

**PART E**  
**WATER AND WASTEWATER SAMPLING**

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# **GROUNDWATER POLLUTION MONITORING**

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## 1. Introduction

The Environmental Protection Division (EPD) of the British Columbia Ministry of Water, Land and Air Protection (MWLAP) has, as part of its mandate, the regulation of permits related to industrial and domestic effluents, storage and transportation of special wastes, and refuse discharge sites. The ministry must also respond to unregulated discharges, whether accidental or intentional, that could result in contaminant loadings to groundwater.

These guidelines are intended to provide appropriate and effective methods to assess the extent of groundwater contamination and the potential for impact on human health and the environment.

Groundwater monitoring programs must be designed and implemented by qualified personnel to ensure consistent and representative sampling. All monitoring and sampling equipment must be operated and maintained in such a manner as to perform to design specifications for the duration of the monitoring program.

## 2. Preliminary Assessment

Groundwater monitoring at a site under investigation is intended to detect unacceptable groundwater contamination whether this results from a permitted operation or from an accidental or intentional discharge of contaminants (a spill). Acceptable contaminant levels are specified by the Manager and will generally be in accordance with the *Approved and Working Criteria for Water Quality - 1994*, published by the Water Quality Branch of the BC Ministry of Environment, Lands and Parks. The type of activity at the permitted site or the nature of the material spilled will dictate the parameters sampled for, and the hydrogeology of the area concerned will govern the sampling location(s), methods, and frequency.

### 2.1 Potential Contaminants

For a site under permit or regulation, the list of regulated parameters and site activities will provide the basis for requested analyses. For non-regulated activities and spill scenarios, investigation may be required to determine what contaminants and parameters need to be determined. This may entail, for example, analysis of the spilled material or tracking of the material through shipping or commercial documentation (e.g., TDG and WHMIS).

## 2.2 Hydrogeological Studies

The location and number of monitoring wells (piezometers) required to adequately describe hydrogeologic conditions will depend upon the site-specific geology, soil, and groundwater regime as well as the suspected character and quantity of the contaminant. Networks of monitoring wells are often developed in phases, with data reviewed at the end of each phase to determine if the hydraulics of the site are being adequately defined. A groundwater monitoring well network will consist of a sufficient number of wells, installed at appropriate locations and depths, to yield samples that represent the quality of both ambient groundwater and leachate that has passed under or through the affected area of the site.

A groundwater monitoring program for a permitted site is a long term project. For example, a landfill groundwater monitoring program may extend through the entire post-closure period (a minimum period of 25 years) as well as during the operational period of the landfill. Non-permitted sites may also require extended monitoring depending on the type of contamination (solubility, etc.) and the potential for impact on human health and the environment. As a consequence, planning for the location and installation of monitoring wells in and around the sites should include consideration of both existing and anticipated site development as well as the type of contaminant plume involved and address any predicted changes in groundwater flow.

## 3. Monitoring System Design

Hydrogeological investigations are required to determine the appropriate location and depth of monitoring wells. Nearly all hydrogeological investigations include a subsurface boring program to define the hydrogeology and local geological conditions of the site. For boreholes that will be completed as monitoring wells, generally at least one groundwater sample should be collected from each lithological zone. If drilling in contaminated materials, care should be taken to prevent contaminants from migrating vertically into clean strata. Boreholes that will not be completed as monitoring wells must be properly decommissioned (e.g., back filled with impervious material if needed).

The number of boreholes required to delineate hydrogeological conditions will vary from site to site. On average, seven holes are drilled for sites with a relatively uniform lithology. There are exceptions; for example, some sites in British Columbia (former Expo lands and a dichloroethane spill near Fort Langley) have required over two hundred test holes, but these would generally be installed over a multi-phase program.

Considerations for selecting drilling sites should include (Piteau, 90):

- Bore holes located both up and down gradient with respect to groundwater flow from the suspected contaminated source

- Bore holes drilled in both permeable zones and zones where low permeable material is expected
- Networks of holes to construct hydrogeologic and contaminant plume profiles.
- Completion of test holes as permanent monitoring wells

The uppermost aquifer and confining layers should be characterized by installing piezometers to determine:

- The direction and rate of groundwater flow (both horizontal and vertical)
- Seasonal/temporal, natural, and artificially induced short-term and long-term variations in groundwater elevations and flow patterns, contaminant concentrations and free product thicknesses.
- The hydraulic conductivity of the stratigraphic units at the site
- The lateral and vertical extent of contamination.

## 4. Monitoring Well Specifications

Groundwater monitoring wells are installed in and around a site to allow measurement of water level and sampling of groundwater for contaminants. Monitoring well construction materials are discussed in section 4.2. Although well construction is not, strictly speaking, part of the sampling protocol, improper drilling techniques and screen slot selection may bias subsequent analyses regardless of the care taken to avoid contamination during collection of the sample.

### 4.1 Well Design and Dimensions

Monitoring wells must include a protective casing that preserves the integrity of the borehole and and if required, be monitored to meet design specifications. This casing must be screened and packed with a filter to enable the collection of sediment-free groundwater samples. Well screen slot size should be based on hydrologic characteristics and on the grain-size distribution of the aquifer being monitored. The primary filter pack material should be a chemically inert material, well rounded, and uniform in size. The most common filter packs are made of sand or gravel. At least two inches of filter pack material should be installed in the annular space and sealed above the sampling depth to prevent contamination of samples. The seals and grout are generally constructed of bentonite and/or cement, as appropriate. Refer to Appendix 3 of this chapter for typical monitoring well design.

Monitoring wells can range in diameter from 25mm-150mm, with a 50mm diameter the most common. The diameter of a monitoring well should be the minimum practical size that will allow for proper development of the well screen and operation of the sampling device. Large diameter wells (greater than 50 mm) are not recommended as they hold large volumes of water that require more purging prior to sampling.

Piezometers should have as short a screened interval as possible for measuring total hydraulic head. Screens can range in length from a few centimetres to tens of metres. They are typically found to be between 0.5-1.5 m in length and are sealed in intervals slightly longer. Short screens provide discrete data while long screens have limited application. Longer screens obtain a sample that represents the “average” chemistry of water flowing through the aquifer and is a function of all of the different heads over the entire length of the screened interval.

Well screens longer than 1.5 metres may be justified. Examples are provided below; however, in such cases, wells with smaller screen lengths must be installed in nest formations to facilitate contaminant sampling.

- When natural water level fluctuations dictate a longer screen length (this may be better accommodated by a longer casing)
- When the interval monitored is slightly greater (thicker) than the appropriate screen length
- When a homogeneous, extremely thick aquifer (i.e., greater than 90m) is being monitored, a longer screen (i.e., 6m), representing a comparatively discrete interval, may be necessary
- Where soils with extremely low hydraulic conductivity are encountered
- When monitoring a significant thickness of a light nonaqueous phase liquid (NAPL) on top of groundwater, or
- When monitoring NAPLs in an aquifer with significant seasonal water table fluctuation.

## 4.2 Materials

Each monitoring program should be considered unique when determining monitoring well construction materials. The choice of construction material will depend on the following factors: cost, availability, strength, and chemical and physical compatibility with groundwater and potential analytes. There are a variety of materials on the market with a wide price range. An assessment of material suitability for monitoring well construction is summarized in Appendix 1.

Due to availability and cost, polyvinylchloride (PVC) tends to be the most common choice. Most often, the piezometer is constructed of 50 mm diameter threaded, sealed PVC pipe with fine slotted manufactured well screens. However, recent studies investigating the absorption and release of organic compounds by rigid PVC have led the EPA to recommend, for EPA protocol sites, the use of well construction materials made of (PTFE) or stainless steel as opposed to PVC. Unfortunately, the costs of stainless steel and PTFE are considerably more expensive than PVC (see Appendix 1). In certain cases it may be advantageous to design a well using more than one type of material. For example, where stainless steel may be preferred in a specific chemical environment, costs may be saved by using PVC in non-critical portions of the well.

Additional components required for the monitoring well (e.g., primary filter pack, riser, etc.), including joints/couplings, should be comprised of material that will not alter the quality of water samples for the constituents of concern. With the exception of the primary filter pack, the additional components are commonly fabricated from PVC, stainless steel, fibreglass, or fluoropolymer. Materials recommended to prevent joints from leaking include PTFE tape for tapered thread joints and o-rings with a known chemistry for flush joint threads. Glued or solvent joints of any type are not recommended, especially where analysis for organic contaminants is anticipated, since glues and solvents may alter the chemistry of water samples (ASTM D5092-90). For further information regarding size specifications and/or installation procedures, refer to ASTM Designations: D 5092-90.

## 5. Well Construction

### 5.1 Drilling Techniques

Well drilling methods commonly used in BC include air rotary, sonic drilling, cable tool, hollow stem auger, and Becker hammer. The method selection is usually dictated by the anticipated ground conditions and the availability of equipment.

Whenever feasible, drilling procedures should be utilized that do not require the injection of water or drilling fluids into the borehole, and that optimize cuttings control at ground surface. Where the use of drilling fluids is unavoidable, the selected fluid should have as little impact as possible on the water samples for the constituents of interest (ASTM D5092-90). Preliminary laboratory testing of the fluid may be useful in determining potential for contamination. Furthermore, extreme care must be exercised when drilling at or near a geo technical liner (a punctured liner would severely impact the effectiveness of a leachate collection system). It is the responsibility of both the driller and the permittee to ensure that the monitoring well is installed correctly and the integrity of the liner is maintained.

A matrix of appropriate drilling methods for use in British Columbia is presented in Appendix 2. A further reference of greater scope and detail is *The Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (Aller et al., 1989). It provides a matrix that uses a rating system to establish the desirability of a drilling method based on the general hydrogeologic conditions and well design requirements.

### **5.2 Monitoring Well Development**

Monitoring well development is intended to correct any clogging or compaction that may interfere with water quality analysis, to improve hydraulic characteristics and to restore ground water properties disturbed during the drilling process. Monitoring well development should follow the installation process and continue until the water is representative and free of the drilling fluid cuttings, or other materials introduced during the drilling process. Representative water is assumed to have been obtained when pH, temperature, and specific conductivity readings have stabilized and the water is virtually clear of suspended solids (ASTM D5092-90). Methods of development include mechanical surging, over pumping, air lift pumping, and well jetting.

The combined use of a jetting tool with air-lift pumping is a particularly effective development method. Mechanical surging, as with a surge block or large bailer, can also be used but is less effective (Sabel and Clark, '85). A well recovery test should be carried out immediately after and in conjunction with well development.

### **5.3 Hydraulic Assessment and Documentation**

All constructed piezometers should be tested to determine the hydraulic conductivity of the formation, and to determine if they are sufficiently responsive to the hydraulic flow system to provide reliable monitoring data. The local groundwater flow system can be determined by installing piezometers to measure the hydraulic heads at various points in the system.

At least three piezometers in a triangular array are needed to define the horizontal hydraulic gradient and direction of groundwater flow in simple flow systems. Vertical gradients are determined with nested piezometers. (Nested piezometers are also needed to delimitate vertical contaminant concentration gradients.) In areas of complex geology, additional piezometers are needed since the flow medium will be heterogeneous and will result in a distorted hydraulic head distribution (Piteau, 1990).

Hydraulic head measurements should be collected at different depths, as well as at different locations on the site. Contours of the hydraulic heads will indicate which areas are located downgradient of the site and are, therefore, at risk of becoming contaminated, and which areas are located upgradient of the site and could thus provide background data. This information is useful for selecting appropriate monitoring sites.

## **6. Sampling Program**

### **6.1 Sampling Schedule**

Sampling frequency is based on the potential human health and environmental impact and on the rate of contaminant movement. Groundwater velocities are usually much less than those of surface waters and, therefore, sampling intervals may be longer. Monitoring parameters and frequency of sampling are site specific.

Water levels should be monitored on at least the same frequency as the regular chemical monitoring. Quarterly monitoring of water levels in all monitoring wells is commonly required to determine seasonal variations in groundwater flow.

A sampling schedule should be developed that takes into consideration the various conditions that influence the extent and direction of groundwater flow and the rate at which potential contaminants migrate into and with the groundwater. Some conditions that influence contaminant transport to the water table are precipitation, temperature, soil permeability, and soil type(s).

### **6.2 Piezometric Records**

It is generally assumed that the flow system of a groundwater system is a steady state situation and that fluctuations in head are minor in comparison to total head drop from recharge to discharge. However, for localized aspects of a system it may be important to quantify and document groundwater level variation. In these cases, piezometric measurements should be recorded on a regular basis to characterize seasonal fluctuations. For wells located near the ocean, tidal effects may be significant and, as well, there is the potential for salt water intrusion to cause variation in chemical composition.

### 6.3 Field Measurements

Regular monitoring of traditional “field parameters” such as odour, colour, pH, conductance, redox potential, and temperature, may provide an indication that a change in groundwater quality has occurred and that sampling for more extensive analysis is warranted.

## 7. Quality Assurance and Quality Control

Monitoring programs should include a quality assurance (QA) and quality control (QC) component in their design in order to provide confidence in the data obtained. Refer to the manual *Quality Assurance in Water Quality Monitoring* produced by Environment Canada, the Quality Control and Quality Assurance chapter of this manual (Part A), or the Quality Assurance section of *Ministry Methods Manual - Permittee Edition -1994*, produced by the EPD of BC MELP for the development and implementation of acceptable water monitoring programs. Laboratories generally have their own internal QC program consisting of regular testing of blanks, spikes, and laboratory duplicates.

A field QA protocol is necessary to verify the reliability and accuracy of the combined field sampling/handling and laboratory procedures and should include the following (Piteau, '90):

- Blind replicate samples: identical field samples are submitted under different sample identities to test for reproducibility of the sampling and analytical procedure (precision)
- Blind reference samples: reference samples (may be certified) are prepared to mimic authentic samples and are submitted under fictitious sample identities to test for analytical bias (accuracy)
- Spiked samples: a field sample is split and a known concentration of a contaminant is added to one-half of the sample to check for systematic errors (bias)
- Blank samples: laboratory reagent (distilled or deionized) water is carried through sample collection and handling (including preservation) to check for contamination, purity of preservatives and other systematic errors occurring from time of sampling

The contaminant concentrations in blanks should be recorded, and if concentrations are more than an order of magnitude greater than the detection limit for the parameter and the sample result is less than 5 times detection limit, the groundwater should be resampled to ensure QA and QC standards have been satisfied.

The laboratory should be contacted prior to sampling to ensure that sample handling, preservation, and shipping methods are appropriate. Sample storage time prior to laboratory analysis must not exceed allowable limits. Refer to Appendix 6 for a generalized flow diagram of groundwater sampling steps.

The calibration and maintenance of field equipment is also an integral component of QA/QC. All equipment must be kept clean and in good working condition, using the techniques described by the manufacturer. Calibrations, prior to the sampling event, should be performed under the same instrumental and chemical conditions as those that will exist at the sampling site. The frequency of calibration will depend on the accuracy requirements of the investigation and the stability of the instrument. To ensure a high standard of QA/QC, monitoring personnel must be adequately trained and supervised.

Where a series of samples is to be collected using common equipment, sampling should begin with the (assumed) lesser contaminated sites and progress to sites with higher anticipated levels of contamination.

A log should be kept for each item of equipment to document calibration, exposure, maintenance, and service.

## **8. Sample Collection**

### **8.1 Sampling and Measuring Methods**

A sampling device is chosen based on the parameters that are to be monitored, the compatibility of the rate of well purging with well yield, the diameter of the well, and the depth from which the sample must be collected. The cost, transportability and ease of use of the sampling device are also important considerations.

Appropriate measures are required to prevent cross contamination between wells during the sample collection procedure. For example, drilling equipment must be decontaminated between boreholes; sampling equipment must be decontaminated between each sampling event and, where appropriate, between specific parameter groups such as organic contaminants. Sampling equipment (including automated models) must be made of materials that are compatible with the type of contaminated groundwater being sampled and must not contribute or remove (e.g., by adsorption) any parameter of interest.

The routine parameters monitored in groundwater include pH, redox potential (Eh), dissolved oxygen (DO), specific conductivity, metals, ammonia nitrogen, chloride, and chemical oxygen demand (COD); other parameters may be added to this list on a site specific basis. The standard industry practice is to use a flow through cell to measure the DO, pH, and conductivity. Other parameters are measured with static

probes or parameter specific test kits. Routine quarterly sampling and in-situ monitoring will establish the presence of any trends, identify any statistically significant changes, locate contaminant plumes and, most importantly, identify those parameters with values that fail to meet the applicable criteria.

Statistically significant refers to a statistically significant increase or decrease from background values or exceedance of a compliance level for each parameter or constituent being monitored. It is the responsibility of the owner/operator or his agent to choose an appropriate statistical method consistent with the number of samples collected, and distribution pattern of the parameter. Examples of appropriate statistical methods and performance standards are outlined in the EPA document Criteria For Municipal Solid Waste Landfills, Subpart E section 258.53 paragraphs (g) & (h).

### **8.2 Immiscible Layers**

Immiscible layers may be either light nonaqueous phase liquids (LNAPLs) or dense nonaqueous phase liquids (DNAPLs). LNAPL layers must be sampled before a well is purged. To determine the presence of an immiscible layer, an interface probe should be used to measure the first fluid level in a well. Once this has been recorded, it should be lowered until the immiscible water interface is encountered. The depth interval, or thickness, of a floating immiscible layer can then be established.

### **8.3 Purging**

Water that has resided in a well casing for an extended period of time has the opportunity to exchange gases with the atmosphere and to interact with the well casing. Water standing in the columns inside the well casing must, therefore, be purged prior to sampling so that a representative sample can be obtained. To adequately purge a well, monitor the pH, temperature, and conductance of the water during the purging process, and assume purging is complete when these measurements stabilize. While 3 to 4 purge volumes are common industry practice, it is recommended that the appropriate number be determined on a site specific basis according to the number required to reach equilibrium.

Purging should be accomplished by removing groundwater from the well at low flow rates using a pump. Because they can operate at variable speeds, pumps such as the submersible and bladder variety are considered particularly useful for purging stagnant water from a well. The use of bailers should generally be avoided as the 'plunger' effect of their use can result in the continual development or overdevelopment of the well. A description of six different kinds of pumps is presented in Appendix 4.

Wells should be purged at rates lower than those used to develop the well. A low purge rate will reduce the possibility of stripping VOCs from the water and reduce the likelihood of mobilizing colloids in the subsurface that are immobile under natural flow conditions. For further reference, refer to the designation guide ASTM D 4448-85a.

If contaminants are suspected in the groundwater prior to purging, then appropriate disposal measures should be performed. The purged groundwater should be collected and tested and disposed of in accordance with established sanitary/stormwater sewer use criteria and other applicable regulatory requirements.

### **8.4 Sample Extraction**

The rate at which a well is sampled should not exceed the rate at which the well was purged. Low sampling rates, approximately 0.1 L/min, are suggested. Pumps should be operated at rates less than 0.1 L/min when collecting samples for volatile organic compound analysis.

Sample withdrawal methods include the use of pumps, compressed air, syringe sampler, and bailers. The selection of the sampling method must be based on the parameters that are to be monitored, the depth from which the sample is collected, and the diameter of the well (Piteau '90). The primary consideration is to obtain a representative sample of the groundwater body by guarding against mixing the sample with stagnant water in the well casing. This is avoided through adequate purging prior to collecting the sample. Refer to Appendix 4 for a description of a number of different sampling devices that are available to extract water from a variety of monitoring well diameters.

#### **8.4.1 Organic Contaminant Sampling**

Groundwater samples collected for analyzing organic constituents should not be field-filtered prior to laboratory analysis. The recommended container for collection is a solvent rinsed, amber coloured glass with an aluminum foil or Teflon liner cap. An emerging technology that promises to provide an alternative to collecting and shipping large samples of water involves a technique called solid phase extraction (SPE). In this technique, a volume of water is passed through a solid phase that adsorbs the organic contaminants. The adsorbent material is sent to the laboratory for extraction and analysis. Consult the manufacturer's literature for further information on this technique. For additional QA details refer to Appendix 5.

#### **8.4.1.1 Volatile Organic Compounds**

Volatile organic compounds (VOCs) must be sampled in a manner that does not cause agitation of the sample or exposure of the sample to air. Pumps that induce suction pressure, such as peristaltic pumps, or that have lift devices, may aerate the sample and are not recommended for sampling VOCs. Positive displacement bladder pumps or bailers constructed entirely of fluorocarbon resin or stainless steel are preferred. VOCs should be the first sample that is collected following the purging process (EPA, Sept '88).

During sampling, the pumping rate should be kept to a rate of less than 0.1 L/min. Samples should be placed directly in glass bottles with no air space left and capped with a Teflon septum cap.

#### **8.4.1.2 Extractable Organic Compounds**

Samples for extractable organics should be collected after the VOCS samples. Glass or Teflon bottles with Teflon lined caps should be used as sample containers (Piteau, '90); alternatively, solid phase extraction (SPE) may be performed on-site.

### **8.4.2 Inorganic Contaminant Sampling**

#### **8.4.2.1 Specific Conductivity**

Specific conductance and temperature should be measured in the field using portable equipment. Since many effluents, and in particular landfill leachate, have substantially higher temperature and specific conductance than natural groundwater, the presence of such a leachate can often be detected using a conductance - temperature probe. Specific conductance can be measured quickly and easily and is useful for estimating the total amount of inorganic dissolved solids.

Specific conductance and pH should ideally be measured both in the field and in the laboratory; differences may indicate that sample degradation has occurred during shipping and storage. For reliable comparisons, it is mandatory that adequate calibration of field instrumentation is maintained. Additional parameters that should be measured in the field include redox potential and dissolved oxygen.

#### 8.4.2.2 Metal Compounds

Groundwater samples collected to monitor total metal contaminants should be collected in an acid-cleaned, plastic container and preserved in an acid solution prior to analysis. Groundwater samples collected for analyzing dissolved metal contaminants should be field-filtered under pressure, collected in an acid-cleaned plastic container, and preserved in an acid solution prior to analysis.

Refer to Appendix 5 for appropriate preservation and collection techniques. Note that samples must not be decanted as an alternative to filtering.

**Note: To avoid contamination, the collection containers for groundwater samples to be analyzed for inorganic contaminants should be precleaned and certified by the supplier or by adequate batch testing. Containers should not be rinsed with sample prior to sample collection as surface concentration effects may occur. For appropriate container and rinsing agents refer to Appendix 5.**

### 8.5 Sample Preservation

To assist in maintaining the natural chemistry of the samples, it is necessary to preserve the sample. Methods of sample preservation are relatively limited and are intended to reduce the effects of chemical reactions, the effects of sorption and to arrest biological actions. Preservation methods are generally limited to pH control, refrigeration, and protection from light. Selected parameters or groups of parameters (e.g., metals) may be preserved by addition of a reagent (e.g., acid) that stabilizes their concentration but may preclude the analysis of that sample for other parameters.

Glass, stainless steel, Teflon, or plastic (polyethylene and polypropylene) are the types of containers acceptable for most kinds of sample collection. There are some exceptions to this general rule; for example, plastic is not acceptable for organics and stainless steel is not acceptable for metals. Containers should be kept full until samples are analyzed to maintain anaerobic conditions. The sample container material should be non-reactive with the sample and especially with the particular analytical parameter to be tested. Sample containers used to transport samples to the lab must undergo pre-treatment procedures. Pre-treated containers may be purchased commercially; however, pre-treatment must be repeated if they are re-used. For appropriate sample containers and preservation methods, refer to Appendix 5.

Samples should be placed in bottles immediately upon collection and, where preservation of the sample is required, it should be carried out immediately. Handling of the sample and contact with the atmosphere should be kept to a minimum. The samples should be properly packaged so as to prevent breakage and should generally be kept at 4°C plus/minus 2°C until analyzed by the laboratory. It is recommended that the sampler consult with the laboratory to discuss sampling protocols and sample treatment options prior to sample collection.

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## 10. Revision History

February 28, 2001: This section republished without change. Bottle types adjusted for mercury in Appendix 5.

November 1996: Initial publication.

**Appendix 1      Recommendations for Screen and Casing  
Materials in Sampling Applications**  
(in decreasing order of preference)

| <b>Material</b>                             | <b>Applications</b>   | <b>Other Considerations</b>   | <b>Approximate Cost (Relative to PVC)</b> |
|---|---|---|---|
| Fluorinated Ethylene Propylene (FEP)        | Recommended for most monitoring situations where corrosive environments are anticipated. Also offers good chemical resistance to volatile organics.   | Lower strength than steel and iron. Not available in British Columbia.                        | > 20 x                                    |
| Polytetrafluorethylene (PTFE) or Teflon (R) | Recommended for most monitoring situations with detailed organic analytical needs, particularly for aggressive, organic leachate impacted hydrogeologic conditions.<br><br>Virtually an ideal material for corrosive situations where inorganic contaminants are of interest. | Low strength, not readily available in British Columbia (- 10 days for delivery).             | 21 x                                      |
| Kynar                                       | Strong material that is resistant to most chemicals and solvents.   | Poor chemical resistance to ketones and acetone. Not commonly available.                      |   |
| Fibreglass                                  | Historically, fibreglass has not been used for monitoring wells due to potential leaching of epoxy resins. Recent advances in fibreglass technology have created a material that is equivalent to or more inert than Teflon, but is also very strong.                         | High strength, not readily available in British Columbia. Not available as 50 mm casing.      | 2 to 5 x                                  |
| Stainless Steel 316 (flush threaded)        | Recommended for most monitoring situations with detailed organic analytical needs, particularly for aggressive, organic leachate impacted hydrogeologic conditions.   | High strength, reasonable availability. May be source of Cr, Fe and Ni in low pH environments | 10 x                                      |
| Stainless steel 304 (flush threaded)        | May be prone to slow pitting corrosion in contact with acidic, high TDS aqueous solutions. Corrosion products limited mainly to Fe and possibly Cr and Ni.  | High strength, good availability. May be source of Cr, Fe and Ni in low pH environments.      | 7.5 x                                     |

## Ground Pollution Monitoring

| Material  | Applications  | Other Considerations*   | Approximate Cost Relative to PVC)* |
|---|---|---|------------------------------------|
| PVC (flush threaded or other noncemented connections) | <p>Recommended for monitoring situations where inorganic contaminants are of interest and it is known that aggressive organic leachate mixtures will not be contacted. Cemented installations have caused documented interferences.</p> <p>The potential for interaction and interferences from PVC well casing in contact with aggressive aqueous organic mixtures is difficult to predict. PVC is not recommended where ppb or corrosive concentrations of organic contaminants are expected.</p> | <p>PVC can be used as casing with stainless steel screens for composite well. Moderate strength, good availability.</p> <p>Deteriorates when in contact with ketones, esters and aromatic hydrocarbons.</p> | 1 x                                |

| <b>Materials below this line are not recommended as they cost more than PVC while rated as inferior.</b> |   |  |             |
|--|---|--|-------------|
| Acrylonitrile Butadiene Styrene (ABS)  | Not commonly used for groundwater monitoring  | Lower strength than steel and iron. Not readily available other than in domestic plumbing format that is not generally suitable for piezometer applications. | 2 x         |
| Polypropylene  | Resistance to mineral acids and moderate resistance to alkalis, alcohols, ketones and esters make polypropylene a suitable material for many applications. It deteriorates when in contact with oxidizing acids, aliphatic and aromatic hydrocarbons. | Low strength, not readily available in British Columbia.   |             |
| Polyethylene: High Density   | Polyethylene is less reactive than PVC but more reactive than PTFE.   | Low strength. Not commonly available in format other than flexible water line. Not threadable.   | 1 x         |
| Low Carbon Steel   | May be superior to PVC for exposures to aggressive aqueous organic mixtures. These materials must be very carefully cleaned to remove oily manufacturing residues.  | Prone to rusting.  |             |
| Galvanized Steel   | Corrosion is likely in acidic, high TDS environments, particularly when sulfides are present. Products of corrosion are mainly Fe and Mn, except for galvanized steel that may release Zn and Cd.   | High strength, good availability. Prone to rusting.  | 1.25 to 3 x |
| Carbon Steel   | Weathered steel surfaces present very active absorption sites for trace organic and inorganic chemical species.   | Prone to rusting.  |             |

(Piteau March 1990. Table 5.2)

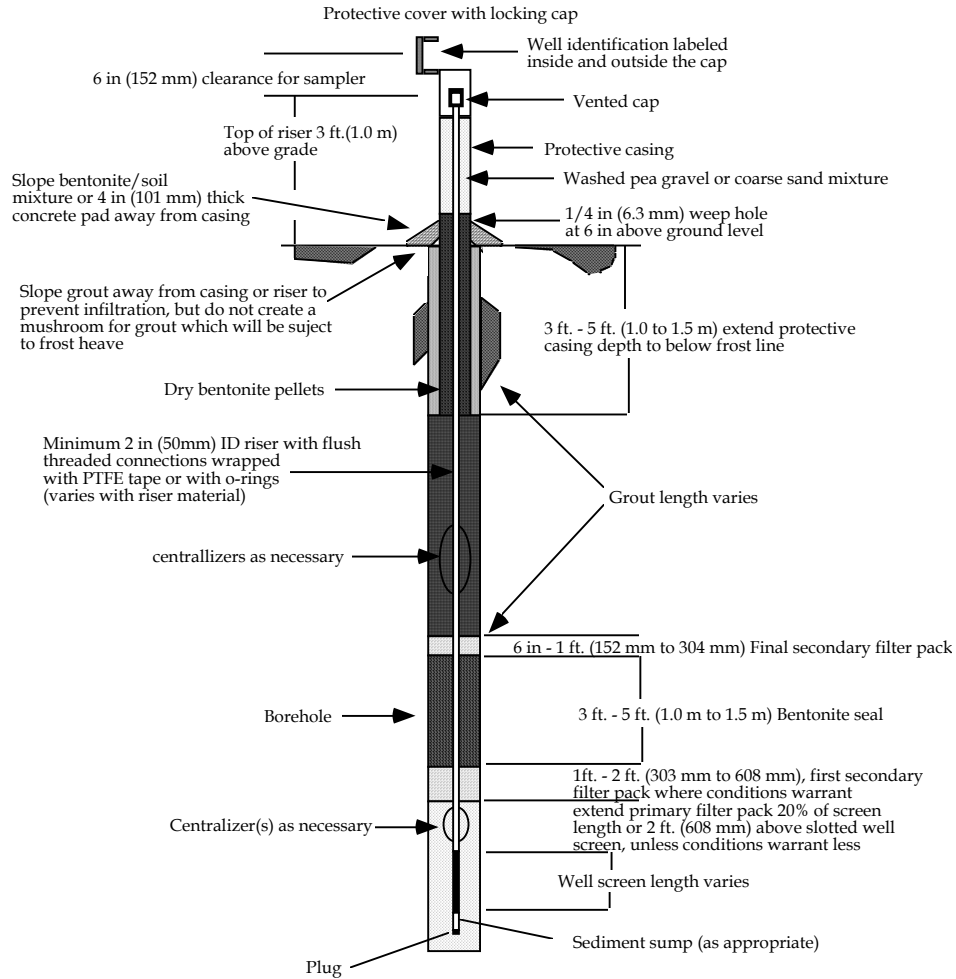
\* Source of availability and relative cost: CPI Equipment, the largest supplier of drilling equipment in B.C.

## Appendix 2 Drilling Methods Matrix

|                                | DRILLING METHODS |            |                   |                |               |            |              |                    |
|--------------------------------|------------------|------------|-------------------|----------------|---------------|------------|--------------|--------------------|
|                                | Air rotary       | Cable Tool | Hollow Stem Auger | Sonic Drilling | Becker Hammer | Mud Rotary | Bucket Auger | Backhoe Excavation |
| <b>Applicable Geology</b>      |                  |            |                   |                |               |            |              |                    |
| Unconsolidated Overburden      | X                | X          | X                 | X              | X             | X          | X            | X                  |
| Fine Grained Sediments         | X                | X          | X                 | X              | X             | X          | X            | X                  |
| Soft Rock                      | X                | X          |                   |                |               | X          |              |                    |
| Cohesive Sediments             | X                | X          |                   | X              |               | X          |              |                    |
| Unconsolidated Sediments       | X                | X          | X                 | X              | X             | X          | X            | X                  |
| Bedrock                        | X                | X          |                   |                |               | X          |              |                    |
| Suficial Sediments             | X                | X          | X                 | X              | X             | X          | X            | X                  |
| Soft to Mod. Dense Sediments   | X                | X          | X                 | X              | X             | X          |              |                    |
|                                |                  |            |                   |                |               |            |              |                    |
| <b>Maximum Depth (m)</b>       | >300             | >200       | 50                |                | 50            | >300       | 10           | 8                  |
|                                |                  |            |                   |                |               |            |              |                    |
| <b>Avg. Hole Diameter (mm)</b> | 150              | 150        | 125               |                | 150           | 150        | 800          | 1,000              |

(After Piteau, 1990)

## Appendix 3 Typical Monitoring Well Design



\* Reprint with permission, from the Annual Book of ASTM Standards, copyright American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103. Figure redrawn for legibility.

## Appendix 4 Sampling Equipment

| Sampling Devices             | How the Sampling Device Operates   | Pumping Rates  | Characteristics  | Disadvantages  |
|------------------------------|--|--|--|--|
| <b>Air Lift Pump</b>         | An air lift pump collects a water sample by bubbling a gas at depth in the well or tube.   | Pumping rates depend on the size of the pump being used and how many pumps are used for each well.   | Air lift sampling can be useful in monitoring wells that need to be pumped only at periodic intervals.                       | Air lift methods result in considerable sample agitation and mixing in the well.   |
| <b>Submersible Pump</b>      | Water is transported to the surface by centrifugal action through an access tube.  | Vary from 26.5-53.0 Lpm depending upon the depth of the pump.  | A submersible pump provides higher extraction rates than most other methods.   | Considerable sample agitation and the potential introduction of trace metals into the sample from pump materials results.  |
| <b>Suction Lift Pump</b>     | Suction lift can be categorized as direct line, centrifugal and peristaltic.   | Vary from 19-151 Lpm for direct line method. Approximately 3.7 Lpm for peristaltic pump method.  | Suction lift approaches offer a simple retrieval method for shallow monitoring.  | Degassing and agitation occur as a result of suction lift.   |
| <b>Bladder Pump</b>          | Water enters the flexible membrane through the lower check valve; compressed gas is injected into the cavity between the stainless steel housing and the bladder.  | The 4.4 cm pump is capable of providing samples (Approx. 2.6 - 5.6 Lpm) from depths in excess of 76m.  | Bladder pumps prevent contact between the gas and water sample and can be fabricated entirely of Teflon and stainless steel. | The large gas volumes required, especially at depth, potential bladder rupture, and the difficulty in disassembling the unit for thorough cleaning. Piezometers must be developed with no fines inside casing. |
| <b>Gas Displacement Pump</b> | A column of water under linear flow conditions is forced to the surface without extensive mixing of the pressurized gas and water.                                 | Flow rates of about 2.8 Lpm at 36.5m are possible with a standard 3.7 cm inner diameter by 4.57 cm long pump.  | Gas displacement pumps provide a reliable means for obtaining a highly representative ground water sample.                   | Possibility of gas water interface, a degree of mixing, and sample degassing can occur during transport.   |
| <b>Gas Piston Pump</b>       | A double piston pump utilizes compressed air to force a piston to raise the sample to the surface.   | Pumping rates of 0.5 Lpm have been reported from 30.5 m; sampling depth of 152 m are possible.   | The gas piston pump provides continuous sample withdrawal at depths greater than is possible with most other approaches.     | Contribution of trace elements from the stainless steel and brass is a potential problem.  |
| <b>Packer Pump</b>           | The hydraulic activated packers are wedged against the casing wall or screen, the sampling unit collects water samples only from the isolated portion of the well. | Vertical movement of water outside the well casing during sampling is possible with packer pumps but depends upon the pumping rate and subsequent disturbance. | A packer assembly allows the isolation of sampling points within a well.   | Deterioration of the expandable material will occur with time thereby increasing the possibility of undesirable organic contaminants entering the water sample.  |
| <b>Inertial Lift Pump</b>    | The operating principle of the pump is based on the inertia of a column of water contained within a riser tubing.  | Pumping rates of between 0.05 to 10.0 Lpm have been recorded.  | The inertial pump is inexpensive and offers multiple uses for ground water monitoring wells.                                 | The tubing coils, though reasonably lightweight, are stiff and may be awkward to transfer from well to well.   |

\* Text extracted from Appendix D, Piteau (1990), from R.D. Morrison (1983).

## Appendix 5      Sample Container and Preservation Criteria

| TYPE OF ANALYSIS                | SIZE                    | TYPE  | PRESERVATION   | HOLD TIME |
|---------------------------------|-------------------------|---|--|-----------|
| <b>WATER-BACTERIOLOGY</b>       |                         |   |  |           |
| Coliform, fecal and/or Total    | 250 mL                  | P, ster   | 4_C, do NOT freeze   | 48 hrs    |
| Standard plate count            | 250 mL                  | P, ster   | 4_C, do NOT freeze   | 48 hrs    |
| BOD                             | 1 L                     | P   | 4_C, exclude all air   | 48 hrs    |
| BOD & TSS                       | 2 L                     | P   | 4_C, exclude all air   | 48 hrs    |
| Chlorophyll/Phaeophytin         | membrane or GF/C filter |   | store frozen in dark, with dessicant   | NA        |
| Microtox                        | 100 mL                  | G, A  | 4_C, exclude all air   | 5 days    |
| Bioassay, Daphnia               | 4 L                     | P   | 4_C, exclude all air   | 5 days    |
| <b>WATER-INORGANIC ANALYSIS</b> |                         |   |  |           |
|                                 |                         | Container size is determined by the type and number of analysis |  |           |
| General chemistry and Anions    | 1 to 4 L                | P   | keep cool 4_C  | 72 hrs    |
| Mercury, Total                  | 1 L or 500 mL           | G (A) or Tf, L (MERCURY)  | 6 mL 10% K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> +6mL H <sub>2</sub> SO <sub>4</sub> per L | 28 days   |
| Metals, Dissolved               | 250 mL                  | P, L (METALS)   | field filter & pres HNO <sub>3</sub> tp pH<2   | 6 mo      |
| Metals, Total                   | 250 mL                  | P, L (METALS)   | pres HNO <sub>3</sub> to pH <2   | 6 mo      |
| Carbon TIC/TOC, Inorg/org       | 100 mL                  | P or G  | 4_C  | 72 hrs    |
| Chemical Oxygen Demand, COD     | 250 mL                  | P   | 0.2 mL H <sub>2</sub> SO <sub>4</sub> / 250 mL   | 72 hrs    |
| Cyanide, SAD and/or WAD         | 1 L                     | P   | NaOH to pH >12   | 72 hrs    |
| Oil & Grease                    | 1 L                     | G   | HCl to pH <2   | 28 days   |
| Phenolics, Total                | 1 L                     | G, A  | H <sub>3</sub> PO <sub>4</sub> to pH 4 + 5mL 20% CuSO <sub>4</sub>                               | 72 hrs    |
| Phosphorus, Low level           | 100, 250 mL             | G, A, R   | keep cool, 4_C   | 72 hrs    |
| Sulphide, Total                 | 500 mL                  | P or G  | 1 mL 2N Zinc Acetate, exclude air  | 72 hrs    |

## Ground Pollution Monitoring

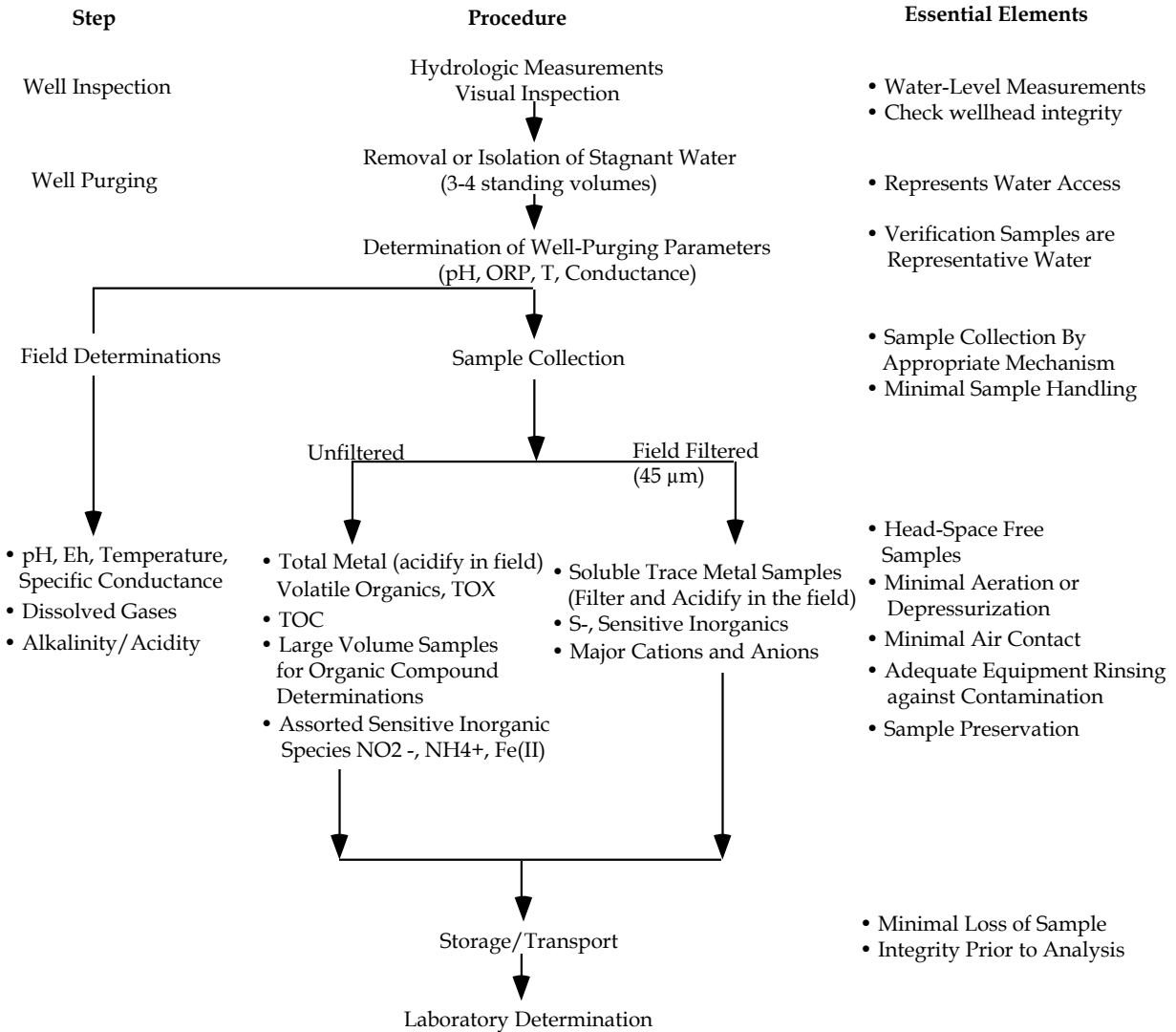
| TYPE OF ANALYSIS                                     | SIZE         | TYPE              | PRESERVATION  | HOLD TIME |
|--|--------------|-------------------|---|-----------|
| <b>WATER-ORGANIC ANALYSIS</b>                        |              |                   |   |           |
| AOX (Adsorbable Organic Halides)                     | 500 mL       | G, A, R, B        | pH to <2 with HNO <sub>3</sub>  | 30 days   |
| Chlorophenols PCP, TTCP, TCP                         | 1 L          | G, A, Solv        | 4_C   | 30 days   |
| Dioxins/Furans                                       | 3 x 1 L      | G, A, Solv        | 4_C   | 30 days   |
| EPA 624, Volatiles or BTEX                           | 3 x 40 mL    | vial, G, B, P & T | headspace-free, 4_C(Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> if chlorinated) | 14 days   |
| EPA 625, CP/OC/PAH/PCB                               | 1 L          | G, A, Solv        | 4_C   | 30 days   |
| AEH, TCMTB   | 1 L/analysis | G, A, Solv        | 4_C   | 30 days   |
| Hydrocarbons   | 500 mL       | G, A, Solv        | 4_C   | 30 days   |
| Copper quinolate                                     | 250, 500 mL  |                   | 4_C, HCl to pH <2   | 30 days   |
| Resin Acids  | 1 L          | G, A, Solv        | 4_C, NaOH to pH 12  | 21 days   |
| Trihalomethanes                                      | 500 mL       | G, A, Solv        | Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> , headspace-free, 4_C               | 14 days   |
| IPBC/DDAC  | 1 L          | P or G            | 4_C, 6N HCl, 2mL/L  | 14 days   |
| <b>SOILS, SEDIMENTS, TISSUES and OTHERS</b>          |              |                   |   |           |
| Asbestos, bulk identification                        | 50 g         | whirl-pak         |   | 6 mo      |
| EOX, Extractable Organic Halides                     | 50 g min     | G, Solv, Fc       | keep cool, 4_C  | 6 mo      |
| Metals (not mercury)                                 | 100 g min    | P, W (T)          | keep cool, 4_C  | 6 mo      |
| Mercury  | 100 g min    | G (A), Tf         | keep cool, 4_C  | 28 days   |
| Organic Carbon                                       | 100 g min    | P or G            | keep cool, 4_C  | 6 mo      |
| Organics-Semivolatile                                | 200 g min    | G, A, W, Solv     | keep cool, 4_C  | 6 mo      |
| Organics-Volatile                                    | 50 g min     | G, W, Solv, B     | keep cool, 4_C  | 14 days   |
| Particle Size Analysis                               | 100 g dry wt | P or G            | keep cool, 4_C  | 6 mo      |
| PQ-8 (copper 8, copper quinolate)                    | 100 g min    | G (A), W Solv     | keep cool, 4_C  | 6 mo      |
| <b>ANALYSIS WITH LIMITED SHELF LIFE</b>              |              |                   |   |           |
| pH, Turbidity, Acidity, Alkalinity                   |              | 72 hr             |   |           |
| Ammonia, TKN, Nitrate, Nitrite                       |              | 72 hr             |   |           |
| Phosphorus (Phosphate) ortho, total, total dissolved |              | 72 hr             |   |           |
| Specific Conductance                                 |              | 72 hr             |   |           |

**LEGEND**

|               |                               |
|---------------|-------------------------------|
| P=plastic     | Ster= sterilized              |
| G= glass      | Solv= solvent cleaned         |
| A= amber      | Fc= foil lined cap            |
| W= wide mouth | R= acid rinsed                |
| T= tissue cup | L ( )= labelled (description) |
| B= baked      | P&T = Purge and Trap Vials    |
| Tf = Teflon™  |                               |

Source: Zenon Environmental Labs Inc., Burnaby, B.C.

## Appendix 6 Generalized Flow Diagram of Groundwater Sampling Steps



Filtration should be accomplished preferably with in-line filters and pump pressure or by N<sub>2</sub> pressure methods. Samples for dissolved gases or volatile organics should not be filtered. In instances where well development procedures do not allow for turbidity-free samples and may bias analytical results, split samples should be spiked with standards before filtration.

Both spiked samples and regular samples should be analyzed to determine recoveries from both types of handling. Assorted Field Blanks and Standards: as needed for good QA/QC.

(Modified Piteau 1990, Fig. 5.7)