GUIDANCE DOCUMENT FOR DETERMINING GROUND WATER AT RISK OF CONTAINING PATHOGENS (GARP) INCLUDING GROUND WATER UNDER DIRECT INFLUENCE OF SURFACE WATER (GWUDI)

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Health Protection Branch
Population and Public Health Division
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BRITISH COLUMBIA

NOTE TO THE READER

The *Guidance Document for Determining Ground Water at Risk of Containing Pathogens (GARP) Including Ground Water under Direct Influence of Surface Water (GWUDI)* was developed to assist water suppliers and regulatory authorities with assessing the level of potential health hazard and risk associated with a ground water source. The implementation of the information and assessment process presented in this document should not be taken as equivalent to provincial or local legislation or standards. Regulatory authorities should be consulted prior to application of this document in site-specific settings.

EXECUTIVE SUMMARY

The B.C. Drinking Water Protection Regulation under section 5(2) states: "For the purposes of section 6(b) of the Act, drinking water from a water supply system must be disinfected by a water supplier if the water originates from (a) surface water, or (b) **ground water that, in the opinion of a Drinking Water Officer, is at risk of containing pathogens."** This guidance document has been developed to assist the drinking water officer (DWO) in formulating an opinion as to whether water originating from a ground water source by way of shallow or deep wells is or is not "at risk of containing pathogens."

This guidance document is also intended to be used by public health officials, water suppliers, professional engineers and geoscientists in investigating and assessing situations where ground water may be at risk of containing pathogens. However, it is up to the drinking water officer to make the final decision about risk and whether or not to require the water supply system to be disinfected. These decisions are based on information provided by the water supplier, among other sources of information.

Ground water at risk of containing pathogens (GARP) is defined herein as any ground water supply likely to be contaminated from any source of pathogens. Potential sources of pathogens include sewage effluent discharge to land, agricultural waste stockpiles and surface water. Ground water under direct influence of surface water (GWUDI) is defined herein, as ground water that is hydraulically connected to surface waters and susceptible to contamination from pathogens. However, GWUDI wells may not be "at risk of containing pathogens" (GARP) under certain conditions. Resolving these uncertainties in a systematic method is in part the intent of this guideline.

The approach followed in this guidance document has been adapted in part on similar protocols utilized by other jurisdictions in Canada and the United States to determine whether a ground water source is GWUDI. The procedures outlined follow a staged approach from initial screening of a ground water source to preliminary and more advanced hydrogeological investigations to assist drinking water officers in determining, where necessary, appropriate treatment requirements for ground water sources. The guideline's investigative process consists of four stages:

Stage 1: Screening Tool

Stage 2: Preliminary Hydrogeological Investigation

Stage 3: Advanced Hydrogeological Investigation

Stage 4: Long-term Water Quality Monitoring

Drinking water officers may deem a ground water source to be at risk of containing pathogens upon reviewing the results of any stage of the investigation, the available evidence at the time and any other known factors or uncertainties. Determining whether a ground water source is GARP is not regarded as a one-time investigation but is subject to the results of continued long-term monitoring of the water supply system and water sources because conditions in an aquifer or watershed may change with time.

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These procedures herein were initially drafted by A. Kohut, PEng with Hy-Geo Consulting in 2007 and subsequently reviewed and modified following consultation with provincial Public Health Engineers, drinking water officers, the Ministry of Health, hydrogeologists with the Ministry of Environment, and hydrogeologists from a number of ground water consulting firms in British Columbia.

ACRONYMS

BCACS	British Columbia Aquifer Classification System
BCMOE	British Columbia Ministry of Environment
CALA	Canadian Association for Laboratory Accreditation
CCME	Canadian Council of Ministers of the Environment
DO	Dissolved oxygen
DWO	Drinking water officer
DWPA	*Drinking Water Protection Act*
DWPR	Drinking Water Protection Regulation
EPA	Environmental Protection Agency
FA	Immunifluorescence Assay
GPR	Ground Water Protection Regulation
GWUDI	Ground Water Under Direct Influence of Surface Water (Other acronyms include GUDI, GUI and GWI.)
GARP	Ground Water at Risk of Containing Pathogens
GWPR	Ground Water Protection Regulation, under the *Water Act*
HHR	Health Hazards Regulation
IMS	Immunomagnetic Separation
MPA	Microscopic Particulate Analysis
ORP	Oxidation-Reduction Potential
PHA	Public Health Act
TOT	Time of Travel
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
WA	Water Act
WPT	Well Protection Toolkit
WTN	Well Tag Number

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

In British Columbia, section 5(2) of the Drinking Water Protection Regulation (DWPR) requires that drinking water from a *water supply system* must be disinfected if the water originates from ground water that, in the opinion of a drinking water officer (DWO), is at risk of containing pathogens.

Ground water, as defined in the *Water Act* (WA), means water below the surface of the ground. *Surface water,* as defined in the DWPR*,* means water from a source which is open to the atmosphere and includes streams, lakes, rivers, creeks and springs. *Pathogens* are human disease-causing microorganisms including various types of *bacteria*, *viruses* and *protozoa* (e.g., *Giardia* and *Cryptosporidium*). The presence of waterborne pathogens in ground water used for human consumption can pose a significant health threat.

Ground water at risk of containing pathogens or GARP is defined as any ground water supply that is likely to be contaminated from any sources of pathogens and must be disinfected. The DWO may also prescribe other levels of treatment. Potential sources of pathogens in ground water may include sewage effluent discharge to land, agricultural waste stockpiles, and surface water that is hydraulically connected to ground water. Ground water that is hydraulically connected to surface water is termed as *ground water under direct influence of surface water* or GWUDI.

The original concept of GWUDI was developed in 1989 by the USEPA under the U.S. National Primary Drinking Water Regulations, Surface Water Treatment Rule; and later modified under the Interim Enhanced Surface Water Treatment rule (USEPA, 1998). The 1998 USEPA definition of GWUDI focuses on water beneath the surface of the ground with significant occurrence of insects or other macro organisms, algae or large-diameter pathogens such as *Giardia lamblia,* and in some cases *Cryptosporidium,* or where there are significant and relatively large shifts in water characteristics such as turbidity, temperature, conductivity or pH which closely correlate to climatological or surface water conditions.

Jurisdictions across Canada have developed varying definitions for GWUDI to meet their respective management requirements and legislative frameworks. *From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water* (CCME 2004) refers to GWUDI as ground water with incomplete or undependable subsurface filtration of surface water and infiltrating precipitation. GWUDI is defined herein, as ground water that is hydraulically connected to nearby surface waters and is susceptible to contamination from pathogens. This definition is less restrictive than the original concept of GWUDI developed by the USEPA. Winter et al (1998) describe a range of hydrologic settings where ground water and surface water are interconnected.

In GWUDI situations, pathogens may be transported through infiltration of surface water into the ground water regime under natural or ground water pumping conditions. Fluctuations in ground water levels and ground water quality may also show a high degree of correlation with changes in surface water levels and surface water quality. The absence of detectable pathogens or other surface water organisms such as insects and algae in a ground water source, however, does not necessarily indicate a non-GWUDI situation. It is also recognized that in some situations where ground water may be hydraulically connected to nearby surface water, site-specific hydrogeological conditions (e.g., *flowing artesian*) and effective subsurface filtration conditions may preclude the transport of some pathogens to a *water supply well*.

1.1 PURPOSE AND SCOPE

This guidance document outlines recommended procedures to assist public health officials, water suppliers, professional engineers and geoscientists in determining and investigating situations where ground water may or may not be at risk of containing pathogens. The procedures outlined in this document follow a staged approach from initial screening of a ground water source to preliminary and then more advanced hydrogeological investigations.

These procedures help public health engineers and DWOs determine, where necessary, appropriate treatment requirements for ground water sources or possible alternatives to treatment. Water treatment, where required, may vary depending on the specific type of pathogens of concern, e.g., bacteria versus protozoa. A glossary of key terms used in this document is in Appendix A.

1.2 RELEVANT LEGISLATION AND REGULATIONS

The main legislative requirements and supporting information relevant to this guidance document are in the *Drinking Water Protection Act* (DWPA), Drinking Water Protection Regulation (DWPR), *Water Act* (WA), Ground Water Protection Regulation (GWPR), *Public Health Act* (PHA), and Health Hazards Regulation (HHR). Pertinent sections from these documents are in Appendix B. The principal requirements are:

***Drinking Water Protection Act*, section 6:**

"Subject to the regulations, a water supplier must provide, to the users served by its water supply system, drinking water from the water supply system that

a) is potable water, and
b) meets any additional requirements established by the regulations or by its operating permit."

Drinking Water Protection Regulation, section 5(2):

"For the purposes of section 6 (b) of the Act, drinking water from a water supply system must be disinfected by a water supplier if the water originates from

a) surface water, or
b) ground water that, in the opinion of a drinking water officer, is at risk of containing pathogens."

Drinking Water Protection Regulation, section 3.1:

"A small system is exempt from section 6 of the Act if

a) the system does not provide water for human consumption or food preparation purposes, and is not connected to a water supply system that provides water for human consumption and food preparation purposes, or
b) each recipient of the water from the system has a point of entry or point of use treatment system that makes the water potable."

Ground Water Protection Regulation:

Establishes standards for the construction, maintenance, alteration and closure of wells in British Columbia.

Health Hazards Regulation, section 8:

Establishes the distance wells must be from possible sources of contamination.

2 DETERMINATION PROCEDURES

2.1 DETERMINATION APPROACH AND FLOWCHART

The approach followed in this guidance document has been adapted in part following a review of similar protocols utilized by other jurisdictions in Canada and the United States to determine whether a ground water source is GWUDI. In the United States, the USEPA required that direct influence must be determined for individual sources in accordance with criteria established by each State and suggested that this may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation (USEPA, 1998).

The USEPA also recommended using a multistep approach to determine whether a ground water source is GWUDI and that determinations be made in conjunction with related activities required by other regulations including for example; sanitary surveys, vulnerability assessments, and wellhead protection programs (USEPA, 1991a and 1991b). Most provinces have developed protocols for assessing GWUDI using a multistep approach.

The determination procedures for this guideline encompass four main stages:

Stage 1: Screening Tool

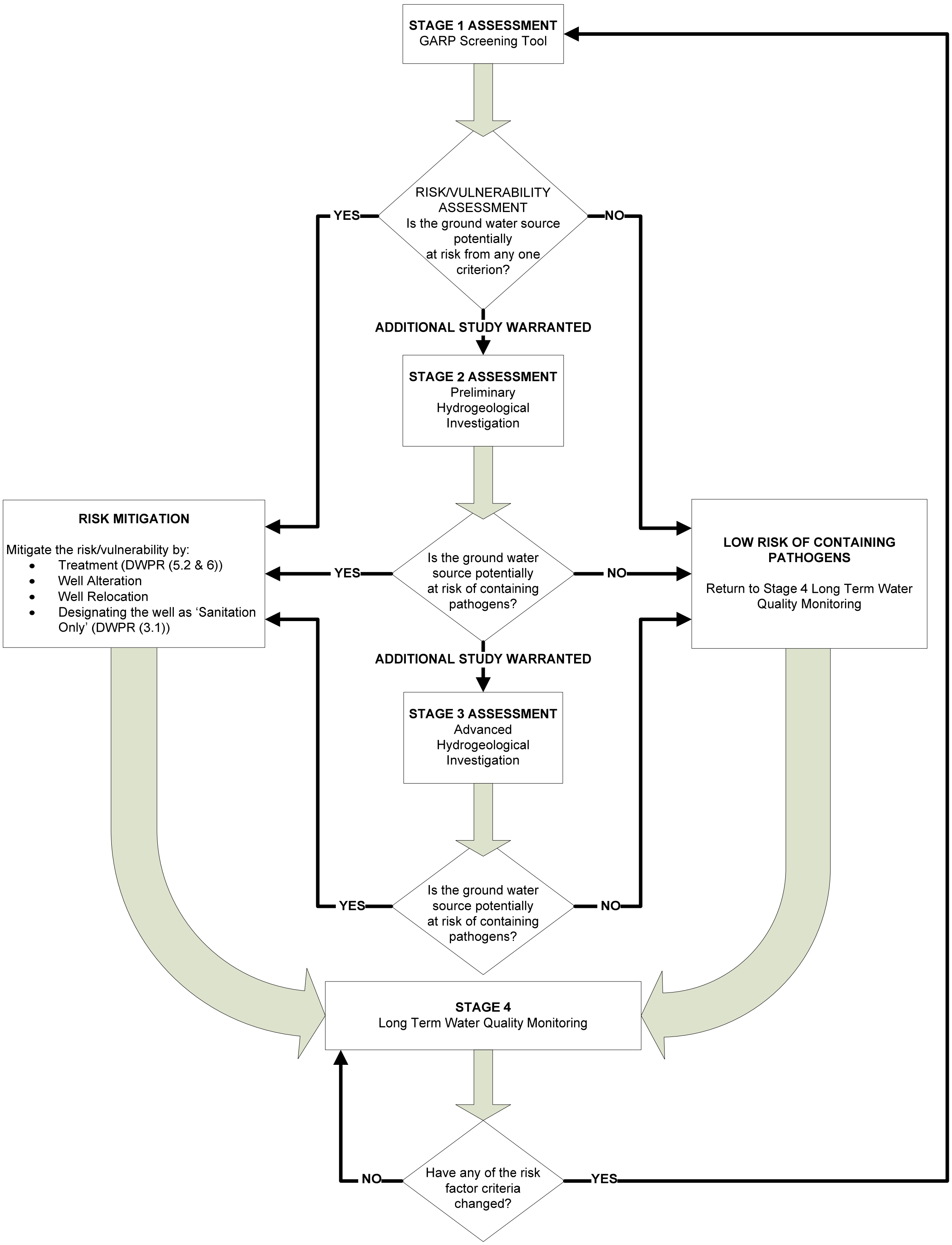
Stage 2: Preliminary Hydrogeological Investigation

Stage 3: Advanced Hydrogeological Investigation

Stage 4: Long-term Water Quality Monitoring

Figure 1 outlines the determination stages and general factors considered. Further details on these stages are outlined below.

Figure 1: GARP Assessment Flowchart



DWOs may deem a ground water source to be at risk of containing pathogens upon the review of the results of any stage of the investigation, the available evidence at the time, and any other known factors or uncertainties. The degree of risk is assessed based on several factors and criteria in the following categories:

1. Where there is evidence of any apparent risk, the ground water source is regarded as "potentially at risk" and further investigation is warranted unless the water supplier opts to treat the ground water source in accordance with the DWPA or chooses another possible alternative agreeable to the health authority.
2. Where there is evidence of low risk in all categories (see Figure 2), the ground water source is regarded as having a "low risk of containing pathogens."
3. Where information on one or more criteria is not available, additional information may need to be collected in a subsequent investigation stage before a risk determination can be made.

Sufficient evidence following any stage of the investigation may preclude the need for conducting additional investigations except for Stage 4: Long-term Water Quality Monitoring, which is recommended for all water supply systems. For ground water sources where the DWO requires further investigation beyond a Stage 1 assessment, a work plan should be developed in consultation with the water supplier to address the issues identified prior to initiating any investigations.

Determining whether a ground water source is at risk of containing pathogens is not regarded as a one-time investigation but is subject to the results of ongoing monitoring of the source. Corrosion of well casings in some situations, for example, and other factors including variations in climatic conditions, extreme hydrologic events, biological vectors and human activities in a watershed may change with time and may affect the likelihood of a ground water source becoming contaminated from new sources of pathogens.

For new (proposed) ground water sources there will likely not be sufficient water quality results or other relevant data to complete the assessment described herein. In such cases, a work plan to assess the level of risk should be developed by the water supplier in conjunction with the public health engineer and DWO and may involve a *qualified professional*.[1] The work plan could include the collection of quality and quantity baseline data, the installation of monitoring wells and staff gauges in nearby surface water sources and conducting specific water quality monitoring during the pumping test for the new well(s).

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[1] Qualified Professionals are individuals who are registered with the Association of Professional Engineers and Geoscientists of British Columbia with competency in the field of hydrogeology and experience in evaluating sources of ground water supply.

2.2 STAGE 1: SCREENING TOOL

The screening tool checklist (see Figure 2) has been developed for health authority staff and others to conduct the first stage of the determination for proposed and existing ground water supplies. It is based on information provided by the water supplier and other sources.

In this first stage, four main risk factors are examined:

1. Water quality results
2. Source type and location
3. Well construction details
4. Aquifer type and setting

These risk factors and associated criteria are described in detail in the following section. If the result of the checklist exercise shows all risk factors and criteria as No (Low Risk), then the water system is considered to be at low risk of containing pathogens and may not require treatment for pathogens under current conditions. The water system will however continue with Long-term Water Quality Monitoring (Stage 4). Any subsequent bacterial water quality issues or changes in risk factors will trigger a revisiting of the Stage 1: Screening Tool assessment. **It should be noted that this is not regarded as a one-time assessment but is subject to the results of ongoing monitoring of the water system including the source(s).**

If the result of the checklist exercise shows any risk factors and criteria as Yes (Potentially at Risk), then a vulnerability assessment and decision making process will need to be conducted. Situations where information on one or more criteria is not available may need to be collected in a Stage 2: Preliminary Hydrogeological Investigation before a risk determination can be made.

Completion of the checklist should involve discussions with the water supplier in addition to a field inspection, which is essential to verify current well site conditions.

Additional sources of information that may be consulted to assist in completing the checklist include documents completed under the guidance of the *Drinking Water Source-to-Tap Screening Tool* (Ministry of Health Services, 2004) and Module 1 of the *Comprehensive Drinking Water Source-to-Tap Assessment Guideline* (Ministry of Healthy Living and Sport, 2011), where these documents have been completed for a water supply system.

Figure 2: Screening Tool Checklist for Ground Water at Risk of Containing Pathogens

WATER SYSTEM NAME	**BCMOE WELL ID PLATE NO.**		
SITE LOCATION	**Well Log Examined (Y/N)**		
	Site Survey Conducted (Y/N)		
RISK FACTORS and CRITERIA	**YES: Potentially At Risk**	**NO: Low Risk**	**COMMENTS**
1. Water Quality Results			
1.1: Water system or well bacteriological sampling shows recurring presence of confirmed total coliform, fecal coliform, or *E.coli.*			
1.2: Water system has historical turbidity issues associated with the source water.			
2. Source Type and Location			
2.1: Well situated inside setback distances of the HHR, from possible source of contamination.			
2.2: Well with intake depth <15 m below ground and located in floodplain / flood-prone area. OR well <100 m outside the high-water mark or natural boundary of surface water feature and intake depth <15 m below the high-water level.			
3. Well Construction			
3.1: Well does not meet GWPR (section 7) for surface sealing.			
3.2: Well does not meet GWPR (section 10) for well caps and covers.			
3.3: Well does not meet GWPR (section 11) for floodproofing.			
3.4: Well does not meet GWPR (section 12) for wellhead protection.			
4. Aquifer Type and Setting			
4.1: Well with intake depth <15 m below ground and situated in a sand and/or gravel unconfined aquifer or fractured bedrock aquifer.			
4.2: Well completed in a karst bedrock aquifer.			

RISK / VULNERABILITY ASSESSMENT DECISION TAKEN AND REASON(S):	
ACTION RECOMMENDATION:	
CHECKLIST / ASSESSMENT COMPLETED BY:	**DATE COMPLETED:**

2.2.1 Description of Risk Factors in Stage 1: Screening Tool

2.2.1.1 Water Quality Results

CRITERION 1.1 Any *water supply system well* that exhibits any one or more occurrences of total coliform bacteria, fecal coliform bacteria, or *Escherichia coli (E. coli).*

An assessment of bacteriological water quality results is a key element in assisting the DWO to formulate his/her opinion on whether a ground water source is potentially at risk of containing pathogens. Testing should be done for *E. coli* and total coliforms. Historic fecal coliform data would also be useful.

Pathogen Indicators
Bacteriological parameters (*E. coli,* fecal coliform, and total coliform) imply the presence/absence of other human microbial pathogens, such as viruses and protozoa. The use of bacteriological parameters as indicators of other pathogens is supported by literature including:

A recent study by Locas et al (2007), which concluded that:

- The absence of total coliforms is suggestive of clean ground water free of viruses.
- Total coliforms were always present at the same time as culturable human enteric viruses.
- Increased levels of coliforms were suggestive of contamination.
- In combination with *E.coli* (as a definitive indicator of fecal pollution), total coliforms results provide a valid assessment of microbiologic quality of ground water and the potential health risk.

According to US Environmental Protection Agency (USEPA) (2006):

- The USEPA believes that the presence of fecal indicators (e.g., *E.coli*) demonstrates that there is a pathway for pathogenic viruses and bacteria to enter ground water sources.
- The use of single fecal indicator (*E.coli*, enterococci or coliphage) provides a cost-effective means of identifying fecal contaminated wells and protecting public health.

According to Health Canada (2004):

- Currently available detection methods do not allow for the routine analysis of all microorganisms that could be present in inadequately treated drinking water. Instead, microbiological quality is determined by testing drinking water for *E. coli*, a bacterium that is always present in the intestines of humans and animals and that would indicate fecal contamination of the water.
- It is not currently possible to establish maximum acceptable concentrations for *Giardia* and *Cryptosporidium* in drinking water.

- *E.coli* can be considered an indicator that *Giardia* and *Cryptosporidium* could also be present.

Number of Samples
With respect to the number of bacteriological samples required to approve a source, the practice has been to require a minimum of three consecutive samples. However, this provides less than 10% assurance that the water is actually free of fecal bacteria.

In determining the number of microbial samples required for the Stage 1**:** Screening Tool assessment, the DWO may wish to use the 2011 Australian Drinking Water Guidelines (see Appendix C), which provides an approach to reviewing bacteriological water quality results with respect to a statistical level of confidence in the water being free of bacteriological contamination. As noted in the Australian Guidelines, in order to have a 95% statistical confidence, 150 or more consecutive negative (i.e., samples that show no evidence of fecal contamination) samples would be needed.

If fecal or total coliforms are found in the distribution system, it may be an indication of potential microbial contamination of the ground water source. This will trigger source water quality monitoring to evaluate whether the total coliforms are present in the distribution system or are due to microbial contamination of the ground water source. Any single report of fecal coliform bacteria, total coliform bacteria or *E. coli* being detected should be verified by additional sampling in both the water system (e.g., distribution system and storage) and at the well source or sources (i.e., before any treatment).

CRITERION 1.2 Any ground water source that has reported turbidity or has a history of turbidity problems associated with the source water.

Turbidity is the measure of the amount of light scattered by a water sample, or the clarity of a sample. Sources of turbidity in water include soil particles from runoff and soil erosion, waste discharges, organic matter, and pathogens. Alternatively, turbidity can be the result of incomplete well development or can be naturally occurring, e.g., rock flour. The source of the turbidity needs to be assessed to determine whether there is the potential presence of pathogens which may indicate a potential health risk.

2.2.1.2 Source Type and Location

CRITERION 2.1 A *water supply system well* that is situated inside any of the setback distances from a possible contamination source as specified in section 8 of the Health Hazards Regulation *(*HHR*,* see Appendix B).

In addition to the potential sources of contamination listed in the HHR, there may be other possible pathogen sources that should be considered, including but not limited to abandoned wells and other waste disposal sites.

CRITERION 2.2 A *water supply system well with:*

a) An *intake depth* less than 15 m (50 feet) below ground that is located in a *floodplain* or flood prone area (e.g., 200-year floodplain) (Figure 3), or

b) An intake depth less than 15 m (50 feet) below the high-water level, that is located less than 100 m (~300 feet) outside of the *natural boundary* or *high-water mark* of any permanent or intermittent *surface water* including *stream* or *stream channels*, ponds, lakes, rivers, creeks, springs[2], ravines, swamps, gulches, drainage ditches, lagoons, reservoirs and marine waters (Figure 4).

The *intake depth* of a well is the depth at which water enters the well and is usually the top of the well screen for a well completed in unconsolidated deposits or the depth of the uppermost water-bearing fracture in a bedrock well. At this step, the above criteria do not differentiate between dug or *excavated wells* and drilled wells, or wells completed in unconsolidated versus bedrock deposits.

Information on floodplain boundaries may be obtained from floodplain maps, where available. Information on floodplain mapping in British Columbia can be found on the BCMOE website.[3] Available online mapping of floodplains can be viewed on iMapBC.[4]

Note that available floodplain maps cover only small areas of the province and that these maps may not be up to date as it is the responsibility of local governments to keep these maps current. If floodplain maps are not available for an area of concern, the high-water mark or 200-year floodplain boundary can be estimated based on field observations and the size of the stream. For example:

- For streams >30 meters wide, the high-water mark could be located up to 1 km from the normal water mark.
- For streams 5 to 30 meters wide, the high-water mark could be located up to 100 meters from the normal water mark.
- For streams < 5 meters wide, the high-water mark could be located up to 30 meters wide from the normal water mark.

Each well or well field will need to be assessed on a site specific basis in the field. Factors that should be considered when estimating the location of the high-water mark include:

- Is there a well developed floodplain that can be easily identified?
- Are there any topographic constrictions, e.g., change of slope at the top of the bank?
- Is there a notable change in vegetation?

[2] Note that while a spring may originate as a ground water discharge, it is regarded as a *stream* under the *Water Act* and as *surface water* under the Drinking Water Protection Regulation.
[3] http://www.env.gov.bc.ca/wsd/data_searches/fpm/index.html and http://www.env.gov.bc.ca/wsd/data_searches/fpm/reports/index.html
[4] http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

Figure 3: Profile Showing Well A in a 200-year Floodplain with an Intake Depth Less than 15 Metres below Ground

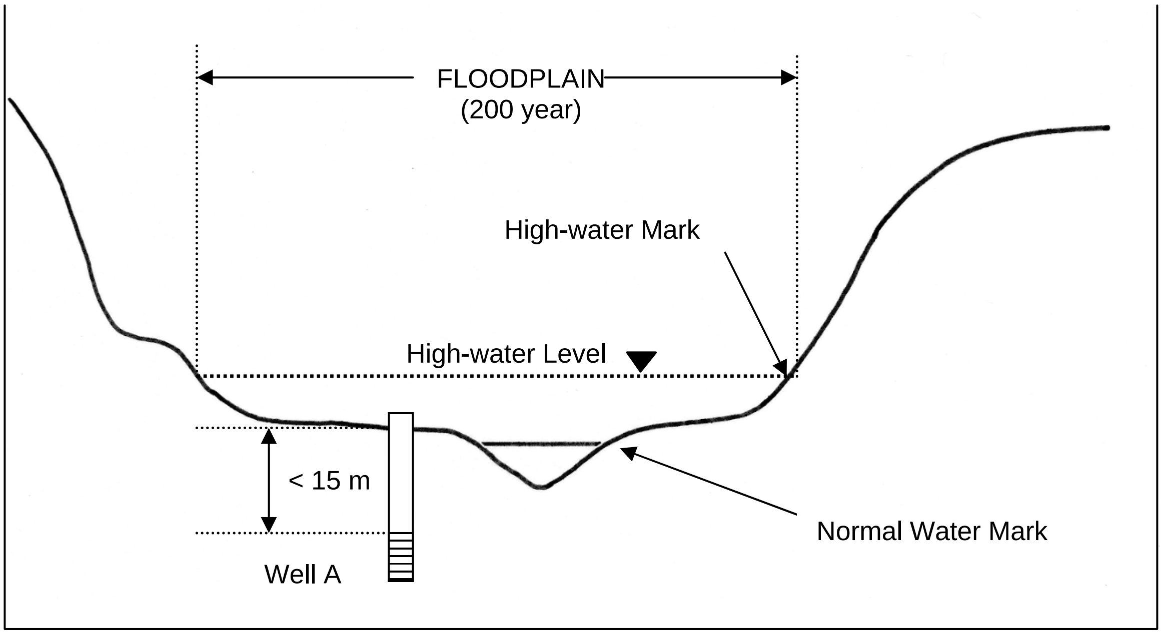
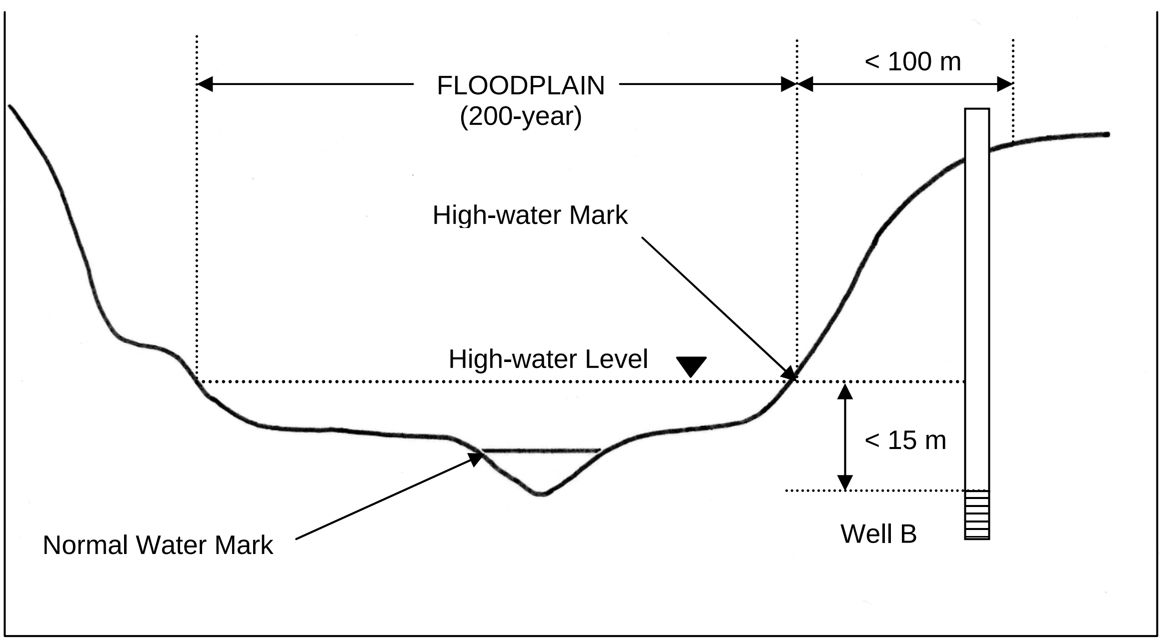


Figure 4: Profile Showing Well B within 100 metres of the High-water Mark (e.g., 200-year Floodplain) with an Intake Depth Less than 15 Metres below the High-water Mark



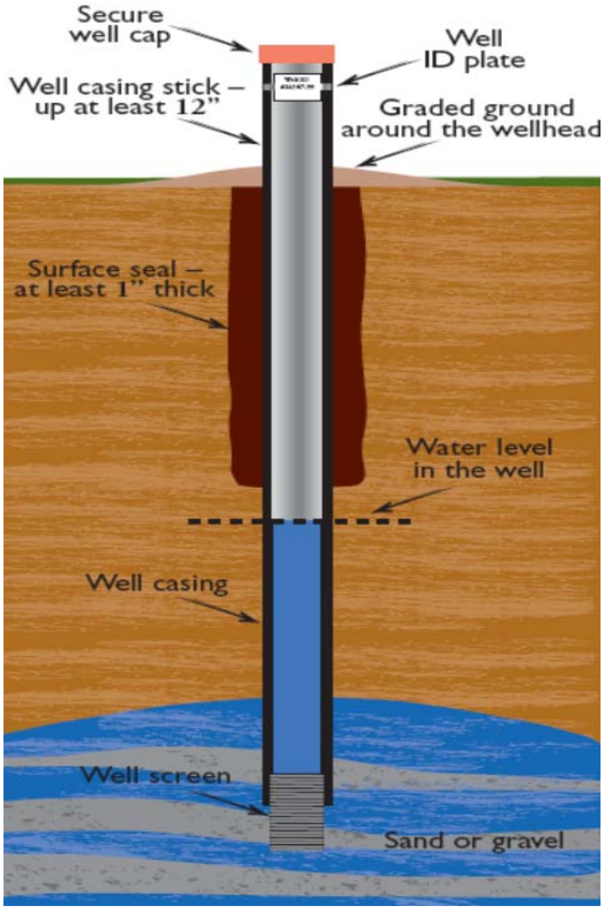
2.2.1.3 Well Construction Details

Proper well construction is one of the best barriers for preventing the entry of pathogens into a well. Failure to meet the well construction standards in the *Ground Water Protection Regulation* will result in the well being deemed potentially at risk of containing pathogens. Field inspection of the well is highly recommended to confirm the site conditions. **Altering the well to meet the well construction standards may result in the well being deemed as low risk of containing pathogens provided that none of the other criteria in the screening process are assessed as being potentially "at risk."**

CRITERION 3.1 TO 3.4 Any *water supply system well* that fails to meet sections 7, 10, 11 or 12 of Part 2 – Ground Water Protection under the GWPR (see Figure 5)

In the GWPR, sections 7, 10, 11 and 12 (Appendix B) cover requirements for *surface sealing*, *well caps* and well covers, floodproofing of wells, and protection of the *wellhead*. (See Figure 5.) Existing wells completed before November 1, 2005 when the GWPR came into force may not necessarily meet any of the requirements of sections 7, 11 and 12 as these were not made retroactive. All existing water supply wells regardless of age, however, must meet the requirements of section 10 regarding well caps and well covers.

Figure 5: Profile of a Well that Meets the Well Construction Standards under the Ground Water Protection Regulation



The GWPR also contains specific requirements in Appendix A – *Code of Practice for Construction, Testing, Maintenance, Alteration and Closure of Wells in British Columbia;* also referred to as the *Code.* The pertinent aspects of these sections are summarized below.

CRITERION 3.1 Surface sealing – section 7 of the GWPR
All newly constructed *water supply wells* after November 1, 2005 must have in place an effective and permanent *surface seal* as indicated in Table 1 of the *Code.* The minimum length of the surface seal, either 0.9 or 4.6 m (3 or 15 ft) depends on the method of well construction (i.e., drilled, excavated, or jetted) and hole depth ≤ or > 4.6 m (15 ft). The seal must also be a minimum of 2.5 cm (1 in) in thickness.

The integrity of the *sealant* must be maintained by the well owner and resealed if an *annular space* develops around the well casing. The sealant must extend to within a foot of the ground surface and may not be visible upon inspection. If there is any question of the existence or integrity of a surface seal, this should be noted and considered for further examination under a Stage 2: Preliminary Hydrogeological Investigation.

Older wells constructed prior to November 1, 2005 may not have any type of surface seal and owners of these wells should be encouraged to install a surface seal, if practical. If these older wells are altered, the owner of the well must ensure any *annular space* that develops is sealed. An *engineer* under the *Water Act* can also require upgrading of the surface seal if the existing well poses a threat of contamination entering a neighbouring well or ground water. For purposes of the screening tool, visual inspection of the immediate area around the well casing may be sufficient to determine whether there is any *annular space* present.

CRITERION 3.2 Well caps and well covers – section 10 of the GWPR
All vertical water supply wells and domestic horizontal[5] *water supply wells* must have a secure and effective well cap or cover that meets the requirements of section 7 of the *Code* to prevent the direct or unintended entry of any surface water, persons, animals or contaminants into the well and to prevent or minimize flow of water from an artesian well.

CRITERION 3.3 Floodproofing of wells – section 11 of the GWPR
All new *water supply system wells* must be located, completed, equipped and maintained to prevent the entry of any flood debris and flood waters and the well or wellhead must be protected from any physical damage due to flood debris, ice or erosion. An *engineer* under the *Water Act* may also require the owner of an existing well supplying a *water supply system* to assess whether a well prevents the entry of any flood debris and flood waters and the well or wellhead is protected from any physical damage due to flood debris, ice or erosion. After considering the assessment, the *engineer* may order the owner to *alter* or maintain the well so that it complies with the floodproofing requirements.

[5] Horizontal domestic water supply wells are to be capped unless a qualified professional who has competency in the field of hydrogeology or geotechnical engineering or an engineer under the *Water Act* confirms in writing that a well cap is not required. Horizontal nondomestic water supply wells do not require a well cap (Table 4, Appendix A of the GWPR).

For the purposes of the screening assessment, if there is any concern regarding the adequacy of floodproofing, this should be noted and considered for separate assessment or for further examination under Stage 2: Preliminary Hydrogeological Investigation of the assessment process.

CRITERION 3.4 Wellhead protection – section 12 of the GWPR
All new *water supply system wells* must have a production casing that extends a minimum of 305 mm (12 inches) above the ground surface adjacent to the well or 305 mm (12 inches) (305 mm) above the floor of a well sump, well pit, or pumphouse. The area immediately around the well must be finished to ensure water does not pond around the well head or area disturbed by the drilling. The well sump, well pit, or pumphouse must also be adequately designed, constructed and maintained to convey water away from the *wellhead*.

Older wells that may not have been constructed to meet these requirements are subject to the potential risks of flooding and/or ponding around the well. In such cases, for purposes of the screening tool, this potential risk should be noted and considered for a separate floodproofing assessment or for further examination under a Stage 2: Preliminary Hydrogeological Investigation.

During examination of the above aspects, a copy of the original well record (where available) should be checked for information on well construction details and verified in the field (e.g., static water level, well diameter, well depth, etc.). Summary information on individual wells can be found in the WELLS Database[6] and the iMapBC[7]. Instruction on how to use these two resources is provided in A *Guide to Finding Water Well Information.*[8] Copies of original well records may also be available directly from the Ministry of Environment in Victoria. The Well ID Plate Number (the number on the tag on the well) and the Well Tag Number (WTN), where these are known, can be used to search for individual well records.

2.2.1.4 Aquifer Type and Setting

CRITERION 4.1 Any *water supply system well* that has both of the following characteristics:

a) an intake depth < 15 m (50 feet) below ground, and
b) is situated in a
   - highly vulnerable aquifer
   - unconfined, unconsolidated aquifer, or
   - any fractured bedrock

[6] http://www.env.gov.bc.ca/wsd/data_searches/wells/index.html
[7] http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc
[8] http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells.html

Highly vulnerable aquifers are designated as "A" aquifers under the B.C. Aquifer Classification System (BCACS) as described by Berardinucci and Ronneseth (2002). The BCACS was developed in 1994 by Kreye and Wei, to identify, classify and rank developed aquifers in the province. The classification component categorizes aquifers based on their current level of ground water development (categories I, II and III for high, moderate and light development, respectively) and vulnerability to contamination (categories A, B and C for high, moderate and low vulnerability, respectively).

Available online mapping of aquifers can be viewed at iMapBC.[9] Note that provincial aquifer mapping may not cover all areas of the province.

CRITERION 4.2 Any *water supply system well* regardless of depth that is completed in a *karst* bedrock aquifer.

Karst terrains, characterized by dissolution channels and caves in limestones and dolomites, occur extensively in some parts of British Columbia (e.g., Rocky Mountains and Vancouver Island) as reported by Stokes and Griffiths (2000). While only a small number of water wells have been completed in these deposits to date, for purposes of the screening tool, these situations may warrant a Stage 2: Preliminary Hydrogeological Investigation.

2.2.2 Stage 1 Risk / Vulnerability Assessment and Mitigation

If the Stage 1: Screening Tool determined that the ground water source is potentially at risk from any of the risk factors listed in the Screening Checklist, the DWO will conduct a risk/vulnerability assessment of those risk factors. From the assessment, the DWO will determine the various option(s) that will need to be considered to form a decision as to whether the ground water source is GARP from either surface water or other source of pathogens, or is at a low risk of containing pathogens.

Potential options for assessing and mitigating each of the risk factors and their respective outcomes are described below. The DWO may also require water treatment by disinfection if other risk mitigation measures are deemed to be insufficient to deal with the health risks identified. If it is not possible to evaluate all the Stage 1 criteria due to lack of readily available information, further information should be collected in order that a risk determination can be made. This may require moving to Stage 2: Preliminary Hydrogeological Investigation.

Once each risk factor is assessed, the ground water source will be deemed as being either at reduced risk of containing pathogens or at risk of containing pathogens for that risk factor. If a source is considered at reduced risk of containing pathogens for a particular criterion,

[9] http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

the DWO should consider this reduced risk in relation to other risk factors that may be present when determining the ground water source's overall risk of containing pathogens.

2.2.2.1 Bacteriological Water Quality Results

When considering available bacteriological water quality results during the Stage 1 assessment, DWOs often encounter one of four situations:

1. They are required to review a new well seeking approval with limited bacteriological water sampling information and must make a decision regarding what treatment requirements (if any) should be imposed on the proposed system.
2. They are reviewing an existing approved well that does not currently employ disinfection and has a limited history of bacteriological water sampling.
3. They are reviewing an existing approved well that does not currently employ disinfection but has a lengthy history of bacteriological water sampling.
4. They are approached by a water supplier that has an existing approved ground water source who wishes to reduce or eliminate the disinfection in place in their system based on either a limited or lengthy bacteriological water sampling history.

What difference does a limited or lengthy sampling history make in the DWO's decision? At the heart of this question is the uncertainty over whether or not water quality sampling results that consistently show no bacteriological presence allow one to assume that future water quality results will be the same.

The use of statistical probability can offer some guidance (Appendix C) by providing a sense of confidence in what a certain number of sample results might mean. However, even statistics are dependent on the DWO knowing their comfort zone for decision making. For example, from a statistical perspective, if the DWO wants to be 95% confident that a well has only a 2% probability of showing a positive presence of bacteria in the next water sample taken (and every sample after that) then they would require at least 150 consecutive negative samples from the well in question. These samples should have been taken consistently across the range of environmental conditions to which the well would commonly be exposed.

The weight that a DWO gives to the water quality sampling results is related to their discretion over what the results indicate about the ground water source. A longer history of negative sampling results taken over time through a range of environmental conditions can provide strong statistical evidence that a ground water source has been consistently without pathogens. However, whether or not the ground water source is at risk from containing pathogens in the future must be a holistic judgment that also takes into account the other three factors in the screening assessment. If a well has a low risk on multiple lines of evidence, a DWO can have greater confidence in what the water quality sampling history may also indicate.

CRITERION 1.1 Recurring presence of confirmed total coliform, fecal coliform, and/or *E.coli*

If there is recurring presence of total coliform and/or *E. coli* (or history of fecal coliform contamination) in the ground water source, the water supplier will be required to investigate, identify, and potentially eliminate the source of bacterial contamination within a reasonable time period. This may involve a Stage 2: Preliminary Hydrogeological Investigation and assessment, if warranted. Following these actions, the ground water source would be considered either:

- *At reduced risk of containing pathogens if:*
  - The source of the bacterial contamination has been identified and eliminated, as demonstrated with confirmatory monitoring of the ground water.

OR

- *At risk of containing pathogens (GARP) if:*
  - Within a reasonable time period, the source of the bacterial contamination has not been identified and/or eliminated.

CRITERION 1.2 Historical turbidity issues

If there are historical turbidity issues associated with the source water, the water supplier will be required, within a reasonable time period, to investigate and identify the source and nature of the turbid material, including bacteriological water quality results. This may involve a Stage 2: Preliminary Hydrogeological investigation, if warranted. Following these actions, the ground water source may be considered either:

- *At reduced risk of containing pathogens if:*
  - Bacteriological water monitoring results over the minimum number of regularly scheduled sampling events specified by the DWO do not show the presence of total coliform (or history of fecal coliform contamination) and/or *E. Coli* in the ground water source during turbidity events, or
  - Bacteriological water monitoring results show recurring presence of total coliform, fecal coliform, and/or *E.coli* associated with turbidity events but the source of contaminated turbidity has been identified and eliminated, as verified with confirmatory monitoring of the ground water.

OR

- *At risk of containing pathogens (GARP) if:*
  - Bacteriological water monitoring results of the ground water source show recurring presence of total coliform, fecal coliform, and/or *E.coli* associated with turbidity events and the source of contaminated turbidity has not been identified and eliminated.

2.2.2.2 Source Type and Location

CRITERION 2.1 Well situated inside setback distances from possible sources of contamination, e.g., septic installations, manure piles, cemeteries, etc., as per the *HHR*

If the well is situated less than the required setback distances to potential sources of contamination in the HHR (see Appendix B), the water supplier must investigate and manage the potential impacts to the ground water source, including a review of bacteriological water quality results. This may occur in parallel with, or as part of, a source-to-tap assessment, and may involve a Stage 2: Preliminary Hydrogeological Investigation and assessment and a possible Stage 3 investigation, if warranted.

Where bacteriological water monitoring results show the recurring presence of total coliform, fecal coliform, and/or *E. Coli*, the water supplier will be required, within a reasonable time period, to identify and eliminate the source of bacterial contamination. Following these actions, the ground water source would be considered either:

- *At reduced risk of containing pathogens if:*
  - The water supplier demonstrates that the potential source of contamination is managed to the satisfaction of the DWO, and
  - Bacteriological water monitoring results do not show the presence of total coliform, fecal coliform, and/or *E.coli* in the ground water source, or
  - The source of the bacteriological contamination has been identified and eliminated, as demonstrated with confirmatory monitoring.

OR

- *At risk of containing pathogens (GARP) if:*
  - The source of the bacteriological contamination has not been identified and eliminated, or
  - The water supplier has not managed the potential source of contamination to the satisfaction of the DWO.

CRITERION 2.2 Well location configurations
Wells failing to meet the location and intake depth conditions (Figures 3 and 4) are, by default, considered to be drawing from surface water (GUDI). In some cases, however, subsurface filtration may provide an adequate level of treatment leading to a reduced risk of containing pathogens in the ground water source drawn from the well.

In these circumstances, a water supplier is required to, within a reasonable time frame, demonstrate to the satisfaction of the DWO that the ground water source``` has a reduced risk of containing pathogens. This may involve a review of bacteriological water monitoring results and, if requested by the DWO, determining the effectiveness of subsurface filtration through a Stage 2: Preliminary Hydrogeological investigation and a possible Stage 3 investigation, if warranted. Following these actions, the ground water source would be considered either:

- *At reduced risk of containing pathogens if:*
  - Bacteriological water monitoring results do not show the presence of total coliform, fecal coliform, and/or *E.coli* in the ground water source.
  - The qualified professional completing the Stage 2 and 3 hydrogeological investigations deems the ground water source to be at low risk of containing pathogens for this criteria, and/or
  - The water supplier demonstrates, to the satisfaction of the DWO, that an effective response plan is in place to manage the water supply during infrequent periods of elevated risk.

OR

- *At risk of containing pathogens (GARP) if:*
  - Bacteriological water monitoring results show recurring presence of total coliform, fecal coliform, and/or *E.coli* associated with surface water, and/or
  - The qualified professional completing the Stage 2 and 3 hydrogeological investigations deems the ground water source to be at risk of containing pathogens.

2.2.2.3 Well Construction

CRITERIA 3.1, 3.2, 3.3 AND 3.4 Surface sealing, well cap and cover, floodproofing, and wellhead protection requirements of the GWPR (sections 7, 10, 11, and 12)

Wells that have deficiencies in well construction are vulnerable to possible pathogenic contamination and the water supplier will be required to alter the well construction to comply with the well construction standards for new wells in the GWPR or equivalent, where practical, followed by disinfection and resampling. Following these actions, the ground water source accessed by the well may be considered:

- *At reduced risk of containing pathogens if:*
  - The water supplier alters the well construction to comply with the instructions of the DWO or the GWPR well construction standards followed by disinfection and confirmatory monitoring (where practical). The DWO may require other mitigative measures in site specific circumstances.

OR

- *At risk of containing pathogens (GARP) if:*
  - The water supplier is unable or unwilling to alter the well construction to comply with the GWPR.

2.2.2.4 Aquifer Type and Setting

CRITERIA 4.1 AND 4.2 Wells in unconfined sand and/or gravel, fractured bedrock, or karst aquifers

Shallow wells in unconsolidated (sand and/or gravel) unconfined aquifers are highly vulnerable to possible sources of pathogenic contaminants finding their way into the shallow well intake and making the ground water potentially at risk of containing pathogens. Similarly, wells completed in fractured bedrock and karst aquifers are vulnerable to contamination as possible sources of pathogenic contaminants may find their way into the aquifer due to potential preferential pathways in the formation.

If a well is completed in such aquifers, the water supplier will be required to demonstrate, to the satisfaction of the DWO, that the ground water drawn from the well has a reduced risk of containing pathogens. This will likely involve a review of bacteriological water quality results and, if requested by the DWO, a Stage 2 (and Stage 3, where warranted) hydrogeological investigations. Following these actions, the ground water source accessed by the well may be considered:

- At reduced risk of containing pathogens if:
  - Bacteriological water monitoring results do not show the presence of total coliform, fecal coliform, and/or *E.coli* in the ground water source, and
  - The qualified professional completing the Stage 2 and 3 hydrogeological investigations (where these investigations have been completed) deems the ground water source to be at low risk of containing pathogens for these criteria.

OR

- At risk of containing pathogens (GARP) if:
  - Ground water monitoring shows a recurring presence of total coliform, fecal coliform, and/or *E. coli* associated with the aquifer type/setting, or
  - The qualified professional completing the Stage 2 and 3 hydrogeological investigations deems the ground water source to be at risk of containing pathogens.

2.2.3 Stage 1 Screening Outcomes

If the risk/vulnerability assessment of criteria and factors indicate that the ground water source is at low risk of containing pathogens, the DWO should advise the water supplier to go to Stage 4: Long-term Water Quality Monitoring. If the risk/vulnerability assessment indicates that the ground water source is potentially at risk of containing pathogens, then the DWO should advise the water supplier to take action on one or more of the following options:

- Correcting problem(s) due to the well's construction or location, such as:
  - Altering the well or correcting significant deficiencies in well construction.

  - Relocating the well source and properly decommissioning the existing well.
  - Providing an alternate source of water.

Once deficiencies or problems are corrected and verified with water monitoring, the ground water source may be considered to be at low risk of containing pathogens, depending on the risk / vulnerability assessment of other criteria.

- Addressing problems due to the source such as:
  - Disinfecting the well water system according to DWPR section 5(2) and any additional requirements established by its operating permit (DWPA section 6(b)).
  - Relocating the well source and properly decommissioning the existing well.
  - Eliminating source(s) of contamination, and ensuring subsequent negative bacterial water quality monitoring results.
  - In the case of small water systems (less than 500 population), establishing a *sanitation only* type of water system under a DWPA (section 6) and DWPR (section 3.1) exemption.
- Conducting a Stage 2, and where warranted, Stage 3 hydrogeological investigation or a combination thereof.
- Deferring disinfection while the water system starts or continues with Stage 4: Long-term Water Quality Monitoring.

2.3 STAGE 2: PRELIMINARY HYDROGEOLOGICAL INVESTIGATION

As outlined in section 18 of the DWPA, the DWO may require or order the water supplier to prepare an assessment of the water source and system (see Appendix B). If there was insufficient information to complete the risk/vulnerability assessment as part of the Stage 1: Screening Tool, the DWO may request a Stage 2: Preliminary Hydrogeological Investigation.

2.3.1 Objective

The objective of a Stage 2: Preliminary Hydrogeological Investigation is to provide preliminary hydrogeological evidence and a professional opinion, based on readily available information and analysis, on whether or not ground water at the water supply system well(s) is at a low risk of containing pathogens under operating conditions.

Any ground water source that meets the following would be deemed to be at low risk of containing pathogens:

- There is no direct hydraulic connection or little evidence of a hydraulic connection between the ground water source and nearby surface waters.

- Where ground water is hydraulically connected to nearby surface waters in GWUDI situations, the subsurface *filtration* or other hydrogeological factors will be effective in eliminating any risk of pathogens reaching the well(s) under operating conditions.
- The *time of travel* (TOT) from a potential source of pathogens to the well, e.g., surface water body, is greater than 100 days.

2.3.2 Stage 2 Investigation Scope

A preliminary hydrogeological investigation is fundamental to determining potential pathways for any pathogens entering a ground water supply source. The preliminary investigation should be designed and undertaken by a qualified professional. The area of investigation should extend beyond the local area around the well(s) and nearby surface water features.

All methods of investigation, observations, findings, uncertainties, conclusions (and supporting reason(s)) and recommendations (both for additional investigations and/or mitigation strategies) should be documented in a written report including all supporting tabulated data, maps, graphs and photographs. Conclusions should summarize the evidence and indicate the need, if any, for additional investigations (i.e., Stage 3), long-term monitoring considerations (i.e., Stage 4) and any recommended mitigation measures such as well alteration or well relocation.

Depending on the nature of the risk factor(s) of concern, the scope of the Stage 2: Preliminary Investigation could be focused or detailed. The investigation should include a site visit, including inspection of works and general site conditions; examination, analysis and interpretation of readily available data; presentation of findings and discussion that may include the following topics:

a) Site location, topography and general drainage features.

b) Climatic conditions.

c) General soils and geology (unconsolidated and bedrock).

d) Well and wellhead conditions.

e) Hydrogeological conditions and aquifer characteristics.

f) Surface water hydrology and general watershed conditions.

g) Hydraulic gradients, water level fluctuations and directions of ground water flow under ambient and pumping conditions.

h) Pumping conditions, capture zones and time of travel estimates.

i) Ground water and surface water quality characteristics.

j) Land use and potential sources of contamination.

k) Conclusions (with supporting reasons).

l) Recommendations for further investigations (if any) and/or mitigations strategies (if any).

As site conditions and availability of information may vary significantly for different water supply situations, professional judgment should determine the most important factors to examine and the necessity for acquiring any additional detailed information. Development of a work plan for the preliminary investigation and discussion with health officials and the water supplier prior to undertaking the work is beneficial, particularly for more complex situations. Uncertainty analysis and critical assessment of data gaps should be included in the Stage 2 evaluation.

Suggested elements that could be considered for these topics are outlined in Table 1. Table 1 may be used as a checklist and guide to assist with the completion of the Preliminary Hydrogeological Investigation. A detailed description of these topics is beyond the scope of this guidance document. It may not be possible to evaluate all the topics (see below in Table 1) due to lack of readily available information.

Table 1: Elements that Should Be Considered for a Preliminary Hydrogeological Investigation

TOPIC	ELEMENTS
a) Site location, topography and general drainage features	Site plan at suitable scale / location of well(s) and surface water features (type, size, natural and constructed) / topographic features and contours / drainage flow directions / drainage features such as dry ditches, swales or depressions near the wellhead / vegetation / distances from potential sources of contamination.
b) Climatic conditions	Location of nearest climate stations / monthly and annual precipitation normals / extreme rainfall events / seasonal patterns / timing of snowmelt.
c) General soils and geology (unconsolidated and bedrock)	Type, thickness and distribution of soils / surficial or unconsolidated deposits and bedrock units / general stratigraphic succession / geomorphological features of deposits / structural features in bedrock.
d) Well and wellhead conditions	Well type, age, design, construction details and physical condition / UTM location coordinates / measured distances from surface water features and neighbouring wells / edge of floodplain / edge of channel / edge of bank / high-water mark / type, diameter and depth of casings and liners / annular space / depth, thickness and condition of surface seal / screen type and location / location of perforated intervals / well cap type, condition and venting / stick up, elevation of wellhead and ground elevation / pump type and condition / pitless adapter depth and condition / condition of check valves, well pits and drainage provisions / lithologic log, depth of water-bearing zones / well yield and well efficiency.

TOPIC	ELEMENTS
e) Hydrogeological conditions and aquifer characteristics	Origin, nature and type of both aquifer and confining units / grain size / primary or secondary porosity, thickness and extent / unsaturated zone thickness / hydrogeological cross-sections to scale showing stratigraphy, aquifers, confining layers, well construction features, nonpumping water levels and relationship to surface water features / pumping test data / conceptual hydrogeological model, including hydrostratigraphic units and geologic boundaries / aquifer parameters including transmissivity, hydraulic conductivity and storativity / recharge boundaries / infiltration from extreme rainfall event in proximity to well / aquifer conditions (unconfined, confined) / BCACS aquifer classification and ranking / assessment of spring sources.
f) Surface water hydrology and general watershed conditions	Historic stream flow data / river stage data / peak flow timing / tidal effects / high- and low-flow monitoring records / normal range / seasonal variations / floodplain conditions and history of flooding / 200-, 100- and 20-year flood levels.
g) Hydraulic gradients, water level fluctuations and directions of ground water flow under ambient and pumping conditions	Nonpumping (ambient) and pumping conditions / presence of artesian or flowing artesian conditions / water levels trends from observation wells / seasonal variations / correlation with precipitation and surface water data / water table and potentiometric surface maps / evidence of vertical gradients / calculation of horizontal gradients / map with flow directions / unsaturated zone flow conditions.
h) Pumping conditions, capture zones and time of travel estimates	Well yield and pumping conditions / pumping rates and volumes with time / normal well operation / preliminary delineation of well capture zone / estimates of time of travel between nearby surface water and well under various pumping and water level conditions / distance-drawdown effects.
i) Ground water and surface water quality characteristics	Comparison of inorganic (major cations and anions) and microbiological parameters (e.g., coliforms, *E. Coli,* Heterotrophic Plate Count, iron-related or sulphate-reducing bacteria) / temperature / conductivity / pH and turbidity / observed variations between ground water and surface water quality with time / role of geochemical reactions.
j) Land use and potential sources of contamination	Type of activity / potential contaminants and distances from wells and surface water drainage features / distances from permitted waste discharges / nearby poorly constructed and/or abandoned wells.
k) Conclusions	Summary of the evidence and the need, if any, for additional investigations, long-term monitoring considerations and any mitigative measures. Supporting reasons, including uncertainties.
l) Recommendations	Recommendations for further investigations and/or mitigative strategies, if any.

Note: Elements for investigation and reporting may vary depending upon availability of information and other site specific factors.

For this level of investigation, where sufficient information on aquifer parameters such as transmissivity and hydraulic gradient are available, delineation of the *well capture zone* for unconsolidated aquifers should be based on analytical equations and *time of travel* (TOT) estimates as outlined in Appendix 2.3 of the *Well Protection Toolkit* (Ministry of Environment, Land and Parks, and Ministry of Health and Ministry Responsible for Seniors, 2000) or comparable approaches. The estimates should also consider TOT values under pumping conditions and indicate any simplifying assumptions utilized.

Some pathogens, including coliform bacteria and viruses, may survive for over a year in ground water (Crowe et al, 2003). The survivability and movement of pathogens in ground water towards a well will be controlled by the combined properties of the soil or aquifer materials (e.g., grain size, porosity), the ground water (e.g., pH, temperature, velocity) and the pathogens (e.g., size, mortality rate).

High ground water flow velocities that favour the movement of pathogens over extended distances of tens to hundreds of metres may occur in very coarse sand and gravel deposits and fractured bedrock situations (Crowe et al, 2003). Ground water flow velocities in fractured bedrock and karst situations can be orders of magnitude higher than unconsolidated deposits. Current scientific knowledge of ground water flow and pathogen transport in fractured rock environments, however, is very limited (Crowe et al, 2003). An investigation of fracture flow conditions would be complex and should trigger a Stage 3 investigation.

For other complex situations involving, for example a number of water supply wells in close proximity with overlapping capture zones, it may be prudent to incorporate the Preliminary Investigation (Stage 2) into an Advanced Hydrogeological Investigation (Stage 3) employing more specialized investigatory techniques such as computer modeling and extended periods of water quality monitoring and pumping tests.

2.3.3 Stage 2 Investigation Outcomes

If the results of the Stage 2: Preliminary Hydrogeological Investigation indicate the ground water source is GARP, next step(s) can include:

- Treating ground water drawn by the well to meet health authority drinking water treatment standards.
- Providing an alternate source of water.
- Altering the well/correcting significant deficiencies in well construction that were not identified in the Stage 1: Screening Assessment.
- Eliminating source(s) of contamination.
- Relocating the well.
- Monitoring surface water/ground water quality.
- Conducting a Stage 3: Advanced Hydrogeological Investigation.

If there was insufficient information during the Stage 2: Preliminary Hydrogeological Investigation to determine whether the ground water source is GARP or not, further information may need to be required through a Stage 3: Advanced Hydrogeological Investigation.

If the results of Stage 2 investigation indicate that the ground water source is deemed at low risk of containing pathogens, move to Stage 4: Long-term Water Quality Monitoring.

2.4 STAGE 3: ADVANCED HYDROGEOLOGICAL INVESTIGATION

2.4.1 Objective

The objective of a Stage 3: Advanced Hydrogeological Investigation is to provide more conclusive hydrogeological evidence and a professional opinion, based on several lines of investigation using scientifically advanced methods, that indicates whether or not the ground water at the water supply system well(s) is at a low risk of containing pathogens under operating conditions.

Findings that would support this include:

- There is no direct hydraulic connection or little evidence of a hydraulic connection between the well source and nearby surface waters.
- Where ground water is hydraulically connected to nearby source(s) of pathogens, the subsurface filtration or other hydrogeological factors will be effective in minimizing the risk of any pathogens reaching the well(s) under operating conditions.
- The time of travel (TOT) from a potential source of pathogens to the well, e.g., surface water body, is sufficient to minimize the risk of any pathogens reaching the well(s) under operating conditions.

2.4.2 Stage 3 Investigation Scope

The advanced investigation should be designed and undertaken by a qualified professional. Collaboration and discussion with health authority officials, the water supplier and other professionals such as those involved in laboratory testing and interpretation (e.g., microbiology and particulate analysis), water system design and operation, and drinking water treatment should be undertaken before and during the investigation.

All methods of investigation, quality control procedures, observations, findings, and recommendations should be documented in a written report including all supporting tabulated data, maps, graphs and photographs. Conclusions should summarize the lines of evidence and indicate the assessment of risk/low risk and the need, if any, for additional and/or long-term monitoring considerations.

The scope of the advanced investigation should build upon the findings of any Stage 2: Preliminary Hydrogeological Investigation and include any measures to fill information gaps and reduce any hydrogeological uncertainties. Professional judgment and consideration of site-specific conditions should determine the most important factors to examine and the selection of the scientifically advanced techniques to be employed. Development of a work plan and discussion with health officials prior to undertaking the advanced work are highly recommended.

Advanced work should consider additional site investigations involving the following topics and methods:

a) Test drilling and completion of monitor wells.
b) Extended aquifer pumping tests to determine aquifer parameters.
c) Computer flow modeling and simulation of extended pumping periods.
d) Advanced capture zone analysis.
e) Reverse particle-tracking and advanced time of travel determinations.
f) Monitoring of water levels and water quality (ground water and surface water) over extended periods of time.
g) Particle counting.
h) Microscopic particulate analysis (MPA) testing.
i) USEPA Method 1623 testing.
j) Isotope testing.
k) Other advanced techniques.

Suggested elements that should be considered for these topics are outlined in Table 2. This table may be used as a checklist and guide to assist with the completion of the advanced hydrogeological investigation. While a detailed description of all of these topics is beyond the scope of this guidance document some aspects of quality monitoring (ground water and surface water) and microbiological testing are discussed below.

Table 2: Suggested Elements for an Advanced Hydrogeological Investigation

TOPIC	ELEMENTS
a) Test drilling and completion of monitor wells	Construction of monitor wells for: water level and water quality monitoring / confirmation of the thickness and extent of aquifers and confining units / preparation of water table and potentiometric surface maps / hydrogeological cross sections to scale showing stratigraphy, aquifers, confining layers, well construction features, nonpumping water levels and relationship to surface water features / UTM well locations.
b) Extended aquifer pumping tests to determine aquifer parameters	Testing of monitor wells and water supply wells / packer testing in fractured bedrock / monitoring of observation wells during testing.
c) Computer flow modeling and simulation of extended pumping periods	Description of numerical model employed, assumptions and limitations / boundary conditions / simulate ground water equipotential contours and flow directions / sensitivity analysis.
d) Advanced capture zone analysis	Use of water level data from monitor wells / description of numerical model employed, assumptions and limitations / boundary conditions / simulate ground water equipotential contours and flow directions / sensitivity analysis.

TOPIC	ELEMENTS
e) Reverse particle-tracking and advanced time of travel determinations	Description of numerical model employed, assumptions and limitations / boundary conditions / simulate ground water equipotential contours and flow directions / sensitivity analysis.
f) Monitoring of water levels and water quality (ground water and surface water) over extended periods of time	Frequent monitoring of water levels and water quality in wells and nearby surface water locations for 3 to 12 months / key quality parameters to include: total coliforms, fecal coliforms, and *E.coli*, conductivity, turbidity and field determinations of temperature, pH, DO and ORP / correlation of variations in ground water with surface water employing statistical methods / correlation with precipitation data / sampling locations / role of geochemical reactions / quality-control procedures during sampling.
g) Particle counting	Sampling and testing of ground water for number and size of particles / comparison with typical sizes of pathogens / one or more samples at different times of the year / quality-control procedures during sampling / sampling locations.
h) Microscopic particulate analysis (MPA) testing	Sampling and testing for surface water organisms including *Giardia* and *Cryptosporidium* in ground water / 1 or more samples at different times of the year / quality-control procedures in sampling / sampling locations.
(i) EPA Method 1623 testing	Sampling and testing for *Cryptosporidium* and *Giardia* in ground water / one or more samples at different times of the year / quality-control procedures during sampling / sampling locations.
(j) Isotope testing	Sampling and testing of natural isotopes of oxygen and hydrogen, tritium, helium-tritium ratios / observed variations between ground water and surface water / origin, probable age and flow history / quality-control procedures during sampling / sampling locations.
(k) Other advanced techniques	Geophysical surveys / down-hole video surveys / environmental or applied tracer tests using dyes, bromide, or other soluble species to assess flow paths and travel times.

Note: Elements for investigation and reporting may vary depending upon availability of information and other site specific factors.

In considering the monitoring of water levels and water quality over extended periods of time (Topic (f)), the design of an adequate program may involve many factors. The Washington State Department of Health (2003a) guidance document, entitled *Potential GWI Sources – Determining Hydraulic Connection Through Water Quality Monitoring* provides a comprehensive approach covering both ground water and nearby surface water sources. Outlining a monitoring plan within the overall investigatory work plan is recommended and should be discussed with health authority staff during its development. Monitoring may also include microscopic particulate analysis (MPA) – see Appendix D.

2.4.3 Stage 3 Investigation Outcomes

If the results of the Stage 3: Advanced Hydrogeological Investigation indicate the ground water source is deemed to be at risk of containing pathogens, depending on the Stage 3 findings, the next step(s) could include:

- Treating ground water drawn by the well to meet health authority drinking water treatment standards.
- Providing an alternate source of water.
- Altering the well/correcting significant deficiencies in well construction not identified in the Stage 2 Investigation.
- Eliminating source(s) of contamination as demonstrated with confirmatory monitoring of the ground water.
- Relocating the well.

If the results of Stage 3 indicate that ground water supply system is deemed at low risk of containing pathogens, move to Stage 4: Long-term Water Quality Monitoring.

2.5 STAGE 4: LONG-TERM WATER QUALITY MONITORING

Long-term water quality monitoring is required for all water sources and water supply systems whether or not the ground water source is at risk of containing pathogens. In addition to bacteriological water quality monitoring requirements, under Schedules A and B of the DWPR, DWOs may require additional monitoring or testing of ground water sources. These requirements should be determined on a case-by-case basis depending upon any findings obtained during the Stage 1 to Stage 3 investigations or any other factors that may be of concern due to changing conditions in an aquifer or watershed or water system.

If water quality issues or changes to the assessment criteria occur (Figure 2) during the course of the Stage 4: Long-term Water Quality Monitoring, the assessment process will be reinitiated starting with the Stage 1: Screening Tool.

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APPENDIX A: GLOSSARY OF TERMS

GLOSSARY REFERENCES

(CCME) Canadian Council of Ministers of the Environment, 2004
(DWPA) *Drinking Water Protection Act*
(DWPR) Drinking Water Protection Regulation
(GWPR) Ground Water Protection Regulation
(WA) *Water Act*
(WPT) Well Protection Toolkit, 2002

Alter: to undertake a structural modification to a well and includes deepening or reaming of the well and replacing or modifying screen assemblies, casings or sealant. (GWPR)

Annular space or annulus: any open space between the outside of the casing of a well and the surrounding geologic formation or the open space or spaces between 2 or more well casings in the same well. (GWPR)

Aquifer:

- a geological formation
- a group of geological formations, or
- a part of one or more geological formations that is water bearing and capable of storing, transmitting and yielding water. (WA)

Bacteria: simple, unicellular organisms with an average size of 1/1,000 mm diameter. (CCME)

Bank filtration: a generic term that refers to water derived or drawn through the banks of lakes and other surface-water bodies (such as reservoirs or artificial recharge into spreading basin), *(Ray et al, 2003)*. A water treatment process that uses a well to recover surface water that has naturally infiltrated into ground water through a river bed or bank(s). Infiltration is typically enhanced by the hydraulic gradient imposed by a nearby pumping water supply or other well(s). River bank filtration provides particle removal, as well as partial or nearly complete removal of organic compounds and pathogenic organisms. (adapted from Ray et al, 2003). The process of collecting water in an infiltration gallery or well located near the bank of a river to allow river water to pass through the soil in the riverbank. (USEPA, 2006)

Code: the Code of Practice for Construction, Testing, Maintenance, Alteration and Closure of Wells in British Columbia, set out in Appendix A of the Ground Water Protection Regulation. (GWPR)

Coliform bacteria: a group of related bacteria whose presence in drinking water may indicate contamination by disease-causing organisms. (CCME)

Cryptosporidium**:** a genus of protozoan parasites potentially found in water and other media; also see oocysts. (USEPA, 2005)

Cyst: a phase or a form of an organism produced either in response to environmental conditions or as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant cell wall; typical size of *Giardia* cysts is (8 to 18 μm long by 5 to 15 μm wide) and shape (oval to round). (USEPA, 2005)

Drinking water officer: a person appointed under section 3 of the *Drinking Water Protection Act.*

***Escherichia coli* (*E. coli*):** a member of the total coliform group of bacteria and is found in the feces of humans and other animals. (BCMOE, 2007b)

Engineer: in relation to the *Water Act*, a professional engineer employed by the government or a government corporation and designated in writing by the comptroller as an engineer and includes a regional water manager. (WA)

Excavated well: a well, commonly known as a dug well, excavated by:

- Digging or boring unconsolidated materials using manual or mechanical methods, or
- Blasting in consolidated materials. (GWPR).

Fecal coliform: a type of bacteria found in the intestines of warm-blooded animals and humans, in bodily waste, animal dropping, and naturally in soil. (MOE, 2007b)

Floodplain: a lowland area, whether dyked, floodproofed, or unprotected, which is at an elevation susceptible to flooding. (BCMOE, 2007a)

Flowing artesian: hydraulic conditions in an aquifer or well where the ground water levels are able to rise to elevations above the ground surface.

Giardia**:** a genus of protozoan parasites potentially found in water and other media; also see cysts. (USEPA, 2005)

Giardia lamblia**:** a species of the genus *Giardia.* (also called *G. intestinalis* or *G. duodenalis*; found in humans and other mammals). (USEPA, 2005)

Ground water (groundwater): water below the surface of the ground. (WA)

Ground water at risk of containing pathogens (GARP): any ground water supply that is susceptible to contamination from any source of pathogens. It includes for example, ground water subject to contamination from sewage effluent discharge to land, agricultural waste disposal and surface water.

Ground water under direct influence of surface water (GWUDI): ground water that is hydraulically connected to nearby surface waters and susceptible to contamination from pathogens. In GWUDI situations, pathogens may be transported through infiltration of surface water into the ground water regime under natural or ground water pumping conditions. Also, fluctuations in ground water levels and ground water quality may also show a high degree of correlation with changes in surface water levels and surface water quality.

High-water mark: visible high-water mark of a lake, river, stream or other water body where the presence and action of the water are so common, usual and long continued in all ordinary years as to mark on the soil of the bed of the lake, river, stream or other body of water a character distinct from that of the banks, with respect to vegetation and the nature of the soil itself. In addition, the high-water mark includes the best estimate of the edge of dormant or old side channels and marsh areas.

Intake depth of a well**:** the depth at which water enters the well and is usually the top of the well screen for a well completed in unconsolidated deposits or the depth of the uppermost water-bearing fracture in a bedrock well.

Intake level of a well**:** the elevation at which water enters the well and is usually the top of the well screen for a well completed in unconsolidated deposits or the elevation of the uppermost water-bearing fracture in a bedrock well.

Karst: landforms produced mainly by the dissolution of rocks, mainly limestone and dolomite. Karst terrains are characterized by (1) closed surface depressions of various sizes and shapes known as sinkholes, (2) an underground drainage network of solution openings ranging in size from enlarged cracks in the rock to large caves, and (3) highly disrupted surface drainage systems, which relate directly to the unique character of the underground drainage system. (Winter et al, 1998)

Natural boundary: the visible high-water mark of any lake, river, stream or other body of water where the presence and action of water are so common and usual and so long continued in all ordinary years as to mark upon the soil of the bed of the lake, stream or other body of water a character distinct from that of the banks thereof, in respect to vegetation, as well as in respect to the nature of the soil itself. In addition, the natural boundary includes the best estimate of the edge of dormant or old side channels and marsh areas. (BCMOE, 2007a)

Normal water mark: the level between high-water that occurs as a result of excessive precipitation and low water that occurs during protracted dry periods. The normal or average water level can be estimated based on field observations by looking at the vegetation, topography and/or a visual estimation.

Oocyst: the encysted zygote of some sporozoa; e.g., Cryptosporidium. The oocyst is a phase or form of the organism produced as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant outer wall; typical size of Cryptosporidium oocysts is (4 to 6 μm) and shape (round to oval). (USEPA, 2005)

Pathogens: disease-causing organisms. (CCME)

Pitless adapter: a mechanical device attached to a well casing, usually below the frost level, for underground conveyance of water to or from the well. (GWPR)

Protozoa: single-celled organisms. More complex physiology than viruses and bacteria. Average size of 1/100 mm diameter. (CCME)

Professional engineer: a person registered with the British Columbia Association of Professional Engineers and Geoscientists.

Professional geoscientist: a person registered with the British Columbia Association of Professional Engineers and Geoscientists.

Qualified professional, in relation to the *Water Act***:** a professional engineer, or a professional geoscientist who is registered or licensed under the *Engineers and Geoscientists Act.* (WA)

Sealant: a nontoxic, commercially available material or mixture of materials, including:

- bentonite clay
- bentonite clay and water mixture
- bentonite clay and sand and water mixture
- neat cement grout
- sand cement grout
- concrete grout

Also, a nontoxic material or mixture of materials that has a lower permeability than the surrounding geologic formation to be sealed. (GWPR)

Stream: includes a natural watercourse or source of water supply, whether usually containing water or not, and a lake, river, creek, spring, ravine, swamp and gulch. (WA)

Stream channel: the bed of a stream and the banks of a stream, whether above or below the natural boundary and whether usually containing water or not, including all side channels. (WA)

Surface water: water from a source which is open to the atmosphere and includes streams, lakes, rivers, creeks and springs. (DWPR)

Surface seal: a sealant placed in the annular space around the outside of the outermost well casing and between multiple well casings and extending to or just below the ground surface. (GPR)

Time of travel: the time it takes water to flow from a given point to a well. (WPT**)**

Viruses: very simple life forms that do not multiply outside of living host cells. Average size of 1/10,000 mm diameter. (CCME)

Water supplier: a person who is the owner of a water supply system. (DWPA)

Water supply system: a domestic water system, other than the following:

- A domestic water system that serves only one single-family residence.
- Equipment, works or facilities prescribed by regulation as being excluded. (DWPA)

Water supply system well: in this document, a *water supply well* that is being used or is planned to be used for a *water supply system***.**

Water supply well: a class of well for extracting and using ground water, but does not include a drainage well, dewatering well or remediation well. (GWPR)

Well: an artificial opening in the ground made for:

- Exploring for ground water, or extracting and using it.
- Testing or measuring ground water.
- Recharging or dewatering an aquifer.
- Ground water remediation.
- Use as a monitoring well, or
- Use as a geotechnical well other than as a monitoring well.

This definition does not include:

- An artificial opening regulated under the Geothermal Resources Act, the Mines Act or the Petroleum and Natural Gas Act, or
- An artificial opening of a prescribed class or made for a prescribed purpose. (WA)

Well cap: a secure, vermin-proof cap or lid that prevents direct and unintended or unauthorized access to the interior of the production casing, and includes a sanitary well seal. (GWPR)

Well capture zone: the land area around a well that contributes water to a well under pumping conditions; the extent and shape of this area will depend upon the pumping rate, duration of pumping and other factors including effects of other wells and recharge boundaries.

Well cover: a secure, vermin-proof cover, lid or structure that prevents direct and unintended or unauthorized access to the well. (GWPR)

Wellhead: the physical structure, facility, cover, adapter or device that is at the top or side of the well, and from or through which ground water flows or is pumped from a well. Also, any casing, cap, valve, grout, liner, seal, vent, drain or pump house relating to the well, but does not include a well pump. (WA)

APPENDIX B: RELEVANT LEGISLATION AND REGULATIONS

PUBLIC HEALTH ACT

Health Hazards Regulation

Distance of wells from possible source of contamination

8 (1) A person who installs a well, or who controls a well installed on or after July 20, 1917, must ensure that the well is located at least

(a) 30 m from any probable source of contamination,

(b) 6 m from any private dwelling, and

(c) unless contamination of the well would be impossible because of the physical conformation, 120 m from any cemetery or dumping ground.

(2) A person who controls a well installed before July 20, 1917, must

(a) remove any source of contamination within the distances set out in subsection (1), or

(b) subject to subsection (3), close the well in accordance with section 6 of the Code of Practice under the Ground Water Protection Regulation, B.C. Reg. 299/2004.

(3) Subsection (2) (b) does not apply to a well located within 6 m of a private dwelling unless it can be shown that the well should be abandoned for a reason other than proximity to a private dwelling.

(4) A well that does not meet the requirements of this section is prescribed as a health hazard.

DRINKING WATER PROTECTION ACT

Part 2 — Drinking Water Supply

Water supply systems must provide potable water

6 Subject to the regulations, a water supplier must provide, to the users served by its water supply system, drinking water from the water supply system that

(a) is potable water, and

(b) meets any additional requirements established by the regulations or by its operating permit.

Floodproofing required for drinking water and other wells

16 (1) If required by regulation, the owner or operator of a well that provides drinking water must floodproof the well in accordance with the regulations.

(2) For the purpose of protecting the drinking water provided by a well that is subject to a requirement under subsection (1), the drinking water officer may, by order,

(a) require the owner or operator of another well that the drinking water officer has reason to believe

(i) is in the same well recharge zone, or

(ii) may otherwise affect the drinking water well

to floodproof the other well in accordance with the regulations, or

(b) if the drinking water officer is not reasonably able to determine who is the owner or operator of the other well, require the owner of the land on which that well is located to floodproof that well in accordance with the regulations.

Part 3 — Water System Assessments and Plans

Water source and system assessments

18 (1) A water supplier must prepare an assessment in accordance with this Part if required by the regulations or ordered by the drinking water officer.

(2) The purpose of an assessment is to identify, inventory and assess

(a) the drinking water source for the water supply system, including land use and other activities and conditions that may affect that source,

(b) the water supply system, including treatment and operation,

(c) monitoring requirements for the drinking water source and water supply system, and

(d) threats to drinking water that is provided by the system.

Drinking Water Protection Regulation

Exemptions

3.1 A small system is exempt from section 6 of the Act if

(a) the system does not provide water for human consumption or food preparation purposes, and is not connected to a water supply system that provides water for human consumption and food preparation purposes, or

(b) each recipient of the water from the system has a point of entry or point of use treatment system that makes the water potable.

Treatment

5 (1) In this section:

"ground water" means ground water as defined in section 1 of the Water Act;

"surface water" means water from a source which is open to the atmosphere and includes streams, lakes, rivers, creeks and springs.

(2) For the purposes of section 6 (b) of the act, drinking water from a water supply system must be disinfected by a water supplier if the water originates from

(a) surface water, or

(b) ground water that, in the opinion of a drinking water officer, is at risk of containing pathogens.

Well floodproofing

14 For the purpose of section 16 of the Act, the following persons must floodproof their wells in the manner described in section 11 (2) (a) and (b) of the Ground Water Protection Regulation:

(a) the owner or operator of a well that provides or may provide drinking water and that is identified in an assessment as being at risk of flooding;

(b) the owner of a well completed after October 31, 2005 that is for the purpose of supplying a water supply system.

WATER ACT

Ground Water Protection Regulation

Part 2 — Ground Water Protection

Surface sealing

7 (1) A person responsible for drilling a new well must complete the well with an effective and permanent surface seal in accordance with the minimum specifications set out in section 4 of the Code to prevent contaminants from the surface or a shallow subsurface zone from entering

(a) the well, or

(b) any aquifer penetrated by the well.

(2) The owner of a new well with a surface seal must ensure that

(a) the integrity of any sealant placed around the well is maintained, and

(b) any annular space that may develop around the well or between multiple well casings including, for example, as a result of any alteration, maintenance, erosion, excavation or subsidence that occurs around the outermost well casing, is resealed.

(3) If an existing well is altered after October 31, 2005 and the alteration impairs the integrity of the existing surface seal or causes the creation of a visible annular space between the outermost casing and the surrounding geologic formation, the owner of the well must ensure that

(a) the integrity of the surface seal is restored, or
(b) the annular space created by the alteration is sealed with a surface seal to at least its original condition.

(4) If an engineer has reason to believe that an existing well may pose a threat of a contaminant entering a neighbouring well or to ground water, the engineer may require the well owner to install or upgrade a surface seal in accordance with

(a) the specifications set out in section 4 of the Code, or
(b) other specifications as directed by the engineer.

Well caps and well covers

10 (1) On completion of the drilling of a new well, the person responsible for drilling the well or the well owner must install a secure well cap, or well cap and well cover, to the opening of the well to do all of the following:

(a) to prevent direct and unintended entry into the well of any water at the surface of the ground, including floodwater and ponded water, or anything that is set out in section 79 (1) of the Act;
(b) to prevent persons or animals entering the well;
(c) to prevent or minimize the flow of water from a flowing artesian well.

(2) On or before October 31, 2007, the owner of an existing well must install and maintain a secure well cap, or well cap and well cover, to the opening of the well to do all of the following:

(a) to prevent direct and unintended entry into the well of any water at the surface of the ground, including floodwater and ponded water, or anything that is set out in section 79 (1) of the Act;
(b) to prevent persons or animals entering the well;
(c) to prevent or minimize the flow of water from a flowing artesian well.

(3) Subsections (1) and (2) do not apply to a geotechnical well or drainage well.

(4) Well caps or well covers must meet the specifications required for well caps or well covers as set out in section 7 of the Code.

(5) If it is not feasible to install a well cap or well cover that meets the specifications set out in section 7 of the Code, the well owner must retain a qualified well driller, qualified well pump installer or qualified professional to design and install an effective well cap or well cover to do all of the following:

(a) to prevent direct and unintended entry into the well of any water at the surface of the ground, including floodwater and ponded water, or anything that is set out in section 79 (1) of the Act;

(b) to prevent persons or animals entering the well;

(c) to prevent or minimize the flow of water from a flowing artesian well.

Floodproofing of wells

11 (1) For the purposes of this section, flood debris and flood waters are a prescribed matter or substance under section 79 (1) (f) of the Act.

(2) The owner of a new well that is for the purpose of supplying a water supply system must locate, complete, equip and maintain the well

(a) to prevent the entry from the surface of anything set out in section 79 (1) of the Act, either directly into the top opening of the well or by entering the well through any annular space along the outside of the outermost well casing, and

(b) to protect the well or wellhead from physical damage due to flood debris, ice or erosion.

(3) An engineer may require the owner of a well that is for the purpose of supplying a water supply system to assess whether

(a) the well prevents the entry from the surface of anything set out in section 79 (1) of the Act, either directly into the top opening of the well or by entering the well through any annular space along the outside of the outermost well casing, and

(b) the well has been maintained in such a way that the well or wellhead is protected from physical damage due to flood debris, ice or erosion,

and the engineer may, after having considered the assessment, order the well owner to alter and maintain the well so that it complies with paragraphs (a) and (b) of this subsection.

(4) An engineer may order the owner of a well that is for the purpose of supplying a water supply system to engage a qualified professional who has competency in the field of hydrogeology to make the assessment required by subsection (3).

(5) An engineer may

(a) require the owner of a well that is in proximity to a well that is for the purpose of supplying a water supply system and that may pose a threat of a contaminant entering the well that is for the purpose of supplying the water supply system, or entering the aquifer supplying the water supply system, to engage a qualified professional who has competency in the field of hydrogeology to assess the threat, and

(b) after having considered the assessment, order the owner of the well that is in proximity to, and that may pose a threat to, the well that is for the purpose of supplying the water supply system,

(i) to alter or maintain the well in accordance with subsection (3) (a) and (b), or

(ii) to deactivate or close the well in accordance with section 9.

(6) Any work to alter or close a well under subsection (3) or (5) must be done by

(a) a qualified well driller,

(b) a qualified professional who has competency in the field of hydrogeology, or

(c) a person under the direct supervision of a person referred to in paragraph (a) or (b).

Protection of wellhead

12 (1) On completion of a new well, the person responsible for drilling the well or the well owner must ensure that the completed production casing is continuous and extends a minimum of 12 inches (0.3 m) above the ground surface adjacent to the well or 12 inches (0.3 m) above the floor of the well sump, well pit or pumphouse.

(2) Subsection (1) does not apply to

(a) a geotechnical well,

(b) a drainage well,

(c) a temporary dewatering well, or

(d) a monitoring well drilled under the supervision of a qualified professional who has competency in the field of hydrogeology or geotechnical engineering.

(3) A new well sump, well pit or pumphouse completed after October 31, 2005 must be designed, constructed and maintained in such a manner that any water entering the well sump, well pit or pumphouse is conveyed away from the wellhead or, if it cannot be conveyed away, is dealt with in a manner recommended by a qualified professional who has competency in the field of hydrogeology or geotechnical engineering.

(4) Subsection (3) does not apply to a monitoring well designed by a qualified professional who has competency in the field of hydrogeology or geotechnical engineering.

(5) The immediate ground area around a new well, or around an existing well altered after October 31, 2005, must be finished to ensure that water does not pond

(a) around the wellhead, and
(b) in the area disturbed during drilling.

(6) If thermoplastic casing is utilized in a new well, the thermoplastic well casing must be completely protected from damage and material breakdown at the ground surface.

(7) Subsection (6) does not apply to a drainage well, borehole, temporary dewatering well or temporary monitoring well.

APPENDIX C: AUSTRALIAN DRINKING WATER GUIDELINE REFERENCE

According to Information Sheet 3.5: Number of Samples Required contained in the 2011 Australian Drinking Water Guideline (Australian Drinking Water Guidelines (2011) http://www.nhmrc.gov.au/guidelines/publications/eh52), if results of 150 samples showed no fecal bacteria, there would be a 95% confidence level that 98% of the well water is free of microbial contamination (see reference graphs below).

It is this level of confidence (95%) that is proposed to be met in order to support an opinion that the ground water source is at low risk of containing pathogens and therefore will not require treatment, under current conditions.

Figure IS3.5.1 *Level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when all samples tested are free of faecal contamination (Source: Ellis 1989, reprinted with permission of the Water Research Centre, Medmenham)*

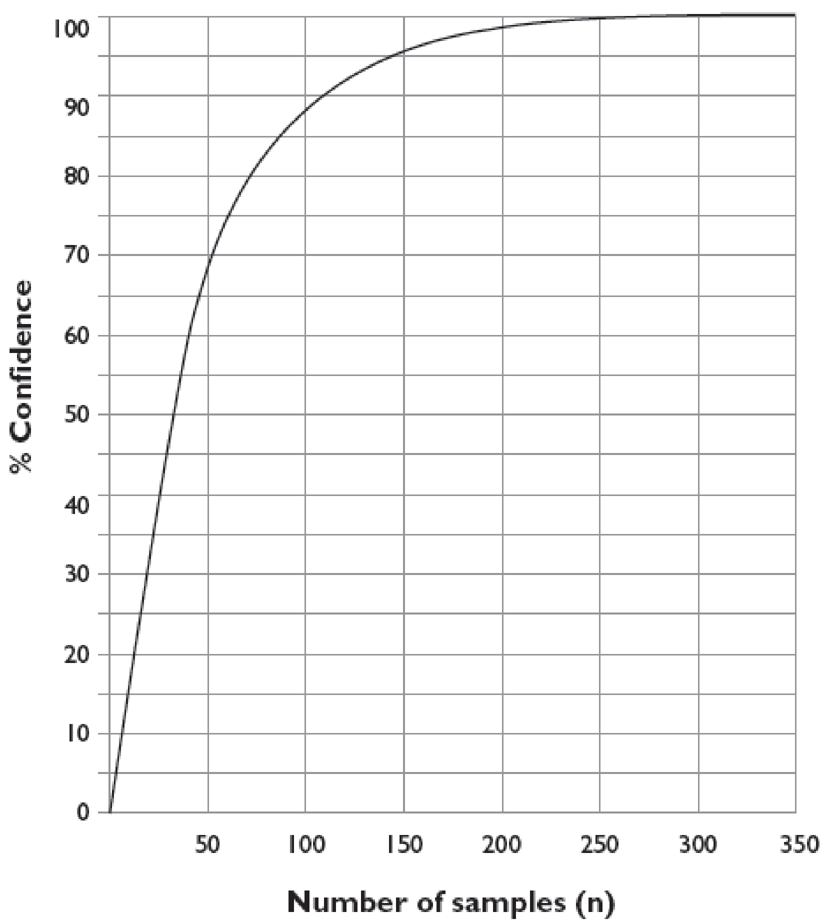
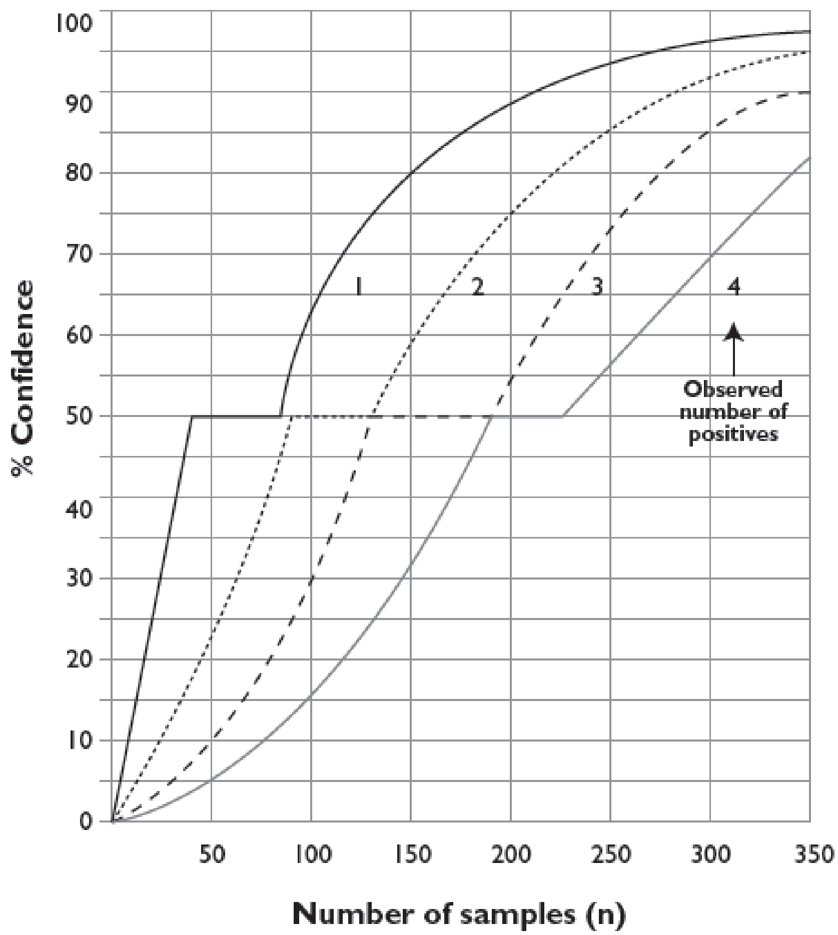


Figure IS3.5.2 *Level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when 1, 2, 3 or 4 samples give positive results (Source: Ellis 1989, reprinted with permission of the Water Research Centre, Medmenham)*



APPENDIX D: SAMPLING GUIDE FOR MPA TESTING

Microbiological sampling and testing may include; microscopic particulate analysis (MPA) and EPA Method 1623 testing. The equipment needed to collect MPA samples and samples for EPA Method 1623 is highly specialized for each test and is provided by the laboratory retained. Careful planning, coordination with the laboratory and strict adherence to sampling procedures and timely transport of samples to the laboratory are critical for obtaining meaningful test results. It is important to discuss what type of test is most appropriate to conduct with health authority staff, the qualified professional and laboratory staff for each particular situation and site. The two methods are described as follows.

MICROSCOPIC PARTICULATE ANALYSIS

Microscopic particulate analysis (MPA) is a laboratory test that evolved from the analysis of *Giardia* and filtration efficiency determinations (USEPA, 1992). It has been useful, based on the EPA Consensus Method for particulate analysis, for the identification of ground water supplies suspected of being under the direct influence of surface water. USEPA recommended in 1991 that the presence of; diatoms and certain other algae, rotifers, coccidia, insect parts, and *Giardia*, be used as indicators of direct surface water influence. The EPA Consensus Method (USEPA, 1992) provides a relative risk score for a particular water supply source based on the significant occurrence of primary and secondary surface water indicator organisms such as algae and *Giardia* cysts. The intent of the test is to identify organisms that only occur in surface waters as opposed to ground waters and whose presence in a ground water would clearly indicate that at least some surface water has been mixed with it (USEPA, 1991a).

The USEPA (1992) emphasized that surface water influence on a ground water source cannot be determined solely on the basis of one or two MPAs, and the absence of *Giardia* cysts, coccidian or other bio-indicators does not ensure that the source is *Giardia* or pathogen free. Conversely, a positive MPA result does not necessarily signify the presence of *Giardia* or other related pathogens (USEPA, 1992). Studies by Jacangelo et al (2001) found that one or two MPA tests may be insufficient to predict future MPA values. The MPA method may involve taking two or more samples over a period of six months to a year or more. Samples should be collected from wells at times of the year such as summer and winter when flow conditions vary, or when there is the greatest potential impact of nearby surface water and also during high pumping demand periods. Timing of sampling should also consider time of travel delays for MPA analysis to be effective.

Sampling procedures for MPA and options are outlined in the USEPA document entitled Consensus Method for Determining Groundwaters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (MPA), (USEPA, 1992). The test involves filtering a significant volume of water (e.g., 4500 litres) to concentrate organisms and debris that are then identified and quantified under a microscope by an accredited laboratory (Alberta Environment, 2006). The Washington State Department of Health

(2003b) guidance document, entitled: Potential GWI Sources – Microscopic Particulate Analysis provides a comprehensive overview of the MPA method.

Hyperion Research Ltd., in Medicine Hat, Alberta is the nearest laboratory to British Columbia in Canada that provides MPA testing services and is Canadian Association for Laboratory Accreditation (CALA) accredited. There are other laboratories in British Columbia that provide similar services, such as MB Laboratories Ltd. in Sidney, but use of these laboratories should be discussed with health authority staff. A guide, incorporating their current water sampling procedures for MPA testing is provided in Table 3 below.

Table 3: Sampling Guide for MPA Testing

STEP	DESCRIPTION	RECOMMENDATIONS
1	Sampling plan and schedule.	• Develop plan including: site locations, number of samples, timing of sampling and discuss with health officials, water system operator and pump installers if involved and the laboratory. • Confirm availability of sampling equipment, filters and sampling procedures with the laboratory. • Plan to sample during the early part of any week, rather than late in a week. • Confirm any changes in the plan with all parties involved.
2	Site verification.	• Verify access conditions for sampling point in the field or with water system operators or pump installers. • Modify works if necessary to enable extracting raw water at the well at a rate of 5 litres/minute.
3	Obtain specific sampling equipment and filters from laboratory.	• **Use Dual Ported FW5 sampler and filter** provided by laboratory. • Check sampling equipment and review setup, filter installation and instruction sheet provided by the laboratory before installing sampling equipment at the site(s). • Use sanitary gloves when handling filters. • Do not install filter until required for sampling and keep in sanitary plastic bag until ready to use.
4	Assemble any additional equipment and materials required.	• Clean cooler chest for shipping samples, 1-litrer sampling bottle, ice packs, sanitary gloves, plastic bags and field notebook. • Water filter submission report sheet provided by laboratory. • Optional field water quality testing equipment for pH, temperature, turbidity, conductivity and total iron.
5	Travel to site and install sampling equipment and filter according to laboratory instruction sheet.	• Contact water system operators or pump installers before traveling to site to confirm sampling arrangements. • Advise laboratory of pending samples to be shipped and anticipated timing.
6	Filter 4000 liters of raw water at specified pressure (max 12 psi) and flow rate of 5 litres/minute	• Start filtering early in the day if possible as sampling period will require about 12 to 14 hours. • Use sanitary gloves when handling filters. • Check and record raw water quality from well and nearby surface for pH, temperature, turbidity, conductivity and total iron.

STEP	DESCRIPTION	RECOMMENDATIONS
7	After filtering is completed, stop flow, remove filter, place in new plastic shipping bag and ship to laboratory as soon as possible including 1 litre sample of nearest surface water source.	• Assign site numbers to the filter sample and water sample for tracking purposes. • Record the quantity filtered and complete other information on the water filter submission report sheet. • Use sanitary gloves when handling filters. • Double bag the filter. • Do not hold filter sample for more than 24 hours. • Ship filter and water sample courier express (one-day delivery) and prepaid to laboratory, in cooler chest with ice packs separated from touching the filter. • Ship cooler chest with copy of completed water filter submission report sheet in separate plastic bag. • Tape chest cover to keep from opening. • Keep all shipping receipts for follow up after 24 hours. • Verify with laboratory that sample was received in time for valid analysis.
8	Following use, run clean water through sampler to remove particulates and drain to prevent damage in freezing weather.	• Invert the sampling unit with the filter housing base removed.
9	Clean the sampler according to laboratory instructions provided with the unit and drain.	• Invert the sampling unit with the filter housing base removed.
10	Return sampler to laboratory if no longer required.	• Send prepaid in shipping container originally provided by laboratory. • Keep all shipping receipts for follow up after 48 hours. • Verify with laboratory that sampler was received in good condition.

Note: Incorporates recommended procedures available from Hyperion Research Ltd., http://www.hyperionlab.ca/

EPA METHOD 1623

In 1999 the USEPA validated a method for simultaneous detection of *Cryptosporidium* and *Giardia* and designated the combined procedure as EPA Method 1623. The latest method was published in 2005 following a number of revisions (USEPA, 2005). Method 1623 is a more sensitive test for *Giardia* compared to the MPA test and especially sensitive for *Cryptosporidium.*

Sampling procedures for Method 1623 and options are outlined in the USEPA document entitled *Method 1623: Cryptosporidium and Giardia in Water by Filtration/IMS/FA* (USEPA, 2005). The test involves filtering a relatively small volume of water (i.e., 100 to 500 liters). Method 1623 may involve taking two or more samples over a period of a year or more. Samples should be collected from wells at times of the year when there is the greatest potential impact of nearby surface water and also during high pumping demand periods. Timing should also consider time of travel delays.

Currently, Hyperion Research Ltd., located in Medicine Hat, Alberta is the nearest laboratory to British Columbia in Canada that provides Method 1623 testing services. A guide, incorporating their current water sampling procedures for Method 1623 testing is provided in Table 4.

Table 4: Sampling Guide for EPA Method 1623 Testing

STEP	DESCRIPTION	RECOMMENDATIONS
1	Sampling plan and schedule.	• Develop plan including; site locations, number of samples, timing of sampling and discuss with health officials, water system operator and pump installers if involved and the laboratory. • Confirm availability of sampling equipment, filters and sampling procedures with the laboratory. • Plan to sample during the early part of any week, rather than late in a week. • Confirm any changes in the plan with all parties involved.
2	Site verification.	• Verify access conditions for sampling point in the field or with water system operators or pump installers. • Modify works if necessary to enable extracting raw water at the well at a rate of 4 litres/minute.
3	Obtain specific sampling equipment and filters from laboratory.	• **Use FW12 sampler and Filta-Max filter** and spanner tool provided by laboratory. • Check sampling equipment and review setup, filter installation and instruction sheet provided by the laboratory before installing sampling equipment at the site(s). • Use sanitary gloves when handling filters. • Do not install filter until required for sampling and keep in sanitary plastic bag until ready to use.
4	Assemble any additional equipment and materials required.	• Clean Styrofoam cooler chest for shipping samples, 1-litre sampling bottle, ice packs, sanitary gloves, plastic bags and field notebook. Water filter submission report sheet provided by laboratory. • Optional field water quality testing equipment for pH, temperature, turbidity, conductivity and total iron.
5	Travel to site and install sampling equipment and filter according to laboratory instruction sheet.	• Contact water system operators or pump installers before traveling to site to confirm sampling arrangements. • Advise laboratory of pending samples to be shipped and anticipated timing.
6	Filter 100 liters of raw water at specified pressure (max 75 psi) and flow rate of 4 litres/minute	• Use sanitary gloves when handling filters. • Check and record raw water quality from well and nearby surface for pH, temperature, turbidity, conductivity and total iron.

STEP	DESCRIPTION	RECOMMENDATIONS
7	After filtering is completed, stop flow, remove filter, place in new plastic shipping bag and ship to laboratory as soon as possible including 1 litre sample of nearest surface water source.	• Assign site numbers to the filter sample and water sample for tracking purposes. • Record the quantity filtered and complete other information on the water filter submission report sheet. • Use sanitary gloves when handling filters. • Double bag the filter. • Do not hold filter sample for more than 24 hours. • Ship filter and water sample courier express (one-day delivery) and prepaid to laboratory, in cooler chest with ice packs separated from touching the filter. • Ship cooler chest with copy of completed water filter submission report sheet in separate plastic bag. • Tape chest cover to keep from opening. • Keep all shipping receipts for follow up after 24 hours. • Verify with laboratory that sample was received in time for valid analysis.
8	Following use, wash the filter housing with warm soapy water and wipe dry.	
9	Return sampler to laboratory if no longer required.	• Send prepaid in shipping container originally provided by laboratory. • Keep all shipping receipts for follow up after 48 hours. • Verify with laboratory that sampler was received in good condition.

Note: Incorporates recommended procedures available from Hyperion Research Ltd., http://ww.hyperionlab.ca/