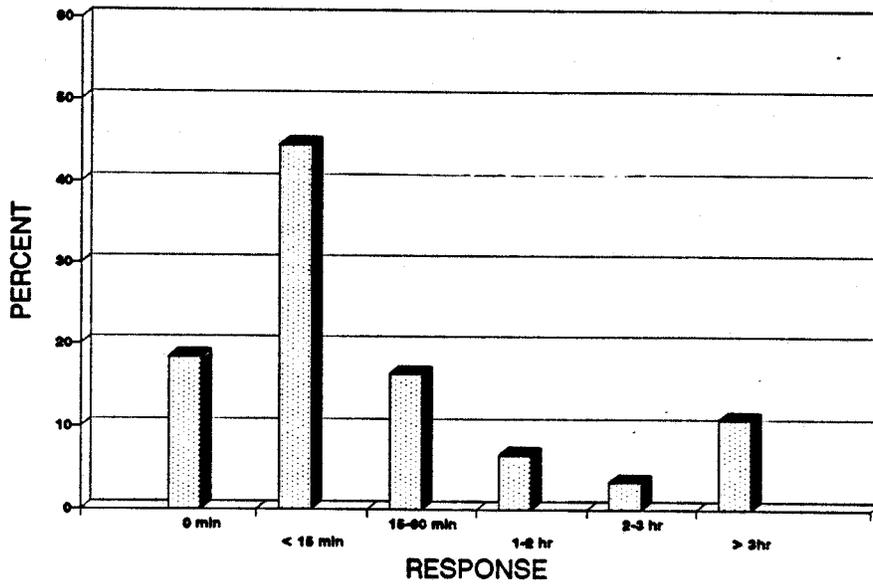


# Do you filter for inorganics and/or metals? If so, where?
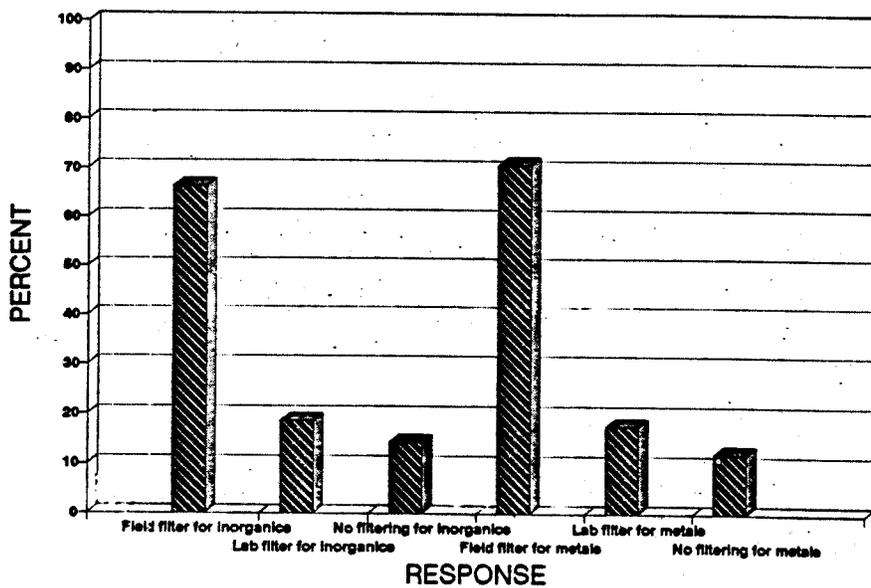
# How long is it between the time you purge a well, and when it is sampled?
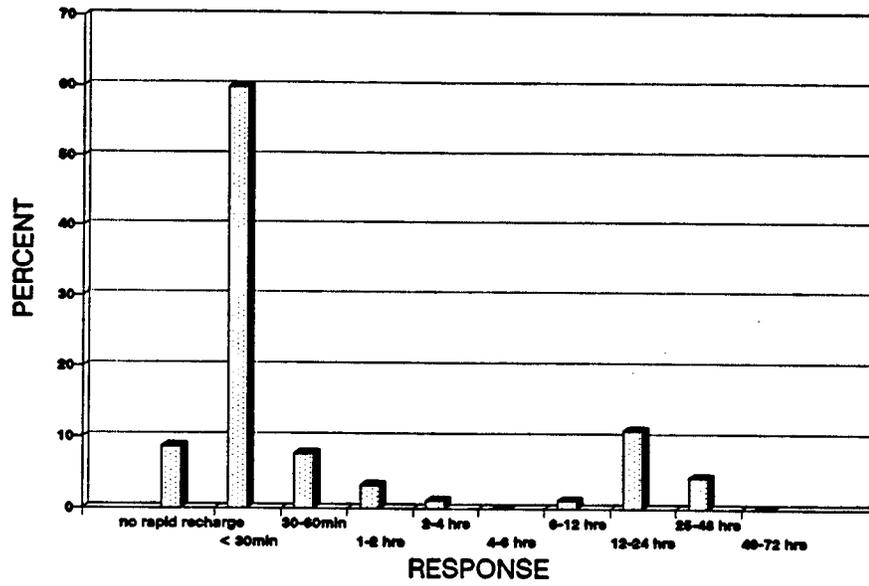
# STATISTICAL COMPARISON OF METAL CONCENTRATIONS IN FILTERED AND UNFILTERED GROUND-WATER SAMPLES

## Robert D. Gibbons & Martin N. Sara

### Introduction

The promulgation of Subtitle D on October 9, 1991 with it's restriction on filtering ground-water samples has generated much controversy. From USEPA's perspective, there is concern that by filtering the sample potential contribution of colloidal transport to off-site migration may be overlooked (i.e., molecules of metals bound to particulate matter in the ground water). From the states and regulated community perspective, there is concern over what is being measured; ground water or the formation adjacent to the monitoring well. Increases in turbidity may lead to higher unfiltered metal concentrations, and since waste disposal facilities invariably have more downgradient than upgradient monitoring wells, the probability of a turbid sample is more likely in a downgradient well than an upgradient well by chance alone. This type of "false positive" result will lead to expensive and unneeded site assessment. Alternatively, if higher turbidity or differences in formation are associated with upgradient well measurements, effects of contamination may go undetected (i.e., false negative results).

### Methodology

Paired measurements *(i.e.,* filtered and unfiltered) were obtained for 16 metals [calcium (Ca), magnesium (Mg), sodium (Na), arsenic (As), cadmium (Cd), mercury (Hg), selenium (Se), silver (Ag), chromium (Cr), copper (Cu), lead (Pb), barium (Ba), manganese (Mn), potassium (K), zinc (Zn), and iron (Fe)] in mg/l, and sample turbidity in NTU, from each of 4 waste disposal companies. Each company had paired data for upgradient and downgradient monitoring wells from several different facilities. This report is based solely on complete samples in which filtered and unfiltered metal concentrations, and turbidity were measured in the ground-water sample.

There were a total of 9689 complete records from 12 sites and 155 monitoring wells. Sample sizes ranged from 506 complete measurements for Ba to 803 complete measurements for Ca. For the purpose of illustration, turbidity was divided into low (< l0 NTU), medium (11-50 NTU), and high (> 50 NTU). These cutpoints were based on the empirical frequency distribution of turbidity such that

the sample would be roughly divided in thirds. The results presented are not dependent on this classification system, and can be replicated with the continuous turbidity measurements as well.

### Results

This section presents results from the comparison of filtered and unfiltered samples using the entire database of complete sample (i. *e.,* those in which turbidity and both filtered and unfiltered measurements were simultaneously available). Summary statistics are presented in Tables 1 and 2. Table 1 displays detection frequency for filtered and unfiltered samples by compound and sample turbidity level *(~.e., low,* medium, and high). Table 2 displays the mean concentration and standard deviation for those cases in which a metal was detected in both filtered and unfiltered samples. Also, Table 2 lists results for each metal and turbidity level.

Table 3, displays summary statistics for Fe overall, and for each turbidity level in 45 upgradient measurements. Table 3 reveals that the average upgradient unfiltered concentration (see Total in Table 3) is five times higher than filtered samples and the standard deviation i.e., variability) is six times higher. Although variability is always higher in unfiltered samples, the magnitude of the difference is proportional to turbidity of the sample.

In addition to the effect of the increased variability of the unfiltered samples on the false negative rate of the statistical test, the relationship with turbidity can produce large numbers of false positive results as well. Table 4 displays the average and maximum iron concentrations for each of the 11 downgradient wells at the facility for filtered and unfiltered samples. Table 4 reveals widespread variability in iron concentrations for the unfiltered samples across downgradient wells. Some wells show consistently high (I and 2) or consistently low (3, 4, 5, and 11) iron concentrations whereas other wells show widespread variation for unfiltered samples i.e., ratio of maximum to mean values of 10 to 1). Results for the filtered samples were far more consistent (ratio of maximum to mean of less than 2 to 1).

The variance component estimates i.e., inter-site, inter-well, and intra-well) for filtered, unfiltered and their difference i.e., unfiltered-filtered) are displayed in Table 5. Table 5 reveals that variability from site to site is reasonably consistent for filtered and unfiltered samples. Variability from well to well is approximately twice as large for unfiltered versus filtered samples. Variability within wells is over five times as large for unfiltered versus filtered samples.

These results suggest that if unfiltered samples are the basis for these analyses, false negative rates i.e., failure to detect

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contamination when it is present) will, in fact, be considerably larger for than if filtered samples are used. Conversely, the doubling of the well to well component of variation for unfiltered samples relative to filtered samples, will produce large numbers of false positive results as well, particularly in upgradient versus downgradient detection monitoring comparisons. Turbid sarnples will continuously be mistaken for contaminated samples and needless site assessments will be routinely performed. On the other hand, an unscrupulous owner/operator might simply churn the upgradient well sarnples i.e., inaease turbidity), and meticulously collect downgradient samples, which would greatly increase statistical limits and rarely result in statistically significant differences whether contamination was present or not. Such practice would have little or no effect on filtered samples.

**Summary**

The data presented show how unfiltered measurements can lead to increases in both false positive and false negative rates due to increased variability of the unfiltered results *(i.e.,* false negative) and the relationship between concentration and sample turbidity that can be mistakenly interpreted as contamination *(ie.,* false positive). The data presented indicate that turbid samples will continuously be mistaken for contaminated samples and needless technical efforts will be expended by both the states' and facility owners' staff. Conversely, by not filtering, upgradient samples collected in turbid wells could mask releases in downgradient wells where unturbid samples were carefully collected.

The purpose of this report is to clearly demonstrate the enorrnous price that is paid in both potential false positive and false negative detection monitoring decisions when unfiltered samples are used as the basis of testing statistical hypotheses regarding site impact. It is clearly shown that unfiltered sample concentrations exhibit extreme variability, which is in large part due to sample turbidity and colloidal transport. Furthermore, even if a statistical adjust for the effects of turbidity was performed (i.e., in effect hold turbidity constant), differences between unfiltered and filtered metal concentrations still exist. Are these differences due to colloidal transport or the effects of the formation? No definitive conclusion can be readily drawn since these effects are confounded in empirical data. It should be noted, however, that there are special geological conditions that are required for colloidal transport, but the increased variability in unfiltered samples is seen consistently in all sites examined regardless of whether conditions are conducive for colloidal transport or not. In addition, the effects are seen both in upgradient and downgradient wells indicating that in these data, the increased concentrations associated with unfiltered samples are not due to colloidal transport of metals released from a facility.

From a statistical perspective, the question is whether filtered or unfiltered samples lead to a preferential balance between false positive and false negative results when used in ground-water detection monitoring programs. To select unfiltered samples to cover the possibility of colloidal transport, at the expense of both greatly inaeased false positive and false negative results is foolish at best. Analysis of extensive monitoring data, from numerous waste disposal facilities using upgradient and downgradient monitoring wells in which both filtered and unfiltered samples were simultaneously collected, clearly showed that filtered samples dramatically minimize both false positive and false negative rates relative to unfiltered samples. The principal factor in this difference was due to the turbidity of the sample.

The results of this study have profound implications for public policy in relation to the monitoring of municipal solid waste landfills. Use of unfiltered sarnples will dramatically increase false negative results in those sites in which upgradient wells exhibit turbidity or are drilled in different formations that vary in terms of their concentration of tht metal in question. Both conditions will lead to large variability in upgradient samples and produce statistical limit estimates that are quite large relative to what could be obtained had filtered samples been used. In contrast, when the small number of upgradient wells are not representative of either the formations or turbidity in the far greater number of downgradient wells, the variability in the upgradient wells will underestimate the true background variability for the site as a whole and large numbers of false positive results will occur. The reason, of course, is that the unfiltered samples are influenced heavily by sample turbidity and geological formation, neither of which is explicitly controlled in the detection monitoring process. To the extent that there are far greater numbers of downgradient wells, there is a correspondingly greater chance of having turbidity or differences in formation adversely impacting the concentration in a, downgradient well and falsely concluding that it is the site that has impacted ground water. Conversely, if the upgradient samples are highly turbid or vary in turbidity, variability in the measured concentrations will be large and statistical tests of contamination will be powerless to detect real contamination when it occurs. All analyses performed in this study yield exactly the same conclusion.

The reader should note that the effects observed here were consistent for both upgradient and downgradient wells. If colloidal transport is the method by which contaminants are transported off-site, why should the same types of variability be observed in upgradient wells? These results clearly show that whether colloidal transport is real or not, the price paid for using unfiltered samples is enormous, both in terms of missing real contamination when it exists and in detecting contamination when it is not present.

**Table 1 Detection Frequencies for Filtered and Unfiltered Samples (Expressed as a Proportion of Total Measurements)**

| Metal | Low Turbidity | | Med Turbidity | | High Turbidity | |
|---|---|---|---|---|---|---|
| | Filtered | Unfiltered | Filtered | Unfiltered | Filtered | Unfiltered |
| Ag | .04 | .07 | .01 | .06 | .02 | .12 |
| As | .08 | .14 | .13 | .22 | .32 | .48 |
| Ba | .23 | .31 | .36 | .48 | .60 | .70 |
| Ca | .99 | 1.0 | 1.0 | 1.0 | .99 | .99 |
| Cd | .10 | .14 | .07 | .18 | .06 | .16 |
| Cr | .04 | .09 | .07 | .15 | .11 | .55 |
| Cu | .22 | .29 | .12 | .29 | .28 | .57 |
| Fe | .58 | .87 | .64 | .98 | .82 | .99 |
| Hg | .01 | .01 | .01 | .02 | .02 | .05 |
| K | .85 | .87 | .94 | .95 | .82 | .83 |
| Mg | .99 | 1.0 | .99 | 1.0 | .98 | 1.0 |
| Mn | .75 | .81 | .84 | .94 | .88 | .99 |
| Na | .92 | .96 | .98 | .98 | 1.0 | 1.0 |
| Pb | .15 | .-23 | .07 | .22 | .24 | .52 |
| Se | .05 | .04 | .04 | .03 | .14 | .08 |
| Zn | .59 | .68 | .61 | .78 | .62 | .76 |

**Table 2 Mean and Standard Deviation (SD) of Metal Concentrations for Filtered and Unfiltered Samples When Both were Detected**

| Metal | Low Turbidity | | | | Med Turbidity | | | | High Turbidity | | | |
| | Filtered | | Unfiltered | | Filtered | | Unfiltered | | Filtered | | Unfiltered | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ag | .005 | .001 | .004 | .001 | .004 | .000 | .023 | .000 | .019 | .043 | .042 | 0.47 |
| As | .010 | .018 | .018 | .024 | .009 | .008 | .014 | .016 | .028 | .055 | .032 | 0.59 |
| Ba | .146 | .174 | .253 | .649 | .139 | .112 | .180 | .153* | .152 | .144 | .461 | .995 |
| Ca | 93.4 | 139. | 96.1 | 120. | 102. | 126. | 108. | 138. | 356. | 1152 | 465. | 1341 |
| Cd | .005 | .003 | .007 | .007 | .009 | .006 | .008 | .006 | .011 | .007 | .011 | .006 |
| Cr | .021 | .016 | .021 | .013 | .023 | .031 | .032 | .032 | .012 | .013 | .051 | .053 |
| Cu | .091 | .134 | .111 | .148 | .143 | .250 | .152 | .242 | .070 | .173 | .146 | .239 |
| Fe | 6.68 | 14.6 | 20.0 | 61.4* | 10.5 | 23.5 | 20.1 | 48.8* | 21.3 | 34.1 | 50.9 | 104* |
| K | 11.9 | 27.0 | 13.2 | 31.7* | 9.87 | 19.5 | 9.71 | 19.4 | 20.5 | 36.7 | 24.2 | 38.6* |
| Mg | 121. | 432. | 114. | 393. | 184. | 654. | 171. | 580. | 163. | 609. | 179. | 640.* |
| Mn | 6.96 | 13.5 | 7.26 | 13.5* | 4.60 | 8.11 | 4.76 | 8.00* | 5.99 | 11.8 | 6.83 | 12.4* |
| Na | 286. | 1001 | 297. | 1055 | 360. | 1178 | 369. | 1216 | 314. | 1163 | 324. | 1174 |
| Pb | .091 | .034 | .073 | .278 | .022 | .030 | .033 | .033* | .158 | .124 | .182 | .134 |
| Se | .016 | .030 | .016 | .031 | .314 | .483 | .347 | .549 | .030 | .036 | .041 | .059 |
| Zn | .350 | .607 | .385 | .638* | .194 | .385 | .217 | .381 * | .350 | 1.18 | .602 | 1.26* |

* indicates statistically significant difference between filtered and unfiltered sarnples based on a paired t-statistic

**Table 3 Summary Statistics for Iron (mg/l) in Filtered and Unfiltered Samples in Upgradient Wells (1/2 MDL substituted for Nondetects)**

| Turbidity | Filtered | | | Unfiltered | | |
| | Mean | SD | N | Mean | SD | N |
|---|---|---|---|---|---|---|
| Total | .439 | .760 | 45 | 2.044 | 4.530 | 45 |
| Low | .152 | .305 | 32 | .369 | 1.014 | 32 |
| Medium | .472 | .348 | 5 | 1.970 | 1.066 | 5 |
| High | 1.569 | 1.145 | 8 | 8.790 | 7.682 | 8 |

**Table 4 Average and Maximum Iron Concentrations (mgA) in Downgradient Wells (1/2 MDL substituted for Nondetects)**

| Well | Filtered | | Unfiltered | | Turbidity | |
|------|------|------|------|------|------|------|
| | Mean | Max | Mean | Max | Mean | Max |
| 1 | 60.05 | 87.30 | 60.02 | 89.70 | 123 | 220 |
| 2 | 62.25 | 106.00 | 56.78 | 104.00 | 392 | 705 |
| 3 | .S0 | 4.90 | .90 | 5.60 | 9 | 49 |
| 4 | .06 | .08 | .41 | 1.16 | 5 | 12 |
| 5 | .06 | .08 | .85 | 1.98 | 21 | 85 |
| 6 | .11 | .94 | 2.65 | 29.50 | 16 | 55 |
| 7 | .39 | 4.80 | 5.27 | 53.50 | 198 | 21 90 |
| S | .06 | .08 | 8.62 | 53.60 | 235 | 1650 |
| 9 | .06 | .08 | 13.55 | 153.00 | 215 | 2550 |
| 10 | 5.90 | 7.89 | 12.58 | 24.40 | 741 | 3470 |
| 11 | .43 | .92 | .49 | 1.00 | 2 | 8 |

**Table 5 GLS Variance Component Estimates for Unfiltered, Filtered, and the Difference Between Filtered and Unfiltered Results For Fe in mg/l**

| Effect | Unfiltered | Filtered | Difference |
|--------|-----------|----------|-----------|
| Inter-Site SD | 17.65 | 14.30 | 11.09 |
| Inter-Well SD | 27.43 | 13.30 | 20.59 |
| Intra-Well SD | 66.72 | 12.30 | 64.65 |

Variance components listed as standard deviations (SD)

# IV. Poster Abstracts

*PRESENTERS*

John D. Gray, New York State Electric and Gas Company

Robert M. Powell, ManTech Environmental Technology, Inc.

Cynthia Paul, U.S. EPA/Robert S. Kerr Environmental Research Laboratory

Nic. E. Korte, Oak Ridge National Laboratory

Natalie Park, Westinghouse Savannah River Company

Daniel Ronen, Weizmann Institute

Gary Robbins, University of Connecticut (no abstract)

# IN-LINE FILTERING OF GROUND WATER SAMPLES FROM MONITORING WELLS IN GLACIAL TILL

**John D. Gray**
**Richard E. Wardwell**

## ABSTRACT

New York State Electric & Gas (NYSEG) conducted an extensive research project at a solid waste (fly ash) landfill to compare and evaluate the analytical results from filtered and unfiltered ground water samples. Two years of site-specific data for dissolved (filtered) and total (unfiltered) concentrations of 22 metals were collected. Elemental analyses of the soil constituents of the glacial till from the site were performed. In addition, field testing of alternative sampling techniques to reduce turbidity in ground water samples was conducted.

The following results were determined from the research project:

- It is theoretically impossible to design a monitoring well filter pack which will prevent the movement of fines (silt and clay) into a well bore during sampling.

- The high percentage of fines in the glacial till and fractured bedrock at the site makes it is impossible to assure a turbid free sample from the site monitoring wells regardless of the well installation or sampling technique.

- The chemical composition of the native soil contains significant amounts of aluminum, chromium, copper, iron, manganese and zinc.

- Unfiltered samples show increases in the fore mentioned metals in direct relation to the amount of turbidity in the ground water sample.

- Filtering removes suspended soil particles but does not change the chemistry of the ground water samples collected at the site.

The results from this study demonstrate that the use of unfiltered samples will produce elevated concentrations for those metals which comprise the soil matrix. These elevated concentrations will trigger invalid exceedances of New York State ground water standards and will mask any water quality trends associated with landfill activities. Therefore, filtered (dissolved metals) concentrations are necessary for assessing the impacts of the landfill because they are more representative of constituents actually moving in the ground water.

# Passive Sampling of Ground Water Monitoring Wells without Purging:  Multilevel Well Chemistry and Tracer Disappearance

**Robert M. Powell and Robert W. Puls**

## ABSTRACT

It is essential that the sampling techniques utilized in ground-water monitoring provide data that accurately depicts the water quality of the sampled aquifer in the vicinity of the well. Due to the large amount of monitoring activity currently underway in the U.S. it is also important that the techniques be efficient. It would be desirable to minimize the requirements of sampling time, equipment, and quantity of contaminated waters pumped to the surface, without loss of data integrity. If representative samples could be acquired without purging the wells, increased sampling efficiency could potentially be achieved.

Purging of multiple borehole volumes is largely routine, based on studies that show changes in the water chemistry as it stands in the casing and is subjected to atmospheric exposure at the top of the column. However, little data is available depicting water chemistry in the screened intervals of wells at equilibrium flow conditions, i.e. with little or no disturbance to the natural flow regime or disruption of the overlying casing waters.

This study examines the differences in water chemistry between the casing and screened interval volumes of four wells at a field site, then compares the results to purged values for the same wells. Tracer experiments, utilizing both colloidal particles and dissolved species as tracers, are presented to illustrate differences in natural flushing between the screened and cased intervals. The data from the tracer removal was then utilized to estimate ground water flow velocities in the vicinities of the boreholes.

# Turbidity Effects on Volatile Organic Contaminants in Ground Water Samples

Cynthia J. Paul, Robert W. Puls and  Lisa R. Secrest

## ABSTRACT

According to the RCRA Ground Water Monitoring Technical Enforcement Document (TEGD), ground water samples collected for contaminant analysis should have a turbidity of less than five nephelometric turbidity units (NTU). Some feel turbidity levels greater than five NTUs would not be representative of the aquifer; however, many monitoring wells produce samples with turbidity levels greater than five NTUs due to site-specific hydrogeochemistry or improper well design or construction. However, our previous work has shown that proper sampling techniques can produce samples with low turbidity values even in wells traditionally considered turbid. Little research has been conducted to determine the impact of turbidity on volatile organic compounds (VOCs) in recovered ground water samples. This study was designed to differentiate turbidity effects from unknown f1eld effects that could influence the apparent concentrations of VOCs in ground water samples. Laboratory batch studies and field investigations were performed to evaluate the effects of solids (turbidity) on VOC concentrations. Three different solids (recovered aquifer material, kaolinite, and Na-montmorillonite) were used in the turbidity "spikes" to assess turbidity effects on sample quality. During the laboratory portion of this study, these solids were used to determine sorption and volume displacement effects on VOC concentrations under controlled laboratory conditions. The procedure included adding known amounts of solid to a simulated ground water solution and then spiking each sample with varying amounts of TCE. The same solids were used in the field portion of the study to differentiate turbidity effects on sampling methodology. Sample VOA vials were prespiked with known amounts of solids. VOC samples were collected into these vials as well as vials containing no solids for comparison purposes. The field study also included alteration of the sampling procedure to intentionally increase turbidity levels by entrainment of natural aquifer materials in the collected samples. Water quality indicators (pH, dissolved oxygen, turbidity, specific conductance, redox, and temperature) were monitored during well purging and samples were collected after all parameters reached equilibration. Results of this study indicate that increased turbidity levels in ground water samples have no impact on VOC concentrations (i.e., TCE and its degradation products). Sampling methodology appears to be the most important consideration when collecting ground water samples for VOCs.

# A Field Comparison of Micropurging and Traditional Groundwater Sampling Using Analytical Data and Observations with the Colloidal Borescope

**Nic E. Korte and Peter M. Kearl**

## ABSTRACT

The recent literature discusses micropurge sampling techniques as a possible replacement for traditional purge and sample methods. Micropurge sampling involves a dedicated sampling pump, a sampling rate of approximately 100 mL/min, and purging of only the sample pump and tubing. If micropurging can yield reliable groundwater samples, then significant quantities of purge water can be eliminated, thereby reducing costs and minimizing waste. Unfortunately, evaluating sampling methods for yielding representative water samples of natural groundwater systems is difficult. The monitoring well represents an unnatural intrusion into the subsurface, and natural variations in the chemistry of the groundwater further complicate the system. One approach to overcoming these problems is to duplicate groundwater sampling using both conventional and repetitive micropurge sampling followed by a statistical comparison of the results. Using this approach, a series of experiments is being conducted at two sites where samples are analyzed for selected organic and inorganic constituents. Analysis of data collated to date using a paired t-test indicates that within a 95% confidence interval, there was no significant difference between the sampling methods for both site contaminants and the majority of naturally occurring analytes. Analytes that showed a significant difference were redox sensitive (e.g., iron and manganese) or were present in such low concentrations that analytical reliability was a factor. The analytical results were supported by observations performed with the colloidal borescope. Borescope observations demonstrated significant impacts on the hydrodynamic flow system when using traditional sampling methods. Results of the study suggest replacing traditional purging and sampling with micropurging, due to the reliability and cost-effectiveness of the method.

# Random Variability of Metals Measurements in Ground Water Reduced through Revised Sampling Techniques

Natalie M. Park

## ABSTRACT

The potential to reduce the random variability or imprecision in metals measurements in groundwater samples by as much as 90% was demonstrated through the application of revised groundwater sampling techniques. Revised ground water sampling procedures incorporated recent research recommendations to cease filtering samples collected for metals analyses and to move away from the conventional approach of "purge a minimum of 3 to 5 well volumes until pH, specific conductance and temperature are stable." Since historical data indicted that pH and conductivity usually reached stability within one to two well volumes, the new approach requires purging a minimum of two-well volumes (as a conservative measure) and uses turbidity instead of temperature as a stabilization parameter. To reduce time, the first two well volumes are purged at a rate that can be sustained without creating surging, generally 2-5 gal/min. Then the purging rate is reduced to 0.25 gal/min and purging continued until pH, conductivity, and turbidity measurements stabilize. Samples collected for metals analyses are not filtered, whereas previously 0.45 micron filters were used.

Dedicated, variable speed pumps replaced faster pumping, single speed submersible pumps in 40 wells. These wells monitor a contaminant plume characterized by low pH (3-5), high nitrate (as N) and sodium concentrations, elevated specific conductance (51 to 2200 μS/cm), and metals including aluminum, iron, manganese, barium zinc, copper, cobalt, cadmium and zinc. Pumps are routinely set toward the bottom of the PVC screens to accommodate fluctuations in water levels. The wells were installed using mud rotary drilling in Coastal Plain interbedded sands, silts and clays at depths of 20 to 70 feet (saturated screened intervals varied from 5 to 15 feet).

After a year of quarterly sampling using the revised method, comparisons with historical data revealed that for some wells there was an average 75% to 90% reduction in random variability for measurements of aluminum, zinc, manganese, barium, iron, cobalt, cadmium and copper. This average reduction in variability was observed for manganese data from 32% of all wells; for iron, zinc and barium data from 25% of all wells; and for 35% of the wells in which cobalt, copper, and cadmium were present. On the average, the reduction in random variability was accompanied by a 50% decrease in metal concentration. Turbidity measurements stabilized below 5 NTU in 38 of the wells sampled; stable values ranged from 0.2 to 50 NTUs and were generally achieved within 15 minutes to 1.5 hours. Since the revised method did not use filtering, the decrease in metals concentrations and variability can be attributed to a combination of the slower pumping rate and the addition of turbidity as a stabilization parameters.

# A Multi-Layer Sampler for the Study and Monitoring of Chemical Processes and Transport Phenomena in Aquifers

**Daniel Ronen**

## ABSTRACT

A multi-layer sampler (MLS) was developed and utilized for: a) sampling detailed undisturbed groundwater chemical profiles; b) sampling gases in both the saturated and the unsaturated zone; c) deriving detailed vertical profiles of the horizontal component of the specific discharge; d) characterizing suspended particles under natural gradient flow conditions. Sampling is based on the dialysis-cell method; the sampling volume is defined by the desired sampling interval. The MLS is portable, cheap and easy to operate.

The results of the field study conducted in Israel revealed: 1) intensive biochemical activity as reflected by the consumption of dissolved $O_2$ with the concomitant oxidation of organic matter and the development of an anoxic layer, and the production of $N_2O$ (up to 400 μg/l) and $CO_2$ (log $PCO_2$ from -1.7 to -1.3); 2) the presence of an almost stagnant water layer ($q = 0.5$ m/y) down to a depth of 60 cm below the water table; 3) the presence of microscale isothermal water parcels (characteristic vertical and horizontal length dimensions on the order of less than 1 m) which differ from each other in their chemical composition and density and are characterized by very sharp boundaries between them; 4) microscale Eulerian variations in the flux, mineralogical composition and size of suspended particles under natural gradient flow conditions ( q = 11 to 16 m/y). It is postulated that the gases produced during the biodegradation of the organic matter accumulate as a distinct gas phase (bubbles) down to a depth of 1 m below the water table, reducing groundwater flow. The replenishment of the aquifer by water of different chemical composition and the almost stagnant conditions prevailing at the water table region (where mechanical dispersion by advection is negligible) lead to the development of microscale parcels of water of different chemical composition. It is suggested that haline convection is a major transport and mixing mechanism at the water table region. It is also postulated that due to the dramatic increase in $pCO_2$ part of the carbonate cement of the rocks dissolve and detrital $CaCO_3$, quartz and clay are released as colloidal particles. In the prevailing anoxic conditions of groundwater at the study site (DO <1 mg/l) colloidal stability is enhanced by organic matter coating of particles.

# V.   Small Group Discussions Summaries

Prior to arriving at the workshop, participants were sent a package which included reference materials, brief abstracts for presentations on the first day, small group discussion topics and focus questions for the small group discussion topics.  In addition, the participants were queried as to their preference for small group discussion assignment.  These assignments were made based on participants' responses, and each participant was assigned to two topical groups.  The focus questions are provided as Appendix B of this document.  These questions were formulated by the Steering Committee in advance of the workshop and as a result of formal meetings, phone conversations, and other communications.  The small groups were directed to attempt to answer as many questions as possible during their respective discussions, but were also granted the latitude to let the group dynamics determine discussion direction as appropriate.

# V.    Small Group Discussions

## Participants
**(by topic area)**

*1.    MONITORING GOALS AND OBJECTIVES*

Group Leaders:  Barcelona, Brown

Participants:    Bourbon, Franks, Gronwald, Lee, Mabey, McKay, Park, Reece, Rightmire, Romero, Stelz, Teplitzky, Willey, Zavala

*2.    WELL DESIGN, CONSTRUCTION, AND DEVELOPMENT*

Group Leaders:  Aller, Gardner

Participants:    Connelly, Franks, Gray, Gronwald, McKay, Nielsen, Parker, Sara, Stelz, Taylor

*3.    WELL PURGING AND SAMPLING*

Group Leaders:  Puls, McCarthy

Participants:    Backhus, Barcelona, Connelly, Gibs, Hall, Korte, Mangion, Martin, Park, Parker, Paul, Pohlmann, Powell, Robbins, Ronen, White, Zavala

*4.    TURBIDITY AND COLLOID TRANSPORT*

Group Leaders:  Ryan, Mangion, Willey

Participants:    Backhus, Lee, Martin, McCarthy, Puls, Reece, Rightmire, Romero, Ronen, Sridharan, Taylor, Teplitzky, White

*5.    SAMPLE HANDLING AND ANALYSIS*

Group Leaders:  Pohlmann, Rosal, Beldsoe

Participants:    Bourbon, Brown, Clark, Gibs, Gray, Hall, Korte, Mabey, Nielsen, Paul, Powell, Robbins, Sara, Sridharan

# Monitoring Goals and Objectives

**Michael J.Barcelona and James R. Brown**

### Introduction

This group considered a number of questions dealing with the goals and objectives of monitoring efforts. From the outset it was recognized that there are a wide variety of monitoring purposes and programmatic goals--each with their own objectives. The group acknowledged that main objectives and the uses of data (i.e., both chemical and hydrogeologic) collected in monitoring programs change with time as the complexity and detail of subsurface conditions become apparent. The participants also noted that much has been learned about techniques which lead to more accurate and reproducible data collection. It was agreed that adoption of improved standards for professional practice in monitoring network design, construction, and operation should be encouraged; and that the use of error-prone monitoring techniques should be discouraged accordingly. In this regard the newest revision of Agency Guidance ("RCRA Ground-Water Monitoring: Draft Technical Guidance," EPA/530-R-93-001) goes a long way towards highlighting the differences between currently recommended practices and traditionally used practices.

### Objectives of Monitoring Programs

Monitoring objectives include four main types (i.e. detection, assessment, corrective-action evaluation and resource evaluation), along with "hybrid" variations such as site-assessments for property transfers and water availability investigations. Monitoring purposes and objectives may change as contamination or water quality problems are discovered. However, there are a number of common objectives for monitoring which should be recognized as important regardless of initial purpose. These objectives include: 1) Development of a conceptual model that incorporates elements of the regional geology to the local geologic framework. The conceptual model development also includes initial site characterization efforts to identify hydrostratigraphic units and likely flow-paths using a minimum number of borings and well completions; 2) Cost-effective and documented collection of high quality data utilizing simple, accurate, and reproducible techniques; and, 3) Refinement of the conceptual model based on supplementary data collection and analysis efforts which evolve in complexity and the level of spatial detail. These fundamental objectives would serve many types of

monitoring programs and provide a basis for future efforts as purposes and objectives expand.

### The Extent that Program Objectives, Site Characteristics, or Constituents of Concern Provide Criteria for Representativeness

The group noted from the outset that this topic applies to the representativeness of chemical and hydrogeologic data collected via wells, borings, piezometers, geophysical and soil gas measurements, lysimeters, and temporary sampling points. There is a need to get more quantitative about our definition of what representativeness entails in the context of controlled evolutionary site characterization and monitoring efforts. Representativeness arises from a recognition of the statistical variability of individual subsurface physical properties, and contaminant or major ion concentration levels with a need to explain extreme values. Subsurface variability is a fact and good professional practice should seek to maximize representativeness by using proven accurate and reproducible techniques to define limits on the distribution of measurements collected at a site. An investigative site characterization model was proposed to more systematically approach the goal of consistent data collection.

The model emphasizes a recognition of the causes of the variability (e.g., use of inappropriate technology such as using bailers to purge wells; imprecise or operator dependent methods) and the need to control avoidable errors.

### Flexible Sampling Designs for Meeting Multiple Monitoring Objectives

Detailed site characterization is central to all purposes and the basis for site characterization resides in the geologic framework and identification of major hydro-stratigraphic units. Fundamental data on subsurface lithology, head-differences and background geochemical conditions for example, should not change much (except to be refined appropriately over time). Each sampling point has a proper use or uses which should be documented at a level which is appropriate for the program's data quality objectives. While these sampling points cannot always fulfill multiple monitoring objectives (e.g., detection, assessment,

Program Objectives

Data Quality Objectives

Evolutionary Site Characterization        Sampling and Analytical Protocols

Protocol Application

Refined Protocols ← — — → Decision-Making
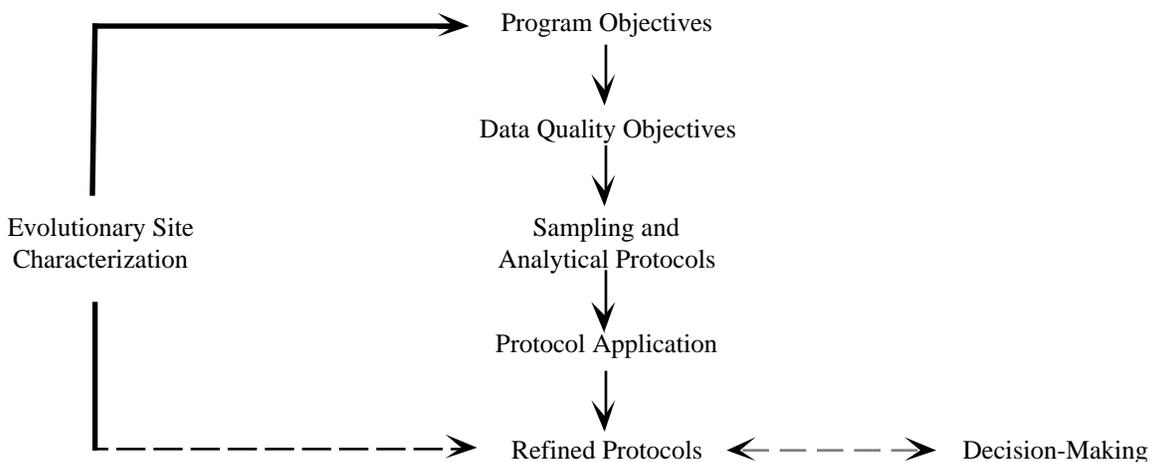
corrective action), the data that they yield will always contribute to the fundamental information needed for any monitoring program.

**Elements of a Sampling Protocol: Accuracy, Precision and Sensitivity Needed to Meet Monitoring Objectives**

A sampling protocol is a documented set of procedures and steps to accomplish a defined task. Since data quality objectives (DQO's) entail the identification of necessary levels of accuracy, precision, sensitivity and completeness for specific analytes (or subsurface properties), the DQO's should drive the complexity of the sampling protocols. It was recognized that data validation methods which focus solely on the analytical process do not assure that data will be of sufficient quality to meet DQO's. The major sources of controllable error occur in the field (e.g., wrong locations, poor technology choices, operator errors and incomplete documentation), and it is vitally important to discourage the continued use of methods proven to be inadequate to meet DQO's. Suggestions were made to expand educational efforts on technology choices, and the potential usefulness of QA summary reports which apply to field as well as laboratory data collection efforts.

**Application of Field-Screening Techniques and Related Performance Criteria**

The value of field-screening techniques to aid in evolutionary site characterization and assessment efforts has been documented in the literature. Since detection efforts involve the evaluation of potential pathways for contaminant movement, and assessment efforts focus on the extent of movement through such pathways, their

monitoring objectives and DQO's are comparable. The levels of accuracy, precision and sensitivity for many constituents of concern approachable by field techniques are sometimes equal to laboratory-based analytical techniques. In some cases (e.g., volatile organics) the use of field techniques may be favored over lab analyses because sample handling, storage, preservation steps are minimized or eliminated prior to sample analysis. Laboratory methods have the advantages of higher sensitivity and specificity (e.g., mass-spectrometry). Their use should be encouraged for confirmation purposes.

In all cases, the performance criteria for all screening methods (including chemical analyses and hydrogeologic analyses), should be determined by the data quality objectives of the monitoring program. After the DQO's are established, field screening procedures/tools can be selected on the basis of their performance capabilities.

Criteria for the use of field screening methods should include: 1) documentation of daily calibration and method control with external standards/audits; 2) laboratory confirmation of a percentage of samples; and, 3) development of a field methods manual analogous to laboratory CLP manuals under Agency auspices.

It is essential that continued training and overall quality improvement should be undertaken to maintain/elevate field practice to the state-of-the-art level. This should include training courses, technical information transfer of important scientific publications, and some form of certification and auditing. The use of "ASTM-like" standards and quality control summary reports would result in quality improvement of hydrogeologic field work.

## Factors (e.g., Sampling Techniques, Extraction Rates, and Location ) that Influence Monitoring Objectives

The group consensus was that program objectives influence the approach and complexity of the sampling and analytical protocols, and not vice-versa. Program objectives are usually motivated by regulation, although considerations of experimental design establish monitoring objectives for research projects. There will always be difficult situations where the availability of water (e.g., low yielding formations), accessibility of specific hydrostratigraphic units, or unpredictable gradients may need to be factored into the objectives; but the specifics of sampling protocols should always be traceable to the DQO's.

## Chemical or Physical Speciation of Contaminants Influence on the Design of a Monitoring Program

Speciation includes the individual physical (i.e., sorbed, colloidal, etc.) and chemical (i.e., mineral, complexed, varying oxidation states) forms of an element or compound which make up the total amount present in a subsurface sample. The potential for multiple species with differences in mobility, toxicity, and stability should necessarily expand the scope of program objectives and influence the detail and rigor of DQO's, sampling, and analytical protocols. In these instances, renewed focus on the characterization of background conditions and the total mass distribution of contaminants becomes very important regardless of program purpose. The proper selection of sample location and sampling for the media in which the bulk of contaminant mass may reside rather than symptoms (e.g. soil, gas or $H_2O$ for sorbed contaminants) are of major concern in this regard.

In addition, the hydrogeochemical conceptual model of the site is as important as the site's geological conceptual model. Ion balance and geochemical assessments should be performed.

## Alternative Methods for Designing Monitoring Networks

Given the fundamental value of a site geologic framework consistent with regional hydrogeology and likely contaminant behavior, alternative design methods include: 1) the diagnostic use of a flow and transport models to select sampling locations where they can provide the most information return; 2) Coupled field-screening/conceptual model refinement and modeling work confirmed by further site characterization and assessment efforts; 3) Integrated use of geostatistical, stochastic fate and transport, and optimization models applied in iterations to identify likely limits on mass distributions and benchmarks for performance as site-characterization proceeds. More sophisticated methods such as decision-analysis/

optimization techniques should be made more accessible to the practitioners via technology improvement and transfer efforts.

## Documentation of Well Construction and Well Development (Extends to demand criteria, three-dimensional site characterization, and sampling protocols)

The group was unanimous in acknowledging the need for improved standards for professional well construction and development practices. This need demands improved detail in documentation of monitoring efforts. Useful inclusions are: geologic descriptions of core material, grain-size determinations prior to well screen design and construction, and the development of meaningful criteria for well development, purging and sampling. Extending the rigor of traditional laboratory-based QA/QC procedures to all aspects of field activities would result in substantial improvements in practice and the value of monitoring data for decision-making.

# Well Design, Construction and Development

## Linda Aller and Steven Gardner

The purpose of a monitoring well is to create a point within the desired monitored zone such that an "unaffected" representative sample can be collected. While the ease or difficulty with which this can be accomplished is dependent in part upon the hydrogeologic setting, additional questions arise in almost any situation. These questions extend to include whether or not even an effective water-level sampling point can be designed in fine-grained materials and fracture-flow dominated formations. More widespread, pervasive questions arise as to what effects the process of drilling and installing the well have on the analytical samples that are desired to be collected from the well. The purpose of this section is to focus on the "artifacts" that are introduced in the well installation process and on the ways and means that are currently available to minimize these effects.

Artifacts can be defined as unwanted residual effects. These effects are introduced through both the drilling process and the well installation process (often through the materials added) and may be either enhanced or minimized by the development process. Other sources of artifacts, such as interconnection of formations, are also of concern. A discussion of the potential artifacts and possible minimization of those artifacts is contained in the following paragraphs. Areas where additional research is needed are also noted.

### Drilling Artifacts

#### *Drilling Techniques*

Drilling techniques are the crudest link in the drilling, installation and sampling scenario. The drilling methods employed to install monitoring wells were adapted from the water well, soil dynamics and oil industry. None of the technologies provided by this historical base have been adequate to provide the rigorous quality control needed for monitoring wells. This is clearly evident when the complexities of the chemical environment being monitored are carefully considered. Typical drilling techniques used for monitoring well installation have been described by Aller et al. (1989), Sara (1994) and USEPA (1992). As such, it is only recently that these techniques are beginning

to be modified to reflect monitoring needs. Smearing of borehole walls, compaction of borehole walls, transport of formation material and drilling fluid into different zones are all areas where artifacts are of concern.

The smearing of borehole walls is a concern where conventional augering techniques are employed or where casing is driven and then pulled back. The smearing effect seals off fractures in fine-grained formations, thereby potentially reducing the amount of flow to the well or even sealing off the formation of concern entirely. Because fractures are typically the most prominent pathways for contaminant migration in the fine-grained formations, the question arises as to whether or not the contaminant pathway has been blocked such that the contaminant will be present in the formation but not be found in the well. One way to minimize smearing of the borehole wall is to minimize auger rotation in the screened zone. The concept is that if the auger can be simply "screwed" in and then retracted without turning, the smearing will be less. Although this can be performed relatively easily in most formations, the typical drilling procedure used is to rotate the auger to move cuttings up the annulus, thereby minimizing the amount of shear that the rig must overcome when withdrawing the augers. There is much practical experience in this area, but little published research that better defines the drilling process and the formation constraints. The working group identified a research need to develop more effective ways to minimize this smearing artifact.

Compaction of borehole walls and transport of formation material is of concern in both augering techniques, casing driving, and in rotary drilling. Compaction of the borehole walls is similar to smearing of the walls as discussed above with the concern being that pathways and therefore contaminants are possibly "shut off." Transport of formation material, along the borehole, downward into the screened zone, is a concern where upper contaminant zones are present. The amount of contaminated material necessary to cause a detection with today's detection limits of parts per quadrillion is minimal. Several techniques for installing monitoring wells in areas where this is a concern have been successfully used. Keely and Boetang (1987) have written about driving casing while augering. Other multiple casing

methods for installing surface casing through the contaminated zone and then drilling deeper have also been successful.

### Drilling Fluids

There is substantial question created by the use of drilling fluids during drilling with regard to artifact effects on the monitoring well. Drilling fluids can be air, water or drilling mud. Using air as a drilling fluid can cause chemical changes in the formation due to oxidation. Lubricants in air necessary for compressor operation can result in the introduction of hydrocarbons through air entrainment into the formation. Use of an in-line filter that has not reached its useful life capacity can minimize this risk.

Adding water as a drilling fluid can: flush and dilute indigenous water; change formation chemistry; precipitate certain minerals, possibly seal off preferential pathways of flow to the well, and substantially alter the soil and water chemistry in the vicinity of the bedrock. Where water is used, the amount of water added should always be measured and the chemistry of the water should be known. Where water is added, the question of how much water must be removed in order to "get all the water back out" assumes that no chemical changes have taken place and it is a matter of just recovering the injected water. Although the amount of water varies by formation and flow characteristics, the rule of thumb for removal of three times the volume added is frequently quoted. Using no water or minimizing water use is the preferred alternative. One alternative is to pump out and reuse formation water where the use of water is needed. Some of the problems with the uses of drilling fluids are discussed in Schalla (1986).

Other concerns related to drilling fluid include the use of drilling mud and additives and the use of lubricants on piping and joints. Drilling with mud involves the formation of a filter cake on the borehole wall as an integral part of the drilling process. Mud intrusion into the formation occurs as part of the drilling process. The depth of intrusion is a function of the geologic formations as imparted by other factors such as wall cake thickness and character. There is always concern that the mud filter cake (wall cake) will not be completely removed during the development process. The result will be that, once again, significant pathways of contaminant migration are permanently sealed off (particularly in fracture-controlled flow). Of concern also is that the clay-sized particles in the mud will attenuate any electrically charged contaminants that do migrate toward the well. Because mud is difficult to remove during the development process, the use of mud should be restricted. The use of additives in mud to overcome drilling difficulties is also inappropriate. This practice simply furthers the potential to cause physical or chemical changes that will be

introduced and remain as a result of the particular additive. Brobst and Brobka (1987) discuss the effects of drilling fluid on sample chemistry.

The use of downhole hammer lubricants and petroleum-based lubricants on rotary drill pipe connections are of concern in monitoring well drilling. However, some type of lubricant is necessary for the drilling machinery to operate without damaging the equipment. Where lubricants are essential, there are non-petroleum based synthetics that are better choices for lubricants.

## Installation Artifacts

### Casing/Screen Artifacts

Installation artifacts are a result of casing and screen materials and/or annular fill materials. Artifacts due to casing and/or screen materials include: long-term incompatibility of casing/screen materials with formation water quality; short-term casing/screen impacts by sorption/ desorption and leaching; impacts by solvent cements; and leakage through casing joints. The ability of the casing and screen material to resist degradation by the water with which it will come into contact is paramount from two different standpoints. First, what are the immediate water quality effects during sampling and second, what are the water quality effects when the casing/screen materials deteriorate and allow water to migrate along the borehole? The corrosion of metal casing has long been a concern in acidic environments. The swelling of polyvinyl chloride (PVC) by solvents is also documented. These are real concerns that should be addressed by choosing casing/ screen materials that are long-term compatible. When wells are installed to meet short-term goals (ie. less expensive materials that might not be longterm compatible), the well may or may not stay a short-term well. Frequently, wells are required to remain in place for a regulatory purpose. In other situations, cost of abandonment may become a factor as funding or priorities change and the well will remain. Finally, personnel familiar with the concept of short-term versus long-term well installation and any anticipated incompatibility problems may be disengaged from the job. With this loss, others may not recognize that a potential problem exists and the well is left in place. Therefore, prudent monitoring well installation does not employ incompatible casing/screen materials.

Short-term effects on sample integrity due to: leaching of analytes of interest or analytes that interfere with analyses; sorption of analytes of interest; possible desorption of analytes of interest should water quality improve; and diffusion of organics through polymeric materials, are also of concern in some environments. Significant discussions

of the "real effects" of different materials including PVC and PTFE are included in the following papers: Bianchi-Mosquera and Mackay (1992), Cowgill (1988), Gillham and O'Hannesin (1990), Hewitt (1989), Hewitt (1992), Jones and Miller (1988), Parker (1991), Parker (1992), Parker et al. (1990), Reynolds et al. (1990), Miller (1982), Reynolds and Gillham (1985), Barcelona and Helfrich (1986), Barcelona and Helfrich (1988), Barcelona et al. (1983), Barcelona et al. (1985), Barcelona et al. (1988), Marsh and Lloyd (1980), Barcelona (1984), Junk et al. (1974), Boettner et al. (1981), Curran and Tomson (1983), Parker and Jenkins (1986), Tomson et al. (1979), and Rivett et al. (1991).

The use of solvent cements in joining polymer casings is inappropriate due to dissolution of the cements and subsequent detection in samples from the wells. Sosebee et al (1983) have documented these problems. The industry, therefore, uses flush-joint threaded casing. However, these joints are of concern when, or if, they are not sealed properly and allow water to enter the well. The use of o-rings and/or wrapping national pipe thread threads (NPT) with polyfluoromer tape minimizes leakage potential. If tape is used on threads that are not NPT, the tape may actually increase the potential for the joint to leak. The American Society for Testing and Materials (ASTM) Standard F-480 specifies pressure ratings for the joints in polymer casing. Usage of materials following this standard with a pressure rating of 25 pounds per square inch (psi) or greater will minimize the potential for joint leakage.

### Annular Fill Artifacts

The materials that may be used in the annular space during monitoring well installation include: the filter pack; fine sand on top of the filter pack to minimize grout contamination; bentonite; bentonite/cement mixtures and cement. All materials may cause sampling artifacts if not installed properly or used in inappropriate situations. A filter pack should consist of inert, non-reactive materials. Not all sands are silica and therefore the material used as a filter pack should be verified during monitoring well installation.

Bentonite is typically added to a monitoring well above the filter pack to minimize grout contamination. The use of bentonite as a "seal" against contaminants is a misnomer. Bentonite is available in a variety of commercial forms and is added either in solid form (by pellets) or in the form of a slurry. If bentonite is introduced in such a manner that formation water moving toward the well screen contacts the bentonite, sorption of electrically-charged contaminants, both organic and inorganic, sorption by the clay particles will occur. In this setting, contaminants within the formation may either be detected in the well in concentrations less than the formation, or not at all. One solution to this situation is to add a physical barrier between

the bentonite and the filter pack, such as a packer. Another approach to this problem is to add a layer of fine sand between the bentonite and the filter pack.

Many questions about the proper use of, and effective emplacement of, bentonite have arisen. If granular bentonite is added to a well and adequate time for hydration is not allowed, the bentonite may not provide the intended purpose. The time of hydration varies by pellet size, but it is questionable whether or not a hydration time less than two hours is appropriate in any situation. When granular bentonite is added through a standing water column, there are questions about whether or not the pellets will "bridge" selectively and thus leave pathways for unwanted water to enter the annular space. Although many pellets are "coated" to delay instant hydration when falling in a water column, it is generally agreed that the maximum column of standing water through which pellets should be attempted to be dropped is 30 feet. Documented studies by manufacturers or researchers are necessary before this recommendation can be changed.

Bentonite is a clay with a high shrink-swell potential. This property makes it effective as long as it remains hydrated. When the bentonite dries out, it shrinks and cracks. The use of bentonite in the unsaturated zone is questionable because of the ability of the bentonite to stay hydrated in the unsaturated zone. Whether or not fully hydrated bentonite will stay saturated in the unsaturated zone in the presence of capillary action on the clay is questionable. The conditions under which the bentonite will remain hydrated are related to the formation material with which it is in contact. If the bentonite does not stay saturated, the clay will crack and an unspecified amount of time and moisture will be necessary to re-swell the clay. The concern is that these cracks will allow rapid movement of contaminants along the annular space in this area until sufficient moisture re-hydrates the bentonite. Restricted use of bentonite in the unsaturated zone is recommended until research has been conducted to determine whether or not fully hydrated bentonite placed the unsaturated zone will remain fully hydrated. Field experience indicates that in some cases, the bentonite dehydrates. Research is needed.

Use of bentonite as an additive to cement is a popular practice. Originally, the bentonite was added to control shrinkage of the cement when it cured and to improve its pumpability. Halliburton research on bentonite/neat cement mixtures indicates that bentonite does not control shrinkage. Research is needed to determine if and where the use of bentonite/cement mixtures are appropriate and/or desirable.

Cement is typically used to fill the annular space above a

bentonite "plug" to the surface.  Cement, if it enters the filter pack, can significantly raise the pH of the water.  Concerns about the precipitation of cations, and elevation of specific conductance are valid if cement contamination of the filter pack occurs.  Steps should be taken to make sure that either fine sand or properly emplaced and hydrated bentonite is used in the well and properly separated from the well screen.  Mixing neat cement at a ratio of 5.5 to 6 gallons of water per 94 pound bag of cement will also minimize grout infiltration by decreasing the mobility of the grout.  When adding cement to the well below the water table, or in wells with an unsaturated zone greater than 20 feet, the grout should be emplaced using a tremie discharge pipe and pumping grout from the bottom of the formation until returns are seen at the surface.   Emplacing cement with a submerged discharge tremie pipe reduces the risk of contamination, through weak zones developing in the grout.

### *Development*

Development is the process by which all artifacts from drilling are supposed to be removed from the well.  However, development becomes more difficult when it must penetrate into the filter pack and/or formation.  For example, the cutting head of a 4.25-inch ID Central Mine Equipment auger creates a borehole of 8.25 inches.  However, Mobile augers create an 11 inch borehole for a 4 inch ID auger flight.  If two inch monitoring wells are installed in this borehole, the filter pack thickness will range between approximately 3 inches and 4.5 inches if the screen is perfectly centered in the borehole.  Removing smearing effects from the borehole wall through the filter pack is difficult, if not impossible.  Other methods have similar limitations, particularly those such as mud rotary that produce a "skin" effect on the borehole wall.  It is very difficult to remove this modified surface from the entire screen length.

Other concerns about development relate to air entrainment, addition of water, and problems caused by excessive sediment in the well during development.  Entrainment of air in the formation has traditionally been associated with development by air lifting.  Acceptable methods of development in monitoring wells do not include air lifting because of the potential for the air to cause chemical alteration of the formation water, to oxidize and/or precipitate constituents within the formation and to physically "block" the formation with air if the well becomes "air-locked".

The addition of water during the development process is a questionable practice.  The addition of water to the formation dilutes the indigenous water and can cause chemical changes resulting in undesirable chemical reactions within the formation.  Precipitation of constituents can physically block pathways of migration for

contaminants.  Water may not be able to be retrieved from the formation and thus may alter the water chemistry permanently.  Most formations should yield enough water to be developed using the formation water if proper methods and techniques are utilized.  The addition of water to compensate for choosing an inappropriate technique is not acceptable.  If enough time is allotted, most wells can be developed with formation water.  This may involve the process being repeated over a number of days in low yield wells.  If water is added, the amount of water that will need to be removed varies based on formation, flow paths and flow regimes.  In the absence of better data, the rule of thumb is to remove no less than three times the volume of water added.  The water should be removed as soon as possible.

Excessive sediment in a monitoring well during development is a concern because of the potential to force the fine sediments into the formation and not be able to retrieve the sediments. Clay-size particles and some clay mineral particles have the potential to sorb contaminants from ground water and also to reduce pathways of migration for contaminants. The latter is especially true in formations where flow is fracture-controlled. The problem of excessive sediment in a monitoring well during development can be minimized by using appropriate development methods and proper techniques. The use of a well "sump" is not a substitute for inadequate development or improper well design.

Monitoring well development should be conducted using only a combination of the following methods: surging/ pumping or overpumping/backwashing. Surging is conducted by using a surging tool that is manufactured or made in the field. The critical design elements of a surging tool are a relatively close fit with the casing and means in the tool by which the water may pass through the tool so that the casing will not collapse during development. During surging, the development takes place by surging an interval (usually approximately two feet), beginning at the top of the screen and continuing until the screen is completely developed. The sediment-laden water must be removed between every interval or two (depending on the amount of fines in the water) to minimize forcing fine material too far into the formation.

Overpumping and backwashing rely on the same principle of moving water in and out of the formation to dislodge and move the finer particles into and out of the well. Methods that only pump in one direction are usually ineffective in proper well development. Historically, a major problem has been that most drilling rigs that are used to install monitoring wells are not properly equipped to develop monitoring wells. This is particularly true with regard to surging and pumping, alternatively.

The most frequently made mistake in well development is "giving up." It is important to recognize that adequate development takes time. Development time may range from two hours to more than three days in order to be effective. Remember that the thicker the filter pack, the longer the development time required, and the greater the energy requirement for surging.

Properly designed wells with appropriately sized well screen and filter packs also minimize well development time. Traditionally monitoring wells were installed with either a 10 or 20-slot screen and a filter pack of material that would bridge (80% or more) on the selected slot size. This "design" is often unsuitable in extremely fine-grained silts and clays, with the resultant wells being high in turbidity when sampled. Very little research has been done on very fine grained, pre-packed filters, ceramic filters, etc. and their impact on sample quality. References on monitoring well design and found in the American Society for Testing and Materials Standard D5092-90 (1990), Aller et al. (1989) and Nielsen (1991).

Questions as to how much of a filter pack volume will be removed during development and the effect that volume reduction will have on the integrity of the well are significant. Similarly, loss of the filter pack to the formation and concomitant volume reduction and associated effects were also questioned. It was agreed that appropriately designing the well with a screen and filter pack picked for the formation at hand should minimize this concern. However, research into these related problems is warranted.

**Other Artifacts**

Other artifacts that may affect the chemistry of water in the monitoring well include: microbial activity in the well; interzonal leakage across a screened zone; and migration along a casing due to ineffective grout adherence to casing materials. Microbes in the well, particularly what are known collectively as "iron bacteria", are not uncommon. These microbes have the capability to alter the natural chemical environment and change reducing conditions to oxidizing conditions and vice versa. The magnitude of the effect of these organisms are not known because the organisms are not well understood. In the water well industry, these organisms are considered as a "nuisance" because they are not toxic. The traditional methods of rehabilitation that have been used to temporarily destroy their protective sheaths are inappropriate in a monitoring well due to addition of chemicals to the well. The chemical methods used in water wells have been relatively ineffective over time. The full effect of these organisms in monitoring wells is not known. This is an area where research is warranted. Clearly, field procedures are lacking.

Where screens cross more than one zone of flow with different hydraulic gradients, two concerns are raised. First, the potential for mixing in the borehole exists; and second the opportunity for interzonal mixing through the well and into the zone with the lower hydraulic head exists. The concern can be minimized by understanding the flow characteristics of the site, developing a site hydrogeologic model and using short, specific screen lengths were the situation is anticipated. It is commonly, and incorrectly assumed, that there is generally "mixing" in an aquifer that is considered to be hydraulically "isotopic". This fails to recognize that most samples are zone specific, and dependent upon specific flow lines.

Questions as to the adherence of casing to certain types of grout have been raised as a possible source of contamination along the casing. Kurt and Johnson (1982) and Molz and Kurt (1979) have looked at some of the issues of grout adherence to casing and effects of temperature on casing materials.

**Well Design**

*Traditional Thinking*

Many of the artifacts mentioned above are the result of the acceptance and desire to install traditional monitoring wells with traditional methods. Indeed the most frequently installed size monitoring well is two inch ID, although some states require four-inch wells in certain programs such as hazardous waste monitoring or underground storage tanks. Further, company policies may also dictate the installation of four-inch monitoring wells. Some deeper wells are also larger diameter and some older wells were built in the days when sampling equipment required larger diameters.

Wells are traditionally installed to address one or more of the following objectives: regulatory monitoring; water level measurement; hydraulic conductivity determination; or " other investigative reasons". Inherent in the "typical thinking" is the necessity to design a monitoring well that will yield enough water to collect the volumes of water necessary to test for regulatory purposes. While this may be desirable, it may not always be practical in low-yield formations.

*Low Yield Formations*

Conventional monitoring well designs are inadequate to meet all the objectives of representative monitoring in low-yield formations. In order to obtain a reliable water quality sample, it is desirable not to dewater the top of the screen when collecting a water sample. It is desirable, in fact, not

to lower the water level at all. This either requires a change in thought pattern or an inventive sampling methodology (which was summarily decided to be outside the scope of this group and to be determined by others).

If it is possible to change our frame of reference, then other options for designing low yield wells exist. Perhaps special purpose wells should be considered. The use of pore water samples from cores may be appropriate in some situations. McKay (1993) has used one-half inch well completions in low yield formations in order to try to minimize many of the artifacts previously discussed. Installation of a small diameter well in a pushed shelby tube, split spoon hole or with a drive point may minimize the smearing effect associated with augering. These types of completions will necessarily limit the sample volume available at any one time. Typically the sample collection rate should be limited to the recovery rate of the well. If the water level is held constant in larger diameter wells, the effect is the essentially the same.

Determination of what is a low-yield formation is particularly important, but difficult with current methods and thinking. It is inappropriate to use only grain size for determination as to when a conventional well design is appropriate. The depositional model, stratigraphic model and diagenetic model are all essential. In fine-grained formations, the fracture flow pathways may override the significance of grain size. McKay et al. (1993a; 1993c) has discussed flow and flow rates in fine grained deposits. One strongly identified research need is for development of better and more accurate ways to measure hydraulic conductivity on a meaningful scale in low-yield formations.

Other traditional problems with turbidity in fine-grained formations were raised. A research need was identified to determine whether or not low flow sampling techniques always yielded turbidity-free samples, (e.g. how is colloidal transport being sampled?).

### Fractured Rock Completions

Open hole completions have been common in the water well industry in fractured rock in order to maximize the amount of water that enters the borehole. However, open hole completions in monitoring wells are not acceptable. Fractured rock monitoring wells should be designed to prevent cross contamination between zones of different hydraulic head as discussed above. The identification of specific zones to be monitored is often very difficult in a rock hole. This technology is to be dealt with elsewhere.

### Overall Monitoring Issues

The discussion about the "true" definition of aquifer in the monitoring well context has been discussed since it has been

desirable to monitor low yield formations. However, the important concept to remember is that monitoring of an aquifer may be desirable, but monitoring of pathways for migration is essential. This necessitates monitoring of zones that have not traditionally been considered as aquifers.

An adequate monitoring well network cannot be designed until a site investigation is completed. For site investigations and monitoring well installation to be effective and to reduce unwanted artifacts, qualified, trained geologists as well as drillers and helpers are needed in the field. Unfortunately, less experienced geologists are traditionally relegated to the field while the "more experienced" personnel move on to more prestigious office and management assignments. This is due, in part, to cost-saving measures by the customer as well as the provider. Further, many of the "field personnel" are not adequately trained, if at all, to make the important field decisions. Indeed, many do not even know that they are making important decisions. Either a complete attitude change is necessary to assign trained individuals to the field, or a more formalized training process is necessary for field personnel. Certification is not necessarily the answer; training is.

Part of a successful site investigation is in depth description of the geology and hydrogeology at the site. In order for the appropriate level of detail to be developed complete and accurate description of samples is necessary. Part of this process relates to training and experience; part relates to the type of information that needs to be collected. There are many classification systems that provide guidance as to the types of information to record when visually classifying samples. The Unified Soil Classification System is most frequently used because it was developed to identify important engineering properties. While these characteristics are important, additional descriptions such as environment of deposition, diagenetic changes, hydrostratigraphic units and lithofacies descriptions are equally important for determining pathways of migration. Characteristics, such as color, must be defined in a reproducible manner. An accepted classification system or combination of systems is necessary to adequately describe lithology for monitoring well purposes. The use of standard references, such as color charts for both soils and rock, add reproducibility to the description. Descriptions of many of the parameters that should be recorded are described in Sara (1994).

Monitoring well design, construction and development are the most important part of a monitoring system. When compared with analytical costs, the installation and development is the least expensive portion of the sampling process. However, costs are typically cut during the installation phase. Later, considerable sums of money are spent on repeat analytical results to justify or rectify poor or inadequate installation. Awareness needs to be raised as to

the importance of spending adequate sums of money up-front for long-term benefit.

Questions were raised as to whether or not it is appropriate to make generalizations about design considerations for hydrogeologic settings. The consensus was that for overview purposes, generalizations were appropriate, but for detailed design this approach was inappropriate. Site specific information and monitoring objectives should always be considered in lieu of using generalizations.

One last statement about monitoring well installation that has been widely publicized, but that is still important is the presence of adequate annular working space during monitoring well installation. A minimum two inch working annular space is necessary to minimize bridging of annular fill materials and to maximize the central placement of the screen within the well. However, it must be remembered that where this annular space is filled with gravel or sand-pack around the screen, the larger the annular space the more difficult the development.

## Summary of Important Items

### General

Although many items were discussed the major points of discussion are summarized as follows:

1) A site investigation must be completed before an adequate monitoring well network can be chosen.

2) We are interested in monitoring "pathways of migration", not necessarily "aquifers" by definition.

3) Do not skimp on monitoring well costs because design, construction and development are the most important parts of the system, and the least expensive over the long haul.

4) Conventional monitoring well designs are inadequate to meet all objectives in low hydraulic conductivity formations. (Detection monitoring water sample volumes may not be possible.) Grain size alone should not be used to determine when conventional wells are appropriate. We need to change our frame of reference. We are not monitoring system "averages" or "typical" zones. We must monitor potential pathways of contamination.

5) Methods are needed to monitor in low hydraulic conductivity formations. Better ways to measure

and evaluate hydraulic conductivity in low hydraulic conductivity formations are needed.

6) There is a need to expand (and possibly standardize) existing visual classification systems for samples (i.e. USCS or other) to include geologic interpretation of environment of depositions and hydrostratigraphic units.

7) The need for qualified, trained field personnel is emphasized.

### Special Considerations

The following were considered important special considerations that should be considered in the future:

1) The use of special purpose wells in low hydraulic conductivity formations (i.e. one half-inch well, lysimeters) should be considered;

2) The use of pore water samples should be considered in low hydraulic conductivity formations;

3) Long, open-hole completions in fractured rock are inappropriate due to the potential for inter-formation migration; and

4) Guidance on well design can be developed for hydrogeologic settings where broad-scale overview and knowledge transfer is the objective. However, this approach is not appropriate for detailed well design.

### Research Needs

1) Smearing along borehole walls during monitoring well installation, particularly in auger drilling, was identified as a problem particularly in low hydraulic conductivity formations and/or where the clay content of the formation is relatively high and flow is primarily in fractures. A research need was identified to better define the components that cause smearing and to suggest and/or design alternatives to overcome and/or minimize this problem.

2) Bentonite is sometimes used in the unsaturated zone as an annular fill material. A research need was identified to answer questions as to whether or not fully-hydrated bentonite placed in the unsaturated zone remains fully hydrated over time. If the bentonite desiccates in only certain situations, these circumstances need to be identified.

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3) Low hydraulic conductivity formations are difficult to monitor using traditional monitoring well designs. However, effectively defining a low hydraulic conductivity formation is even more difficult. Traditional methods for measuring hydraulic conductivity have been proven to yield hydraulic conductivity values orders of magnitude too low. A research need was identified to develop testing methods (both in the laboratory and in-situ) that will be more representative of the flow characteristics of the formation that intersects the fractures as well as through the bulk of the formation.

## Guidance Needs

There was strong agreement that guidance on wells in low conductivity formations needs to be developed.

## Reference Documents

There are many documents that will help to understand the issues that were discussed by this group. The following documents provide basic information and contain references on additional subjects. The reference section contains additional references that deal with more specific subject matter.

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# Well Purging and Sampling

## Robert W. Puls and John F. McCarthy

Traditional approaches to purging and sampling ground water involve purging a well at a high pumping rate until a fixed number of casing volumes (usually 3-5) is evacuated, followed by sample collection at a lower pumping rate. This approach has raised concerns about the representativeness of samples collected using these methods, especially if the sampling objectives include monitoring of contaminants. Briefly, the concerns include entrainment of immobile particles (Puls et al. 1992) and the possible need to filter samples to remove those artifacts (Puls and Powell, 1992; Backhus et al. 1993), costs of pumping and disposing of large volumes of contaminated water (Barcelona et al., 1994; Korte and Kearl, this report), and uncertainties in interpreting the source of the sampled water (Martin-Hayden and Robbins, in revision). The goal of this discussion group was to evaluate approaches to purging and sampling and determine if new techniques should be recommended. Group discussions addressed questions related to the objectives of purging, methods of well purging and sampling, the advantages and disadvantages of low-flow rate purging, site-specific considerations in purging and sampling methods, and trade-offs among sampling devices.

The general consensus of the discussion group was that, in many cases, new methods should be adopted for purging and sampling wells; the recommended method is generally referred to as low-flow, minimal drawdown purging and sampling. The principal differences between this and more traditional approaches centers on the rate of pumping and the criteria for deciding that purging is complete. The newer method calls for slow flow rates for purging and sampling in order to minimize chemical and hydrological disturbance in and around the well. Furthermore, the completion of purging is gauged on site-specific chemical criteria (stabilization of water quality parameters) rather than on a fixed number of well volumes pumped.

### Objectives of Well Purging

The objective of well purging is to obtain formation water from the targeted sampling point with no alteration of water chemistry. The location within the subsurface from which that formation water is actually drawn depends on a number of factors including how we purge. There was general agreement among the members of the discussion group that water in the well casing, and perhaps even water in the screened interval of the well, is different than the formation water. This is due to a variety of factors including the following: gas diffusion into and out of the standing water column, potential alteration of water chemistry from contact with the well casing, filter pack and annular sealing materials, and surface infiltration. The similarity of the water in the screened interval to that of the formation will depend on the following: ground water flow velocity and direction, screen length, well diameter, well depth, distance from the screen to the water table, geologic and hydrologic heterogeneities in the screened interval and the degree of connectedness of the well to the aquifer. It was also generally agreed that these same factors and considerations would apply whether the sampling approach involved 'portable', or 'semi-permanent' dedicated sampling systems, multilevel samplers or whether the sampling was carried out in monitoring wells or using screening tools (e.g. Geoprobe). The volume of water that needs to be purged to obtain formation water will, however, depend on the particular sampling approach, and monitoring system selected, and the hydrogeologic characteristics of the site.

### Methods of Well Purging and Sampling

It was generally agreed by the discussion group that disturbance of the sampling zone or point should be minimized and that purging methods which tend to alter water chemistry or the integrity of the sample should be avoided. The objectives of the sampling program should be considered in selecting a purging method. There was general agreement that consistency and adequate documentation are essential and currently lacking in many sampling programs.

For purposes of site assessment and remedial performance, low-flow purging which produces minimal drawdown of the water table was generally recommended, with no change of flow rates during sampling. Conceptually, formation water flowing across the screened section of the well is sampled no faster than it enters the well bore under natural hydrological flow conditions. The criteria for the appropriate rate for purging and sampling is hydrological: pumping rates should produce no net (or at least minimal) drawdown of the water table. There are several advantages to this method, a principal one being that the volume of purge water is much less than for more traditional purging methods. Low-flow sampling conditions have been demonstrated to remove water from only the screened zone, without the need for packers to isolate the stagnant

overlying casing water (Powell and Puls, 1993; Gillham et al. 1985; Robin and Gillham, 1987). Although flow rates are slower, much less water needs to be purged, with the benefit that, in contaminated sites, a much smaller volume of water will require subsequent waste disposal. More fundamentally, however, a key benefit of the decreased volume of purge water is that a smaller section or volume of the aquifer is sampled. This represents a significant improvement in our ability to detect and resolve contaminant distributions, which may vary greatly over small distances in three-dimensional space.

The traditional method of evacuating a standard 3-5 well volumes samples a much larger portion of the aquifer, and provides a larger volume-averaged concentration. That averaged value is directly related to the volume of water purged, the geologic setting, and the placement of the sampling point. For some sampling objectives, such as determining a large volume-averaged number for water resource analysis purposes, the traditional approach may be valid. However, much of the discussion centered around contaminant detection and long-term monitoring at landfills and hazardous waste sites. In most cases, the large volume of aquifer sampled complicates interpretation of data concerning the concentration and spatial distribution of contaminants. If the well screen is long and intersects only a small portion of a contaminant plume, a biased low concentration value would be produced due to mixing of uncontaminated portions of the aquifer. Similarly, in a fractured clay or rock, most of the water comes from the fractures. Because the fracture porosity is so small, the sampling process may draw in water from a very large volume of the deposit. This could greatly dilute the concentration of contaminants in the sample.

Recent research has highlighted the significant chemical and physical heterogeneities that exist even within porous media (Davis et al. 1993; Nikolaidis et al. 1994). Flow problems analogous to those associated with fractured rock can occur in granular aquifers due to vertical heterogeneities in hydraulic conductivity in typically layered sediments (Hess et al. 1991). For this reason, it was generally agreed that for many sampling purposes the use of smaller screen lengths (1-5 ft) was best. Multi-level samplers, which are available in combination with pumps or which use dialysis cells for the 'passive' collection of water (Ronen et al. 1987), were also recommended for further resolution of the spatial distribution of contaminants in a formation. These sampling devices may the best choice for sampling water in low-permeability formations and in fractured rock (in combination with packers). It was suggested that low-flow purging and sampling techniques or the use of multilayered sampling devices might also be capable of obtaining useful information in long-screened wells. However, this would depend on the establishment of good hydraulic connection between the well and the adjoining formation. This topic requires additional research.

The group consensus was that common water quality indicator parameters, such as specific conductance, dissolved oxygen and turbidity should be used to determine the endpoint of purging, i.e., when formation water has been accessed. Ideally, the concentration of a contaminant (or other species of interest) would be measured over time during purging to determine when its concentration stabilized. In most cases, this approach would not be practical. However, some studies (Puls et al. in review; Barcelona et al. 1994; Backhus et al. 1993) have indicated correlation of some indicator parameters with different classes of contaminants (e.g. dissolved oxygen with volatile organic compounds, and turbidity with metals and hydrophobic organic compounds). While the measurement of dissolved oxygen can be problematic at low concentrations (< 1 ppm), many reliable field-portable chemical measurement techniques (colorimetric) and improved dissolved oxygen probes have recently been developed which should help in obtaining more accurate and stable measurements. A conservative approach was recommended which included the use of dissolved oxygen and specific conductance for volatile contaminants, turbidity, dissolved oxygen and specific conductance for metals (and metalloids) and semi-volatiles, and perhaps also the use of oxidation-reduction (redox) potentials in both cases. It must be recognized that erroneous or highly variable parameter measurements can result from improper methods of sample collection or analysis. Dissolved oxygen or electrode potential measurements will change rapidly if a sample is open to the atmosphere, and turbidity can increase within a few minutes if air is introduced into a sample containing ferrous iron. In many cases, sampling practitioners are using flow-through cells which can be connected in-line with the sampling system. These devices generally include most of the above-mentioned indicator parameters as well as pH and temperature. The latter two measurements are useful data, but are generally insensitive as purging indicators. In addition to measurements to determine stabilization of the water quality parameters, time-series measurements of the change in the depth to the water table should also be recorded to assure hydrologic stabilization with minimal drawdown of the water table. The frequency for measurement of the indicator parameters, and the criteria to decide that the parameters are stabilized needs to consider pump flow rate and the precision of the monitoring instruments. Some suggested criteria were discussed: stabilization to within 10% (for turbidity and dissolved oxygen) for three consecutive readings taken three minutes apart under conditions where flow rates ranged from 100-500 ml/min; three successive readings within five times the reproducibility of the instrument; and, individual well evaluation of indicator parameter stabilization plots.

The same use of indicator parameters was recommended in fractured rock settings.

Finally, it was concluded that education and training of ground-water samplers should be expanded, and certification programs possibly initiated. It was strongly recommended that EPA be involved in these technology-transfer activities. Field sample collection currently represents the greatest potential source of error in site assessment and remedial evaluations. Increased education and certification and the establishment of quality-assured and consistent sampling protocols is critical to the future success of multi-million dollar environmental restoration programs.

## Low-Flow Purging

Low-flow purging refers to the intake velocity of the sampling device downhole and the resulting induced formation water velocity, not the average flow rate at the surface. The latter can be manipulated using flow valves or other obstructions to produce low surface flow rates while the subsurface induced flow may be extremely rapid and impart significant disturbance within the sampled zone. The overall objective is a more passive approach to sample extraction with the ideal being to match the intake velocity with the natural ground water flow velocity thus inducing minimal drawdown of the water table.

Required purge volume or duration is evaluated through continuous monitoring of water quality parameters such as dissolved oxygen, specific conductance, oxidation-reduction (redox) potential and turbidity for evaluation of the presence of formation water. Research has shown that purging at these lower rates with various types of pumps (peristaltics, low-speed submersibles, and bladder pumps) does indeed produce low turbidity and generally high quality samples (Puls et al. 1992; Kearl et al. 1992). A perceived disadvantage of such strategies is the additional time required to remove the traditional 3 to 5 casing volumes. In general, however, the volumes required to access formation water are much less than 3 to 5 casing volumes, and in deeper wells are actually only fractions of a casing volume. Indeed the volume of water extracted to access formation water is generally independent of well size and capacity (Puls et al. in review; Puls, this report). The criteria for the initiation of sampling are stabilization of the water quality indicator parameters listed above. It should be noted that excessively stringent stabilization guidelines may result in longer purging. If chemically distinct zones exist within the formation adjacent to the screened interval, they may be accessed with prolonged pumping and result in changes in water quality indicator values. The design of such sampling points should be discouraged; however where they already

exist, caution should be exercised in acquiring and interpreting the data from such sampling points.

The most important parameters affecting purge volume appear to be hydraulic and geologic heterogeneity, water chemistry, pumping rate, device size and whether the sampling devices are used in a portable or dedicated fashion. Significant reductions in purge volume have been noted when the problems associated with disturbances during installation of pumps immediately prior to sampling are avoided (Puls and Powell, 1992). This can be achieved by installing portable pumps at least a day before sampling, or through the use of dedicated pumps. A thorough economic analysis may show dedicated systems to be a cost-effective alternative for routinely-sampled monitoring wells.

In general, the advantages of low-flow purging include the following:

- low turbidity samples which are representative of the 'mobile' load of contaminants present (dissolved and colloid-associated),
- minimal disturbance of the sampling point,
- reduced stress on the formation (minimal drawdown),
- less mixing of stagnant casing water with formation water,
- reduced need for filtration and therefore less time required for sampling,
- smaller purging and sampling volume which decreases waste disposal costs and sampling time.

Whereas the disadvantages of low-flow purging are:

- resistance to change on the part of sampling practitioners due to lack of long-term data base,
- problems with data comparison and interpretation of temporal trends due to differences in sample collection methods,
- increased time that may be required for purging and sampling at slow flow rates,
- the need for additional (& costly) equipment,
- difficulty of implementation, and
- potential for increased gas exchange and sorption of contaminants onto tubing surfaces due to increased residence time of fluid in the tubing.

Recognizing the disadvantages, the advantages of the low-flow-rate sampling in providing a higher quality sample that more closely represents the mobile dissolved and colloidal components in the formation suggest that this is the direction that the state of professional practice must proceed.

Regardless of the purging and sampling protocols selected for a particular sampling objective, proper well construction

and well development is important and intimately interrelated to the issue of well purging. A detailed understanding of the hydrologic and geologic variability of the system is also essential in establishing sampling points and in designing the overall sampling program. There was general agreement among the group from a technical perspective, that minimal drawdown, low-flow purging was a better way to sample for most ground water sampling programs.

## Site-Specific Considerations

The overall goals of the sampling program or the sampling objectives will drive how the sampling points are located, installed, and the choice of sampling methods. Likewise, site-specific hydrogeologic factors will affect these decisions. Unlike water supply wells, wells installed for ground-water quality assessment and restoration programs are often installed in low water yielding settings. In fact, it was the consensus of the group that the use of "typical" ground-water monitoring wells in such locations should undergo a serious review. Alternative types of sampling points and sampling methods are needed in these types of environments. The discussions focused on five general classes of hydrogeologic settings:

- high permeability formations, screened below the water table;
- high permeability, water table wells (i.e. screened across the water table);
- low permeability formations, deep, screened below the water table;
- low permeability formations, screened across the water table; and
- fractured rock.

For the high permeability wells, either screened deep and below the water table or screened across the water table, it was generally agreed that use of low-flow purging and sampling techniques was the preferred method for sample collection in most instances. The use of low-flow techniques were also advocated for the low-permeability, deep wells, with the caveat being to avoid dewatering of the screened interval. This may require extremely low-flow purging (< 100 ml/min) and may be technology-limited. Where devices are not readily available to pump at such low flow rates, the primary consideration was still to avoid dewatering of the well screen. This may require repeated recovery of the water during purging while leaving the pump in place within the well screen. It was suggested that comparisons be made between samples recovered using low-flow purging techniques and using passive sampling techniques. The latter would essentially entail acquisition of the sample with no or very little purging using a dedicated sampling system

installed within the screened interval.

The most problematic of the above settings were those in low permeability water table wells and fractured rock. In the former case, there was a serious concern that an adequate sample could not be obtained using traditional monitoring wells and standard sampling devices. The group consensus was that, once again, the primary consideration in purging such wells was to avoid dewatering the well screens. Use of low-flow techniques may be impractical in these settings, depending upon the water recharge rates. The sampler and the end-user of data collected from such wells needs to understand the limitations of the data collected, i.e. a strong potential for underestimation of actual contaminant concentrations for volatile organics, potential false negatives for filtered metals and potential false positives for unfiltered metals. Once again it was recommended that more passive sampling techniques be investigated and compared with current and low-flow purging techniques.

In fractured rock formations, a low- to no-flow purge was recommended in conjunction with the use of packers to isolate the sampling zone in the borehole. It is imperative in such settings to identify flow paths or water-producing fractures prior to sampling, using tools such as borehole flowmeters. The spatial resolution issue referred to above is particularly of issue in fractured rock. That is, the volume purged can make a dramatic difference on the constituent concentrations obtained.

For low-yielding wells or fractured rock formations, the unnecessarily large sample volumes often required by some regulatory programs is a significant problem. For example, in a rock with a fracture porosity of 10-4, the 10 L sample volume required by many protocols could conceivably include the water from a volume of 100 $m^3$ of rock. This could greatly dilute the concentration of contaminants in the sample and the concentrations may not be in equilibrium with the adjoining matrix (McKay, this report). It was strongly recommended that the different EPA programs review their sample volume requirements. In many cases they are unnecessary, and in fact have the result of encouraging poor sampling practices.

## Sampling Systems and Devices

The use of standard monitoring wells and devices to sample ground water in low permeability formations should be reevaluated and research should be directed toward the development of alternative approaches. In most other settings, many currently available devices (e.g. bladder pumps, low-speed centrifugal submersible pumps etc.) are entirely appropriate and adequate for the collection of water samples. There was extensive discussion on the merits of

using bailers of any type. The majority of participants agreed with the statement that "the standards of professional practice have passed bailers by" for most situations. Bailers were deemed useful in water table wells and for sampling light non-aqueous phase liquids (LNAPL's). Variability in sampling technique was considered a major limitation to their use in providing representative and reproducible data. Production of excessive turbidity and aeration were also seen as significant drawbacks or limitations.

It was recommended that studies be undertaken to evaluate the cost-effectiveness of using dedicated sampling systems as opposed to portable sampling systems for some sampling programs. Research has indicated (Puls, this report; Barcelona, 1994) that the benefits of low-flow purging and sampling techniques are more fully realized in such sampling systems. These include: less purge volume, time savings in the field and in field preparation, less decontamination and production of additional wastes from decontamination procedures, and improvements in sampling consistency and sampling results (e.g. better reproducibility). The potential disadvantages from dedicated systems were unknown effects from system deterioration over the long term and up-front costs for installation and implementation.

## Documentation

Throughout the group discussions, the topic of documentation of all sampling activities, including sampling preparation and subsequent sample handling, transportation and storage was brought up. It was unanimously agreed that current documentation efforts and documentation requirements are inadequate, regardless of environmental program. This was targeted as a major need or area for improvement in the ground-water sampling field. Included in the appendix of this document are examples of a field-sampling log forms which would be useful for providing some of this information. Regardless of the sampling objective or sampling approach employed, insufficient documentation will make the interpretation of the resulting data inadequate.

## Research Needs

Identified research needs by the group included the following:

- more thorough comparison of low-flow sampling data (unfiltered) with filtered conventional sampling data,
- comparison of low-flow sampling and "passive" sampling techniques,

- evaluations of cost-effectiveness of dedicated sampling systems,
- development of new methods and instruments for acquiring water samples in low water-yielding formations.

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# Turbidity and Colloid Transport

**Joseph N. Ryan, Steve Mangion and Dick Willey**

## Background

Realization of the potential role of colloids in facilitating contaminant transport (McCarthy and Zachara, 1989) has heightened our awareness of the need to obtain ground water samples that are representative of the naturally mobile colloids. Carefully collected field evidence shows that the commonly-used sampling protocols (bailing, rapid pumping) produce ground water samples in which colloids have been artificially entrained (Puls et al., 1992; Backhus et al., 1993). In such samples, the naturally mobile colloid fraction is overestimated. That is, bailed and rapidly pumped samples often contain substantial turbidity that is not representative of conditions within the subsurface. In practice, the suspended particles causing this turbidity have been removed from the samples by filtering in the field. Usually, membrane filters with 0.45 μm pores have been used to remove turbidity despite the biases introduced by their use (Kennedy et al., 1974; Danielsson, 1982; Johnson and Wangersky, 1985).

Recently, the Solid Waste Program of the U.S.E.P.A. issued regulations that banned the field filtration of ground water samples (40 CFR, 1993). The ban requires samples from ground water monitoring systems be analyzed for the total amounts of contaminants in unfiltered samples. If the samples have been obtained using techniques that overly stress the subsurface system, the resulting samples may be highly turbid. Such samples, when analyzed, typically have high contaminant concentrations.

The field research cited above has also demonstrated that ground water samples relatively free of turbidity can be obtained without resorting to filtering by withdrawing ground water at relatively slow rates. Collecting ground water samples following these low-stress protocols requires an investment in equipment and time that some site investigators contend that they cannot afford. It should also be noted that low-stress protocols minimize the amount of purge water that may need special handling and eliminate time needed to conduct the field filtration step.

The goal of these subgroup discussions was to reach a consensus on the best protocol (based on current scientific knowledge) for obtaining ground water samples that are representative of the actual mobile colloid load. As a premise to these discussions, the attendees agreed that, for certain low-solubility contaminants like radionuclides, metals, and high-molecular weight hydrophobic organic compounds, research has shown that colloid-facilitated transport is significant. The discussions leading to consensus on following four important topics will be presented in this report:

1. Criterion for Adequacy of Well Purging
2. Distinguishing Dissolved and Colloid-Bound Contaminants
3. Distinguishing Mobile Colloids and Artifactual Colloids
4. Identifying Sites with Colloid-Facilitated Transport Potential

Owing to the recent promulgation of the U.S.E.P.A. ban on field filtering, the discussions often included debates over the adequacy of collecting turbid ground water samples and "fixing" the improperly collected samples by field filtering. After summaries of the consensuses on the four topics listed above, this report will address field filtering.

## Criterion for Adequacy of Well Purging

A suspended sediment concentration criterion should be established to obtain ground water samples that are representative of the mobile colloid load. This criterion should specify that the suspended sediment concentration should reach a stable level during purging and prior to sampling. This criterion should be applied in a manner analogous with the monitoring of other parameters during purging; i.e., the sample turbidity should be monitored during purging and purging should continue until a stable turbidity is achieved. The best means to achieve the stable suspended sediment concentration is through pumping the ground water from the well. Based on the scientific evidence currently available, low-stress purging is recommended. The best way to specify low-stress pumping is to require minimal or no drawdown of the water level.

The scientific evidence presented at the workshop clearly demonstrated that the suspended sediment concentration of the sample decreases during purging to some stable level. It is this stable suspended sediment concentration that is

representative of the actual mobile colloid load. Careful field sampling has shown that this stable colloid concentration range from <1 to as high as 100 mg $L^{-1}$ with higher concentrations typically occurring in shallow, unconfined aquifers subjected to changes in pore water chemistry (McCarthy and Degueldre, 1993).

In the field, the decrease in suspended sediment concentration toward a stable level can be effectively monitored by some type of light scattering technique. A turbidity meter is the most practical instrument to use for this purpose. The extracted ground water can be routed through a flow-through cell in the turbidity meter for constant monitoring of the suspended sediment concentration (measured in nephelometric turbidity units, NTU) without exposing the sample to the atmosphere. The turbidity meter can be added to the suite of instruments used to monitor the stabilization of other chemical parameters during purging (pH, dissolved oxygen, specific conductance, etc.). Careful field tests have shown that these chemical parameters typically stabilize more rapidly than the suspended sediment concentration of the extracted ground water (Puls et al., 1992; Backhus et al., 1993).

A stable colloid concentration is easily achieved by withdrawing ground water using a pump positioned at a fixed depth during purging and sampling. Careful field studies have demonstrated that low-stress pumping produces samples with stable suspended sediment concentrations that are two to three orders of magnitude lower than those produced by bailing in the same wells (Puls et al., 1992; Backhus et al., 1993). The tests by Backhus et al. (1992) showed that bailing continued to produce samples with high turbidity even after 60 pore volumes of purging and that bailed samples also contained up to 750 times greater concentrations of high molecular weight polycyclic aromatic hydrocarbons than pumped samples from a coal tar-contaminated site.

The careful field studies currently recommend that pumping be performed at relatively slow withdrawal rates to minimize suspension of "artifactual" colloids, or sediment that is attached to sediments at natural ground water flow velocities. Calculations have shown that a pumping rate of about 100 mL $min^{-1}$ will keep shear rates below those believed to mobilize attached colloids in a typical unconfined aquifer (Ryan, 1988). Rather than specify a particular withdrawal rate, which is strongly dependent on aquifer properties, a "minimal-" or "no-drawdown" guideline appears to be the best way to assure that the pumping-induced flow rates near the well were not "stressing" the aquifer and causing artifactual colloid mobilization. However, some field data shows that pumping at a range of withdrawal rates has no effect on the stable suspended sediment concentration (Puls et al., 1992). In fact, at higher pumping rates, the stable level was reached in a shorter purging time, although the higher pumping rates produced larger colloids. Further research is needed to elucidate the effect of pumping rate on the stable suspended sediment concentration.

A particular concern of many of the attendees was sampling from "borderline" aquifers -- formations with low permeability. Sampling and purging requirements are difficult, if not impossible to meet, in such formations. However, it is clear that bailing samples from these formations will exacerbate turbidity problems, while low-stress pumping ("minimal drawdown") produce samples of lower turbidity. Also, there is a possibility that passive sampling techniques (Magaritz et al., 1990) may prove especially valuable in such formations.

**Distinguishing Dissolved and Colloid-Bound Contaminants**

A representative sample used to determine the transport of the contaminant should include both the mobile dissolved and mobile colloidal fractions of the contaminant. For some contaminants (e.g., volatile organic compounds), the mobile colloidal fraction may be deemed insignificant a priori based on published partitioning values. If the transport behavior of the contaminant capable of significant partitioning to colloidal phases is to be determined and predicted, then it is always necessary to measure and distinguish between the dissolved and colloidal fractions. However, in a monitoring mode, where only the presence of the contaminant is to be determined, it is not necessary to distinguish between the dissolved and colloidal fractions; only the total mobile contaminant concentration is needed.

Scientific evidence shows that certain low-solubility contaminants are susceptible to colloid-facilitated transport (McCarthy and Zachara, 1989). These low-solubility contaminants are generally those that are surface-reactive; i.e., they adsorb strongly to mineral and organic colloids. In the field, colloid-facilitated transport has been observed for radioactive (e.g., Pu, Am, U, Co, Sr, Cs) and non-radioactive metal (Cu, Pb) in the cationic form (Means et al., 1978; Buddemeier and Hunt, 1988; Magaritz et al., 1990; Penrose et al., 1990). Laboratory experiments have shown that the transport of metals and other inorganic elements typically present in the anionic form (e.g., Cr(VI), As) is facilitated by positively charged metal oxides. Organic colloidal phases (NOM) also enhance the transport of high molecular weight organic compounds (PAH, pesticides, polychlorinated biphenyls, etc.) in laboratory columns, but direct evidence of this phenomenon has not been observed in the field.

For contaminants that do not fit into the categories listed above, colloid-facilitated transport is unlikely. Once the nature and abundance of the colloidal fraction is known,

specific estimates of the potentially colloid-bound fraction can be estimated based on known partition coefficients. Given some reasonable safety margin, it is reasonable to state that colloid-facilitated transport can be ruled out for many low molecular weight, non-surface-reactive contaminants. In these cases, it is not necessary to obtain representative samples of the mobile colloidal fraction; hence, many of the added precautions (turbidity monitoring, low-stress pumping) recommended for sampling for colloids may not be needed. However, the site investigator should keep in mind an important caveat before dispensing with the colloid sampling precautions: samples collected without taking precautions to avoid nonrepresentative suspended sediment can never be used to make judgements about the transport of contaminants that may be colloid-associated.

The need for quantifying separate dissolved and colloidal fractions of contaminants depends on the reason for collecting the data. If the ground water sample has been collected solely to monitor the containment of the contaminant (e.g., a landfill), then the site investigator need only be concerned with total mobile contaminant concentrations without regard for the dissolved or colloidal fraction. Note, however, that sampling techniques designed for colloids still must be used for this measurement because part of the total mobile contaminant may be colloid-bound. If the groundwater sample has been collected to assess the fate and transport of the contaminant, then it is essential to quantify both the dissolved and colloidal fractions because the transport of each fraction will be different.

Uncertainty still exists concerning the best method for distinguishing between the dissolved and colloidal fractions of a contaminant. The most common technique to isolate the dissolved fraction is filtration. Currently, the 0.45 μm pore size filters are needed to accurately isolate the dissolved fraction. Improvements in the separation have been made by using membrane filters with pore sizes ranging from 1.0 down to 0.01 μm; however, these filters are subject to rapid clogging. A more efficient means of isolating the dissolved fraction is high molecular weight ultrafiltration (10 to 100K nominal molecular weight cutoff). Ultrafiltration must be performed in the laboratory; thus, it requires more careful sample handling and storage techniques. Centrifugation, another laboratory technique, may also be useful in separating the dissolved and colloidal fractions (Salbu et al., 1985).

**Distinguishing Mobile Colloids and Artifactual Colloids**

Collecting samples following the low-stress protocol is our best assurance that we have obtained samples representative of the truly mobile colloid population. However, it is still necessary to ascertain that the colloids retrieved truly mobile or artifactual. At many sites, this may not be "readily" achievable. Detailed knowledge of the site

hydrogeochemistry and proper characterization of the colloids are necessary to make this decision. Colloid "veracity" can be determined by consideration of colloid size, composition, possible origin, and the geochemistry of "background" vs. "contaminated" samples.

Even after collecting ground water samples using techniques designed to obtain representative dissolved and colloidal fractions of the contaminant, the site investigator must judge whether the colloids in the sample are truly mobile or not. To do this, the site investigator must characterize the colloids and gain thorough knowledge of the site hydrogeochemistry. Without this thorough analysis of the "veracity" of the colloids, the site investigator runs the risk of accounting for colloid transport when, in fact, the colloids are not truly mobile.

Colloid characterization techniques are considered esoteric by all but the research community; however, many of the analyses are more "routine" and less expensive than many site investigators may realize. Such analyses include scanning electron microscopy (colloid size, morphology, and concentration), energy- or wave-dispersive x-ray spectroscopy (elemental composition), photon correlation spectroscopy and other light scattering techniques (size and concentration), microelectrophoresis (surface charge), and x-ray diffraction (mineralogy). Detailed methods for these characterization techniques have been summarized in the literature (McCarthy and Degueldre, 1993).

Knowledge of the colloid character is not sufficient; the site investigator must seek to gain a thorough understanding the hydrologic, geologic, and chemical character of the site. This necessarily includes knowledge of (1) the direction and velocity of the ground water flow, (2) the mineralogic composition of the aquifer, (3) chemical composition of the groundwater. Also, the site investigator must know how these properties have been changed or been influenced by the contaminant plume. This knowledge can be used to assess the likelihood of mobile colloids in the samples. The presence of colloids in the ground water must "make sense" in the hydrogeochemical setting at the site. To make this judgement, site investigators must become familiar with the basics of colloid transport.

Key to this assessment is the presence of wells sampling both "background" and "contaminated" portions of the aquifer. The background and contaminated samples can be used to explain the possible effect of the contaminant plume on colloid mobilization. The geochemical changes wrought by the advancing plume may mobilize colloids through some change in the pore water chemistry; in these cases, colloid transport may advance no further than the contaminant plume which caused its mobilization. In such a case, detailed understanding of the colloid transport may not be necessary. Currently, field data is needed to substantiate this phenomenon.

## Identifying Sites with Colloid-Facilitated Transport Potential

Given a contaminant for which colloid-facilitated transport is possible, the potential for colloid-facilitated transport cannot be ruled out based on the hydrogeochemical character of a site because colloids have been found everywhere they have been sought. With our current understanding of colloid mobilization and transport, it is possible to identify geochemical conditions under which colloid-facilitated transport would be likely.

Using careful sampling methods, colloids have been found everywhere that researchers have looked for them (McCarthy and Degueldre, 1993). The nature and abundance of colloids varies widely from site to site; however, colloids are apparently ubiquitous. Whether or not the colloids present are capable of facilitating contaminant transport is a question that must be addressed on a site-by-site basis. At each site, we must consider whether the mobile colloids are present at a sufficiently high concentration and are capable of sufficiently strong binding of contaminants to significantly enhance contaminant transport. Based on the hydrogeochemical characteristics of sites, we cannot rule out the possibility of colloid-facilitated transport *a priori*.

We can identify combinations of aquifer mineralogy and pore water chemistry where we expect colloid mobilization to be significant. Two good examples of aquifers susceptible to colloid mobilization have been presented in the literature. The first involves the infiltration of anoxic, organic matter-rich water (an analog for a landfill leachate) into a sediment composed of quartz sand coated by ferric oxyhydroxides and kaolinite. The infiltrating water promoted the mobilization of the kaolinite colloids by dissolution and reversal of the surface charge of the ferric oxyhydroxide cement (Ryan and Gschwend, 1990; 1992). The second involves the infiltration of acidic, carbon dioxide-rich water into a carbonate-cemented aquifer. The carbonate cement dissolved and released aluminosilicate mineral colloids (Gschwend et al., 1990; Ronen et al., 1992). Based on field observations such as these and general knowledge of colloidal interactions, we can predict that colloid mobilization may be a particular problem for certain sites.

## Bailing and Field Filtering

The general consensus of the Turbidity and Colloidal Transport subgroup was that, based on scientific evidence, bailing and field filtering do not provide samples that are representative of the mobile colloid fraction. Nevertheless, a number of the attendees, particularly those representing state regulatory agencies, contended that E.P.A. ban on field

filtering should be rescinded for detection monitoring at solid waste facilities (subtitle D). These regulators were solely concerned with ground water sampling for monitoring purposes. They foresaw that the ban would result in an unusually large number of "false positive" analyses in samples collected by bailing, the most common sampling method. Although the intent of monitoring is to measure only the mobile form of the compound of interest, analyses of unfiltered turbid samples would measure both mobile and immobile forms of the compound of interest as well as natural forms of the compound.

Metals leaching from landfills was the major concern of the state regulators. Currently, many state regulations require the routine monitoring of metals in samples from landfill monitoring wells. Because metals interact with colloidal mineral surfaces and organic matter, the importance of accurately determining the truly mobile metal fraction and the potential for colloid-facilitated transport is heightened.

Representatives from the states of Wisconsin and Michigan were particularly concerned with highly turbid samples taken from glacial till aquifers, which are common in those states. Glacial till contain abundant clay that can be mobilized by the high groundwater velocities induced by bailing. It is thought that the metals adsorbed to the mobilized clays are actually immobile in the aquifer, hence the suspended sediment is currently filtered out using 0.45 $\mu$m filters to attempt to isolate the mobile fraction of the metals. This filtrate is typically called the "dissolved" fraction, although it is well known that (1) some dissolved metals may become adsorbed to the suspended sediment trapped on the filter and (2) some colloidal metal (associated with colloids smaller than the pore size) may pass through the filter.

The state of Washington representative was concerned with the inability to distinguish between natural levels of certain compounds and levels caused by contamination. Many Washington ground waters and sediments contain high levels of arsenic, making the distinction between natural levels and contamination difficult. Bailed samples containing abundant suspended sediments may contain natural arsenic originally present in mineral lattices that is released by sample acidification and analyzed as a contaminant.

The state regulators agreed that current scientific evidence shows that the low-stress pumping protocol for obtaining metals samples is the best method. In defense of the bailing and field filtering protocol, the state regulators (and others) raised two issues: (1) cost and (2) consistency. The state regulators asserted that most site investigators required to monitor ground water cannot afford the equipment and time required to sample ground water properly. They also point

out that a change in sampling techniques will render their extensive data bases inconsistent with newly-acquired results.

Some members of the subgroup, particularly those from academic and federal research laboratories, countered these arguments by reiterating that (1) the perceived necessity of field-filtering highlighted the fact that bailing was inappropriate for collecting samples for metals and (2) filtering introduces an unknown bias into metals analysis (i.e., filtering could result in either under- or overestimation of the mobile metal concentration). The researchers pointed out that the cost of making decisions on poorly-collected samples is potentially much greater than the cost of sampling correctly. Following the same reasoning, continuation of inappropriate sampling methods for the sake of consistency is not a valid reason -- if bad data were collected before, that makes collection of good data even more important.

Some of the researchers did not share the state regulators' concern for "false positive" measurements of high metal concentrations. High metal concentrations in a turbid sample may simply indicate that metals adsorbed to the sediments were pulled into the well by the vigorous bailing action. These metals must have been mobile enough to reach that point. The contention that high natural levels of some metals obscures our ability to distinguish contributions from leaking landfills was also not deemed a valid excuse to continue poor sampling techniques (e.g., high As concentrations in Washington). Increases in levels of metals above natural levels should be evident from properly located background wells. If such wells are not available, then it is scientifically advisable to discontinue monitoring the troublesome metal and substitute a more easily measured parameter indicative of leachate (e.g., organic carbon, chloride).

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# Sample Handling and Analysis

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### Objectives of Sampling Program

Program objectives must be sufficiently defined so that data collection efforts are designed and carried out in a way that will produce data appropriate for the needs of the program. "Data quality objectives" are developed to define the types, quality, and quantity of data required by the various aspects of the program. In this sense, "data quality" addresses the purpose(s) for which the data are to be used. Once these data objectives are defined, appropriate sampling and analytical methodology (protocol) are evaluated and chosen. Examples of several types of programs that might have different data quality objectives are detection and assessment monitoring related to regulatory activities, resource evaluation, and geochemical modeling.

Most decisions regarding sampling methodology are made before field operations begin, however, flexibility must be built into the sampling protocol to deal with unexpected or changing conditions. The group leaned toward basing decisions on well or site-specific conditions as opposed to applying general rules governing all sites, regardless of site-specific conditions.

### Field Measurements

Three categories of field measurements were defined: in situ, purging, and field analyses. "In situ measurements" are absolute values of constituents of properties that, because of their unstable nature, must be made under conditions as close to in situ conditions as possible, usually conducted in a well or in situ device. Examples include temperature and dissolved gases. Note that project objectives may not require the additional efforts required to collect data of this resolution.

"Purging measurements" are conducted to evaluate the progress or efficiency of monitoring well purging and are usually conducted at the well head. Because these measurements are made on samples that have been removed from their native physicochemical environment, their accuracy may be lower than for in situ measurements. Use of a flow-through cell may make measurements easier but doesn't necessarily improve data accuracy or precision. Examples of purging parameters include temperature, EC, pH, DO, turbidity, other field analytes, and lab analytes.

Measurements of the constituents of interest to the sampling program are preferred but are not often practical. Note that the sampling device may influence the quality of certain parameters; such as DO and turbidity from bailed samples, and temperature from many devices. Therefore, these parameters may not be equally weighted as purging criteria. The last value measured is often taken as representing sample conditions, however, the accuracy of these measurements must be evaluated to determine whether they meet data quality objectives. Field evidence suggests that if measurements are made in-line, turbidity should be measured first to avoid potential particle settling in flow-through cells for other measurements. However, some turbidimeters may heat the ground-water leading to error in temperature measurements. Also, the effect of flow-through cells on pump discharge rate should be considered; they can act as flow restrictors. When they are disconnected for bottle filling (as recommended), pump discharge rates may increase dramatically.

"Field analyses" are made for the purpose of on-site characterization or are measurements of constituents and properties considered too unstable for laboratory analysis. Field-deployable analytical techniques (GC, GC/MS, XRF, ion chromatography, immunochemistry, fiber optics) may be useful for both detection and assessment but will require the development of strong, standardized protocols for quality control. Current use is primarily for site characterization, but application of these techniques to routine monitoring may reduce the costs and uncertainty associated with sample collection, handling, and analysis, particularly for aromatic hydrocarbons. Examples of unstable parameters that are usually best measured at the well head include pH, turbidity, DO, metals speciation (Fe II, Cr IV), alkalinity, sulfide, nitrite, dissolved gases, and electrode potential (for Eh). Note that holding times for some of these parameters is 24 hours. Constituents that require preservation for later analysis are those traditionally analyzed in the laboratory, including major ion chemistry, trace metals, organics, colloids, etc. Preservation techniques are described below.

### Field Filtration

The decision to collect filtered or unfiltered samples must be based on data quality objectives and, therefore, the

objectives of the overall program. Field-filtering of certain constituents should not be the default, however. Consideration should be given to what the application of field-filtration is trying to accomplish. The group agreed that specific reasons exist for collection of both filtered and unfiltered samples, as outlined below.

Under conditions of excessive turbidity caused by certain geologic or sampling conditions, field filtration is often suggested to reduce artifacts caused by the presence of excessive loads of suspended sediments that threaten to bias the analyses. However, potential implications on sample accuracy and overall data quality must be recognized and evaluated. For example, filtration with 0.45 μm filters may remove particles important to transport of colloidally-associated contaminants (both larger than the initial pore size and smaller, as the filter cake builds up). It was generally agreed that field-filtration should not be used to correct for improperly designed or constructed monitoring wells, inappropriate sampling methods, or poor sampling technique. The objective should be to carry out all aspects of sampling so as to produce a sample that is minimally disturbed. Turbidity may be a good criterion to evaluate sample disturbance and the question was raised as to whether turbidity guidelines could be developed.

Truly dissolved concentrations of major ions and trace metals are used for flow system analysis and equilibrium geochemical modeling. Therefore, samples collected for these purposes must be filtered because inclusion of particulate material in the analyses may lead to erroneous dissolved concentrations that will impact geochemical equilibrium calculations. Alkalinity samples must also be filtered if significant particulate calcium carbonate is suspected. The presence of this material is likely to impact the alkalinity titration although filtration itself may alter the $CO_2$ composition of the sample and therefore affect the results. Field filtration may also be conducted to maintain consistency with historic data collected with routine field-filtration of samples. This approach may be appropriate in certain situations (e.g. flow system analysis) but the determination must be made as to whether filtration is appropriate to program objectives. Samples for analysis of colloid composition should be collected on membrane filters or by field ultrafiltration (Backhus et al., 1993).

Although filtration may be necessary in the cases suggested above, filtration of a sample may cause a number of unintended changes to occur, possibly leading to filtration-induced artifacts during sample analysis and uncertainty in the results (Horowitz et al., 1992). Some of these unintended changes may be unavoidable but the factors leading to them must be recognized. Also, their effects can be minimized by the consistent application of certain filtration guidelines. These issues, which include filter type,

media, pore size, and others, must be addressed to identify and minimize potential sources of uncertainty when filtering samples.

In-line filtration was generally considered the most desirable approach because it allows better consistency through less sample handling, and minimizes sample exposure to the atmosphere. In-line filtration can be accomplished through the use of disposable filter cartridges or membrane filters in an in-line filter apparatus. Disposable filter cartridges have the advantage of greater sediment handling capacity when compared to traditional membrane filters. The filter media, including materials and pore structure may impact break-through of certain metals. To obtain truly dissolved constituents, the smaller pore size the better. The smallest pore size practical in the field seems to be 0.1 μm, but the choice depends on particle loads, required sample volume, and project objectives. Also, the commercial availability of filter pore sizes less than 0.45 μm is limited.

Conditioning is required to remove preservatives, wetting agents, residues of filter manufacturing, and leachable compounds from filter media. Volumes of sample water of 500 mL to 1 L are generally accepted, but the volume necessary depends on sample turbidity. If turbidity is high, the filters may have to be preconditioned with DI water. For analysis of very low metal concentrations, the filters may require acid-washing. Once filtration has begun, a filter cake may develop as particles larger than the pore size accumulate on the filter membrane. The result is that the effective pore diameter of the membrane is reduced and particles smaller than the stated pore size are excluded from the filtrate. Possible solutions include prefiltering, minimizing particle loads to begin with, and reducing sample volume. Finally, an inert environment may be necessary during off-line filtration to minimize oxidation of highly reduced species and may be accomplished through the use of oxygen-free sample bottles in a glove box. For in-line filtration, oxygen-free bottles alone will suffice.

If the objective of the sampling program is total recoverable constituents, whether they be major ions or trace metals, then the samples must not be filtered. In particular, samples for the analysis of colloid-associated constituents must be collected unfiltered. Likewise, samples for certain classes of analytes are generally collected unfiltered, such as many organics and nutrients. Particle load may be immaterial to analysis of certain types of organic compounds (Paul et al., in preparation).

Collecting unfiltered samples eliminates many of the uncertainties associated with field-filtration but should not be attempted without addressing the issue of sample collection. For example, sampling methods that disturb the sampling zone and sample may suspend normally immobile

particles and entrain them in the sample (e.g. bailers and pumps at high flow rates) leading to analysis of naturally-occurring matrix metals and "false positive" results. This is a particular problem in turbid wells, where excessive turbidity may result from improper design, construction, and development. The following approaches may be useful in minimizing potential sources of uncertainty when collecting unfiltered samples.

Well design, construction, and development must be appropriate to hydrogeochemical conditions present at the site. Disturbance of the geologic matrix during drilling must be minimized to reduce the effects of well construction artifacts. When purging and sampling, low pumping rates (300 mL/min and below) have been demonstrated to minimize disturbance of the sample zone and sample when compared to high pumping rates and bailing. The key is to minimize particle concentrations in the sample thereby minimizing artifacts from well design, construction, and installation; purging; and sampling. However, the pump intake position must be carefully chosen when using low pumping rates because water drawn into the pump originates in a relatively small vertical segment of the well intake. If the pump intake is positioned away from the zone of contamination, dilution within the wellbore may prevent detection of the contaminant of interest. A borehole velocity survey may provide indication of most conductive zones; other techniques may also be applied to detect contaminated zones. The measurement of selected field parameters during purging, particularly in-line measurements of DO and turbidity, provides an indication of the progress of purging and when parameter equilibrium conditions have been attained. Other parameters may lead to underpurging while turbidity may be too conservative. Disturbance of the sampling zone may be minimized, in turn reducing purge volumes, through the use of dedicated sampling systems rather than portable systems.

Finally, compatibility of unfiltered samples with the analytical method must be considered, especially if the samples contain significant quantities of suspended particles. Also, make sure the lab doesn't filter the sample that was painstakingly collected unfiltered in the field!

**Preservation of Samples**

It should be recognized that potential uncertainty associated with sample preservation may be reduced or eliminated for certain analytes by conducting the analyses in the field. Although routine field analysis is not currently widespread, it appears that present trends are leading in that direction. For those analyses conducted in the laboratory, there are several important issues that must be addressed to ensure sample integrity is preserved from the field to the lab.

The transfer of the sample from the sampling device (bailer, pump tubing) to bottle (or filtration device if filtration is conducted off-line) must be accomplished with as little disturbance to the sample as possible. This operation is relatively straightforward when using low-speed pumps but can be more problematic when using bailers , although several techniques are currently available for simplifying the transfer and reducing agitation of samples from bailers. If field filtration is conducted, the operation must be carried out in such a way that sample integrity is preserved, as discussed above. To minimize oxidation of highly reduced species, an inert environment may be necessary during off-line filtration.

Chemical preservation is used to minimize reactions such as precipitation of metal oxides and hydroxides and biodegradation of organic compounds. Chemicals may also be used to control a specific reaction; such as addition of sulfuric acid to samples collected for ammonia determination to lower the pH and form the stable ammonium ion. These preservation techniques have evolved over many years of laboratory analyses and appear adequate in most cases (see SW-846). However, questions remain about preservation of samples collected for analysis of volatile organic compounds. Recommended chemical preservatives include HC1, sodium bisulfate, sulfuric acid, and mercuric chloride. These substances have proven effective for preservation, particularly for aromatic hydrocarbons, which are highly susceptible to biodegradation, greatly increasing holding times past the standard 14 days (Maskarinec et al., 1990; Roe et al., 1989). Increasing the holding times of chemically-preserved organic samples might reduce project costs associated with resampling when holding times were not met. On the other hand, some studies suggest that if not chemically preserved, samples for volatile aromatic hydrocarbons may biodegrade in very short time periods (Roe et al., 1989).

Physical preservation includes temperature of the samples during transport to the laboratory and type of sample containers. Maintenance of sample temperature at 4°C may be critical to control biodegradation in organic samples that are not chemically preserved. However, the question was raised whether ice chests arrive at the laboratory at the required temperature, and what actions are taken if the samples are warmer. In contrast, SW-846 does not specify cooling of samples collected for most metal analyses, but this is a common practice in the field. Under certain conditions, cooling of metal samples may lead to precipitation of certain constituents. For very sensitive analyses, maintaining the samples near in situ ground-water temperature may be a better approach. Questions were raised as to the effect of collecting samples in bottles that may have been stored on ice (for convenience) and therefore

are much cooler than ground water. Likewise, concerns were expressed about the effects on VOC concentrations of filling VOA vials that had been warmed by exposure to the sun.

The types of sample containers appropriate for a wide range of analytes are given in SW-846. Because organic compounds may diffuse through plastic bottles and caps, glass bottles and PTFE-lined caps are specified for samples collected for organic analyses. Though plastic bottles and caps are considered acceptable for many inorganic analyses, the use of glass bottles minimizes exchange of gases with the atmosphere that might lead to sample degradation of very sensitive constituents (e.g., oxidation of highly reduced metals species). Likewise, stoppers designed to eliminate headspace may also be necessary to minimize this sample degradation. Other physical preservation requirements are given in SW-846.

Reducing the volume of samples sent to the laboratory can minimize some of the problems discussed above under filtration. Other advantages of reducing sample volumes include increased ability to collect samples in low-yield wells, lower bottle filling times at low pumping rates, lower bottle costs, lower shipping costs, and reduced sample disposal problems at the laboratory. Sample volume can easily be reduced over many present practices. For example, a full suite of metals can easily be analyzed from a 50 to 100 mL sample, and only 5 mL is required for purge and trap GC analysis of organics.

Shipment of samples to the laboratory remains controversial. Sample preservation techniques and holding times would suggest that certain samples (e.g., metal) could be shipped via conventional ground methods. However, this method causes samples from the same sampling event to be "split up" since VOC samples are commonly shipped by overnight carrier, and might possibly lead to chain-of-custody problems.

## Documentation

There was clear consensus that more and better documentation is required at virtually every step of the sampling process in order to better interpret data collected (field and lab) and to aid identification of areas where data quality objectives are not being met. Discussion of general topics follow.

Detailed descriptions of all methods, activities, and data are critical. Examples include field conditions (well, weather) that might be significant to the results, personnel, purging methods (device, depth, rate, indicator parameters), sampling methods (device, depth, rate), field measurement instrumentation (type, methods, calibration data), specific preservation information (filtration, chemical, physical), and

shipping information. Standardization of documentation (data forms) at some level was discussed. Generic "templates" of various forms could be developed and adapted for widespread or project-specific use. More widespread and uniform documentation is facilitated by standardizing data records. Likewise, detailed, comprehensive forms prompt for information that might otherwise go unrecorded.

Automation of documentation is a future direction and has some very appealing advantages. For example, permanent bar codes applied directly to sample bottles in the field might streamline sample tracking from the field to the lab and into the final report. Personal Data Assistants may provide an effective means for field data entry and storage (for example all purging data could be recorded directly). A copy of the data diskette sent to the laboratory with the samples would provide laboratory personnel with a better understanding of conditions under which the samples were collected, and how they have been preserved.

Communication between field and lab personnel must be open and proceed in both directions. As examples, lab personnel should be fully aware of field conditions and measurements, while field personnel should be cognizant of laboratory requirements and the results of QC sampling. Sending field notes with samples may facilitate this communication.

## Field Operations

Virtually all hydrogeologic and hydrochemical analyses are based on information that is either measured in the field or analyzed from samples collected in the field. As a result, it is imperative that field personnel be qualified to carry out the tasks required to ensure that data are of the quality required to meet program objectives. At a minimum, structured training of field personnel should provide an understanding of project objectives, background in the operating principles of field instrumentation and other equipment, overview of the principles of sample preservation, and guidance in documenting the sampling event. A certification program might be initiated if certain minimum qualifications for field personnel could be developed. Since certification programs exist for analytical laboratories, it seems reasonable that some type of certification be instituted at the point where the data originates. Regular audits of field operations might also be useful for ensuring that appropriate procedures are followed to meet established data quality objectives (QA/QC program).

## Research Needs

1. Although there was general agreement that minimizing disturbance of ground-water samples

provides higher quality data, questions remained about the steps that must be taken to achieve significant improvement in results. In particular, there was some concern expressed as to whether low-flow pumping/unfiltered samples actually provided results that were of significantly higher quality than more traditional approaches and whether the improvements in results justified the costs associated with major changes in sampling protocol.

2. There was also a general interest in improving our understanding of colloid-facilitated transport in different hydrogeologic environments. Questions such as How mobile are colloids? How far do they travel? What are they composed of? and What types of contaminants are likely to be associated with colloids? were raised. In reality, many of these questions are currently being addressed in the literature. The overriding question was Are colloids actually important to contaminant transport at solid waste landfills, or is their role in facilitating contaminant transport rather insignificant? What might be needed to answer this question is a comprehensive survey of the colloid-transport literature to complement the work that comes out of Group 4 (Turbidity and Colloid Transport).

**Guidance Needs**

Several important issues were raised that may warrant the development of technical guidance or recommendations and are summarized below.

1. The important potential and increased use of field-deployable analytical techniques requires the development of strong, standardized protocols for quality control.

2. Standardized turbidity guidelines should be developed to assist evaluation of sample disturbance.

3. The issues of sample holding times, chemical preservation of certain classes of organic samples, and sample shipment methods could be revisited to update current practices.

4. Documentation could be improved and made more uniform through development of standard data forms, templates, etc.

5. There was concern about the inappropriate application of low-flow techniques, particularly in monitoring wells with long screens. If the pump intake is positioned away from the zone of contamination, dilution within the wellbore may prevent detection of the contaminant. A borehole velocity survey may provide indication of the most conductive zones but may be impractical and doesn't detect the contaminated zones. Therefore, alternatives should be investigated and reported.

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# Appendix A - Steering Committee

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**Appendix B -**

**Questions to Consider
for
Small Group Discussions**

# Monitoring Goals and Objectives

1.  What are the objectives of the monitoring programs?

2.  To what extent do/should the program objectives, site characteristics, or constituents of concern provide criteria for representativeness?

3.  Can we identify purpose and objective-driven sampling designs if monitoring networks are to be used for different purposes over the life of the networks (e.g., detection networks phased into assessment networks which may later be phased into corrective action networks)?

4.  Given a sampling protocol, will the data collected meet monitoring objectives?  What accuracy and sensitivity will the sampling and analysis protocol provide?

5.  Can field screening techniques be applied equally to detection and assessment monitoring programs?  How can we provide performance criteria for field analyses that are credible and reliable?

6.  Knowing that contaminant concentration values are dependent upon how the sample is collected, its rate of extraction, and the point where it's drawn - how do these factors influence monitoring objectives?

7.  What effects do/should the physical/chemical speciation of contaminants play in the design of a monitoring program?

8.  What alternative methods are available for designing monitoring well networks?

9.  Do we need better documentation of well construction and well development?

# Well Design, Construction, Development

1.  What artifacts are introduced by well design, construction, and development?  How do these arti-
    facts compare in magnitude to sampling procedure errors?

2.   What procedures/criteria should be followed to reduce the artifacts associated with well design,
    construction, and development?  Can general guidelines be recommended? What existing guidance
    documents are avilable for reference?  Are there needs for new guidance?

3.   What are reliable/effective monitoring well development techniques and criteria?

4.   Can guidance on well design be developed for specific hydrogeologic settings (i.e., grain size/
    sorting/uniformity coefficient/hydraulic conductivity ranges)?

5.   Can we provide criteria for properly designed wells without identifying some grain size/sorting/
    uniformity coefficient/hydraulic conductivity ranges for specific types of installations?

# Well Purging and Sampling

1.  Why do we purge wells?  Are the reasons/justification the same for dedicated and non-dedicated sampling systems?

2.  How should wells be purged?  What should be the endpoints of sufficient purging?  Do we need better documentation of how wells are purged?  Is there a difference between different purging methods?

3.  What are the advantages and disadvantages of low-flow purging and sampling techniques?

4.  Is one set of criteria of endpoints sufficient to define "acceptable" purging and sampling for all cases, or will endpoints of purging be site-specific? (i.e., do hydrogeological conditions affect how we should purge and sample, e.g., unconsolidated formations, fractured rock, low-yielding wells, Karst solution cavities).  How does purging and sampling affect the spatial resolution of information on contaminant distribution in different hydrogeological environments?

5.  Can/should we formulate a short list of recommended types of sampling devices?  What are the trade-offs of dedicated vs. non-dedicated pumps?  Are bailers useful and under what conditions?

# Turbidity & Colloidal Transport

1. Is it advisable to have a turbidity criteria for well purging, and if so what would it be?

2. Does a representative sample always include the mobile solute and mobile colloids? Is it always necessary to distinguish between dissolved and colloid-bound contaminants?

3. Can we readily distinguish between truly mobile colloids and immobile solids or artifacts solids from sampling?

4. Can we identify hydrogeochemical characteristics for sites where colloidal mobility could be a significant transport mechanism?

# Sample Handling and Analysis

1.  How does filtering/not filtering produce "representative" samples and/or address the objectives of the sampling program?

    What is "dissolved"?  What is "mobile"?  What is "total"?

2.  If filtration is deemed necessary, how can sampling/filtering-induced error (artifacts) be reduced?

3.  If a decision is made to not filter, what approach is required to reduce error, particularly with regards to sample collection?

4.  What ground-water constituents must be (or are easily) analyzed in the field and what constituents require preservation for later analysis?

5.  What must be done at the time of sample collection to best preserve samples for later analysis in the laboratory?

6.  Do we need better documentation of sample handling and preservation procedures used?

# Appendix C -Bibliography

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# Appendix D - Glossary

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**Absorption**
The process by which one substance is taken into and included within another substance, as the absorption of water by soil or nutrients by plants.

**Acid-extractable metals**
The concentration of metals in solution after treatment of an unfiltered sample with hot dilute mineral acid.

**Adsorption**
The increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles.

**Advection**
The process by which solutes are transported by the motion of flowing ground water.

**Aggregation**
The act of soil particles cohering so as to behave mechanically as a unit.

**Aliquot**
One of a number of equal-sized portions of a water sample that is being analyzed.

**Anisotropy**
The condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of flow.

**Annular space, annulus**
The space between two concentric tubes or casings, or between the casing and the borehole wall. This would include the space(s) between multiple strings of tubing/casings in a borehole installed either concentrically or multi-cased adjacent to each other.

**Aquifer**
A geologic formation, group of formations, or part of a formation that is saturated, and is capable of providing a significant quantity of water.

**Aquifer, confined**
An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer.

**Aquifer, unconfined**
An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Watertable aquifer is a synonym.

**Aquitard**
A lithologic unit that impedes ground water movement and does not yield water freely to wells or springs but that may transmit appreciable water to or from adjacent aquifers. Where sufficiently thick, may act as a ground water storage zone. Synonymous with confining unit. (9)

**Artifact**
A product of artificial character due to extraneous agency.

**Assessment (investigation)**
The study of a particular area or region for defining the appropriateness of the area for waste disposal.

**Assessment monitoring**
An investigative monitoring program that is initiated after the presence of a contaminant in ground water has been detected. The objective of this program is to determine the concentration of constituents that have contaminated the ground water and to quantify the rate and extent of migration of these constituents.

**ASTM cement types**
Portland cements meeting the requirements of ASTM C 150 (Standard Specifications for Portland Cement). Cement types have slightly different formulations that result in

various characteristics which address different construction conditions and different physical and chemical environments.  They are as follows:

ASTM Type I (Portland) A general-purpose construction cement with no special properties.

ASTM Type II (Portland) A construction cement that is moderately resistant to sulfates and generates a lower heat of hydration at a slower rate than ASTM Type I.

ASTM Type III (Portland; high early strength) A construction cement that produces a high early strength.  This cement reduces the curing time required when used in cold environments, and produces a higher heat of hydration than ASTM Type I.

ASTM Type IV (Portland) A construction cement that produces a low heat of hydration (lower than Borehole Log: The record of geologic units ASTM Types I and II) and develops strength at a slower rate.

ASTM Type V (Portland) A construction cement that is a high sulfate resistant formulation.  Used when there is severe sulfate action from soils and ground water.

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| **Bailer** | A hollow tubular receptacle used to facilitate withdrawal of fluid from a well or borehole. |
| **Ballast** | Materials used to provide stability to a buoyant object (such as casing within a borehole filled with water). |
| **Bar** | A unit of pressure equal to one million dynes per square centimeter. |
| **Baseline** | A surveyed condition which serves as a reference point to which later surveys are coordinated or correlated**.** |
| **Bedrock** | The more or less continuous body of rock which underlies the overburden soils. |
| **Bentonite clay** | An altered deposit of volcanic ash usually consisting of sodium montmorillonite clay. |
| **Blow-in** | The inflow of ground water and unconsolidated material into a borehole or casing caused by differential hydraulic heads; that is, caused by the presence of a greater hydraulic head outside of a borehole/casing than inside. |
| **Borehole** | A circular open or uncased subsurface hole created by drilling. |
| **Borehole geophysics** | The general field of geophysics developed around the lowering of various probes into a well. |
| **Borehole log** | The record of geologic units penetrated, drilling progress, depth, water level, sample recovery, volumes and types of materials used, and other significant facts regarding the drilling of an exploratory borehole or well. |
| **Bulk density, soil** | The mass of dry soil per unit bulk volume.  The bulk volume is determined before drying to constant weight at 105 degrees Centigrade. |

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| **Bulk specific gravity** | The ratio of the bulk density of a soil to the mass of unit volume of water. |
| **Bulk volume** | The volume. including the solids and the pores, of an arbitrary soil mass. |
| **Caliper log** | A borehole log of the diameter of an uncased well. |
| **Capillary forces** | The forces acting on soil moisture in the unsaturated zone, attributable to molecular attraction between soil particles and water. |
| **Capillary fringe** | The zone immediately above the water table, where water is drawn upward by capillary attraction. |
| **Casing** | Pipe, finished in sections with either threaded connections or bevelled edges to be field welded, which is installed temporarily or permanently to counteract caving, to advance the borehole, and/or to isolate the zone being monitored. |
| **Casing, protective** | A section of larger diameter pipe that is emplaced over the upper end of a smaller diameter monitoring well riser or casing to provide structural protection to the well and restrict unauthorized access into the well. |
| **Casing, surface** | Pipe used to stabilize a borehole near the surface during the drilling of a borehole that may be left in place or removed once drilling is completed. |
| **Cation-exchange** | The interchange between a cation and solution and another cation on the surface of any surface-active material such as clay colloid or organic colloid. (1) Cation-exchange capacity (CEC): The sum total of exchangeable cations that a soil can absorb. Expressed in milli-equivalents per 100 grams or per gram of soil (or of other exchangers such as clay). |
| **Caving; sloughing** | The inflow of unconsolidated material into a borehole which occurs when the borehole walls lose their cohesive strength. |
| **Cement; Portland cement** | Commonly known as Portland cement. A mixture that consists of calcareous, argillaceous, or other silica, alumina-, and iron-oxide-bearing materials that is manufactured and formulated to produce various types which are defined in ASTM C 150. Portland cement is also considered a hydraulic cement because it must be mixed with water to form a cement-water paste that has the ability to harden and develop strength even if cured under water (see ASTM Cement Types). |
| **Channels** | Voids that are significantly larger than packing voids. They are generally cylindrical shaped and smooth walled, have regular conformation, and have relatively uniform cross-sectional size and shape. |
| **Chemical activity** | The molal concentration of an ion multiplied by a factor known as the activity coefficient. |
| **Clay films** | Coating of clay on the surfaces of soil peds and mineral grains and in soil pores. (Also called clay skins, clay flows, illuviation cutans, argillans or tonhautchen.) |
| **Clay** | (a) A soil separate consisting of particles > 0.002 mm in equivalent diameter. (b) A textural class. |

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| **Clay mineral** | Naturally occurring inorganic crystalline material found in soils and other earthy deposits, the particles being clay sized; that is, > 0.002 mm in diameter. |
| **Coarse texture** | The texture exhibited by sand, loamy sands, and sandy loams except very fine sandy loams. |
| **Colloid** | The phase of a colloidal system made up of particles have dimensions of 10 - 10,000 angstroms (1 - 1000 manometers) and which is dispersed in a different phase. |
| **Colloidal particles** | Particles that are so small that the surface activity has an appreciable influence on the properties of the particle. |
| **Conceptual model** | A written or illustrated visualization of geologic/hydrogeologic/environmental conditions of a particular area. |
| **Conductance (specific)** | A measure of the ability of the water to conduct an electric current at 770 F (250C). It is related to the total concentration of ionizable solids in the water. It is inversely proportional to electrical resistance. |
| **Conductivity, hydraulic** | See soil water. |
| **Confining bed** | A body of material of low hydraulic conductivity that is stratigraphically adjacent to one or more aquifers. It may lie above or below the aquifer. |
| **Confining unit** | A term that is synonymous with "aquiclude," "aquitard," and "aquifuge;" defined as a body of relatively low permeable material stratigraphically adjacent to one or more aquifers. |
| **Contaminant** | An undesirable substance not normally present or an unusually high concentration of a naturally occurring substance in water or soil. |
| **d-10** | The diameter of a soil particle (usually in millimeters) at which 10% by weight of the particles of a particular sample are finer. Synonymous with the effective size or effective grain size. |
| **d-60** | The diameter of a soil particle (usually in millimeters) at which 60% by weight of the particles of a particular sample are finer. |
| **Darcy's law** | A law describing the rate of flow of water through porous media. (Named for Henry Darcy of Paris who formulated it in 1856 from extensive work on the flow of water through sand filter beds.) |
| **Deflocculate** | (a) To separate the individual components of compound particles by chemical and/or physical means. (b) To cause the particles of the disperse phase of a colloidal system to become suspended in the dispersion medium. (1) |
| **Degradation** | The breakdown of substances by biological action. |
| **Degree of consolidation (percent consolidation)** | The ratio, expressed as a percentage of: (1) The amount of consolidation at a given time within a soil mass, to (2) The total amount of consolidation obtainable under a given stress condition. |

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| **Degree of saturation** | The extent or degree to which the voids in rock contain fluid (water, gas, or oil). Usually expressed in percent related to total void or pore space. |
| **Density** | The mass or quantity of a substance per unit volume. Units are kilograms per cubic meter or grams per cubic centimeter. |
| **Deposit** | Material left in a new position by a natural transporting agent such as water, wind, ice. or gravity, or by the activity of man. |
| **Depression curve** | Record of profile of water table as a result of pumping. |
| **Detection monitoring** | A program of monitoring for the express purpose of determining whether or not there has been a contaminant release to ground water. |
| **Diagenesis** | The chemical and physical changes occurring in sediments before consolidation or while in the environment of deposition. |
| **Differential water capacity** | The absolute value of the rate of change of water content with soil water pressure. The water capacity at a given water content will depend on the particular desorption or adsorption curve employed. Distinction should be made between volumetric and specific water capacity. |
| **Direct methods** | Methods (e.g., boreholes and monitoring wells) which entail the excavation or drilling, collection, observation, and analysis of geologic materials and water samples. |
| **Direct precipitation** | Water that falls directly into a lake or stream without passing through any land phase of the runoff cycle. |
| **Discharge area** | An area in which there are upward components of hydraulic head in the aquifer. Ground water is flowing toward the surface in a discharge area and may escape as a spring, seep, or baseflow, or by evaporation and transpiration. |
| **Discharge velocity** | An apparent velocity, calculated from Darcy's law, which represents the flow rate at which water would move through an aquifer if the aquifer were an open conduit. Also called specific discharge. |
| **Direct methods** | Methods (e.g., boreholes and monitoring wells) which entail the excavation or drilling, collection, observation, and analysis of geologic materials and water samples. |
| **Discontinuity** | (a) Boundary between major layers of the Earth which have different seismic velocities. (b) Interruption of the homogeneity of a rock mass (e.g. joints, faults, etc.). |
| **Disperse** | (a) To break up compound particles, such as aggregates, into the individual component particles. (b) To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water. |
| **Disposal** | The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters. |

**Dissolved metals**  Those constituents (metals) of an unacidified sample that pass through a 0.45pm membrane filter.

**Dissolution**  The process where soluble organic components from DNAPL dissolves in groundwater or infiltration and forms a groundwater contaminant plume. The duration of remediation measures (either clean-up or containment) is determined by the 1) the rate of the dissolution process that can be achieved in the field, and 2) the mass of soluble components in the residual DNAPL trapped in the aquifer.

**DNAPL**  A Dense Non-aqueous Phase Liquid. Also known as free product or a sinking plume (sinker).

**DNAPL entry location**  The area where DNAPL has entered the subsurface.

**DNAPL site**  A site where DNAPL has been released and is now present in the subsurface as an immiscible phase.

**DNAPL zone**  The portion of a site affected by free-phase or residual DNAPL in the subsurface either the vadose zone or saturated zone). The DNAPL zone has organics in the vapor phase (unsaturated zone), dissolved phase (both unsaturated and saturated zone), and DNAPL phase (both unsaturated and saturated zone).

**Downhole geophysics**  Techniques that use a sensing device that is lowered into a borehole for the purpose of characterizing geologic formations and their associated fluids. The results can be interpreted to determine lithology, resistivity, bulk density, porosity, permeability, and moisture content and to define the source, movement, and physical/chemical characteristics of ground water.

**Drawdown**  A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of ground water from wells.

**Drill cuttings**  Fragments or particles of soil or rock, with or without free water, created by the drilling process.

**Drilling fluid**  A fluid (liquid or gas) that may be used in drilling operations to remove cuttings from the borehole, to clean and cool the drill bit, and to maintain the integrity of the borehole during drilling.

**Dynamic equilibrium**  A condition in which the amount of recharge to an aquifer equals the amount of natural discharge.

**Effective porosity**  The amount of interconnected pore space through which fluids can pass, expressed as a percent of bulk volume. Part of the total porosity will be occupied by static fluid being held to the mineral surface by surface tension, so effective porosity will be less than total porosity.

**Effective solubility**  The actual aqueous solubility of an organic constituent in groundwater that is in chemical equilibrium with a mixed DNAPL (a DNAPL containing several organic constituents). The effective solubility of a particular organic chemical can be estimated by multiplying its mole fraction in the DNAPL mixture by its pure phase solubility.

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| **Equilibrium constant** | The number defining the conditions of equilibrium for a particular reversible chemical reaction. |
| **Equivalent diameter** | In sedimentation analysis, the diameter assigned to a non-spherical particle, it being numerically equal to the diameter of a spherical particle of the same density and velocity of fall. |
| **Equipotential line** | A line in a two-dimensional ground-water flow field such that the total hydraulic head is the same for all points along the line. |
| **Equipotential surface** | A surface in a three-dimensional ground-water flow field such that the total hydraulic head is the same everywhere on the surface. |
| **Equivalent weight** | The concentration in parts per million of a solute multiplied by the valence charge and then divided by its formula weight in grams. |
| **Field capacity** | The maximum amount of water that the unsaturated zone of a soil can hold against the pull of gravity. The field capacity is dependent on the length of time the soil has been undergoing gravity drainage. |
| **Fill** | Man-made deposits of natural soils or rock products and waste materials. |
| **Film water** | A layer of water surrounding soil particles and varying in thickness from 1 or 2 to perhaps 100 or more molecular layers.  Usually considered as that water remaining after drainage has occurred because it is not distinguishable in saturated soils. |
| **Fine texture** | Consisting of or containing large quantities of the fine fractions, particularly of silt and clay. (Includes all clay loams and clays; that is, clay loams, sandy clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes.  Sometimes subdivided into clayey texture and moderately fine texture.) See soil texture. |
| **Fissure flow** | Flow of water through joints and larger voids. |
| **Flow net** | The set of intersecting equipotential lines and flowlines representing two dimensional steady flow through porous media. |
| **Flow, steady** | The flow that occurs when, at any point in the flow field, the magnitude and direction of the specific discharge are constant in time. |
| **Flow, unsteady** | The flow that occurs when, at any point in the flow field, the magnitude or direction of the specific discharge changes with time.  Also called transient flow or nonsteady flow. |
| **Fluid potential** | The mechanical energy per unit mass of fluid at any given point in space and time. |
| **Flush joint or flush coupled** | Casing or riser with ends threaded such that a consistent inside and outside diameter is maintained across the threaded joints or couplings. |
| **Fracture** | A break in a rock formation due to structural stresses.  Faults, shears, joints, and planes of fracture cleavage are all types of fractures. |

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| **Fracture trace** | The surface representation of a fracture zone. It may be a characteristic line of vegetation or linear soil-moisture pattem or a topographic sag. |
| **Free energy** | A measure of the thermodynamic driving energy of a chemical reaction. Also known as Gibbs free energy or Gibbs function. |
| **Free-phase DNAPL** | Immiscible liquid exiting in the subsurface with a positive pressure such that it can flow into a well. If not trapped in a pool, free phase DNAPL will flow vertically through an aquifer or laterally down sloping fine-grained stratigraphic units. Also called mobile DNAPL or continuous phase DNAPL. |
| **Free water (gravitational water) (ground water) (phreatic water)** | Water that is free to move through a soil or rock mass under the influence of gravity. |
| **Gamma-gamma radiation log** | A borehole log in which a source of gamma radiation as well as a detector are lowered into the borehole. This log measures bulk density of the formation and fluids. |
| **Geohydrology** | Science of the occuffence, distribution, and movement of water below the surface of the Earth. |
| **Geomorphology** | The description of the present exposed surfaces of the crust of the Earth, and seeks to interpret these surfaces in terms of natural processes (chiefly erosion) which lead or have led to their formation. |
| **Geophysical borehole logging** | See Downhole Geophysics. |
| **Geophysics** | The study of all the gross physical properties of the Earth and its parts, particularly associated with the detection of the nature and shape of unseen subsurface rock bodies by measurement of such properties and property contrasts. Small scale applied geophysics is now a major aid in geological reconnaissance. |
| **Geotechnical** | Pertaining to Geotechnics, which is the application of scientific methods to problems in engineering geology. |
| **Gradation (grain-size distribution) (texture)** | The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges. |
| **Grading** | A 'well-graded' sediment containing some particles of all sizes in the range concerned. Distinguish from 'well sorted', which describes a sediment with grains of one size. |
| **Grain-size analysis (mechanical analysis) (particle/size analysis)** | The process of determining grainsize distribution. |
| **Granule** | A natural soil aggregate or ped which is relatively nonporous. See soil structure and soil structure types. |
| **Gravelpack** | Common nomenclature for the preferred terminology, primary filter of a well (see primary filter pack). |

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| **Gravel** | Round or semirounded particles of rock that will pass a 3-in. (76.2 mm) sieve and be retained on a No. 4 (4.75 mm) U.S. standard sieve. |
| **Ground water** | (a) The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer. (b) The portion of the total precipitation which at any particular time is either passing through or standing in the soil and the underlying strata and is free to move under the influence of gravity. |
| **Ground-water basin** | A rather vague designation pertaining to a ground-water reservoir which is more or less separate from neighboring ground-water reservoirs. A ground-water basin could be separated from adjacent basins by geologic boundaries or by hydrologic boundaries. |
| **Ground water, confined** | The water contained in a confined aquifer. Pore-water pressure is greater than atmospheric at the top of the confined aquifer. |
| **Ground-water flow** | The movement of water through openings in sediment and rock which occurs in the zone of saturation. |
| **Ground water level** | The level below which the rock and subsoil, to unknown depths, are saturated. |
| **Ground-water mining** | The practice of withdrawing ground water at rates in excess of the natural recharge. |
| **Ground water, perched** | The water in an isolated, saturated zone located in the zone of aeration. It is the result of the presence of a layer of material of low hydraulic conductivity, called a perching bed. Perched ground water will have a perched water table. |
| **Ground water regime (ground water)** | Water below the land surface in a zone of saturation. |
| **Ground water, unconfined** | The water in an aquifer where there is a water table. |
| **Grout** | A low permeability material placed in the annulus between the well casing or riser pipe and the borehole wall (i.e., in a single cased monitoring well), or between the riser and casing (i.e., in a multi-cased monitoring well), to maintain the alignment of the casing and riser and to prevent movement of ground water or surface water within the annular space. |
| **Head, total** | The sum of the elevation head, the pressure head, and the velocity head at a given point in an aquifer. |
| **Heterogeneous** | Pertaining to a substance having different characteristics in different locations. A synonym is nonuniform. |
| **Homogeneous** | Pertaining to a substance having identical characteristics everywhere. A synonym is uniform. |
| **Horizon** | See soil horizon. |
| **Hydration** | The physical binding of water molecules to ions, molecules, particles, or other matter. |
| **Hydraulic conductivity** | A coefficient of proportionality describing the rate at which water can move through a |

permeable medium. The density and kinematic viscosity of the water must be considered in determining hydraulic conductivity.

**Hydraulic diffusivity**      A property of an aquifer or confining bed defined as the ratio of the transmissivity to the storativity.

**Hydraulic gradient**      The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

**Hydraulic head**      The elevation with respect to a specified reference level at which water stands in a piezometer connected to the point in question in the soil. Its definition can be extended to soil above the water table if the piezometer is replaced by a tensiometer. The hydraulic head in systems under atmospheric pressure may be identified with a potential expressed in terms of the height of a water column. More specifically it can be identified with the sum of gravitational and capillary potentials, and may be termed the hydraulic potential.

**Hydrochemical facies**      Bodies of water with separate but distinct chemical compositions contained in an aquifer.

**Hydrodynamic dispersion**      The process by which ground water containing a solute is diluted with uncontaminated ground water as it moves through an aquifer.

**Hydrograph**      A graph that shows some property of ground water or surface water as a function of time.

**Hydrogeology**      The study of the natural (and artificial) distribution of water in rocks, and its relationship to those rocks. Inasmuch as the atmosphere is a continuation of the hydrosphere, and is in physical and chemical balance with it, there is a close connection with meteorology.

**Hydrologic equation**      An expression of the law of mass conservation for purposes of water budgets. It may be stated as inflow equals outflow plus or minus changes in storage.

**Hydrologic unit**      Geologic strata that can be distinguished on the basis of capacity to yield and transmit fluids. Aquifers and confining units are types of hydrologic units. Boundaries of a hydrologic unit may not necessarily correspond either laterally or vertically to lithostratigraphic formations.

**Hydrostatic pressure**      A state of stress in which all the principal stresses are equal (and there is no shear stress).

**Hydrostratigraphic unit**      A formation, part of a formation, or a group of formations in which there are similar hydrologic characteristics allowing for grouping into aquifers or confining layers.

**Hygroscopic water**      Water adsorbed by a dry soil from an atmosphere of high relative humidity, water remaining in the soil after "air-drying" or water held by the soil when it is in equilibrium with an atmosphere of a specified relative humidity at a specified temperature, usually 98% of relative humidity at 25 degrees Centigrade.

**Ideal gas**      A gas having a volume that varies inversely with pressure at a constant temperature and that also expands by 1/273 of its volume at 0°C for each degree rise in temperature at constant pressure.

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| **Immobilization** | The conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues. |
| **Indirect methods** | Methods which include the measurement or remote sensing of various physical and/or chemical properties of the earth (e.g., electromagnetic conductivity, electrical resistivity, specific conductance, geophysical logging, aerial photography). |
| **Infiltration** | The flow of water downward from the land surface into and through the upper soil layers. |
| **Infiltration capacity** | The maximum rate at which infiltration can occur under specific conditions of soil moisture.  For a given soil, the infiltration capacity is a function of the water content. |
| **Infiltration rate** | (a) A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water. (b) The rate at which a soil under specified conditions can absorb falling rain or melting snow; expressed in depth of water per unit time (cm/sec; in/hr). |
| **Injection well** | A well drilled and constructed in such a manner that water can be pumped into an aquifer in order to recharge it. |
| **Interflow** | The lateral movement of water in the unsaturated zone during and immediately after a precipitation event.  The water moving as interflow discharges directly into a stream or lake. |
| **Intermediate zone** | That part of the unsaturated zone below the root zone and above the capillary fringe. |
| **Intrinsic permeability** | Pertaining to the relative ease with which a porous medium can transmit a liquid under a hydraulic or potential gradient.  It is a property of the porous medium and is independent of the nature of the liquid or the potential field. |
| **Ion exchange** | A process by which an ion in a mineral lattice is replaced by another ion which was present in an aqueous solution. |
| **Isotropy** | The condition in which hydraulic properties of the aquifer are equal in all directions. |
| **Jetting** | When applied as a drilling method, water is forced down through the drill rods or casing and out through the end aperture.  The jetting water then transports the generated cuttings to the ground surface in the annulus of the drill rods or casing and the borehole.  The term jetting may also refer to a development technique (see well screen jetting). |
| **Kinematic viscosity** | The ratio of dynamic viscosity to mass density.  It is obtained by dividing dynamic viscosity by the fluid density.  Units of kinematic viscosity are square meters per second. |
| **Laminar flow** | That type of flow in which the fluid particles follow paths that are smooth, straight, and parallel to the channel walls.  In laminar flow, the viscosity of the fluid damps out turbulent motion.  Compare with Turbulent flow. |
| **Law of mass action** | The law stating that for a reversible chemical reaction the rate of reaction is proportional to the concentrations of the reactants. |
| **Leach** | To cause water or other liquid to percolate through soil. |

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| **Leaky conflning layer** | A low-penneability layer that can transmit water at sufficient rates to fumish some recharge to a well pumping from an underlying aquifer. Also called aquitard. |
| **Lineament** | A natural linear surface feature longer than 1500 meters. |
| **Lysimeter** | A field device containing a soil column and vegetation which is used for measuring actual evapotranspiration. |
| **Lysimeter** | (a) A device for measuring percolation and leaching losses from a column of soil under controlled conditions. (b) A device for measuring gains (precipitation and condensation) and losses (evapotranspiration) by a column of soil. |
| **Maximum contaminant level** | The highest concentration of a solute permissible in a public water supply as specified in the National Interim Primary Drinking Water Standards for the United States. |
| **Molality** | A measure of chemical concentration. A one-molal solution has one mole of solute dissolved in 1000 grams of water. One mole of a compound is its formula weight in grams. |
| **Morphology** | See soil morphology. |
| **Multi-cased well** | A well constructed by using successively smaller diameter casings with depth. |
| **Multiport systems** | A single hole device in which points are installed that are capable of sampling or measuring at multiple levels within a formation or series of formations. |
| **N-value** | The number of blows required to drive the sampler of the Standard Penetration test its last 12 inches (300 mm). |
| **Natural gamma radiation log** | A borehole log that measures the natural gamma radiation emitted by the formation rocks. It can be used to delineate subsurface rock types. |
| **Neat cement** | A mixture of Portland cement (ASTM 150) and water. |
| **Negative pressure** | A pressure less than the local atmospheric pressure at a given point. |
| **Neutron log** | A borehole log obtained by lowering a radioactive element, which is a source of neutrons, and a neutron detector into the well. The neutron log measures the amount of water present; hence, the porosity of the formation. |
| **Observation well** | A nonpumping well used to observe the elevation of the water table or the potentiometric surface. An observation well is generally of larger diameter than a piezometer and typically is screened or slotted throughout the thickness of the aquifer. |
| **Overburden** | The loose soil, sand, silt, or clay that overlies bedrock. |
| **Overland flow** | The flow of water over a land surface due to direct precipitation. Overland now generally occurs when the precipitation rate exceeds the infiltration capacity of the soil and depression storage is full. Also called Horton overland flow. |
| **Oxidation-reduction potential** | The potential required to transfer electrons from the oxidant to the reductant and used as 2 qualitative measure of the state of oxidation in wastewater treatment systems. |

**Packer**                          A transient or dedicated device placed in a well that isolates or seals a portion of the well, well annulus, or borehole at a specific level.

**Parent material**                 The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soil is developed by pedogenic processes.

**Particle density**                The mass per unit volume of the soil particles. In technical work, usually expressed as grams per cubic centimeter. See bulkeny, soil.

**Particle size**                   The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

**Particle-size analysis**          Determination of the various amounts of the different separates in a soil sample, will usually be sedimentation, sieving, micrometry, or combinations of these methods.

**Particle-size distribution**      The amounts of the various soil separates in a soil sample, usually expressed as weigbt percentages.

**Penetrability**                   The ease with which a probe can be pushed into the soil. (May be expressed in units of distance, speed, force, or work depending on the type of penetrometer used).

**Percent saturation**              The ratio, expressed as a percentage, of. (a) The volume of water in a given soil or rock
**(degree of saturation)**          mass, to (b) The total volume of intergranular space (voids).

**Perched water table**             A water table usually of limited area maintained above the normal free water elevation by the pressure of an intervening relatively impervious confining stratum.

**Percolation**                     The flow or trickling of a liquid downward through a contact or filtering medium. The liquid may or may not fill the pores of the medium.

**Permeability, soil**              (a) The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different soil horizons vary in permeability, the particular horizon under question should be designated. (b) The property of a porous medium itself that relates to the ease with which gases, liquids, or other substances can pass through it. Previously, frequently considered the "k" in Darcy's law. See Darcy's law and soil water.

**Permeameter**                     A laboratory device used to measure the intrinsic permeability and hydraulic conductivity of a soil or rock sample.

**pH, soil**                        The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil-water ratio, and expressed in terrns of the pH scale.

**Physical properties (of soil)**   Those characteristics, processes, or reactions of a soil which are caused by physical forces and which can be described by, or expressed in, physical terms or equations. Sometimes confused with and difficult to separate from chemical properties; hence, the terms "physical-chemical" or "physiochemical". Examples of physical properties are bulk density, water-holding capacity, hydraulic conductivity, porosity, pore-size distribution, etc.

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| **Phreatic water** | Water in the zone of saturation. |
| **Piezometer** | A nonpumping well, generally of small diameter, which is used to measure the elevation of the water table or potentiometric surface A piezometer generally has a short well screen through which water can enter. |
| **Piezometer nest** | A set of two or more piezometers set close to each other but screened to different depths. |
| **Piezometric surface** | (a) The surface at which water will stand in a series of piezometers. (b) An imaginary surface that everywhere coincides with the static level of the water in the aquifer. |
| **Piping** | An underground flow of water with a sufficient pressure gradient to cause scour along a preferred path. |
| **Piston sampler** | A tube with an internal piston used for obtaining relatively undisturbed samples from cohesive soils. |
| **Plume** | The zone of contamination containing organics in the dissolved phase. The plume usually will originate from the DNAPL zone and extend downgradient for some distance depending on site hydrogeologic and chemical conditions. To avoid confusion, the term "DNAPL plume" should not be used to describe a DNAPL pool; "plume" should be used only to refer to dissolved-phase organics. |
| **Pool and lens** | A zone of free-phase DNAPL at the bottom of an aquifer. A lens is a pool that rests on a fine-grained stratigraphic unit of limited areal extent. DNAPL can be recovered from a pool or a lens if a well is placed in the right location. |
| **Pollutant** | Any solute or cause of change in physical properties which renders water unfit for a given use. |
| **Pore-size distribution** | The volume of the various sizes of pores in a soil. Expressed as percentages of the bulk volume (soil plus pore space). |
| **Pore space** | The volume between mineral grains in a porous medium. |
| **Porosity** | The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment. |
| **Potentiometric surface** | A surface that represents the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer. |
| **Primary filter pack** | A clean silica sand or sand and gravel mixture of selected grain size and gradation that is installed in the annular space between the borehole wall and the well screen, extending an appropriate distance above the screen, for the purpose of retaining and stabilizing the particles from the adjacent strata. The term is used in place of "gravel pack." |
| **Profile, soil** | A vertical section of the soil through all its horizons and extending into the parent material. |

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| **PTFE tape** | Joint sealing tape composed of polytetrafluoroethylene. |
| **Pumping cone** | The area around a discharging well where the hydraulic head in the aquifer has been lowered by pumping. Also called cone of depression. |
| **Pumping test** | A test made by pumping a well for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the well and the hydraulic characteristics of the aquifer. Also called aquifer test. |
| **Radial flow** | The flow of water in an aquifer toward a vertically oriented well. |
| **Rating curve** | A graph of the discharge of a river at a particular point as a function of the elevation of the water surface. |
| **Reaction, soil** | The degree of acidity or alkalinity of a soil, usually expressed as a pH value. Descriptive terms commonly associated with certain ranges in pH are: extremely acid, less than 4.5; very strongly acid, 4.5 to 6.0; slightly acid, 6.1 to 6.5; neutral, 6.6 to 7.3; slightly alkaline, 7.4 to 7.8; moderately alkaline, 7.9 to 8.4; strongly alkaline, 8.5 to 9.0; and very strongly alkaline, greater than 9. 1. |
| **Recharge area** | An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area. |
| **Recharge basin** | A basin or pit excavated to provide a means of allowing water to soak into the ground at rates exceeding those that would occur naturally. |
| **Recharge boundary** | An aquifer system boundary that adds water to the aquifer. Streams and lakes are typical recharge boundaries. |
| **Recovery** | The rise in water level in a pumping well and nearby observation wells after ground-water pumpage has ceased. |
| **Regolith** | The upper part of the earth's surface that has been altered by weathering processes. It includes both soil and weathered bedrock. |
| **Representativeness** | The characteristic of a specific scientific experiment that makes it an adequate sample of the general case. |
| **Representative point** | a) A location in surface waters or ground waters at which specific conditions or parameters may be measured in such a manner as to characterize or approximate the quality or condition of the water body; or b) A location in process or waste waters at which specific conditions or parameters are measured and will adequately reflect the actual condition of those waters or waste waters for which analysis was made. |
| **Riser** | The pipe extending from the well screen to or above the ground surface. |
| **Residual** | Immiscible phase liquid held in the pore spaces or fractures by capillary forces (negative pressure on DNAPL), Residual will remain trapped within the pore of the porous media unless the viscous forces (caused by the dynamic force of water against the DNAPL ) are greater than the capillary forces holding the DNAPL in the pore. At most sites the hydraulic gradient required to mobilize all of the residual trapped in an aquifer is usually much greater than can be produced by wells or trenchers. |

**Residual saturation**        The fraction of available pore space containing residual DNAPLS, or the saturation level where free-phase DNAPL becomes residual DNAPL. In the vadose zone, residual saturation range up to 20% of total pore volume while in the saturated zone residual saturations range up to 50% of total pore volume.

**Resistivity log**        A borehole log made by lowering two current electrodes into the borehole and measuring the resistivity between two additional electrodes. It measures the electrical resistivity of the formation and contained fluids near the probe.

**Rock**        Natural solid mineral matter occurring in large masses or fragments.

**Runoff**        The total amount of water flowing in a stream. It includes overland flow, return flow, interflow, and baseflow.

**Sand**        (a) A soil particle between 0.05 and 2.0 mm in diameter. (b) Any one of five soil separates, namely: very coarse sand, coarse sand, medium sand, fine sand, and very fine sand. See soil separates. (c) A soil textural class. See soil texture.

**Sand model**        A scale model of an aquifer, which is built using a porous medium to demonstrate ground-water flow.

**Sanitary landflll**        The disposal of solids and, in some instances, semisolid and liquid wastes by burying the material to shallow depths, usually in unconsolidated materials.

**Saturated zone**        The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

**Saturation**        A condition reached by a material, whether it be in solid, gaseous, or liquid state, that holds another material within itself in a given state in an amount such that no more of such material can be held within it in the same state. The material is then said to be saturated on in a condition of saturation.

**Secondary filter pack**        A clean, uniformly graded sand that is placed in the annulus between the primary filter pack and the over-lying seal, or between the seal and overlying grout backfill or both, to prevent movement of seal, or grout, or both into the primary filter pack.

**Secondary porosity**        The porosity developed in a rock after its deposition or emplacement, through such processes as solution or fracturing.

**Sediment sump**        A blank extension beneath the well screen used to collect fine-grained material from the filter pack and adjacent strata. The term is synonymous with rat trap or tail pipe.

**Sedimentation**        The process of subsidence and deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material.

**Seepage velocity**        The actual rate of movement of fluid particles through porous media.

**Seismic refraction**        A method of determining subsurface geophysical properties by measuring the length of time it takes for artificially generated seismic waves to pass through the ground.

| | |
|---|---|
| **Silt** | (a) A soil separate consisting of particles between 0.005 and 0.002 mm in equivalent diameter. See soil separates. (b) A soil texture class. See soil texture. |
| **Single-cased well** | A monitoring well constructed with a riser but without an exterior casing. (9) |
| **Single-point resistance log** | A borehole log made by lowering a single electrode into the well with the other electrode at the ground surface. It measures the overall electrical resistivity of the formation and drilling fluid between the surface and the probe. |
| **Site assessment** | A formal means of exploring and characterizing a proposed waste management facility or location so that all physical factors are identified and so quantified as to serve as the basis of an environmentally sound design and operational plan. |
| **Slug test** | An aquifer test made by either pouring a small instantaneous charge of water into a well or by withdrawing a slug of water from the well. A synonym for this test, when a slug of water is removed from the well, is a bail-down test. |
| **Soil** | (a) The unconsolidated mineral material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. (b) The unconsolidated mineral matter on the surface of the Earth that has been subjected to and influenced by genetic and environmental factors of: parent material, climate (including moisture and temperature effects), macro- and microorganisms, and topography, all acting over a period of time and producing a product, soil, that differs from the, material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. |
| **Soil auger** | A tool for boring into the soil and withdrawing a small sample for field or laboratory observation. Soil augers may be classified into several types as follows: (a) Those with worm-type bits, unenclosed; (b) Those with worm-type bits enclosed in a hollow cylinder; and those with a hollow cylinder with a cutting edge at the lower end. |
| **Soil mineral** | (a) Any mineral that occurs as a part of or in the soil. (b) A natural inorganic compound with definite physical, chemical, and crystalline properties (within the limits of isomorphism), that occurs in the soil. |
| **Soil moisture** | The water contained in the unsaturated zone. |
| **Soil morphology** | (a) The physical constitution, particularly the structural properties of the soil profile as exhibited by the kinds, thickness, and arrangement of the horizons in the profile, and by the texture, structure, consistency, and the porosity of each horizon. (b) The structural characteristics of the soil or any of its parts. |
| **Soil physics** | The organized body of knowledge concerned with the physical characteristics of soil and with the methods employed in their determinations. |
| **Soil science** | That science dealing with soils as a natural resource on the surface of the Earth including soil formation, classification, and mapping, and physical, chemical, biological, and fertility properties of soil per se; and these properties in relation to their management. |
| **Soil separates** | Mineral particles, < 2.0 mm in equivalent diameter, ranging between specified size limits. The names and size limits of separates recognized in the U.S.D.A. system are: very coarse sand, 2.0 to 1.0 mm; coarse sand, 1.0 to 0.5 mm; medium sand, 0.5 to 0.25 mm; |

fine sand, 0.25 to 0.10 mm; very fine sand, 0.10 to 0.05 mm; silt, 0.05 to 0.002 mm; and clay, < 0.002 mm. The U.S.C.S. particle and size range are as follows: coarse sand, 2.0 to 4.76 mm; medium sand, 0.42 to 2.0 mm; fine sand, 0.074 to 0.42 mm; fines (silt and clay), < 0.074 mm. (Note: U.S.C.S. silt and clay designations are determined by response of the soil to manipulation at various water contents rather than by measurement of size.)

**Soil solution**               The aqueous liquid phase of the soil and its solutes.

**Soil structure**              The combination or arrangement of primary soil particles into secondary particles, units, or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive, characteristic pattern. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades, respectively.

**Soil suction**                A measure of the force of water retention in unsaturated soil. Soil suction is equal to a force per unit area that must be exceeded by an externally applied suction to initiate water flow from the soil. Soil suction is expressed in standard pressure terms.

**Soil texture**                The relative proportion of the various soil separates in a soil as described by the classes of soil texture.

**Soil water diffusivity**      The hydraulic conductivity divided by the differential water capacity (care being taken to be consistent with units), or the flux of water per unit gradient of moisture content in the absence of other force fields.

**Soil water pressure**         The pressure (positive or negative), relative to the external gas pressure on the soil water, to which a solution identical in composition to the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water. May be identified with the capillary potential defined above.

**Soil water**                  A general term emphasizing the physical rather than the chemical properties and behavior of the soil solution.

**Soil-moisture tension**       See moisture tension (or pressure).

**Solid waste disposal facilities**   A facility or part of a facility at which solid waste is intentionally placed into or on any land or water, and at which waste will remain after closure.

**Solubility product**          The equilibrium constant that describes a solution of a slightly soluble salt in water.

**Specific capacity**           An expression of the productivity of a well, obtained by dividing the rate of discharge of water from the well by the drawdown of the water level in the well. Specific capacity should be described on the basis of the number of hours of pumping prior to the time the drawdown measurement is made. It will generally decrease with time as the drawdown increases.

**Specific electrical conductance**   The ability of water to transmit an electrical current. It is related to the concentration and charge of ions present in the water.

**Specific retention**          The ratio of the volume of water the rock or sediment will retain against the pull of gravity to the total volume of the rock or sediment.

| | |
|---|---|
| **Specific weight** | The weight of a substance per unit volume. The units are newtons per cubic meter. |
| **Specific yield** | The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur. |
| **Spontaneous potential log** | A borehole log made by measuring the natural electrical potential which develops between the formation and the borehole fluids. |
| **Stability** | The condition of a structure or a mass of material when it is able to support the applied stress for a long time without suffering any significant deformation or movement that is not released by the release of stress. |
| **Stagnation point** | A place in a ground-water flow field at which the ground water is not moving. The magnitude of vectors of hydraulic head at the point are equal but opposite in direction. |
| **Subsoil** | In general concept, that part of the soil below the depth of plowing. (2) |
| **Static water level** | The elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping or conditions related to well installation, hydrologic testing, or nearby pumpage. |
| **Storage, specific** | The amount of water released from or taken into storage per unit volume of a porous medium per unit change in head. |
| **Storativity** | The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to the specific yield. Also called storage coefficient. |
| **Stratified** | Arranged in strata, or layers. The term refers to geologic material. Layers in soils that result from the processes of soil formation are called horizons; those inherited from the parent material are called strata. |
| **Structure** | One of the larger features of a rock mass, like bedding, foliation, jointing, cleavage, or brecciation; also the sum total of such features as contrasted with texture. Also, in a broader sense, it refers to the structural features of an area such as anticlines or synclines. See also soil structure. |
| **Subsoil** | In general concept, that part of the soil below the depth of plowing. (2) |
| **Surface sealing** | The orientation and packing of dispersed soil particles in the immediate surface layer of the soil, rendering it relatively impermeable to water. |
| **Suspended metals** | Those constituents (metals) of an unacidified sample that are retained by a 0.45 mm membrane filter. |
| **Target monitoring zone** | The ground water flow path from a particular area or facility into which monitoring wells will be screened. The target monitoring zone should be a stratum (strata) in which there is a reasonable expectation that a vertically placed well will intercept migrating contaminants. |

| | |
|---|---|
| **Target** | In detection monitoring programs, the ground water flow path from a particular area or facility into which monitoring wells will be screened.  The target monitoring zone should be a stratum (strata) in which there is a reasonable expectation that a vertically placed well will intercept migrating contaminants. |
| **Tensiometer** | (a) A device used to measure the soil-moisture tension in the unsaturated zone. (b) A device for measuring the negative pressure (or tension) of water in soil in situ; a porous, permeable ceramic cup connected through a tube to a manometer or vacuum gauge. |
| **Tension** | The condition under which pore water exists at a pressure less than atmospheric. |
| **Tension, soil water** | The expression, in positive terms, of the negative hydraulic pressure of soil water. |
| **Test pit** | A shallow excavation made to characterize Transpiration: water loss from leaves and other plant the subsurface. |
| **Total metals** | The concentration of metals determined on an unfiltered sample after vigorous digestion, or the sum of the concentrations of metals in both dissolved and suspended fractions. |
| **Throughflow** | The lateral movement of water in an unsaturated zone during and immediately after a precipitation event.  The water from throughflow seeps out at the base of slopes and then flows across the ground surface as return flow, ultimately reaching a stream or lake. |
| **Time-series** | A series of statistical data collected at regular intervals of time; a frequency distribution in which the independent variable is time. |
| **Total potential (of soil water)** | The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water, at a specified elevation and at atmospheric pressure, to the soil water (at the point under consideration).  The total potential (of soil water) consists of the following: |
| **Transects** | In ecology, a sample area (usually elongate or linear) chosen as the basis for studying a particular assemblage of organisms. |
| **Transmissivity** | The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient.  It is a function of properties of the liquid, the porous media, and the thickness of the porous media. |
| **Tremie pipe** | A pipe or tube that is used to transport filter pack materials and annular sealant materials from the ground surface into the borehole annulus or between casings and casings or riser pipe of a monitoring well. |
| **Turbidity** | Heavily suspended and colloidal organic and inorganic material in water. |
| **Turbulent flow** | That type of flow in which the fluid particles move along very irregular paths.  Momentum can be exchanged between one portion of the fluid and another.  Compare with Laminar flow. |
| **Undisturbed sample** | A soil sample that has been obtained by methods in which every precaution has been taken to minimize disturbance to the sample. |
| **Unsaturated flow** | The movement of water in a soil which is not filled to capacity with water. |

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| **Unsaturated zone** | The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched ground water, may exist in the unsaturated zone. |
| **Uppermost aquifer** | The geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary. |
| **Vadose water** | Water in the zone of aeration. |
| **Viscosity** | The property of a fluid describing its resistance to flow. Units of viscosity are newton-seconds per meter squared or pascal-seconds. Viscosity is also known as dynamic viscosity. |
| **Void ratio** | The ratio of. (a) The volume of void space, to (b) The volume of solid particles in a given soil mass. |
| **Voids** | Entities which are interconnected with each other either through voids of dissimilar size and shape, through narrow necks, or through intersection with voids of similar size and shape. |
| **Water content** | The ratio of the volume of soil moisture to the total volume of the soil. This is the volumetric water content, also called volume wetness. |
| **Water table** | The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells. |
| **Weathering** | All physical and cbemical changes produced in rocks, at or near the earth's surface, by atmospheric agents. |
| **Well completion diagram** | A record that illustrates the details of a well installation.. |
| **Well, fully penetrating** | A well drilled to the bottom of an aquifer, constructed in such a way that it withdraws water from the entire thickness of the aquifer. |
| **Well interference** | The result of two or more pumping wells, the drawdown cones of which intercept. At a given location, the total well interference is the sum of the drawdowns due to each individual well. |
| **Well, partially penetrating** | A well constructed in such a way that it draws water directly from a fractional part of the total thickness of the aquifer. The fractional part may be located at the top or the bottom or anywhere in between the aquifer. |
| **Well screen** | A filtering device used to retain the primary or natural filter pack; usually a cylindrical pipe with openings of a uniform width, orientation, and spacing. |
| **Well screen jetting (Hydraulic Jetting)** | When jetting is used for development, a jetting tool with nozzles and a high pressure pump is used to force water outwardly through the screen, the filter pack, and sometimes into the adjacent geologic unit. |

**Appendix E- Sample Forms**

# Ground Water Sampling Log

Project_____ Site_____ Well No._____ Date_____
Well Depth_____Screen Length_____ Well Diameter _____ Casing Type____
Sampling Device_____ Tubing type_____
Water Level (before sampling)_____ Water Level (after sampling)_____
Measuring Point_____ Other Info _____
_____
Sampling Personnel_____
Pump Rate_____

| Time | pH | Temp | Cond | Dis.O$_2$ | Turb | []Conc | | | Notes |
|------|-----|------|------|-----------|------|--------|--|--|-------|
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Type of Samples Collected_____
Information: 2 in = 617 ml/ft, 4 in = 2470 ml/ft; $Vol_{cyl} = \pi r^2 h$, $Vol_{sphere} = 4/3\pi r^3$

**Ground Water Sampling Log**
(with automatic data logging for most water quality parameters

Project_____ Site_____ Well No._____ Date_____
Well Depth_____Screen Length_____ Well Diameter _____ Casing Type____
Sampling Device_____ Tubing type_____
Measuring Point_____ Other Info _____
_____
Sampling Personnel_____

| Time | Pump Rate | Turbidity | Alkalinity | [ ] Conc | Notes |
|------|-----------|-----------|------------|----------|-------|
|      |           |           |            |          |       |
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|      |           |           |            |          |       |
|      |           |           |            |          |       |

Type of Samples Collected_____
Information: 2 in => 617 ml/ft, 4 in => 2470 ml/ft; $Vol_{cyl} = \pi r^2 h$, $Vol_{sphere} = 4/3\pi r^3$

# WILLIAMS AIR FORCE BASE
# SAMPLING INFORMATION FORM

Job Number:_____          Sample I.D._____

                                     Well Number:_____

Sampling Method:

☐ Pump        ☐ Submersible     ☐ Bladder      ☐ Piston       ☐ Peristaltic

☐ Bailer      ☐ PVC             ☐ Teflon       ☐ Stainless

Field Instruments:

| | Brand | Serial / I.D. # |
|---|---|---|
| ☐ pH | | |
| ☐ Temperature | | |
| ☐ Conductivity | | |
| ☐ Turbidity | | |
| ☐ Dissolved Oxygen | | |

|  | Date | Time | Initials |
|---|---|---|---|
| Measured Water Level Depth (before sampling)  = | | | |
| Measured Water Level Depth (after sampling) = | | | |

Description of Sample Water: _____
(include color, odor, etc.)

☐ Field Filtration Performed

## SAMPLE MEASUREMENTS

| Temp. ($^{O}$C) | pH (S.U.) | Cond. (units) | Turbidity (NTU) | Dissolved $O_2$ (mg/l) | Date | Time | Initials |
|---|---|---|---|---|---|---|---|
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Print Name:_____          Print Name:_____

Signature:_____          Signature:_____

# WELL PURGING - FIELD WATER QUALITY MEASUREMENTS FORM*

Side 1 of 2*; Sheet____ of ____

Location (Site/Facility Name) _____  Date _____
Project Name / # _____
Field Personnel _____
Sampling Organization _____
Submersible pump with direct line to Flow Cell used for all measurements?  (Y, N)*

Sampling Point (common name) _____
Facility ID (for IGWIS data entry only) _____
Station ID (for IGWIS data entry only) _____
Purging Device (type of pump, bailer, etc):* _____
Pump Intake or Bailer set at (ft. below MP) _____

| Time | DTW below MP (ft.) | Purge Rate (specify units below) ( ) | Cumulative Volume Purged (specify units below) ( ) | Water Column Volumes Purged | Temp. (C) | Electical Conducivity (uMhos/cm) | Specific Conductance (uMhos/cm) | pH | Eh (mv) | DO (mg/l) | Turbidity (NTU) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
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**CALIBRATION**

| | Date | Time: military | Comment* |
|---|---|---|---|
| 1 or 2 pt. | | | |
| k= | | | |
| Buffers | | | |
| Type | | | |

Field Measurements protocol followed with no exceptions (Y, N)*   Form completed by _____  Date_____

Form GWS #1

E-5

# WELL PURGING - FIELD WATER QUALITY MEASUREMENTS FORM*

Side 2 of 2*; Sheet ____ of ____

Location (Site/Facility Name) _____

Project Name / # _____

Sampling Point (common name) _____

| Calibration | Temp. (°C) | Electrical Conductivity (uMhos/cm) | pH | Eh (mv) | DO (mg/l) | Turbidity (NTU) | Guidance Remarks | Comments |
|---|---|---|---|---|---|---|---|---|
| Date | | | | | | | | |
| Time | | | | | | | | |
| Type of Calibration | | | | | | | e.g., standard KCL solution, Zobels solution, in air/water etc. | |
| List 1st Standard | | | | | | | e.g., pH = 7.02 @ 25°C, KCL solution= 1000uMhos/cm | |
| Instrument Reading | | | | | | | actual reading from instrument | |
| Calibrated to +/-? | | | | | | | difference between calibrated instrument display and standard | |
| List 2nd Standard | | | | | | | e.g., repeat calibration with 2nd buffer or by alternate method | |
| Instrument Reading | | | | | | | " | |
| Calibrated to +/-? | | | | | | | | |
| Correction Factor | | | | | | | e.g., cell constant, "K" | |
| Calib. Successful? | | | | | | | enter YES or NO | |
| Satisfies Protocol? | | | | | | | Did calibration meet criteria in the sampling protocol? (Y or N) | |
| Calibration by | | | | | | | Signature or initials | |
| Instrument ID# | | | | | | | serial # or other ID# | |
| Location | | | | | | | specify "field," "lab," "office," etc. | |

Well Purging Equipment (more details): _____

List/Describe Field Instruments: _____

Discussion of Protocol Exceptions: _____

Other Comments: _____

Form Completed by _____ Date _____

Form GWS # 1R

E-6

# GROUND WATER SAMPLING INFORMATION FORM*

## General Information

| | | | |
|---|---|---|---|
| Location (Site/Facility Name) | _____ | Sampling Point (common name) | _____ |
| Project Name/# | _____ | Type (mon. well, spring, etc.) | _____ |
| Field Personnel | _____ | Field Sample (Event) ID#* | _____ |
| Sampling Organization | _____ | Facility ID (for IGWIS data entry) | _____ |
| Weather          ☼ ? | _____ | Station ID (for IGWIS data entry) | _____ |

## Sampling Station (Well) Details

Read from left to right            ☞                                                                    top -- bottom

| | | | | | |
|---|---|---|---|---|---|
| Well Depth (ft. below MP) | _____ | Casing Diameter (inches) | _____ | Open Interval (depth below GS) | _____ (0.1 ft) |
| Static Depth to Water (below MP) | _____ (0.01 ft) | Static DTW (ft below GS) | _____ (0.1 ft) | Date _____ Time | |
| Water Column Length (L) (ft) | _____ | One WC Volume (cu ft) | _____ | One WC Volume (gals) | _____ |
| Condition: Securely Locked? | __ Y or N __ | Station (Well) Damaged? | __ Y or N __ | Surface Contamination (visible) | __ Y or N __ |

## Purging

| | | | | |
|---|---|---|---|---|
| PID/FID Reading @ Wellhead* | Concentration | _____ ppm | Background Conc. | _____ ppm |
| Free Product (circle: LNAPL of DNAPL)* | Detected/Sampled? | Y or N / Y or N | Appearance | _____ |
| Well Purging Equipment | Pump, bailer? | _____ | Type* | _____ |
| Purging Date/Time | Start ⌚ | _____ / | Finish ⌚ | _____ / |
| Pump/Bailer Intake Set at | Feet below MP | _____ | Avg. Purge Rate | _____ gpm |
| Amt. Purged before Sampling | Gals/WC Volumes | _____ / | Purge Protocol of___ WCV's met? | __ Y or N __ |

## Field Water-Quality Measurements and Observations

Date/Time Measurements Began _____ / _____ Purge Rate for Measurements (gpm) _____

Submersible Pump with direct line to Flow Cell used for all Field Water Quality Measurements? ____ Y or N ____

All Field Measurement Instruments Calibrated according to Protocol? ____ Y or N ____

All Field Water Quality Parameters Stabilized according to Protocol Criteria just before filling sample containers? ____ Y or N ____

The Measurements below Represent: (1) stabiliization, (2) sample water collected, (3) both a and 2, (4) other*: _____

Sample Appearance: 👁 _____ Odor: _____

| Field Measurement | Value | Military Time | Comments* |
|---|---|---|---|
| Temperature | °C | | |
| Electrical Conductivity | µMhos/cm | | = meter reading x magnitude x k |
| Specific Conductance | µMhos/cm | | EC corrected to 25 °C |
| pH | Standard Units | | |
| Dissolved Oxygen | mg/l | | |
| Eh | mV | | |
| Turbidity | NTU | | |

## Sample Collection

| | | | |
|---|---|---|---|
| Sampling Device (type of pump/bailer)* | | Sample Medium (well water, LNAPL, etc.)* | |
| Permanently Installed Pump? __ Y or N __ | Dedicated Equipment? __ Y or N __ | Used Same Equip. for Purge? | __ Y or N __ |
| Pump Intake/Bailer Set at (ft below MP) | _____ | Interval Samples Represent (ft below GS) | Top = _____ / Bottom = _____ |
| Date / Time Sampling Began | _____ | Date / Time Sampling Finished | _____ |
| Depth to Water (ft below MP) | _____ | Depth to Water (ft below MP) | _____ |
| QC Samples Collected? __ Y or N __ ( see reverse*) | | Sample Withdrawal Rate | _____ |

**All Field Protocols were followed with no exceptions (Y,N)**          **Enter Protocol Codes* 1.____ 2. ____**

Remarks (1)* (include protocol exceptions) _____

Form Completed by _____  Y or N   ( see reverse*)   Date _____

👓 _____ *Site 2 of this form contains definition of abbreviations, protocol codes, additional room for equipment specification, QC sample description and other comments

Form GWS #2
Revised 9-2-93

# GROUND WATER SAMPLING INFORMATION FORM*

(Reverse Side)

## ABBREVIATIONS

| | | | | | |
|---|---|---|---|---|---|
| ft. | feet | MP | Measuring Point | GS | Ground Surface |
| DTW | Depth to Water | WC | Water Column | cu. ft. | cubic feet |
| Y | Yes (circle if appropriate) | N | No (circle if appropriate) | gals | gallons |
| PID | Photo Ionization detector | FID | Flame Ionization detector | ppm | parts per million |
| gpm | gallons per minute | Amt. | amount | k | cell constant |
| EC | Electrical Conductivity | LNAPL | light non-aqueous phase liquid (floater) | DNAPL | dense non-aqueous phase liquid (sinker) |

## GENERAL INFORMATION

The "Field Sample (Event) ID#" should be constructed from the date and time that the first sample container of a purposefully associated set of sample containers is filled. This set of samples would normally be collected vary closely together in time and include containers for a number of analytical parameters and QC samples. QC samples are normally assigned temporary aliases (see below). For example, if the first of a set of containers is filled at 1:30 PM on December 19, 1992, the Field Sample Event ID# for all containers in the set should be 9212191330.

## WELL INFORMATION

The water column length (L) is calculated by subtracting the depth to water (DTW) from the well depth. L = well depth - DTW. However, both of these distances must be referenced to the same datum: either from the measuring point (MP) or from ground surface (GS). This form was designed with the assumption that both the well depth and static water level values are referenced to the MP.

For convenience, a blank was included to also enter depth to water below GS in case the well depth referenced to the MP is unknown or cannot be measured directly. In addition, this value will indicate where the static water level is relative to the open (screened) interval which is referenced to GS. For the calculation of L in this case, the "stick up", the distance from the MP to GS, needs to be looked up or measured in the field. If the MP is above GS, then the stick up is a positive number for this calculation. Enter the stick up distance here____ft. (to the nearest 0.1 ft.) DTW (from GS) = DTW (from MP) - stick up; L = well depth (from GS) - DTW (from GS).

One water column volume = $\pi r^2 L$. The units conversion from cubic feet to gallons is as follows: $\pi r^2$ [ft.$^2$] L [ft.[ [7.48 gallons/ft3]. r = well radius in feet (since well specifications are normally given as diameter in inches, the diameter must be converted from inches to feet and then divided by one-half to yield r, in feet). Examples of well diameter/gallons per ft. of WC: 1"/0.041 gals; 2"/0.163; 4"/0.653; 6"/1.47; 8"/2.61.

## PURGING

Measure the concentration of organic vapors inside the well immediately after removing the wellhead cap. On the front side of this form, circle whether a PID or a FID was used, then enter wellhead and ambient background readings. Here specify the calibration gas _____ , lamp voltage_____make & model # of the instrument here_____.
If free product was detected, describe appearance, thickness, etc. (free product samples collected {Y, N }): _____
Supplemental description of purging equipment: _____

## FIELD WATER QUALITY MEASUREMENTS AND OBSERVATIONS

If a flow cell was not used, describe how measurements were taken (note whether or not measurements were taken down hole):
_____
Other Comments and Observations _____

## SAMPLE COLLECTION

Sampling equipment details (Mfgr., Model#, tubing, etc.): _____

### Quality Control Samples

Fictional sampling point name(s) end field sample event ID#(s) (aliases) can be used for QC samples on sample labels and chain of custody sheets to distinguish them from primary samples without tipping off laboratories. List aliases here to document their association with primary sample identifiers on front side of sheet. Name(s)/ID#(s) Indicate total # of QC samples collected: Replicates____Splits____Trip blanks_____Field ambient air blanks _____ Field methods blanks_____

Protocol codes: 1. Indicate the type of sampling protocol followed by selecting from codes (A-F) below and entering it on the front of this form. Specify the name of the agency_____and the name of the agency program_____that approved the protocol. If none, write "none. ") A slightly modified agency program standard sampling protocol, approved as a non-site-specific protocol B) An unmodified or slightly modified agency program standard sampling protocol, approved as a non site-specific protocol C) A non site-specific protocol approved by an agency D) A detailed but non agency-approved, site-specific sampling protocol with adequate QA/QC procedures was followed; E) A detailed but non agency-approved sampling protocol without adequate QA/QC procedures was followed; B) None of the above protocol conditions were known to be met (comment): _____

Protocol code: 2
A) Sampling observed by_____(agency) to meet all field protocols except as noted below: (agency signature)
B) Sampling observed by "neutral" observer (signature) all field protocols except as noted below;
C) Neither A or B applies (comment): _____

## PROTOCOL EXCEPTIONS

List/discuss protocol exceptions for sampling-related field work (attach additional sheet if necessary): _____
Other Remarks(2) _____