



USE OF FILTERS FOR GROUNDWATER SAMPLING

TECHNICAL MEMORANDUM AND GUIDANCE

**BUREAU OF WATER PROTECTION AND LAND REUSE
REMEDATION DIVISION**

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1.0 SUMMARY

This technical memorandum introduces DEEP's non-binding opinion on the use of filters during groundwater sampling. This document is not a policy discussion, but is intended to guide the environmental practitioner through the thought process of how to determine whether a filter is needed and what DEEP's expectations are for technical justification of this non-standard approach.

The Connecticut Remediation Standard Regulations (RSRs), Sections 22a-133k-1 through -3 of the Regulations of Connecticut State Agencies, require that any compliance data set be representative of the environmental conditions at a site. Groundwater characterization and compliance determinations under the RSRs optimally use analytical data from a low turbidity (typically 5 NTUs or less), unfiltered groundwater sample to achieve this data quality objective.

Elevated total suspended solid levels, normally correlated with turbidity, can produce a non-representative sample of potentially contaminated groundwater. Occasionally, filters are used to reduce turbidity levels in groundwater sampling. Filtration of groundwater samples has been identified by the Connecticut Department of Energy and Environmental Protection (DEEP) as a concern because it could produce false analytical test results, thus negatively impacting the decision-making process during site characterization and/or regulatory compliance demonstration. Consequently, the use of filtered groundwater samples for site characterization and compliance monitoring is generally considered inappropriate.

There are four major factors that should be considered in terms of reducing turbidity before it can be concluded that filtration is needed for obtaining representative samples. They are: 1) stratigraphy and constituents of concern; 2) well design and construction; 3) well development; and 4) use of low-flow sampling techniques. DEEP recognizes that groundwater samples taken from certain geological profiles (i.e., silt/clay-rich layers) are likely to produce elevated turbidity. This guidance and a set of recommendations (Appendix A) were designed to provide direction to the environmental professional in determining the potential cause of turbidity (especially if greater than 5 NTUs). The goal is that by knowing the cause of turbidity, the environmental professional would be able to optimize well performance and reduce turbidity levels, eliminating the need for filtration.

A filter should be used only if **all** avenues to reduce turbidity have been exhausted. If a filter is used for characterization purposes, it is highly recommended that both filtered and unfiltered samples are analyzed to support the rationale that the data quality objectives have been achieved and to demonstrate that groundwater sampling produced representative data. Ultimately, in the event that the site's investigation is led by a Licensed Environmental Professional (LEP), it is the responsibility of the LEP to decide if the use a filter (as well as the filter size) is appropriate to produce representative samples and is consistent with the guidelines contained in this document.

2.0 INTRODUCTION

The potential problem with using filters in groundwater sampling is that it ignores issues related to: a) particulate transport in fractured bedrock, b) colloid transport, c) precipitation of dissolved solids upon exposure to oxygen, and d) representativeness. Consequently, interpretation of the data obtained upon analysis may be flawed.

When interpreting the data, the main challenge is to determine whether filtering will produce a representative sample that is appropriate for demonstrating compliance with the RSRs. A representative sample is one that reflects conditions of the sampled medium in the sampled location as closely as possible. A representative sample should have its measured physical and chemical properties only minimally impacted or altered by the means of access to the sample location (such as a well), the method of sample acquisition (such as a pump), and the methods used for handling, preservation, storage, transportation, and analysis.

The data objectives of the investigation will often guide the specifics of data interpretation and the decision on the need to filter groundwater samples. For example, in some scenarios, the objective may be to better understand fate and transport mechanisms, and comparison of appropriately filtered samples with unfiltered samples can be used to evaluate transport mechanisms. When interpreting the data, considerations should be given to potential turbidity sources such as stratigraphy, the installation of a well in fractured bedrock, or the reduction-oxidation (redox) chemistry influences on the precipitation and dissolution of metals. Consideration should be given to how specific transport mechanisms may carry contaminants to receptors, especially in fractured bedrock or in porous media where permeability is high enough to allow migration of colloids. Colloid transport will also influence a determination that filtration is appropriate to obtain representative samples.

Redox-driven precipitation of metals can make for an unrepresentative sample resulting in a false positive or false negative outcome. For instance, manganese is a major constituent in the steel used in well casing as it increases the steel's capacity to harden. Oxidation of the steel well casing commonly occurs creating a coating of manganese dioxide along with ferric oxide and hydroxides. As the casing oxidizes with time, it leaches iron and manganese. It also generates an increase in turbidity in the well water. Sample acquisition for metal testing requires preservation of the groundwater sample in an acidic media which could later be re-acidified one more time as part of the laboratory analysis protocol. As a result, acidification of weathered well casing material can cause metals, such as iron and manganese, to be leached out into solution resulting in a false positive indication of dissolved iron/manganese contamination. Another point to consider is that the amount of metals measured as dissolved in a groundwater sample may change with time due to a number of factors including but not limited to changes in redox conditions or pH changes, regardless of whether a filter is used or not.

It should be noted that in the particular case in which a particulate filter system is used at a home, water passing through the particulate filter becomes more acidic with time and is then more likely to dissolve the potential contaminant that is adsorbed to the particulate matter retained by the filter. Consequently, the potential contaminant becomes more mobile. It should also be noted that filtering cannot be used for engineering evaluations of solid waste disposal areas. DEEP Guidelines for Engineering Evaluations of Solid Waste Disposal Areas specifically state that groundwater samples "shall not be field filtered prior to laboratory" analysis.

3.0 TECHNICAL BACKGROUND

This section is intended to provide the reader with a brief review of the technical concepts associated with suspended solids, turbidity, mobility, and adsorption and how these factors are related to filtration.

Suspended matter or suspended solids, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms, cause turbidity in water. Metals, certain semi-volatile organic compounds (SVOCs), petroleum hydrocarbons, and polychlorinated biphenyls (PCBs) easily adsorb to suspended solids. Similarly, metals and SVOCs are associated with the matrix of solids in urban fill. Thus the presence of suspended solids in a groundwater sample can provide false positive test results. However, in formations that allow the migration of fines through the aquifer, filtration of a sample may remove constituents of concern that would otherwise be part of the fate and transport

system of groundwater, providing a false negative test result (i.e., a test result that is incorrect because the test failed to recognize an existing condition or finding).

Emphasis should be placed on appropriate well construction methods, materials and groundwater sampling procedures to limit turbidity and the necessity to evaluate and justify the use of filters.

3.1 TURBIDITY

Turbidity is one of the field parameters monitored while evaluating hydrogeologic conditions of a site. Turbidity is a relative value of a qualitative measurement of the amount of light that is scattered or absorbed by suspended particles.

EPA suggests that a properly constructed well should be capable of yielding samples with a turbidity of 5 NTUs or less. This is approximately the point where:

- 1) Suspended solids cannot be seen by the naked eye;
- 2) A stable drawdown is attained (avoids turbulence); and
- 3) Microbial activity is minimal.

The targeted threshold of 5 NTUs has a wide use and acceptance within the community of environmental professionals. However, it should not be treated as an automatic trigger for the use of filters if turbidity is found to be marginally higher (e.g., 6 or 7 NTUs), unless there is cause to believe the turbid sample results are not representative.

3.1.1 TOTAL SUSPENDED SOLIDS

Total Suspended Solids (TSS) refers to solids suspended in water which will not pass through a filter. TSS and turbidity should not be confused; however scientific studies have revealed that there is a strong linear relationship between them. Normally this relation is found to be site-specific depending on the particular stratigraphic unit but it can be described by the following relation:

$$1 \text{ mg TSS/L} \sim 1.0 \text{ to } 2.1 \text{ NTUs (Fink, 2005; Hach, 2003; Sadar, 2003)}$$

TSS is more precise because it is a quantitative measurement that provides an actual weight of the particulate material present in the sample. Turbidity, although less precise, can be easily measured in the field.

3.1.2 CAUSES OF TURBIDITY IN WELLS

There are two major causes of turbidity in monitoring wells. The first is geologic; the second is geochemical.

Geologic Turbidity: In Connecticut, many wells are completed in glacial or glacial fluvial deposits containing significant fine-grained deposits. Care must be taken to construct and develop wells that minimize the entrainment of silt in groundwater samples. Slot and filter pack size should be designed with consideration of aquifer grain size to limit potential for migration of fine-grained aquifer matrix components that increase turbidity in a water sample. In conjunction with proper filter pack design, the well should be developed in a manner that ensures the filter pack appropriately functions in conjunction with the aquifer material to limit migration of fine-grained material into the well.

This type of turbidity is essentially an artifact of the installation of a well into an undisturbed aquifer, and often does not reflect actual chemical transport mechanisms. This is especially true for metals that may be present in the mineral aquifer matrix, rather than as contaminants.

If false positive results are suspected, comparison of filtered and unfiltered samples, with data interpretation examining the nature of the differences, may be informative. The mineralogy of the solids trapped on the filter can also be compared to that of the aquifer matrix. For example, in the case of metals present in the aquifer material, turbidity could be a problem because acquisition of the sample requires preserving the sample in an acidic media which could then be re-acidified if turbidity is found to be greater than 1 NTU, as part of the standard protocol for metal analysis by inductively coupled plasma (Method 6010). Acidification of turbidity can cause dissolution of the aquifer framework's metal composition that in turn could result in a false positive indication of dissolved contaminants in groundwater.

Geochemical Turbidity: Turbidity in groundwater samples may also be of geochemical origin. Fine-grained materials can be transported in many aquifers as mineral or organic colloids, which are a potential origin of turbidity in a sample. Also, when groundwater containing detectable levels of ferrous iron or reduced manganese is sampled, it often becomes oxygenated, which prompts iron oxide to precipitate along with many other pollutants. This concept is applicable to metal oxides in general and may occur due to reduced conditions associated with fuel releases or landfill leachate.

An increase in microbial activity can increase turbidity as a result of the microbial production of enzymes and byproducts that alter subsurface conditions. Therefore, an increase in microbial activity could contribute to a false positive for certain pollutants.

If these bio-materials, fine-grain materials, and associated contaminants are in transport under subsurface conditions, they are appropriately considered as representative of the groundwater conditions, even if the sample exceeds 5 NTUs. Filtering a sample with turbidity of this origin is inappropriate because it would produce a false negative result by removing pollutants that are actually being transported under aquifer conditions.

3.1.3 TURBIDITY MEASUREMENT READINGS

Turbidity meter readings may yield varying results depending on the sampling method used, the water color, water temperature, particle size distribution, atomic/molecular structure, and the amount of dissolved organics that absorb light. For example, to measure light scattering, optical turbidity probes can use a variety of different wavelengths, recording units, and sensor types. Probes need frequent calibration to prevent equipment drift. Certain turbidity kits recommend shaking the sample first, but do not specify how soon after shaking the measurement should take place. These factors can contribute to the generation of varying turbidity measurements and measurement errors for the same sample.

Also, consider that groundwater turbidity readings taken from sampling bedrock wells are likely to have more variability than those taken from overburden wells.

3.2 CONTAMINANT FATE AND TRANSPORT

If a well yields excessively turbid groundwater samples, they should be evaluated to determine if they are representative samples meeting the project data quality objectives. The decision to reduce turbidity by filtration and the selection of filter size is complex, and should incorporate consideration of the contaminant's fate and transport characteristics within the site aquifer material. In terms of colloidal transport, turbid samples that are filtered to remove solids may not be equivalent to samples from that same well that has initially low turbidity. The following provides technical information that will guide the LEP in developing the rationale to filter or not in context of data objectives.

3.3 ADSORPTION / DISSOLUTION PROCESSES

Adsorption refers to the process by which a constituent binds to the surface of a solid particle. Dissolution is the process by which a solid material moves into a liquid solution. In evaluating adsorption and dissolution processes, as related to turbidity, interpretation of data and sample representativeness, the following concepts should be considered:

- Chemical elements and compounds tend to adsorb more easily to smaller particles than to bigger particles.
- Colloids exhibit different redox properties and different retention strengths than their larger counterparts.
- Small particles will dissolve more easily.
- Small particles will have more surface area per volume and, hence, have a larger chemical reactivity.
- If redox potential drops, constituents (e.g., iron, manganese) are likely to reduce and dissolve. Once dissolved, these constituents may migrate and precipitate, thus enhancing turbidity.
- An increase in redox potential in an anoxic aquifer, such as may be caused by sampling aeration, can cause dissolved iron and manganese to oxidize and precipitate, forming colloids upon which other contaminants may be adsorbed.
- Even if the particle/contaminant is migrating as a colloid, a change in pH may affect its solubility. Once dissolved, it may precipitate again if the conditions exist as mentioned in the previous bullet.

Therefore, contaminants that adsorb onto a colloid or precipitate as a colloid upon oxidation should generally not be evaluated using a methodology that filters out colloids.

3.4 CONTAMINANT MOBILITY

Mobility refers to the contaminant's ability to move in the subsurface. The mobility and fate of contaminants in soil environments is controlled to a large extent by their affinity to the solid immobile phase relative to their affinity to the liquid (and vapor) mobile phase (Schulthess 2005).

To determine if a contaminant is likely to affect the water quality, it is important to understand the potential mechanism that affects it. With this in mind, as it relates to mobility, consideration should be given to the following:

- If the contaminant is adsorbed to particles, then it might be immobile.
- If the particle is mobile, the adsorbed contaminant is also mobile.
- Small mobile particles can carry contaminants a long distance.
- The optimum size for mobility of particles in the groundwater is 1 μm , which would be removed from a sample by a 0.45 micron filter, but not a 50 micron filter (which is typically used on a residential sediment filter system).
- A change in pH might mobilize the contaminant due to desorption, dissolution, or increased colloid mobility.

Other physical factors affecting mobility are: groundwater hydraulic gradient, hydraulic conductivity, porosity and bulk density. In the case of metals, mobility is strongly influenced by the soil's pH, the soil type and its cation exchange capacity. All these processes, including adsorption and dissolution affecting mobility, are interconnected. Contaminants with a transport mechanism that can include colloidal transport should generally be evaluated using a methodology that does not filter out the most transportable colloid sizes.

4.0 CHARACTERIZATION AND VERIFICATION

In a scenario in which there is a need to determine if a release has occurred, there may be a need to differentiate a release from a naturally occurring substance. Knowing the data quality objective, in this case, is essential. For the purpose of characterization, it is necessary to be able to determine why the turbidity is high and how it is going to affect the sample results and if filtration will introduce false negatives or false positives. False positive results are environmentally conservative by nature, which means that remedial work may be required. A combination of filtered and unfiltered samples will provide a point of comparison upon which a differentiation of releases from naturally occurring substances can be made.

If contaminants of concern (COCs) are not found to be in excess of RSR criteria in unfiltered samples, then there is no need to filter. Conversely, if a COC exceeds RSR criteria in unfiltered

samples, it would be necessary to determine whether the unfiltered samples are representative and if the well is properly designed.

For the purpose of verification, the data should be usable to the extent that the LEP could defend his/her rationale for using filtration and demonstrate that the samples are representative of site conditions. DEEP's expectation is that if filters are used, the use and the size of the filter selected is justified, based on the partitioning of the dissolved contaminant, the mobile particulate phase with sorbed contaminant, and the aquifer framework. It is extremely important that if filtration is performed, the environmental professional is prepared to: a) defend the rationale for its use within the framework of verification; b) provide an evaluation of potential false positive and false negative results; and c) demonstrate that he/she has made his/her best efforts to reduce turbidity with proper well construction and to sample appropriately before choosing filtration.

While DEEP recognizes an LEP's interest in avoiding false positives, DEEP also seeks to minimize false negative errors in order to ensure protection of human health and the environment.

5.0 GUIDANCE CONSIDERATIONS

Appendix A of this document contains a list of items that should be considered to evaluate potential sources of elevated turbidity, as well as to develop and document a rationale for the use of filters.

Once the causes of turbidity are known, corrective actions should be taken to decrease the turbidity, prior to using filters during groundwater sampling. The following provides an explanation of the significance of each item in the checklist with regard to evaluating the causes of turbidity.

5.1 SECTION I - STRATIGRAPHY

The purpose of the stratigraphy section is to develop and document an understanding of the geological conditions that could be contributing to turbidity and whether filtration is appropriate for the given geological conditions. Documenting stratigraphy is crucial to providing justification for filtration.

5.1.1 BEDROCK WELL

Depending on the data quality objectives, filtering may or may not be appropriate for a bedrock well. Wells located in fractured bedrock may be influenced by a variety of materials being transported and could act as a direct migration pathway from the contamination source area to the well. In the case of sampling a bedrock well, proper well development should be used to achieve stabilization of physical parameters (e.g., turbidity) while using the low-flow technique.

Case Study - Consider a proposal for a long-term monitoring program using a set of 200-foot, 6" diameter bedrock wells. The proposal includes use of low flow sampling, but little is known about where groundwater is entering the wells or through which fractures the plume may be migrating to reach the wells. Once field parameters stabilize during low-flow sampling, the sample that is obtained is considered a representative sample. The 3 purge volume rule of thumb is unlikely to be achieved in a reasonable time and would also be dependent on stabilization of field parameters for a determination of adequacy of purge. Data from these wells will necessarily reflect conditions in the borehole nearest the point of intake close to the water table. In theory, the borehole conditions will be in equilibrium with the surrounding aquifer in the absence of purging (the principle behind passive samplers), so the sample should reflect the water quality at the elevation of a yielding zone. Failure to understand the yielding zones in the borehole relative to the point where groundwater is extracted lends uncertainty to what is actually being sampled. There may be vertical flow within the bedrock borehole if there are two fractures connected by the borehole thus affecting representativeness and understanding of the borehole dynamics which in turn affects the determination to use a filter and the rationale for using it. At a minimum, a comprehensive understanding of the elevation of yielding zones and any vertical flux in the well are necessary for the data to be understood. Borehole logging should include video/caliper/other fracture zone identification, packer testing of the zones, vertical flow measurements, temperature profiling, and perhaps more sophisticated techniques such as temperature micro gradients to determine flow directions in the well. This data would need to be synthesized to determine the optimum location for the intake for low flow sampling, which could then be used to minimize the purge volume and thereby reduce turbidity. Separate risers, placed at different depths, can be used to collect discreet samples using low flow methods.

In instances where water samples are taken from bedrock aquifers where potable supply wells may be present, it may be most appropriate to use the total metals results, even if a non-turbid sample cannot be obtained, as the total concentration of metals, including those entrained on

particulates would be considered more representative of the true potential for exposure to potentially contaminated groundwater.

One of the problems related to wells in fractured bedrock is the difficulty to install and prevent the filter pack materials from moving into the fractures. This may interfere with migration of contaminants in the subsurface. Further discussion on this issue is provided in the sections below.

5.1.2 ANAEROBIC CONDITIONS, IRON

Geochemical turbidity may occur if iron is exposed to aerobic conditions. The following should be considered in making the decision to use a filter:

- Is the subsurface of the site being investigated rich in iron?
- Does the potential contaminant react with iron?
- Are the conditions anaerobic or aerobic?
- Are there subsurface conditions that, especially when combined with redox often associated with plumes of contamination, result in migration of pollutants and aquifer matrix issues?

Case Study - Both the contaminant and the iron are combined and mobile: A sample is poured into a jar (the sample is now in an oxygen rich environment) and submitted to the lab for analysis. Iron precipitates out, which translates into turbidity. However, in this case, it will be difficult to determine iron concentrations because what was dissolved is now precipitated, and the precipitate entrains the pollutants. Also consider that in general, if the contaminant is in a subsurface area that has a lot of iron and is anaerobic, then it can be expected to be immobile but an increase in oxygen will enhance its mobility.

It should be noted that DEEP would accept an in-line filter under anaerobic conditions, but precipitation might still occur after filtering, depending on the sample acquisition technique. In the case of anaerobic aquifer conditions where turbidity is associated with sample redox changes, filtering should be carefully evaluated to understand what is actually being measured in the sample and how it relates to subsurface conditions.

5.1.3 STRATIGRAPHY CONTAINING CLAY LAYERS OR LENSES

DEEP recognizes that groundwater samples taken from certain geological profiles (e.g., silt/clay-rich layers) are likely to produce elevated turbidity. In the case of clay, filtration may sometimes be deemed appropriate if the formation yielding water to a properly constructed and developed well persistently contains significant amounts of fine particles present.

Turbidity may also occur as a result of disturbing the formation materials during well installation. In this case, clay particles may or may not be transporting contaminants. Site characterization activities should be able to provide this information. Although well development should address the turbidity issues presented in this example, an argument can be made to support filtering where clay particles are not transporting contaminants but whose presence in the aquifer is due to the disturbance of the clay while installing the well. Again, the key here is to be able to demonstrate that the clay particles are not transporting contaminants.

Despite the best well construction, some silt may enter a well. DEEP recommends that silty wells be redeveloped if possible, as experience indicates that many older monitoring wells in Connecticut were underdeveloped. In addition, DEEP recommends use of low-flow sampling methodology to limit disturbance of the borehole environment during sampling. Alternatively, a no purge sampling methodology may be considered appropriate for the target contaminant of concern as long as some consideration is given to the sampling depth (e.g. if the sample is collected close to the bottom of the well).

5.2 SECTION II - CONSTITUENTS OF CONCERN (COCS)

As mentioned previously, suspended matter or suspended solids, such as clay, silt, finely-divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms, cause turbidity in water. Metals, certain semi-volatile organic compounds (SVOCs), extractable petroleum hydrocarbons (ETPH), and polychlorinated biphenyls (PCBs) can easily be adsorbed to the suspended solids. Similarly, metals and SVOCs may be associated with the matrix of solids. Thus, the presence of suspended solids in a sample can cause false positive test results in groundwater. There may be a need to examine the nature of the chemical and physical turbidity to evaluate the importance of transport mechanisms versus the false positive potentially associated with coarser aquifer material entering a sample.

Even if it is determined that filtering is needed for metals, there may be some constituents that should not be analyzed from a filtered sample. For example, petroleum hydrocarbons, if not actually sorbed onto particulates, have an affinity for the filter medium due to surface tension. Filtration in the case of petroleum hydrocarbons would provide a false negative. In the case of metals, it is strongly suggested to do TCLP or SPLP analyses on potentially impacted soils.

This discussion presumes that data for unfiltered and filtered samples have been obtained. If there is no significant difference, then there is no justification to continue filtering. If there is a significant difference, the data should be evaluated in a site-specific manner in the context of the information provided in this technical memorandum.

Filtering is not appropriate when sampling for VOCs because:

- There is no need to filter since particulate matter does not impact the results.
- VOC loss may occur while filtering, resulting in a false negative.
- There is a potential for possible adsorption in the filters which are generally made of plastic and have organic filter material. Although special filters can be used, the LEP should be prepared to the rationale of its intended purpose.

In the setting of urban fill, the main concern is that if the fill is near the screen, the groundwater sample is likely not to be representative. Fine-grain waste material is usually associated with urban fill. Turbidity generated by the fill is likely not to be mineral based.

5.3 SECTION III - WELL DESIGN, CONSTRUCTION, AND DEVELOPMENT

It is not DEEP's intent to allow filtration of samples to become a default alternative to the proper design, installation, development, and sampling of monitoring wells whether they are Geoprobe-type installations, or larger diameter, more conventionally constructed monitoring wells. DEEP is concerned that the potential for erroneous omission of COCs or sampling suites due to the misapplication or over-application of filtration is too great to allow the use of groundwater filtration. However, as presented in this guidance document, there may be physical settings that necessitate filtration as an alternative, on a case by case application.

Filtering cannot be justified based on poor-quality wells. Appropriate well design and construction are necessary precursors for evaluating whether sample filtration is appropriate. The objective of this section is to focus on specific well construction issues that affect turbidity.

In summary, the following steps are technically appropriate actions to minimize turbidity:

1. Well Design: Careful consideration must be given to the well design. An appropriate selection of slot size, screen length and of filter sands to best suit the formation materials is critical to minimize the potential for turbidity in the monitoring well.
2. Well Development: Following installation, appropriate development of the well must be completed to clear the bore hole and filter pack of construction materials and formation soils, and a sufficient period of time must be allowed for aquifer stabilization.

5.3.1 WELL DESIGN AND CONSTRUCTION

A proper well design should meet the following objectives (Driscoll, 1986):

- High yield;
- Minimal drawdown;
- Good water quality;
- Free of solids or sediments; and
- Long serviceable timeframe.

There should be nothing in the well design and construction that will result in high turbidity samples (e.g., a broken well casing allows fine particles to enter the well). Secondly, each well should be designed taking into consideration the individual stratigraphic units the well will intercept. For example, a well constructed with the screened interval within a clay-silt layer, without an appropriate filter pack, may yield water with excessive turbidity.

The placement of a well screen should take into account three-dimensional hydrogeological flow as well as any heterogeneity in the aquifer that may affect chemical transport. The design methodology selected should be appropriate for the site conditions and data quality objectives of the investigation.

A screen should be designed to retain 90% of the filter pack after development in order to retain most of the formation material around it. If the sand pack is not properly sized, it will produce a silty well. It is not appropriate to reduce turbidity caused by improper well construction by using filters.

Proper well grouting and sealing are important, as with improper sealing, water entering the well can become highly alkaline and contribute both clay-related metals and cement-related carbonates to the water sample, especially when collected soon after installation of the well. Unwanted surface materials or contaminants can also be introduced through the well into groundwater if the well is inadequately grouted.

A bentonite slurry used as a seal should be allowed time to hydrate before and after placement to ensure integrity of the seal. Well development should not take place until the seal has been achieved. Likewise, if cement is used, manufacturer's guidelines for the preparation and placement of the cement should be followed to minimize the potential for dilution of the cement slurry and the bridging of the mixture with upper formation material (Aller et al, 1991). Failure to follow the manufacturer's guidelines for bentonite and cement can be the cause of turbidity.

In addition, when designing a well, the constituents that are being sampled for should be considered. For example, is there a need to sample for metals or not? If the answer is yes, then a silty well should be avoided. If metals are not a concern, then there may be less concern about developing a siltier well. For organic constituents, if a well is not in an area of polluted soil, the potential for a false positive test result due to excess silt may be less of a concern.

The use of direct push technologies (i.e., Geoprobe®) may not in all cases be appropriate for use in fine soil formations, especially if the limited capacity for development of the monitoring point is considered.

5.3.2 WELL DEVELOPMENT

All new wells should be developed before being used for their intended purpose. Doing so will help to achieve the optimal hydraulic transmissivity and turbidity levels. Developing a well repairs the damage done to the formation caused by the drilling operations as well as ensures the well's highest specific capacity (Driscoll 1986). For example, if during purging of a bedrock well before sampling, it is observed that the water level drops or rises very quickly and its turbidity is high (in excess of 5 NTUs), this may indicate that the well design and/or construction is faulty. In this case, the high turbidity could be due to the introduction of materials through fractures or because new fracture pathways have been created. The turbidity observed in this case may be reduced through redevelopment or further purging until physical parameters are stabilized.

There are different methods for developing a well. Each well development method may produce issues that may be problematic in achieving sample representativeness. For example, a surge block may force fine materials back into the formation before it can be removed from the well. If groundwater samples are collected before well development is complete, fine particles may come out of the formation creating turbidity. Development can be determined to be completed whenever stable hydraulic conditions have been established through the measurement of field parameters. Useful field parameters are: dissolved oxygen (DO), pH, temperature, oxidation reduction potential, and electrical conductivity. Subsurface areas characterized by high permeability will be affected the most during well development because groundwater will be moving the fastest through those areas. High hydraulic conductivity or significant variation of the hydraulic conductivity (due to different stratigraphy) could enhance turbidity.

Appendix B, although not a comprehensive list, references a number of documents that provide specific information for proper well design and construction.

Well construction diagrams should be part of the documentation for environmental investigation. Each well should have its own construction and documentation.

5.4 SECTION IV - MONITORING AND SAMPLING METHODS

Many contaminants can adsorb to solids and organic matter that does not settle out of water. It was mentioned previously that turbidity can produce false negative/positive test results. Purging samples, either by using a bailer or a high speed pump, tends to stir up the water column thus increasing turbidity. Low-flow purging tends to prevent turbidity thus improving sample quality. However, water level stabilization may be difficult when low-flow purging is used on low-yield wells.

Groundwater sampling should be conducted pursuant to EPA protocol low stress (low flow) purging and sampling methodology, including measurement and stabilization of other key indicator parameters prior to sampling. While low-flow sampling is not specifically necessary or required for Geoprobe-type well points, care should be taken to minimize the potential for uptake of particulates, and to stabilize other parameters prior to sampling. EPA documents support the concept that a properly constructed well should be capable of yielding samples with turbidity of 5 NTUs or less. If turbidity levels are not above 5 NTUs, then there is no issue with turbidity and filtration need not be used.

For example, if during purging of a bedrock well before sampling, it is observed that the water level drops or rises very quickly and its turbidity is high (in excess of 5 NTUs), this may indicate that the well design and/or construction is faulty. In this case, the high turbidity could be due to the introduction of materials through fractures or because new fracture pathways have been created. The turbidity observed in this case may be reduced through redevelopment or further purging until physical parameters are stabilized.

False negative results can be obtained because filters are likely to remove colloidal-sized particulates that are mobile in the aquifer matrix prior to chemical analyses, which in turn provides inaccurate information on constituents and their true mobility in groundwater. “Analytical methods used to determine metal concentrations have historically used 0.45-micron filters to separate dissolved and particulate phases. If the purpose of such determinations is an evaluation of mobile species in solution, significant underestimations of mobility may result, due to colloidal associations. Colloidal particles interact strongly with fluids but do not mix homogeneously. On the other hand, if the purpose of such filtration is to determine truly dissolved aqueous species, the passage of colloidal material less than 0.45-microns in size may result in the overestimation of truly dissolved concentrations” (Puls and Barcelona, 1989).

As an example of appropriate representativeness where the data objective is to evaluate the impact to a supply well, consider that a 50-micron particulate filter is typically used at homes equipped with a water filtration system. If a decision is made to use a 0.45-micron in-line filter during groundwater sampling, the water sample results are likely not to be the same as those obtained using a 50-micron filter. Therefore, an analysis of metals using such filters is not likely to produce water quality results that are comparable. Therefore, in this case, the field filtered sample cannot be determined to be representative of the water ingested.

5.4.1 SAMPLING METHODS AFFECTING TURBIDITY

The goal of sampling groundwater is to obtain a sample that is representative of the existing conditions. Sample access and acquisition methodology should be evaluated to determine how the representativeness of the sample might be affected.

Filling sample containers during sample acquisition may expose the groundwater sample to: i) aeration, which in turn could cause oxidation and precipitation of metals and organic matter; ii) increased turbidity due to sample agitation; and iii) cross-contamination. It could also cause the loss of contaminants such as VOCs and SVOCs. Precipitation of metals enhances adsorption causing a decrease in dissolved metals. However, samples that are filtered to remove solids are

not necessarily comparable to low turbidity samples. The non-filtered sample may have large particles in it that settle to the bottom of the sample vial. As the sample is preserved in an acidic media, the particles may leach resulting in a different analytical result.

In the case of a low yield well, as the water levels near the bottom of the well, sediment may also be removed during sampling. To avoid collecting sediment in the groundwater sample, a water level meter should be used to alert the sampler from pumping the well dry. Collecting a less-than-optimal turbid groundwater sample with such sediment may be better than collecting no sample. Information from a turbid sample can still be evaluated, as long as the cause of turbidity is understood. Understanding the cause of turbidity will allow the environmental professional to determine if the sample can be representative. This scenario is more likely to occur with an overburden well rather than a bedrock well.

Other factors may affect the turbidity and representativeness of a groundwater sample:

- A borehole opened to the atmosphere can affect groundwater quality and the quality of the sample obtained.
- If a filter is used, it must be an in-line filter to avoid exposing the sample to reducing conditions and enhancing geochemical turbidity.
- Always measure and document the dissolved oxygen before and after filtering to ensure the groundwater sample was not oxygenated.
- Test and document the electrical conductivity before and after filtering to have a better understanding of the relative amount of solid metals retained by the filter.

5.4.2 LOW-FLOW SAMPLING

It was mentioned previously that to minimize the need for filtration, the first step is to make sure that there is nothing in the well design and construction that will lead to high turbidity. The second step consists of knowing the stratigraphy of the area and developing the well properly. The third step is related to the use of low-flow sampling techniques.

What affects water quality sampling the most is the water level achieved in the well during purging. Keeping drawdown to a minimum is essential to achieving consistent results. That is the goal of low-flow sampling. Of course, there will be wells that cannot be sampled by low-flow because the permeability is too low. Choice of sampling methodology is also dependent on water level in the well in relation to the screened interval. If the wells are screened below the

water table, water should not be purged below the top of the screen. The water level should be allowed to recover and then field screened for indicator parameters. This process should be repeated until parameters are stable before a water sample is collected. If the water level is in the screen, there are limitations to the quality of sampling data that may be obtained from this well and re-installation may be advisable.

Low-Flow sampling is a technique that minimizes the hydraulic stress on the aquifer thus producing samples that are more representative of groundwater chemistry than samples collected using traditional bailing and purging techniques. Minimal hydraulic stress and drawdown of the water level in a well is achieved by using an adjustable rate pump that removes water from the screened zone (Puls and Barcelona, 1996). The pump rate depends on site-specific hydrogeological conditions. DEEP endorses the fact that a representative sample could be obtained using other than low-flow techniques but will not accept filtering in sampling methods other than low-flow. If low-flow sampling does not reduce the turbidity and the well is designed, constructed and developed properly, then it is appropriate to use a filter.

If 5 NTUs can be reached using low-flow sampling, the use of filters is not necessary. If with low-flow sampling, the turbidity is above 5 NTUs, DEEP's recommendation is to proceed with the checklist to determine if filtering is justified.

APPENDIX A. GUIDANCE CONSIDERATIONS

ITEMS TO BE ADDRESSED WHEN EVALUATING THE USE OF FILTERS IN GROUNDWATER SAMPLING

SECTION I - STRATIGRAPHY

SUBSURFACE	
	1. Have you documented the stratigraphy?
	2. Does any stratigraphy unit contain clay or silt either as a poorly graded material or as interbedded lenses?
	3. Is the soil subsurface rich in iron?
	4. Is the soil subsurface anaerobic?
	5. Are the problematic monitoring wells located in fractured bedrock?
	6. Are any potential affected supply wells located in fractured bedrocks?

SECTION II - CONSTITUENTS OF CONCERN

DETECTION	
	1. Were metals detected in unfiltered groundwater samples?
	2. Were VOCs/SVOCs detected in unfiltered groundwater samples?
	3. Was ETPH detected in unfiltered groundwater samples?
	4. Is urban fill present near the screened interval?
	5. Are PCBs a Constituent of Concern?

SECTION III – WELL CONSTRUCTION, DESIGN, AND DEVELOPMENT

DESIGN, CONSTRUCTION, AND DEVELOPMENT	
	1. Has a well construction diagram been submitted?
	2. Is the well construction diagram representative of all the wells?
	3. Is the well producing an acceptable yield?
	4. Were the wells constructed using Direct Push Method (e.g., Geoprobe)?
	5. Are the filter pack and screen size appropriate for this formation? What percent passing material did you use in the design?
	6. Were the grouts/seals placed carefully to isolate the screened interval?
	7. Did you follow the manufacturer's guidelines on the hydration of bentonite and cement?
	8. Was the hydraulic conductivity determined for the formation?
	9. Was a surge block used in the development?
	10. How was it determined that the development was completed?
	11. Did you observe any erratic water level reading? When?

SECTION IV - MONITORING AND SAMPLING METHODS

TURBIDITY	
	1. Are turbidity levels for the wells you seek to filter above 5 NTUs?
PURGE METHOD	
	1. If you filtered for characterization purposes, are there any differences between various filtered and unfiltered samples?
	2. Have the well purge and sampling rates been recorded?*
	3. Were bailers or air-lift arrangements used in developing or sampling the well?
SAMPLING	
	1. Did you record any sudden changes in turbidity or purging behavior during sampling?
	2. Was any water remaining in the casing purged between sampling periods?
	3. Was the stagnant water purged at flow rates below those used in the development?
	4. Are you planning to use an in-line filter?
	5. Was the well pumped dry during development or sampling? If so, what was the recovery rate?
	6. Did you use the Low-Flow sampling technique?
	7. Has Low-Flow sampling been used in any of the turbid wells?
	8. Does the use of Low-Flow sampling result in samples above 5NTUs?

*Note: Some of the elements of the checklist can be applicable to the Well Development section.

APPENDIX B. BIBLIOGRAPHY

Aller, L., et.al.; Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells; United States Environmental Protection Agency and NGWA; March 1991.

Bureau of Reclamation; Engineering Geology Field Manual; United States Department of the Interior; 1991.

CT DEP; Guidelines for Engineering Evaluations of Solid Waste Disposal Areas; Connecticut Department of Environmental Protection; July 1993.

Driscoll, Fletcher G., Groundwater and Wells, Second Edition; Johnson Filtration Systems; 1986.

Hach Company. "Analytical Procedures, Determining the Relationship Between Turbidity and Total Suspended Solids", May 2003. Web 21 February 2012 <<http://www.google.com/url?q=http://images.vertmarkets.com/crlive/files/downloads/f8c0f787-7a07-4345-a9bf-36171b3b8a01/TurbiditySuspendedSolids.pdf&sa=U&ei=JMtDT57FOYeC0QHKhbm5Bw&ved=0CB4QFjAG&usq=AFQjCNEWOKUDPR915lyFhR2JpnBBENt6Rw>>

ITRC; The Use of Direct Push Well Technology for Long-Term Environmental Monitoring in Groundwater Investigations; Interstate Technology and Regulatory Council; March 2006.

Fink, Jessie. "The Effects of Urbanization on Baird Creek, Green Bay, Wisconsin", Chapter 4: Establishing a Relationship Between Sediment Concentrations and Turbidity, May 2005. Web. 21 February 2012 <http://www.uwgb.edu/watershed/fink/Fink_Thesis_Chap4.pdf>

Neilsen, David M., editor; Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring; CRC Press; 2006.

Sadar, Michael J. "Turbidity Science", Technical Information Series-Booklet No. 11. May 2003. Web. 21 February 2012 <<http://www.hach.com/asset-get.download-en.jsa?code=61792>>

Schulthess, C.P. 2005. Soil Chemistry with Applied Mathematics. 292 pages, paperback, Trafford Publishing, Victoria, BC, Canada. ISBN 1-4120-3585-6.

USACE; Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites; United States Army Corp of Engineers; November 1, 1998.

USGS; Ground-Water Data-Collection Protocols and Procedures for the National Water Quality Assessment Program: Selection, Installation and Documentation of Wells and Collection of Related Data; United States Geological Survey Open File Report 95-398; 1995.

USEPA; RCRA Ground-Water Monitoring: Draft Technical Guidance; United States Environmental Protection Agency; November 2001.

USEPA, Region 4; Environmental Investigations Standard Operating Procedures and Quality Assurance Manual; United States Environmental Protection Agency; November 2001.

USEPA, Puls, R. and Barcelona, M.; Superfund Ground Water Issue, Ground Water Sampling for Metals Analyses; United States Environmental Protection Agency; March 1989.