GUIDANCE DOCUMENT FOR DETERMINING GROUNDWATER AT RISK OF CONTAINING PATHOGENS (GARP)

VERSION 3

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HEALTH PROTECTION BRANCH
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NOTE TO THE READER

The *Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP*) was developed to assist water suppliers and regulatory authorities with assessing the level of potential risk that a ground water source may become, or may already be, contaminated by pathogens. This document helps to establish a scientifically defensible basis for the discussion, planning and resolution of public health-related concerns.

The implementation of the information and procedure presented in this document should not be taken as equivalent to provincial or local legislation or standards; rather, it is intended to inform regulatory decisions. Consequently, regulatory authorities should be consulted prior to the site-specific use of this document.

ACKNOWLEDGEMENTS

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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 is intended to assist the drinking water officer (DWO) in formulating an opinion, and discussing with a water supplier, whether water originating from a ground water source is “at risk” or “at low risk” of containing pathogens. Water suppliers who wish to self-assess their ground water source may also complete this procedure, in consultation with the DWO.

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, continuously or intermittently. Potential sources of pathogens include sewage discharge to land, leaking municipal sewage pipes (especially force mains), agricultural waste stockpiles, runoff intrusion into poorly constructed wells, and surface water.

This document is intended to be used by public health officials, water suppliers, and professional engineers and geoscientists, to assess situations where ground water may be at risk of containing pathogens. Ground water sources determined to be GARP require disinfection to achieve the provincial ground water treatment objectives for the delivery of potable water. However, under regulation the DWO must make the final determination about risk and apply their discretion to decide the extent to which the water source must be treated. These decisions are based on information provided by the water supplier, observations made by health authority staff, as well as any data and opinions provided by a qualified professional.

The procedure outlined in this document follows a staged approach from initial screening and assessment through to the determination of GARP and reviewing risk mitigation options. The guideline’s process consists of four stages:

Stage 1: Hazard Screening and Assessment

Stage 2: GARP Determination

Stage 3: Risk Mitigation

Stage 4: Long-term Monitoring

DWOs may determine a ground water source to be at risk of containing pathogens upon reviewing the results of any stage of the process, based on 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 process but is subject to the results of continued long-term monitoring of the water supply system and the conditions of the aquifer, well capture zone, and watershed over time.

ACRONYMS

BCACS	British Columbia Aquifer Classification System
MECCS	British Columbia Ministry of Environment and Climate Change Strategy
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
GWUDI	Ground Water under Direct Influence of Surface Water
GARP	Ground Water at Risk of Containing Pathogens
GWPR	Groundwater Protection Regulation (2016), under the *Water Sustainability Act*
HHR	Health Hazards Regulation
IMS	Immunomagnetic Separation
MPA	Microscopic Particulate Analysis
ORP	Oxidation-Reduction Potential
PHA	*Public Health Act*
qPCR	quantitative polymerase chain reaction
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
WSA	*Water Sustainability Act*
WPT	Well Protection Toolkit
WTN	Well Tag Number

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1 INTRODUCTION

In British Columbia (B.C.), section 5(2) of the B.C. 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*. The presence of pathogens in ground water used for human consumption can pose a significant drinking water health hazard that endangers the public health. This guidance document outlines recommended procedures to assist public health officials, *water suppliers*, and *professional engineers* and geoscientists in determining if a ground water source is at risk.

Ground water at risk of containing pathogens (GARP) is defined as any *ground water source* that is likely to be contaminated from any sources of human disease-causing microorganisms (pathogens) including various types of *bacteria*, *viruses* and *protozoa* (e.g., *Giardia* and *Cryptosporidium*). Contamination may be continuous or, as is more often the case, intermittent. Potential sources of pathogens may include sewage discharge to land, leaking municipal sewage pipes (especially force mains), agricultural waste stockpiles, runoff intrusion into poorly constructed *wells*, and *surface water* that is hydraulically connected to ground water.

In contrast to GARP, many jurisdictions across Canada utilize varying definitions for *ground water under direct influence of surface water* (GWUDI or GUDI) to meet their respective management requirements and legislative frameworks. Generally, these definitions encompass not only the potential for contamination by surface water sources, but also contamination from infiltration and anthropogenic sources.

Determining GARP instead of GWUDI in B.C. serves to highlight that ground water contamination is not limited to hydraulic connections to surface water sources. Furthermore, it recognizes that in some GWUDI situations, site-specific hydrogeological conditions (e.g., *flowing artesian condition*) or effective *subsurface filtration* may preclude the transport of some pathogens to a *water supply system well*. GARP is an umbrella term meant to take into account all the ways a particular ground water source could be at risk, including the hydrogeological conditions associated with GWUDI wells.

A glossary of key terms is provided in Appendix A. Words contained in the glossary are highlighted using *italics* the first time the word is introduced in the document.

1.1 PURPOSE AND SCOPE

Under section 5.2 of the DWPR, a DWO determines whether a ground water source is GARP, in which case it must be disinfected. This document describes a procedure for making this determination. This document does not specify the level of disinfection required to make a GARP source potable; this is outlined in the *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia* (MOH, 2015). In other words, this document assists water suppliers and DWOs in determining if a ground water source requires disinfection, but not what degree of disinfection may be required of a water system.

This document does not include an assessment of chemical contaminants that may be present in ground water, either naturally or human caused. Chemicals commonly of concern in B.C. groundwater include nitrates, fluoride, and metals such as arsenic, uranium, lead, and copper. Chemical testing of raw water can be completed by a private laboratory.

1.2 RELEVANT LEGISLATION AND REGULATIONS

The main legislative requirements and supporting information relevant to this guidance document are in the *B.C. Drinking Water Protection Act* (DWPA), the DWPR, the *B.C. Water Sustainability Act* (WSA), the B.C. Ground Water Protection Regulation (GWPR), the B.C. *Public Health Act* (PHA), and the B.C. Health Hazards Regulation (HHR). The principal requirements are:

DWPA, 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."

DWPR, 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

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

and DWPR, section 3.1:
"The following are exempt from section 6 of the Act:

a) a small system, if

(i) each recipient of the water from the small system has a point of entry or point of use treatment system that makes the water potable, and

(ii) the water supplier ensures that the location of non-potable water discharge and nonpotable piping are identified by markings that are permanent, distinct and easily recognized;

b) a water supply system, including a small system, if

(i) the system does not provide water for human consumption or food preparation purposes,

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

(iii) the water supplier ensures that the location of non-potable water discharge and non-potable water piping are identified by markings that are permanent, distinct and easily recognized.”

GWPR:
Establishes standards for the siting, drilling, construction, maintenance, alteration and closure of wells in B.C.

GWPR, section 18

The person responsible for drilling a proposed water supply well must site the proposed well so that the horizontal setback distance is not less than 15 m from any part of the proposed well to an existing water supply well, unless the existing water supply well is not in use and is not intended to be in use, or the owner of the proposed well also owns the existing water supply well and only one well is proposed to be drilled. Alternative specifications may be set in conjunction with a qualified professional or engineer.

GWPR, section 29

For the purposes of drilling, altering, developing and rehabilitating a well, a person may introduce acids, lubricants, bactericides or other similar substances into a water supply well in order to perform the activity; however, promptly after using the substances the person responsible for the activity must remove groundwater from the water supply well until the substances in the remaining groundwater in the well would not prevent the use of the water supply well for its intended purpose. The person must also dispose of the groundwater removed from the water supply well in a manner that does not pose a threat to the aquatic ecosystem of a stream or an aquifer or to property, public safety or the environment.

GWPR, section 63

“The owner of a well constructed or altered for the purpose of supplying a water supply system must ensure that the well is completed, equipped and maintained in a manner that

a) (a) prevents any foreign matter from entering from the surface of the ground into the well, either directly into the top of the well or through an annular space, and
b) (b) protects the well and wellhead from physical damage due to flood debris, ice or erosion.”

HHR, section 8:
“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."

1.3 WHO SHOULD USE THIS DOCUMENT

The determination of GARP is made by the DWO. This determination becomes the basis for establishing the reasonable measures a water supply system needs to take to ensure that public health is protected. It is in the interests of a water supplier, having chosen to use a particular water source, to provide information to the DWO that assists in that determination.

Therefore, completing the procedure outlined in this document should be a coordinated effort between the water supplier who identifies and assesses hazards, and the DWO who makes the overall determination. A *qualified professional*[1] may also be retained by the water supplier at any point to undertake hydrogeological investigations and to contribute a professional opinion regarding the hazards to the water source.

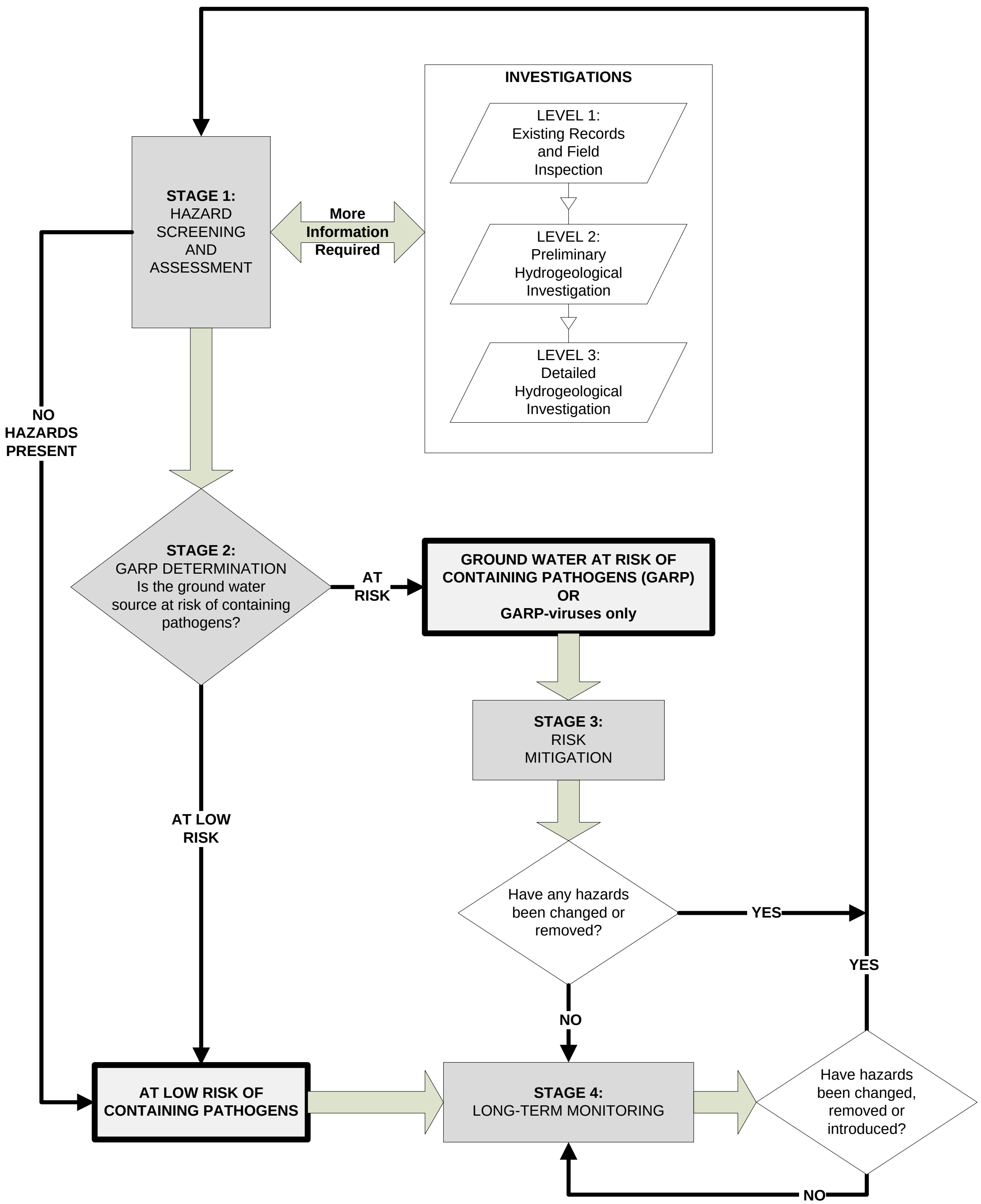
Whether the assessment is self-initiated or requested by the DWO, the water supplier and the DWO should collaborate to confirm information needs, to set appropriate timelines, and to ensure that the rationale for a GARP determination reflects a shared understanding of the water source.

The GARP assessment should also be considered part of the siting of a new well to help select a location that minimizes exposure to hazards and to anticipate hazards that may require mitigation. Water suppliers should ensure that a drilling contractor is aware of the hazards described in this document.

[1] Qualified professionals are individuals registered with the Association of Professional Engineers and Geoscientists of BC with competency in the field of hydrogeology and experience in evaluating ground water sources.

2 OVERVIEW OF GARP DETERMINATION PROCEDURE

Figure 1: GARP Determination Flowchart



2.1 DETERMINATION STAGES

The procedure for determining GARP involves four stages (Figure 1):

Stage 1: Hazard Screening and Assessment

Stage 2: GARP Determination

Stage 3: Risk Mitigation

Stage 4: Long-term Monitoring

In Stage 1, the water source is screened for 13 hazards. Hazards that are considered to be present are then assessed individually as to whether the hazard makes the source potentially GARP. In Stage 2, the hazards that make a source potentially GARP are reviewed cumulatively in order to make an overall determination if the source is GARP or at low risk of containing pathogens. Systems with sources determined to be GARP would move to Stage 3: Risk Mitigation to address the risk of containing pathogens, either through addressing specific hazards or through disinfection.[2] All systems then move to Stage 4: Long-term Monitoring.

2.2 WATER SOURCE INVESTIGATIONS

To complete the GARP determination, an understanding of the water source is needed. This may require up to three levels of investigation (section 8):

Level 1: Existing records and field inspection

Level 2: Preliminary hydrogeological investigation

Level 3: Detailed hydrogeological investigation

Screening for hazards would typically not require anything beyond a Level 1 investigation, using basic information already available. Information collected under other procedures, such as the *Comprehensive Drinking Water Source-to-Tap Assessment Guideline* (MHLS, 2010), or data gathered from previous hydrogeological studies or studies completed by a qualified professional, would be considered part of the existing records referred to in a Level 1 investigation. For untapped (or proposed) ground water sources, there may not be sufficient water quality results or other relevant data to complete the Stage 1 screening.

Where a DWO or a water supplier feels that additional information is necessary to complete the Stage 1 screening and assessment, more detailed investigations (Level 2 and 3) completed by a qualified professional may be pursued to collect the additional information.

[2] Disinfection objectives are outlined in the *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia* (MOH 2015).

If Level 2 and/or 3 investigations are required, a work plan should be developed by the water supplier in consultation with the DWO to identify the areas of concern to be examined. Level 2 investigations typically involve a thorough analysis of available information to develop an understanding of hydrogeological conditions. Level 3 investigations build on the understanding gathered by a Level 2 investigation, utilizing more involved methods such as modelling, sampling, and extended monitoring programs (section 8).

A water supplier may not pursue a Level 2 or 3 investigation if they choose to disinfect the ground water source to provincial standards, or choose to develop an alternative risk mitigation approach in consultation with the DWO.

2.3 DETERMINATION OUTCOMES

A DWO may determine that a ground water source is at risk of containing pathogens upon the review of the results at any stage of the procedure based on the available evidence at the time, any other known factors, or significant uncertainties as to the quality of the water source.

A GARP determination can result in three possible outcomes:

- **At risk of containing pathogens (GARP):** If one or more identified hazards pose an obvious risk of pathogenic contamination of a ground water source, the source would be determined to be **"at risk"** or **GARP**.
- If the DWO has reason to believe that the source is only at risk of containing viruses (i.e., only hazard B4 was present), the source would be determined to be "**GARP-viruses only**."
- **At low risk of containing pathogens (Non GARP):** Where no hazards are present, or they have all been confirmed as low risk, the ground water source would be determined to be **"at low risk"** of being GARP.

2.4 LONG-TERM MONITORING

Determining whether a ground water source is at risk of containing pathogens is not regarded as a one-time process. A GARP determination is subject to the results of ongoing monitoring of the water source. For example, the integrity of well casings and *well caps*, the severity and frequency of flood events, sources of contamination, and the presence of human activities can change over time and introduce hazards that should be assessed.

Conversely, under certain conditions, hazards and sources of contamination could diminish over time, resulting in reduced likelihood of contamination. Stage 4: Long-term Monitoring should be implemented by all water supply systems drawing from a ground water source regardless of being "at risk" or "at low risk."

3 STAGE 1: HAZARD SCREENING AND ASSESSMENT

3.1 HAZARD SCREENING

The first stage of the GARP determination involves screening the water source for hazards that increase the risk of a ground water source containing pathogens. There are 13 hazards in four main categories, as shown in Table 3-1. The hazards are not in any priority or rank, and all hazards need to be considered to determine whether or not the water source is at risk of containing pathogens (GARP). An example screening checklist is provided in Appendix D.

Table 3-1: Hazards associated with water supply system wells drawing from ground water sources at risk of containing pathogens

Hazard Category	No.	Hazard: Water Supply System Well
Water Quality Results	A1	Exhibits recurring presence of total coliform bacteria, fecal coliform bacteria, or *Escherichia coli* (*E. coli*).
	A2	Has reported intermittent turbidity or has a history of consistent turbidity greater than 1 NTU.
Well Location	B1	Situated inside setback distances from possible sources of contamination as per section 8 of the HHR.
	B2	Has an intake depth <15 m below ground surface that is located within a natural boundary of surface water or a flood prone area.
	B3	Has an intake depth between the high-water mark and surface water bottom (or < 15 m below the *normal water level*), and located within, or less than 150 m from the natural boundary of any surface water.
	B4	Located within 300 m of a source of probable enteric viral contamination without a barrier to viral transport.
Well Construction	C1	Does not meet GWPR (Part 3, Division 3) for surface sealing.
	C2	Does not meet GWPR (Part 4) for well caps and covers.
	C3	Does not meet DWPA or DWPR (Section 16 of the DWPA, Section 14 of the DWPR) for floodproofing.
	C4	Does not meet GWPR (Division 5) for wellhead completion.
Aquifer Type and Setting	D1	Has an Intake depth <15 m below ground surface.
	D2	Is situated in a highly vulnerable, unconfined, unconsolidated or fractured bedrock aquifer.
	D3	Is completed in a karst bedrock aquifer, regardless of depth.

The hazard screening should consider features of both the ground water source and the water supply system well location and construction. Where multiple wells are connected into a well field, each well should be individually assessed.

The hazard screening utilizes information provided by the water supplier and existing records. Completion of the checklist should involve discussions with the water supplier, a field inspection and any additional information that can help to verify current well site conditions (Level 1 investigation). Additional sources of information may be consulted to assist in completing the checklist, including documents completed under the guidance of the *Drinking Water Source-to-Tap Screening Tool* (B.C. Ministry of Health Services, 2004) and Module 1 of the *Comprehensive Drinking Water Source-to-Tap Assessment Guideline* (MHLS, 2010).

Situations where information is not available, or is inadequate to assess one or more hazards, may require further research of existing records, or the completion of Level 2 or 3 hydrogeological investigations. Conversely, a DWO may form the opinion that a water source is GARP in the absence of complete information for some hazards if the risk is strongly evident from the information available.

If none of the hazards are present, the water source is considered to be “at low risk” of containing pathogens. If one or more of the hazards are present, further assessment is needed.

3.2 HAZARD ASSESSMENT

Hazards determined to be present from the screening are assessed individually as to the likelihood that the hazard will cause or enable contamination of the water source.

Risk rating commonly considers risk as a product of the likelihood of an event occurring combined with the impact of the event. As the impact of microbiological contamination is potential human illness or mortality, under the DWPR, these impacts are considered a constant when pathogens are likely present. For this reason, the assessment presented herein simply categorizes each hazard based on its likelihood of the water source being ‘at risk’ or ‘at low risk’ of containing pathogens.

Factors to consider when assessing each of the hazards are described in the following sections. If it is not possible to evaluate a hazard due to a lack of readily available information, the DWO may request that additional information be provided so that the assessment can be made. This may require a Level 2 or 3 hydrogeological investigation (section 8).

4 HAZARD SCREENING AND ASSESSMENT

4.1 A. WATER QUALITY RESULTS

4.1.1 Hazard A1 – Microbiological Test Results

4.1.1.1 Description

A water supply system well that exhibits recurring presence 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 their opinion on whether a ground water source is potentially at risk of containing pathogens. Testing should be done 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, and total coliforms. Historic fecal coliform data would also be useful.

Bacteriological samples should be representative of operating conditions and account for seasonal variation or other factors that may increase the risk to the ground water.

4.1.1.2 Hazard Assessment

If there is a recurring presence of total coliform and/or *E. coli* (or history of fecal coliform contamination) in the ground water source, the water supplier would be required to investigate, identify, and, where possible, eliminate the source of bacterial contamination within a reasonable time period. This may involve a Level 2 investigation, if warranted. During this time period, the users of the water system should be made aware of the potential health risk and also what actions the water purveyor is taking to eliminate the hazard. Following these actions, the ground water source would be considered either:

- At low 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.

4.1.1.3 Supplementary Information

Pathogen Indicators

Bacteriological water quality monitoring is accomplished through the testing of water for indicator organisms (pathogen indicators) such as *E. coli* as an indicator of fecal contamination and total coliforms as an indicator of general water quality (Health Canada, 2011). Water quality monitoring results alone cannot determine if a well is at low risk of containing pathogens and are not intended to be interpreted in isolation from the other hazards listed in the checklist. As part of the checklist, monitoring results can provide a quantitative confirmation of the absence of hazards or the efficacy of control measures put in place to mitigate known hazards.

Health Canada (2012a) considers *E. coli* to be the best available indicator of fecal contamination, given that it is fecal specific, does not multiply in the environment, and is excreted in high numbers in feces, which allows for detection even when heavily diluted. It is a preferred indicator organism for routine bacteriological monitoring and a cost-effective means of identifying fecal contaminated wells for the protection of public health (USEPA, 2006). Historically, fecal coliform monitoring was also used but it is now considered redundant to *E. coli* monitoring (Health Canada, 2012a).

Total coliforms, which can be found in both fecal and non-fecal environments, are not necessarily an indicator of fecal pollution or pathogenic to humans, but are useful as a measure of general water quality. Total coliforms are not generally found in protected ground water when wells are appropriately maintained and so their presence is indicative of interaction with the surrounding environment (Health Canada, 2012b).

While it is possible to detect specific pathogenic bacteria, protozoa and viruses in water, such tests are considered impractical for routine monitoring due to factors such as uneven distribution of pathogens in water, sampling difficultly and duration, and analytical expenses (Health Canada, 2012a). Testing of pathogen indicators provides an economical and rapid means of determining if there is a likelihood that pathogens are present. There are differences between bacterial indicators and those used for protozoa and viruses; indicator analytical results should be interpreted with these differences in mind.

Given the higher survivability of protozoa over indicator organisms, the absence of fecal indicators or total coliforms does not necessarily indicate the absence of protozoa. In a survey of water quality data associated with outbreaks, Craun *et al.* (1997) found that very few protozoan related outbreaks corresponded to instances where total coliforms exceeded accepted limits.

Numerous studies have also found that there is little to no correlation between protozoa and fecal indicators such as *E. coli* (Health Canada, 2012a). Therefore, water quality monitoring results for fecal indicators alone are insufficient for assessing the risk of protozoa, though they remain the best available indicators for verifying microbiological water quality (Health Canada, 2012a).

Clostridium perfringens is a potential indicator for *Giardia* and *Cryptosporidium*, but is only suitable for detection of human, not animal, fecal contamination (Payment *et al.*, 2001). Microscopic particulate analysis (MPA), which provides information on the nature of the particulates in the water (Payment *et al.*, 2001) is sometimes used to infer the presence or absence of protozoa (see Appendix C for more details), however, reliance on this one time snapshot of water quality is not considered a suitable replacement for long-term water quality monitoring results, nor an understanding of a well's hydrogeological setting (gained through a Level 2 or 3 investigation).

Viruses can survive longer and are capable of travelling longer distances than indicator organisms such as total coliforms and *E. coli*. The correlation between indicators and viruses has been studied extensively, with varying results:

- Locas *et al*. (2007) found that 100% of positive samples for viruses (cell culture) were also positive for the total coliforms, and 78% for *E. coli*.
- Borchardt *et al*. (2012) found that 20% of positive samples for viruses using *quantitative polymerase chain reaction* (qPCR) were also positive for total coliforms, and 0% for *E. coli*. Note that qPCR testing does not distinguish between infectious and non-infectious viruses.
- Abbaszadegan *et al*. (2003) found no correlation between positive samples for viruses (qPCR and cell culture) and total coliforms, enterococci, and bacteriophage indicators.
- Craun *et al*. (1997) found that outbreaks associated with viruses always had positive total coliform readings, concluding that coliforms are an adequate indicator for waterborne viruses.
- Lieberman *et al*. (2002) found that, on a per site basis, total coliform, *E. coli*, enterococci, bacteriophage results did not correlate in a statistically significant manner with enteric viruses.

Due to the variability of the studies cited above, the absence of pathogen indicators is not considered to guarantee the absence of enteric viruses (Health Canada, 2011). The presence of indicators can however, be considered an indication of the likely presence of viruses. While this may not be the case on a per sample basis, studies by Abbaszdegan *et al.* (2003) and Lieberman *et al.* (2002) found that sites that tested positive for an indicator (total coliforms, enterococci, and *E. coli*) also tested positive for viruses at some time during their respective studies.

There are methods capable of detecting and measuring viruses in drinking water, such as cell cultures and qPCR (see Appendix C), however, they are not practical for routine monitoring because of methodological and interpretation limitations (Appendix C). The microbiological quality of drinking water, including viruses, continues to be verified by relying on the monitoring of pathogen indicators such as *E. coli* and total coliforms.

Coliforms in Distribution System Samples

If fecal or total coliforms are found in the distribution system, it may or may not be an indication of microbial contamination of the ground water source. Source water quality monitoring is required to evaluate whether the total coliforms are due to microbial contamination of the ground water source or if they were introduced during distribution. 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 the ground water source or sources (i.e., untreated raw water).

Data Availability

When considering available bacteriological water quality results, DWOs often encounter one of three situations:

1. They are required to review a new well seeking approval with limited bacteriological water sampling information and must make a decision regarding the need for disinfection.
2. They are reviewing an existing approved water system 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.

A DWO will need to consider how a limited bacteriological water quality sampling history, or alternately a long-term record of results, is able to characterize the risk of a ground water source of containing pathogens, both over time and across all environmental conditions. Uncertainty with sampling results can be reduced by increasing the number of samples and observing consistent results across a range of environmental and operating conditions.

Number of Samples

With respect to the number of bacteriological samples required to approve a ground water source of drinking water, regulatory practice typically requires a minimum of three consecutive samples. However, from a statistical standpoint, three samples provide less than 10% assurance that the water source is actually free of fecal bacteria. The number of negative bacteriologically-tested water samples required to provide a sufficient level of statistical confidence that the negative sampling results illustrate a water source free from pathogens must be judged on a case by case basis.

Statistical probability estimates can provide a sense of 'confidence' in what a certain number of consistent sample results might indicate about the overall water quality (NHMRC, 2011 and Appendix B), however, there will always be a level of uncertainty. The more consecutive negative bacteriological water quality results that are collected over time, the higher the level of statistical confidence that a water source is free of microbiological contamination. For example, if the DWO wants to be 95% confident that the water from a well is free of fecal contamination, then at least 150 consecutive negative samples would be required from the well in question. These samples would have to be taken consistently across the range of environmental and operating conditions that the well would commonly experience.

In the case of new water sources, or water sources that have not yet accumulated a large number of results from lab samples, a DWO should also consider how broader contextual factors (such as the other hazards in the screening checklist) affect what statistical level of confidence might be appropriate. Negative lab results are not a stand-alone assessment of overall risk to a water source; they will either be in agreement with, or in opposition to, what is indicated by the other hazards. For example, a DWO might be satisfied with a low number of negative samples (therefore a low statistical confidence) if the water source has no other potential hazards. Conversely, the DWO may wish to have a greater number of negative samples if other hazards are present. Ultimately, a determination of 'low risk' for any single hazard is subject to the results of ongoing monitoring (Stage 4).

4.1.2 Hazard A2 – Turbidity

4.1.2.1 Description

A water supply system well that has reported intermittent turbidity or has a history of consistent turbidity greater than 1 NTU.

Turbidity is the measure of the amount of light scattered by suspended matter in a water sample, or the clarity of a sample, usually described in nephelometric turbidity units (NTUs). Causes of turbidity in surface water include soil particles, organic matter, human waste discharge, and pathogens. If surface water infiltrates a ground water source it can introduce these materials, and this cause of turbidity may place the ground water at risk of containing pathogens.

4.1.2.2 Hazard Assessment

For ground water sources that show intermittent or constant turbidity greater than 1 NTU, the cause of the turbidity and the nature of the suspended particles should be determined to best assess the risk of containing pathogens. In the absence of knowing what the cause of the turbidity may be, the DWO may conclude that the water source is at risk from this hazard until sufficient evidence can be provided that there is no associated pathogenic risk.

If there are historical turbidity issues associated with the ground water source, the water supplier should, within a reasonable time period, investigate and identify the cause and nature of the material causing the turbidity. This may involve further testing or it could be addressed as part of a Level 2 investigation. In the absence of such testing, DWOs have the option of considering available bacteriological testing results, which may indicate if there is a correlation between turbidity events and the presence of coliforms (and hence the potential for other pathogens) in the ground water source.

The ground water source may be considered either:

- At low 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; and
    - testing shows that the turbidity is not a result of organic particles or biological organisms; or
    - a Level 2 or 3 investigation has been completed and the qualified professional deems the ground water source to be at low risk of containing pathogens for this hazard.

OR

- At risk of containing pathogens (GARP) if:
    - testing shows that the turbidity is a result of organic particles or biological organisms (see Sources of Turbidity below); or

- 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 after the bacteriological testing was completed; or
- a Level 2 or 3 investigation has been completed and the qualified professional deems the ground water source to be at risk of containing pathogens for this hazard.

4.1.2.3 Supplementary Information

Field vs. Lab Analysis

Turbidity measurements may be completed in the field or in the lab. Measurements conducted in the field can be more representative of in situ conditions, particularly for mineralized ground water, as precipitates can increase the turbidity of a sample during transport time and prior to analysis in a lab. Refer to section 8.2.3 of this guide for additional information.

Sources of Turbidity

Turbidity in ground water can be the result of underground causes, such as well construction materials, particles of rock, sand, silt and clay from the process of well development, or other geologic material in the aquifer such as iron and manganese. Turbidity caused by this subsurface, non-organic material does not introduce pathogens, and commonly poses an aesthetic concern rather than a health risk.

The GCDWQ turbidity guideline technical document (Health Canada, 2012d) places the potential causes of turbidity into three classes:

1. Inorganic particles (silt, clay, natural precipitants such as $CaCO_3$, MnO_2, Fe_2O_3).
2. Organic particles (decomposed plant and animal debris, humic substances).
3. Biological organisms (algae, cyanobacteria, zooplankton, filamentous or macrobacterial growth).

Suspended inorganic particles and colloidal matter (such as clay or silt) in ground water can be a result of the geologic media of the aquifer or infiltration of well construction materials. The method of sample collection may also determine how turbid a sample appears. Additional samples may be needed to confirm that turbidity is not an artifact of the sampling method.

4.2 B. WELL LOCATION

4.2.1 Hazard B1 – Setbacks from Sources of Contamination

4.2.1.1 Description

A water supply system well that is situated inside setback distances from possible sources of contamination as per section 8 of the HHR.

In addition to the setbacks in the HHR (see section 1.2 of this guide), the DWO may consider whether or not the well is adjacent to other potential sources of pathogens such as sources of human fecal matter and agricultural animals, other domesticated animals, or wildlife (Health Canada 2012).

4.2.1.2 Hazard Assessment

If the well is situated less than the required setback distances from the potential sources of contamination as identified in the HHR, the water supplier must investigate 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 Level 2 or 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 if possible. During this time period, the users of the water system should be made aware of the potential health risk and the actions the water purveyor is taking to eliminate the hazard. Following these actions, the ground water source may be considered either:

- At low risk of containing pathogens if:
  - the water supplier demonstrates that the potential source of contamination is addressed to the satisfaction of the DWO; and
  - subsequent 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 addressed the potential source of contamination to the satisfaction of the DWO.

4.2.1.3 Supplementary Information

Potential Sources of Pathogens

Human and animal feces, especially from cattle, are the main sources of pathogenic bacteria and protozoa. Since viruses are host specific, viruses found in animal feces generally do not cause illness in humans, although there are exceptions (Health Canada, 2011). Consequently, human feces are the primary source of pathogenic viruses.

Ground water can become contaminated by pathogens in a number of ways including, but not limited to, contact with surface water, infiltration of waste from the ground surface, and leaking below-ground infrastructure. Waste containing animal and human feces present on the surface from activities such as manure spreading, wastewater irrigation, and waste disposal sites can potentially contaminate an aquifer through the infiltration of feces-contaminated surface runoff into the subsurface. Waste management infrastructure, such as wastewater lagoons, wastewater injection sites, failing onsite sewerage systems, and leaking municipal sewage pipes (especially force mains) are potential below-ground sources of contamination by human feces.

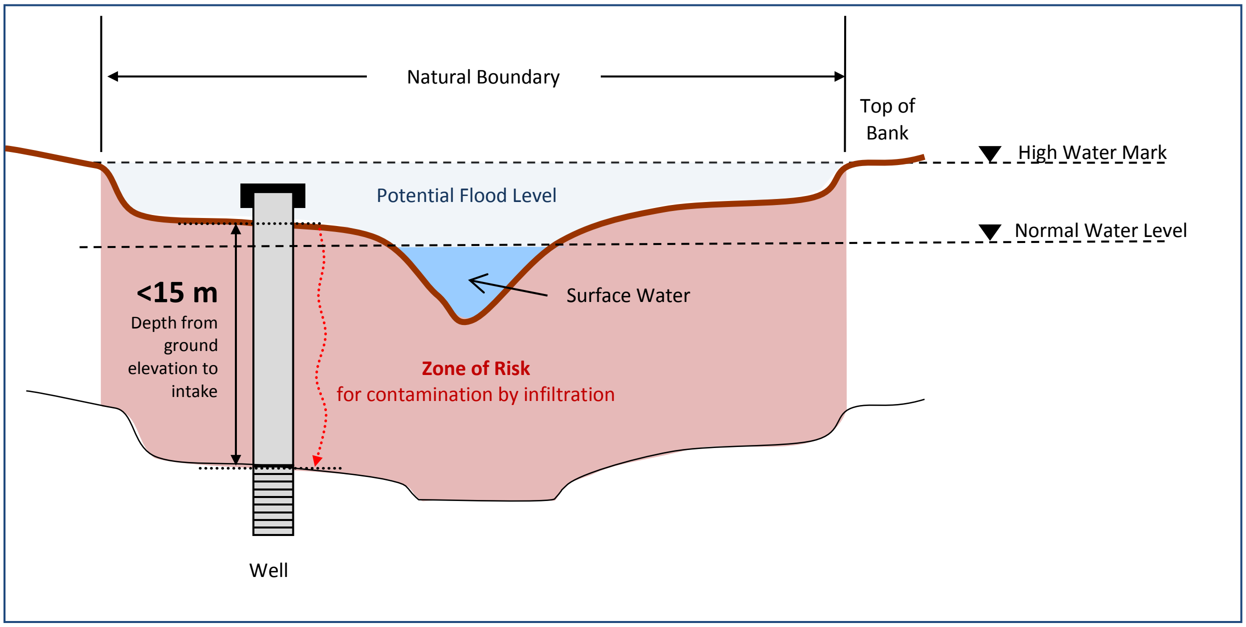
4.2.2 Hazard B2 – Flood Risk

4.2.2.1 Description

A water supply system well with an intake depth less than 15 m below ground surface that is located within a *natural boundary* of surface water or a flood prone area (Figure 2).

The *intake depth* of a well is the depth at which water enters the well. It 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.

Figure 2: Flood risk hazard (Hazard B2) screening criteria



4.2.2.2 Hazard Assessment

If the well is located within the natural boundary of a surface water body and has an intake depth less than 15 m below ground surface, a water supplier is required to demonstrate, within a reasonable time frame and to the satisfaction of the DWO, that there is a low risk of floodwater infiltration into the well. The DWO may consider a review of bacteriological water monitoring results and well setting as sufficient, or they may request a Level 2 or 3 investigation.

Following these actions, the ground water source may be considered either:

- At low 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 a Level 2 or 3 investigation deems the ground water source to be at low risk of containing pathogens for this hazard; and/or
- the water supplier demonstrates to the DWO's satisfaction that an effective response plan is in place to protect 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 a Level 2 or 3 investigation deems the ground water source to be at risk of containing pathogens for this hazard.

4.2.2.3 Supplementary Information

Wells Deeper than 15 m

The DWO may, depending on the location of the well and the geologic materials the well is completed in, determine that the 15 m depth may not be appropriate due to, for example, highly vulnerable aquifers or, conversely, the presence of an *aquitard* or *aquiclude*. Where available, the well log should be reviewed to better understand the specific characteristics of the aquifer and the overlying geologic material.

Estimating Natural Boundary

A visible natural boundary often indicates the expected extent of recurring flooding. Each well needs to be assessed on a site specific basis in the field. Factors that should be considered when estimating the extent of the natural boundary or flood prone area include:

- Are there any topographic constrictions, e.g., change of slope at the top of the bank or evidence of past erosion?
- Is there a notable change in surficial soil/sediment deposits or vegetation?
- Is there an artificial structure in place, such as a dike, to address major flood hazards?
- Is the *high water mark* easily identified? Depending on adjacent topography, the location of the high water mark can often be related to the size of the *stream*:
  - For streams < 5 m wide, the high water mark could be located up to 30 m from the *normal water level*.
  - For streams 5 to 30 m wide, the high water mark could be located up to 100 m from the normal water level.
  - For streams >30 m wide, the high water mark could be located up to 1 km from the normal water level.

4.2.3 Hazard B3 – Hydraulic Connection to Surface Water[3]

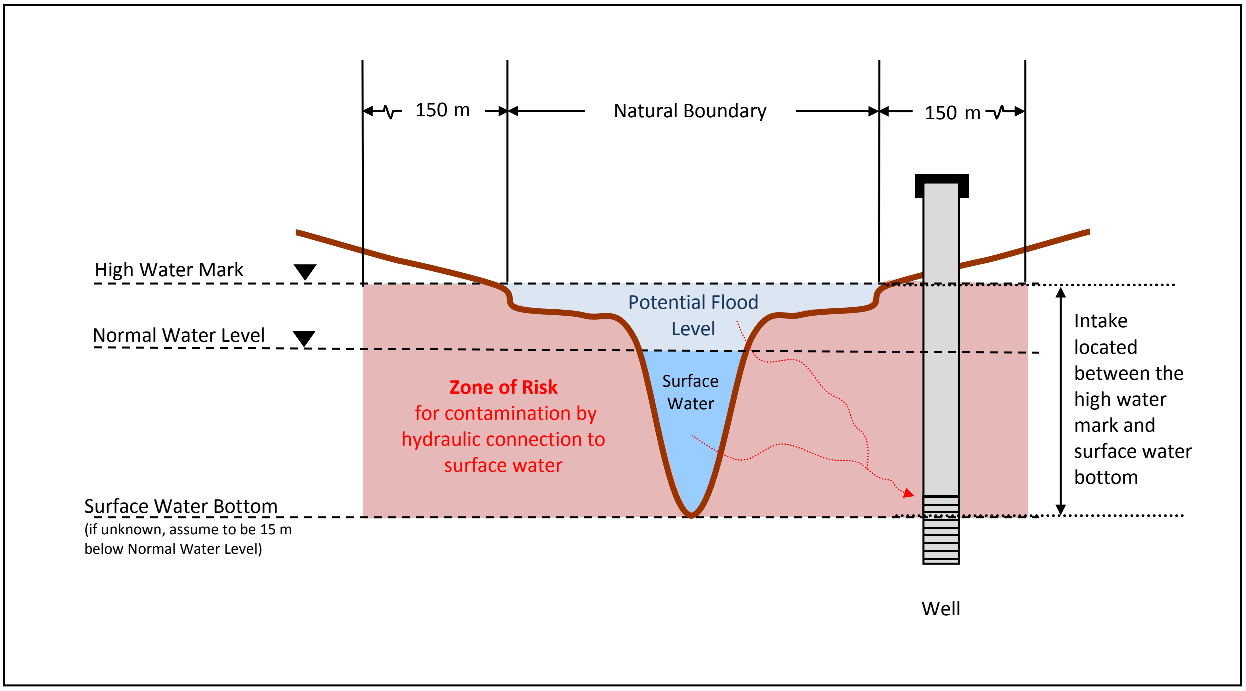
4.2.3.1 Description

A water supply system well with an intake depth:

a) between the high-water mark and surface water bottom, or if information is not available on surface water depth, less than 15 m below the normal water level, and

b) located within, or less than 150 m from the natural boundary of any permanent or intermittent surface water, drainage ditch, lagoon, reservoir or marine water (Figure 3).

Figure 3: Connection to surface water hazard (B3) screening criteria



The DWO may, depending on well characteristics (e.g., horizontal collector wells, high withdrawal rates), determine that a hydraulic connection to surface water likely exists at depths below the surface water bottom. This may require further study through a Level 2 investigation.[4]

[3] http://a100.gov.bc.ca/appsdata/acat/documents/r50832/HydraulicConnectMW3_1474311684426_4310694949.pdf

[4] Supplement Information: Determining the Likelihood of Hydraulic Connection (Wei et al. 2016) http://a100.gov.bc.ca/appsdata/acat/documents/r50832/HydraulicConnectMW3_1474311684426_4310694949.pdf

4.2.3.2 Hazard Assessment

Wells meeting the location and intake depth criteria of hazard B3 are considered to be connected to surface water. However, it is possible that a hydraulic connection may not exist between the well and the surface water, or that subsurface filtration provides an adequate level of treatment.

In these circumstances, a water supplier is required to demonstrate, within a reasonable time frame and to the satisfaction of the DWO, that there is no hydraulic connection to surface water or that subsurface filtration is adequate. The DWO may consider a review of bacteriological water monitoring results and well setting as sufficient, or they may request a Level 2 or 3 investigation or a subsurface filtration study.[5]

Following these actions, the ground water source may be considered either:

- At low 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 a Level 2 or 3 investigation or subsurface filtration study deems the ground water source to be at low risk of containing pathogens for this hazard; and/or
    - the water supplier demonstrates, to the satisfaction of the DWO, that an effective response plan is in place to protect 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 a Level 2 or 3 investigation or subsurface filtration study deems the ground water source to be at risk of containing pathogens for this hazard.

4.2.4 Hazard B4 – Viruses

4.2.4.1 Description

A water supply system well located within 300 m of a source of probable enteric viral contamination without a barrier to viral transport.

Hazard B4 differs from the other GARP hazards in that an assessment of this hazard can result in an overall GARP determination that a ground water source is at risk of containing viruses only. Viruses require specific consideration in the assessment of a ground water source because

[5] Further information on subsurface filtration studies can be found in Appendix A of the *Drinking Water Treatment Objectives (Microbiological) for Ground Water in British Columbia (MOH, 2015)*.

they can be pathogenic at low concentrations, and their small size, negative charge, and longevity, relative to other pathogens, potentially allows for the transport of viable viruses over long distances from a source of contamination.

A water supply well that meets this hazard's criteria is potentially at risk of containing viruses. The well may also be at risk of containing bacteria and protozoa as per the criteria in hazard B1.

4.2.4.2 Hazard Assessment

If potential sources of fecal contamination are present within 300 m of the well[6], the water supplier must investigate and, if necessary, address the potential impacts to the ground water source. This may occur in parallel with, or as part of, a source-to-tap assessment.

Where a source of contamination exists, but a barrier to viral transport is believed to protect the aquifer from contamination, it should be kept in mind that subsurface geological features may be variable in thickness and/or discontinuous in location. If a barrier to viral transport is a key part of a 'low risk' determination, it may be necessary to confirm through a Level 2 or 3 investigation that the barrier extends across the well's entire capture zone or within the *time of travel* necessary to inactivate viruses (see section 8.2.2 of this guide), if determined.

If the aquifer lacks a barrier to impede the migration of viruses, the water supplier may still be able to demonstrate low risk to the satisfaction of the DWO if the ground water flow from the potential viral source is in a direction away from and outside the capture zone of the well (downgradient), that the time of travel from a potential source of contamination is sufficiently long to inactivate viruses, or that attenuation and removal of viruses is occurring in the subsurface due to mechanisms such as subsurface filtration, predation, and inactivation.

If further study of these mechanisms is required, it will likely involve the completion of a Level 2 or 3 hydrogeological investigation. Alternately, a water supplier may elect to consider the well is 'at risk' under this hazard and move to Stage 3: Risk Mitigation to address the specific risk from viruses.

The ground water source may be considered either:

- At low risk of containing pathogens if:
  - the source of the viral contamination has been identified and eliminated; or
  - the water supplier demonstrates that the potential source of contamination is addressed to the satisfaction of the DWO; or
  - a Level 2 or 3 investigation has been completed and the qualified professional involved deems the ground water source to be at low risk of containing pathogens for this hazard.

OR

[6] A 300 m radius is consistent with the specifications for a contaminant source inventory outlined in the *Comprehensive Drinking Water Source-to-Tap Assessment Guideline* (MHLS, 2010) and the Arbitrary Fixed Radius parameter recommended by the BC MOE as one method for delineating well capture zones (BC MOE, 2006).

- At risk of containing pathogens (GARP) if:
  - within a reasonable time period, the source of the viral contamination has not been identified and eliminated;
  - the water supplier has not addressed the potential source of contamination to the satisfaction of the DWO; or
  - a Level 2 or 3 investigation has been completed and the qualified professional deems the ground water source to be at risk of containing pathogens for this hazard.

4.2.4.3 Supplementary Information

Refer to section 8.2.2 of this guide for further information regarding viruses in ground water, and section 4.2.1.3 for further information on potential sources of pathogens.

Virus Transport

The transport and longevity of viruses is affected by many factors such as ground water temperature, soil particle size, aquifer stratigraphy, preferential pathways of movement, and the presence of organic matter in the substrate.

Some studies have shown that viable viruses can travel hundreds of meters from a source of viral contamination to a well, depending on the amount of contamination and the hydrogeology of the aquifer (Borchardt *et al.*, 2007 and Locas *et al*., 2007). These studies suggest that although wells may not have many of the hazards outlined in this procedure they may still be at risk of containing viruses.

Indicator Organisms for Viruses

While Locas *et al*. (2007) was able to demonstrate a correlation between total coliform and viruses, bacteriological sample results alone were considered insufficient to determine if a risk of viruses exists. There are no standardized, practical methods to detect and measure viable viruses in ground water (Health Canada, 2011). In lieu of a quantitative method, wells are screened in this assessment based on their proximity to a potential source of contamination and the presence or absence of a barrier to viral transport

Screening Radius

Potential sources of contamination located within 300 m of a ground water well suggest that the ground water source at the site of the well is potentially at risk of containing viruses. The 300 m radius is consistent with the contaminant source inventory outlined in the Comprehensive Drinking Water Source-to-Tap Assessment Guideline (MHLS, 2010), and the Arbitrary Fixed Radius parameter recommended by the B.C. MOE for delineating *capture zone* areas where limited hydrogeological information is available (BCMOE, 2006).

The DWO may accept that a source of contamination within 300 m does not pose a risk to a well if there is reasonable evidence that the source of contamination is outside of the well's capture zone, is downgradient from a well, has a time of travel to the well of greater than 200 days, or there is a barrier to viral transport.

4.3 C. WELL CONSTRUCTION

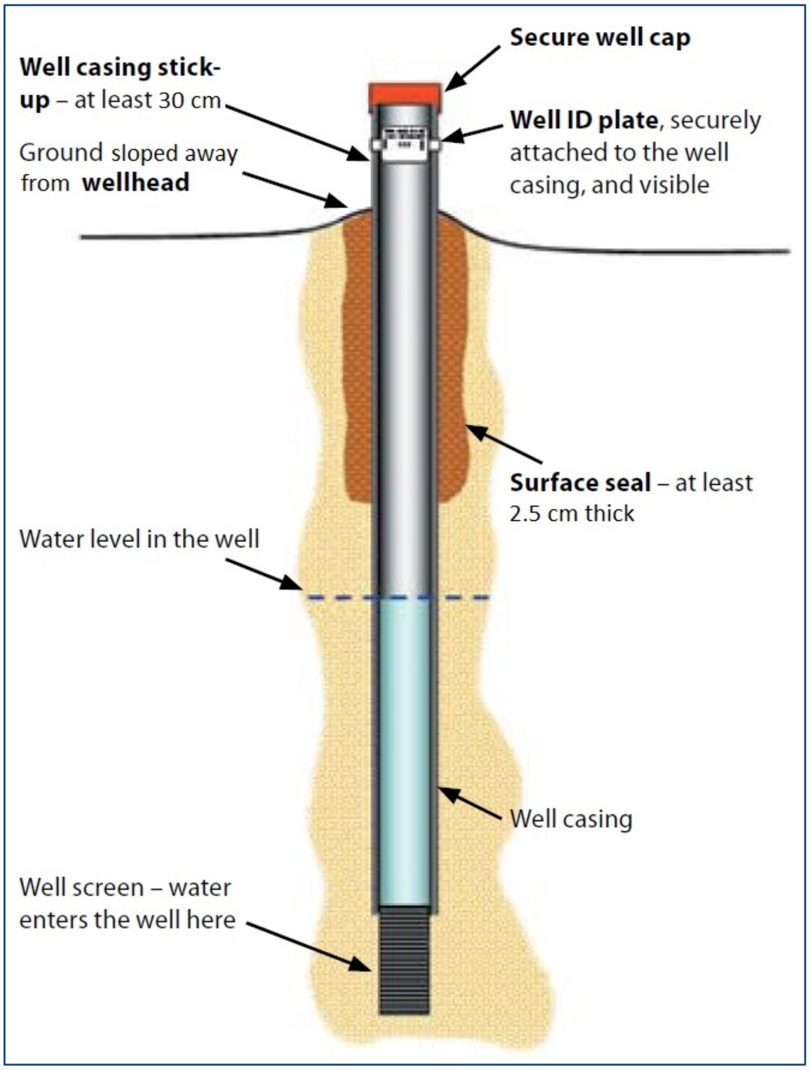
Proper well construction is one of the best barriers for preventing the entry of pathogens into a well from surface runoff and flooding.

GWPR Part 3, Part 4 and Part 7 cover requirements for well construction including *surface sealing*, *well caps* and *well covers* and protection of the *wellhead* (Figure 4). GWPR section 63 and DWPA Section 16 address *floodproofing of wells*. WSA section 54 also addresses *well caps* and *well covers*.

The GWPR sets out the minimum standards required under the WSA for the accurate construction, identification, reporting on, testing, maintenance, alteration, deactivating and decommissioning of wells. If a well fails to meet the well construction standards then the water source is considered to be at risk of containing pathogens. Field inspection of the well is highly recommended to confirm current conditions. **Altering the well to meet the well construction standards may prevent the water source from being considered at risk of containing pathogens.**

A DWO may wish to consult with a Groundwater Protection Officer on hazards concerning the requirements of the GWPR.

Figure 4: Basic Well that Meets the GWPR Well Construction Standards (adapted from MOE 2007c)



4.3.1 Wells Pre-dating the Groundwater Well Regulation

Existing wells completed before November 1, 2005 – the date well construction became regulated in BC— may not necessarily meet any of the requirements of the well construction requirements as these were not made retroactive[7]. All existing *water supply wells* regardless of age must meet the requirements of Section 54 of the WSA and Part 4 of the GWPR regarding well caps and well covers. A DWO may reasonably decide that the lack of the protective

[7] The current Groundwater Protection Regulation came into force February 29, 2016. The previous Ground Water Protection Regulation came into force Nov 1, 2005.

measures as described in GWPR (Part 3, Div. 3, Div. 5 and Part 7) and DWPA (section 16) presents a public health risk (even if those sections do not apply to a particular well because of its date of construction) or request that well construction be included for further examination under a Level 2 investigation (section 8.2 of this guide).

4.3.2 Well Records

During examination of well construction, a copy of the original well record (where available) should be checked for information on well construction and verified in the field (e.g., static water level, well diameter, well depth, etc.).

Summary information on individual wells, where available, may also be found in the WELLS Database[8] and iMapBC[9]. Instruction on how to use these two resources is provided in A Guide to Finding Water Well Information.[10] The Well ID Plate Number (the number on the tag attached to the well) and the Well Tag Number (WTN – a database number), where these are known, can be used to search for individual well records. Well information may also be found by referencing the well's water licence. All non-domestic groundwater users (including water utilities) must have a water licence associated with their well.

4.3.3 Hazard C1 – Surface Sealing

4.3.3.1 Description

A well that does not meet GWPR (Div. 3) for surface sealing.

All water supply wells constructed after November 1, 2005 must have in place an effective and permanent surface seal as indicated in GWPR (Part 3, Div. 3).

For purposes of the screening checklist, visual inspection of the immediate area around the well casing may be sufficient to determine whether there is any annular space present. 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 may extend to within 0.3 meters of the ground surface and therefore 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 Level 2 investigation (see section 8.2 of this guide).

A surface seal for a water supply well must not be less than 5 meters in length unless the depth of the water is insufficient to have a seal of this length or the method of drilling is by driving, in which case the surface seal must not be less than 1 m in length (GWPR s. 23). If bedrock is encountered within 5 meters of the surface the surface seal must extend to a minimum depth of 1 m into competent bedrock. Refer to the well record to verify the length of the surface seal.

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[8] http://www.env.gov.bc.ca/wsd/data_searches/wells/index.html
[9] http://maps.gov.bc.ca/ess/sv/imapbc/
[10] http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-wells/guide_to_finding_water_well_information.pdf

4.3.3.2 Hazard Assessment

Wells that do not have a surface seal are vulnerable to possible pathogenic contamination and the water supplier will be required to alter the well construction to comply with the surface seal standards for new wells in the GWPR or equivalent, where practical, followed by disinfection and re-sampling. Following these actions, the ground water source accessed by the well may be considered:

- At low risk of containing pathogens if:
  - the water supplier corrects the surface seal deficiencies in accordance with the instructions of the DWO[11]; and/or
  - the DWO assesses any deficiencies and, although in need of correction, they are not considered to increase the risk of pathogen contamination in the water source. [12]

OR

- At risk of containing pathogens (GARP) if:
  - surface seal deficiencies place the ground water source at risk and the water supplier is unable or unwilling to correct the surface seal in accordance with the instructions of the DWO.

4.3.3.3 Supplementary Information

Surface Seal Upgrades

If older wells (drilled prior to November 1, 2005) are altered, the owner of the well must ensure any annular space that develops is sealed[13]. Under the *Water Sustainability Act (Section 91(4)(a); Sections 93(1)(g) and 93(2)(d)),* the comptroller, engineer, and /or officer can also require upgrading of the surface seal if the existing well poses a threat of contamination entering a neighbouring well or ground water.

4.3.4 Hazard C2 – Well Caps and Covers

4.3.4.1 Description

A well that does not meet GWPR (Part 4) for well caps and covers.

[11] Construction and retrofitting work on a well should be undertaken by a qualified well driller, qualified pump installer or a person under the direct supervision of a qualified well driller, qualified well pump installer or a qualified professional who has competency in the field of hydrogeology or geotechnical engineering.

[12] Noncompliance with the GWPR is a separate issue from determining if a deficiency in well construction creates a GARP situation. While a DWO may state that a non-compliant well does not make a water source 'at risk' (GARP), this does not waive the need for wells to be compliant with the GWPR as required.

[13] Construction and retrofitting work on a well should be undertaken by a qualified well driller, qualified pump installer or a person under the direct supervision of a qualified well driller, qualified well pump installer or a qualified professional who has competency in the field of hydrogeology or geotechnical engineering (as per the WSA and GWPR).

All water supply wells must have a secure and effective well cap or cover that meets the requirements of GWPR Part 4 and WSA section 54 to prevent the direct or unintended entry of any surface water, persons, animals or foreign matter into the well and to prevent or minimize flow of water from a flowing artesian well. Well caps must be commercially manufactured or fabricated from durable material having strength suited to the location of the well cap and the local environmental conditions.

4.3.4.2 Hazard Assessment

Wells without a well cap or cover are vulnerable to possible pathogenic contamination and the water supplier will be required to install a cap or cover to comply with the GWPR, followed by disinfection and re-sampling. Following these actions, the ground water source accessed by the well may be considered:

- At low risk of containing pathogens if:
  - the water supplier installs a well cap or cover in accordance with the instructions of the DWO ; and/or
  - the DWO assesses any deficiencies and, although in need of correction, they are not considered to increase the risk of pathogen contamination in the water source.

OR

- At risk of containing pathogens (GARP) if:
  - deficiencies in well construction place the ground water source at risk and the water supplier is unable or unwilling to install a well cap or cover in accordance with the instructions of the DWO.

4.3.5 Hazard C3 – Floodproofing of Wells

4.3.5.1 Description

A well that does not meet GWPR (section 63) and DWPA (section 16) for floodproofing.

For the purposes of the screening checklist, if there is any concern regarding the adequacy of floodproofing, this should be noted and considered for further consideration under a Level 2 investigation (see Section 8.2 in this guide).

4.3.5.2 Hazard Assessment

Wells that have deficiencies in floodproofing are vulnerable to possible pathogenic contamination and the water supplier will be required to improve floodproofing to comply with the well construction standards for new wells in the GWPR or equivalent (e.g. DWPR), where practical, followed by disinfection and re-sampling. Following these actions, the ground water source accessed by the well may be considered:

- At low risk of containing pathogens if:
  - the water supplier corrects the deficiencies in floodproofing in accordance with the instructions of the DWO ; and/or

  - the DWO assesses any deficiencies and the water supplier demonstrates, to the satisfaction of the DWO, that an effective response plan is in place to protect the water supply during infrequent periods of elevated risk.

OR

- At risk of containing pathogens (GARP) if:
  - deficiencies in flood-proofing place the ground water source at risk and the water supplier is unable or unwilling to alter the well construction in accordance with the instructions of the DWO.

4.3.5.3 Background Information

New Wells

All new water supply system wells must be located, completed, equipped and maintained to prevent the entry of any flood debris and flood waters, including into any annular space along the outside of the well casing, and the well or wellhead must be protected from any physical damage due to flood debris, ice or erosion.

Existing Wells

Under section 63 of the GWPR, the owner of a well supplying a water supply system must ensure that the well is completed, equipped and maintained in a manner that prevents any foreign matter from entering from the surface of the ground into the well, either directly into the top of the well or through an annular space, and protects the well and wellhead from physical damage due to flood debris, ice or erosion. An engineer may order the owner to alter or maintain the well so that it complies with the flood-proofing requirements.

4.3.6 Hazard C-4: Wellhead Protection

4.3.6.1 Description

A well that does not meet GWPR (Part 3 Div. 5 and Part 7) for wellhead protection.

All new water supply system wells must have a production casing that extends a minimum of 0.3 m above the ground surface adjacent to the well or 0.3 m above the floor of a well pump, well pit, or pumphouse. The area immediately around the well must be finished to ensure water does not pond around the wellhead 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.

4.3.6.2 Hazard Assessment

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

- At low risk of containing pathogens if:
  - the water supplier corrects the deficiencies in wellhead protection in accordance with the instructions of the DWO; and/or
  - the DWO assesses any deficiencies and, although in need of correction, they are not considered to increase the risk of pathogen contamination in the water source.

OR

- At risk of containing pathogens (GARP) if:
  - deficiencies in wellhead protection place the ground water source at risk and the water supplier is unable or unwilling to correct the deficiencies in wellhead protection in accordance with the instructions of the DWO.

4.3.6.3 Operation and Maintenance

To properly minimize the risk of pathogen contamination wells must be properly maintained to retain the design specifications required by the GWPR. Failure to properly maintain the well and the area around the well in a manner that is consistent with Part 7 of the GWPR risks contaminating the source and placing those who rely on the source in jeopardy.

4.4 D. AQUIFER TYPE AND SETTING

4.4.1 Hazard D-1: Shallow wells

4.4.1.1 Description

A water supply system well with an intake depth < 15 m below ground surface.

Shallow wells are highly vulnerable to possible sources of pathogenic contaminants finding their way into the shallow well intake, making the ground water potentially at risk of containing pathogens.

4.4.1.2 Hazard Assessment

If a well is completed in a shallow aquifer, a water supplier may be able to demonstrate, to the satisfaction of the DWO, that the ground water drawn from the well has a low risk of containing pathogens. This will likely involve a review of bacteriological water quality results, aquifer type and quality of aquitards (where they exist) and, if necessary, a Level 2 (and Level 3, where warranted) investigation to verify subsurface conditions. Following these actions, the ground water source accessed by the well may be considered:

- At low risk of containing pathogens if:
  - there is a barrier to flow from the surface that is considered by the DWO to be sufficient to place the well at low risk and sufficient bacteriological water monitoring results do not show the presence of total coliform, fecal coliform, and/or *E. coli* in the ground water source; and/or

  - a qualified professional, possibly after completing a Level 2 or 3 investigation, deems the ground water source to be at low risk of containing pathogens for this hazard.

OR

- At risk of containing pathogens (GARP) if:
  - The DWO considers the barrier to flow from the surface (if any) to be insufficient; and/or
  - the qualified professional completing a Level 2 or 3 investigation deems the ground water source to be at risk of containing pathogens for this hazard.

4.4.2 Hazard D-2: Vulnerable Aquifers

4.4.2.1 Description

A water supply system well that is situated in a highly vulnerable, unconfined, unconsolidated, or fractured bedrock aquifer.

Wells completed in vulnerable, unconfined, or unconsolidated aquifers or fractured bedrock aquifers are vulnerable to contamination as pathogens may find their way into the aquifer due to potential preferential pathways in the formation.

4.4.2.2 Hazard Assessment

If a well is completed in a highly vulnerable, unconfined, unconsolidated, or fractured bedrock aquifer, the well is, by default, considered at risk of containing pathogens (GARP). Despite this, a water supplier may be able to demonstrate, to the satisfaction of the DWO, that the ground water drawn from the well has a low risk of containing pathogens. This will likely involve a review of bacteriological water quality results, well depth and subsurface conditions. If necessary, a Level 2 (and Level 3, where warranted) investigation may be completed to verify subsurface conditions. Following these actions, the ground water source accessed by the well may be considered:

- At low risk of containing pathogens if:
  - despite being in a vulnerable setting, sufficient bacteriological water monitoring results do not show the presence of total coliform, fecal coliform, and/or *E. coli* in the ground water source; and/or
  - the DWO considers the well depth and subsurface conditions sufficient to place the well at low risk of containing pathogens; and/or
  - a qualified professional, possibly after completing a Level 2 or 3 investigation, deems the ground water source to be at low risk of containing pathogens for this hazard.

4.4.2.3 Supplementary Information

Vulnerable Aquifers

Highly vulnerable aquifers are designated as "A" aquifers under the BC 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, relative to aquifer productivity, 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. Note that provincial aquifer mapping exists only where sufficient information is available. Not all aquifers in B.C. have been mapped and assessed. If there is doubt as to the vulnerability of the aquifer, further assessment of this hazard should be done.

4.4.3 Hazard D-3: Karst

4.4.3.1 Description

A water supply system well that is completed in a karst bedrock aquifer, regardless of depth. Even deep wells in karst aquifers are considered vulnerable to contamination.

4.4.3.2 Hazard Assessment

If a well is completed in karst, the well is by default considered at risk of containing pathogens (GARP). As well logs may not provide sufficient detail to identify karst deposits/features, for the purposes of the Stage 1 assessment these situations may warrant a Level 2 or 3 investigation.

Despite this, a water supplier may be able to demonstrate, to the satisfaction of the DWO, that the ground water drawn from the well has a low risk of containing pathogens. This will likely involve a review of bacteriological water quality results and, if necessary, a Level 2 (and Level 3, where warranted) investigation to verify subsurface conditions. Following these actions, the ground water source accessed by the well may be considered:

- At low risk of containing pathogens if:
  - despite being in a karst bedrock aquifer, sufficient bacteriological water monitoring results do not show the presence of total coliform, fecal coliform, and/or *E. coli* in the ground water source; and/or
  - a qualified professional, possibly after completing a Level 2 or 3 investigation, deems the ground water source to be at low risk of containing pathogens for these hazards.

4.4.3.3 Supplementary Information

Karst Distribution in B.C.
Karst terrains, characterized by dissolution channels and caves in limestones and dolomites, occur extensively in some parts of B.C. (e.g., Rocky Mountains and Vancouver Island) as reported by Stokes and Griffiths (2000). It is assumed that only a small number of water wells have been completed in these deposits to date.

5 STAGE 2: GARP DETERMINATION

In Stage 2 the DWO makes the overall determination as to whether or not the ground water source is at risk of containing pathogens (GARP). While a qualified professional can provide their opinion as to whether the source is at risk or at low risk of containing pathogens as part of a Level 2 and/or 3 hydrogeological investigation, it is the DWO who, under the DWPR, forms the final opinion as to whether a ground water source is GARP.

A GARP determination can result in three possible outcomes:

- **At risk of containing pathogens (GARP):** If one or more identified hazards pose an obvious risk of pathogenic contamination of a ground water source, the source would be determined to be **"at risk"** or **GARP**.
- If the DWO has reason to believe that the source is only at risk of containing viruses (i.e., only hazard B4 was present), the source would be determined to be **"GARP-viruses only."**
- **At low risk of containing pathogens (Non-GARP):** Where no hazards are present, or they have all been confirmed as low risk, the ground water source would be determined to be **"at low risk"** of being GARP.

During Stage 2, all of the hazards noted in the Stage 1 hazard screening and assessment must be considered together to determine the overall risk of the source being GARP. Although an individual hazard may be assessed as being "low risk," any one hazard may pose enough of a concern for the DWO to determine that a water source is GARP. However, the absence of any one hazard, for example, the lack of positive water quality results, may be insufficient to deem the water source at low risk of containing pathogens as well.

The weight that a DWO gives to the water quality sampling results is related to their understanding of what the results indicate about the ground water source. A longer history of negative sampling results taken over a range of environmental conditions can provide strong statistical evidence that a ground water source is at low risk of containing pathogens. However, the overall risk of containing pathogens now or in the future must also take into account all hazards outlined in Stage 1. Although a statistically sound bacteriological water quality sampling program can generate a high degree of confidence in the safety of a water source, sampling results are only one factor among several to be considered.

The DWO should specify what hazards form the basis for the determination and note the likely sources and pathways of contamination. For water sources determined to be "at low risk" the DWO may wish to identify hazards that may require special attention for long term monitoring (Stage 4).

Determinations that a water source is "at risk" (GARP) must implement risk mitigation (Stage 3) prior moving to long term monitoring in Stage 4. Determinations that a water source is "at low risk" can proceed to Stage 4.

6 STAGE 3: RISK MITIGATION

Risk mitigation means removing a hazard, changing the conditions that make a hazard a contamination risk, or addressing the potential presence of pathogens in the source water through disinfection. If a DWO has determined that a ground water source is GARP due to one or more hazards, the water supplier must either remove or mitigate the specific hazard(s) causing the risk, or ensure that water drawn from a GARP source is made potable before consumption. Risk mitigation options include:

- Altering the well or correcting significant deficiencies in well construction.
- Drilling a new well in a safer location and properly decommissioning the existing well in accordance with the requirements of the GWPR.
- Providing an alternate source of water.
- Establishing an exemption from section 6 of the DWPA under the provisions of section 3.1 of the DWPR.
- Eliminating source(s) of contamination, and ensuring subsequent negative bacterial water quality monitoring results. This may also be completed as part of a Source to Tap Assessment. If necessary, users of the water system should be notified that their drinking water is at risk during the time period required for eliminating the contamination source and retesting the water to confirm the absence of pathogens.
- Conducting a Level 2 and (where warranted) a Level 3 investigation, or a combination thereof, and with this supplementary information, return to the Stage 1 hazard screening and reassess the water source.
- Deferring a decision on risk mitigation requirements, including disinfection, while the water system starts or continues with Stage 4: Long-term Monitoring.
- Disinfecting the source water as required under DWPR section 5(2) and meeting any additional treatment requirements established by the water system operation permit (DWPA section 6(b)). Guidance on the treatment requirements for “GARP” and “GARP – viruses only” water sources is provided in the *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia* (MOH, 2015).

If a water supplier feels that they will be able to mitigate the hazards identified in Stage 1 by removing sources of contamination and/or through well improvements, they should develop a work plan with the DWO that identifies the specific measures to be taken, targets and timelines for work to be completed, and a post-mitigation review of the hazards addressed.

7 STAGE 4: LONG-TERM MONITORING

Ground water sources are considered either "at risk" or "at low risk" of containing pathogens, but never at "no risk" of containing pathogens. For this reason, 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 (DWPA section 11).

In addition to the bacteriological water quality monitoring requirements specified under Schedules A and B of the DWPR, DWOs may require additional monitoring or testing of ground water sources based on the results of the GARP determination. These requirements should be determined on a case-by-case basis depending upon any findings of the Stage 1 assessment, information from Level 2 or 3 investigations (if completed), or any other factors that may be of concern due to changing conditions in an aquifer, watershed, or water system.

If source water quality issues arise, existing hazards change, or new hazards emerge, the GARP determination procedure should be reinitiated starting with Stage 1: Hazard Screening and Assessment. Other strategies, such as the Comprehensive Drinking Water Source-to-Tap Assessment Guideline (MHLS 2010), and a well protection plan (BCMOE, 2006), may assist a water supplier in mitigating new hazards, maintaining an awareness of, and addressing, changing conditions.

8 WATER SOURCE INVESTIGATIONS

An understanding of a well's construction, its historical records, and its hydrogeologic setting is required to screen and assess (Stage 1), and make a GARP determination (Stage 2) of a ground water source. Information used in the GARP determination process may come from existing records (Level 1 investigation). Where this information is considered to be insufficient, the DWO may request Level 2 and/or 3 hydrogeological investigation(s), which require the services of a qualified professional.

Should subsurface filtration have the potential to mitigate pathogen risk, a water supplier may wish to incorporate studies on subsurface filtration as part of a Level 2 or 3 investigation. For more information on what should be included to complete a subsurface filtration study, refer to the *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia* (MOH 2014).

Water suppliers may choose to implement risk mitigation measure(s) (as in section 6) rather than pursue hydrogeological investigations, based on a consideration of both the capital investment and, for disinfection, ongoing costs versus the cost of an investigation. In some cases, such as for smaller water systems, the cost of further investigation may be comparable to, or higher than, the long-term cost of risk mitigation measures such as disinfection.

A Level 2 Preliminary Hydrogeological Investigation involves the review and analysis of available hydrogeological information and is intended to establish an understanding of aquifer conditions and the hazards that may place a well at risk of containing pathogens. A Level 2 investigation does not typically involve the collection of samples for advanced analyses, such as microscopic particulate analysis (MPA), or *Giardia* and *Cryptosporidium* testing (USEPA Method 1623.1). It is critical to first develop an understanding of the hydrogeological conditions of the water source prior to conducting more detailed testing. Without this understanding, it is difficult to interpret the results from procedures such as MPA and USEPA Method 1623.1, both of which only provide a snapshot of water quality. Consequently, advanced water quality testing is considered to be part of a Level 3 or a combined Level 2/3 investigation and is intended to support the conclusions drawn from a Level 2 study.

8.1 LEVEL 1: EXISTING RECORDS AND FIELD INSPECTION

A Level 1 investigation utilizes existing records at hand, may involve an informal field inspection, and may be completed by, or on behalf of, a water supplier, or the DWO. Level 1 is the base line level of information that should be available for an aquifer, a water system, an existing well, and/or a newly drilled well prior to a water system being constructed. Examples of existing records include well logs, information carried in registration systems such as the BC WELLS – Ground Water Wells and Aquifer Database,[14] water quality records, *floodplain* mapping[15], and aquifer classification (see links provided in section 3).

8.2 LEVEL 2: PRELIMINARY HYDROGEOLOGICAL INVESTIGATION

If there was insufficient information to complete the Stage 1 screening and assessment a DWO may request that a water supplier retain a qualified professional to complete a Level 2 investigation.

The Level 2 investigation provides a thorough analysis of available hydrogeological information, usually with some formal field investigation of the well and aquifer characteristics, and results in a professional opinion as to whether the ground water source is at risk, or at low risk, of containing pathogens under operating conditions. Data collection may be broad or focused on assessing specific hazards. The DWO takes the professional opinion into consideration when completing the assessment in Stage 1 and Stage 2 GARP determination.

Findings that would support a professional opinion that the water source is at *low* risk of containing pathogens include:

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

[14] http://www.env.gov.bc.ca/wsd/data_searches/wells/

[15] Floodplain boundaries may also be established from floodplain maps. Information on floodplain mapping in BC can be found on the B.C. MOE website 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. Floodplain mapping has also been made available on iMapBC: http://maps.gov.bc.ca/ess/sv/imapbc/

- Where ground water is hydraulically connected to surface water, there are subsurface filtration or other hydrogeological factors that are effective in minimizing the risk of pathogens (including viruses) from reaching the well(s) under operating conditions.[16]
- The time of travel from a source of pathogens (such as a surface water body) to the well is greater than 100 days for bacteria and protozoa, and 200 days for viruses (see section 8.2.2 in this guide).

8.2.1 Level 2 Investigation Scope

A preliminary hydrogeological investigation is fundamental to determining potential subsurface pathways for pathogens to enter a ground water source, and the scope may be focused or broad. The preliminary investigation should be designed and undertaken by a qualified professional, in consultation with the DWO. The area of investigation should consider nearby surface water features and risks beyond the local area around the well(s).

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., moving to a Level 3 investigation), long-term monitoring considerations (i.e., specifics to be included in Stage 4) and any recommended mitigation measures such as well alteration or well relocation.

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 a discussion that may include the following topics:

- Site location, topography and general drainage features.
- Climatic conditions.
- General soils and geology (unconsolidated and bedrock).
- Well and wellhead conditions.
- Hydrogeological conditions and aquifer characteristics.
- Surface water hydrology and general watershed conditions.
- Hydraulic gradients, water level fluctuations and directions of ground water flow under ambient and pumping conditions.
- Pumping conditions, well capture zones and time of travel estimates.
- Ground water and surface water quality characteristics.

[16] More information on subsurface filtration studies can be found in the *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia* (MOH 2014).

- Conditions that support virus transport and survival.
- Land use and potential sources of contamination.
- Conclusions (with supporting reasons).
- Recommendations for further investigations (if any) and/or mitigations strategies (if any).

As site conditions and availability of information may vary significantly among different water supply situations, professional judgment should determine the most important factors to be examined and what additional detailed information might need to be acquired. It is essential that consultation between the DWO, the water supplier and the qualified professional takes place as a work plan is developed for this preliminary investigation. Uncertainty analysis and critical assessment of data gaps should be included in the Level 2 investigation.

Suggested elements that could be considered for these topics are outlined in Table 8-1. This may be used as a checklist to assist with the development of the preliminary hydrogeological investigation. A detailed description of these topics is beyond the scope of this guidance document. The table should be considered only as a guide as it may not be possible to evaluate all the topics due to lack of readily available information.

Table 8-1: Potential Elements for a Level 2 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.
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, aquitards or aquicludes, well construction features, non-pumping water levels and relationship to surface water features / pumping test data / conceptual hydrogeological model, including hydrostratigraphic units and geologic boundaries / aquifer parameters

Topic	Elements*
	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) Conditions that support virus transport and survival	Soil characteristics that promote attachment of viruses to soil particles / mean annual ground water temperature / extent of aquitard or impermeable layer / aquifer characteristics (fractured, unconsolidated, etc.) / travel time from contamination source to well / well capture zone
k) 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.
l) Conclusions	Summary of the evidence and the need, if any, for additional investigations, long-term monitoring considerations and any improvements to be made. Supporting reasons, including uncertainties.
m) Recommendations	Recommendations for further investigations and/or mitigative strategies, if any.

* 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* estimates as outlined in Appendix 2.3 of the Well Protection Toolkit (BCMOE, 2006) or comparable approaches (e.g. the Comprehensive Drinking Water Source-to-Tap Assessment Guideline (MHLS 2010)). The estimates should also consider time of travel 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 is restricted 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 meters may occur in very coarse sand and gravel deposits and fractured bedrock situations (Crowe *et al*., 2003). In fractured bedrock and karst settings, ground water flow velocities can be orders of magnitude higher than unconsolidated deposits, and can provide less attenuation along the flow path 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 would require the resources of a Level 3 investigation.

For more complex situations, such as a number of water supply wells in close proximity with each other that have overlapping capture zones, it may be prudent to incorporate elements of both Level 2 and Level 3 investigations to employ more specialized investigatory techniques such as computer modeling, pumping tests, and extended periods of water quality monitoring. Please note, the GWPR requires a distance of 15 m between wells unless alternative specifications have been agreed upon (GWPR s. 18)

8.2.2 Considerations for Virus Transport

Where an assessment of virus transport and longevity is required, the Level 2 investigation should include an assessment of the pathways and conditions that influence the survivability and movement of viruses in the subsurface.

The longevity of viruses within an aquifer and the pathways for viral contamination are affected by a number of factors which increase the likelihood of viable viruses reaching a ground water well (WQRA, 2010 and USEPA, 2003). These factors may include: the distance of the contaminant source from the water table, presence and integrity of barriers to viral transport, the capacity of the soil media to adsorb viruses, as well as the length and time of travel of the flow path from the source of contamination to the well (USEPA, 2003).

The migration of viruses from a source of contamination is highly dependent on soil conditions and factors such as soil pH, water content and temperature (Health Canada, 2011) as well as the presence of preferential flow paths, such as those found in heterogeneous coarse-grained materials, fractured bedrock, and karst formations. Preferential flowpaths may also be anthropogenic (human caused) such as annular spaces along wells accessing the same aquifer.

There is an increased likelihood of viral presence in ground water wells if there is a contamination source close to the water table in saturated conditions, a presence of preferential flow paths, and a short time of travel from the source of contamination to the well (USEPA, 2003).

Based on modeling information provided in Yates *et al*., 1985, a conservative estimate of average time of travel from a source of viral contamination to a well screen, to achieve up to a 4-log inactivation of viruses, is 200 days (at an average ground water temperature of 5°C). Temperature, rather than chemical water quality parameters (such as pH or nitrates) has the most significant effect on virus survival (as the temperature increases, the survival time decreases).

The estimate of 200 days is considered conservative as it does not account for filtration, adsorption or predation of viruses, all of which would hasten a 4-log reduction of viruses, and work to shorten the necessary time of travel. To account for the effects of both adsorption and inactivation, the model developed by Schijven *et al*. (2006) may be considered in order to refine the time of travel based on site specific aquifer conditions.

8.2.3 Considerations for Turbidity

The GCDWQ classification of the causes of turbidity may be identified in a water sample in two distinct but complementary ways:

1. directly, but qualitatively, through microscopic particulate analysis (MPA); or
2. indirectly, but quantitatively, through gravimetric analysis.

Organic particles or biological organisms in ground water are indicative of surface water influence and hence they suggest a risk of pathogens also being present (see also Hazard A2, Section 4.1.2). If the turbidity is inorganic then there may not be any increased risk of pathogens. It may be acceptable for some ground water systems to operate under conditions of greater than 1 nephelometric turbidity units (NTU) without requiring filtration or additional disinfection provided that there are no hazardous microbiological factors present at greater turbidities and that greater turbidities do not negatively impact any treatment processes that may be required.

8.2.4 Level 2 Investigation Outcomes

The information collected via a Level 2 investigation should address the uncertainties around specific hazards identified in Stage 1. This should allow for the completion of the hazard assessment and to determine whether or not a water source is “at risk” or “at low risk” of being GARP (Stage 2). If there is insufficient information generated by the Level 2 investigation to complete the assessment in Stage 1, a Level 3 detailed hydrogeological investigation may be warranted.

8.3 LEVEL 3: DETAILED HYDROGEOLOGICAL INVESTIGATION

The Level 3 investigation provides more conclusive hydrogeological evidence and a professional opinion, based on several lines of investigation using scientifically advanced methods, whether or not the ground water at the water supply system well(s) is at a low risk of containing pathogens under operating conditions. It provides information to resolve any uncertainties encountered in the hazard assessment of Stage 1 which could not be resolved through a Level 2 investigation.

Findings that would support a professional opinion that the water source is at *low* risk of containing pathogens include:

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

8.3.1 Level 3 Investigation Scope

The Level 3 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 for specific hazards, and the need, if any, for specific long-term monitoring considerations.

The scope of a detailed hydrogeological investigation should build upon the findings of any Level 2 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 detailed techniques to be employed. Development of a work plan and discussion with health officials prior to undertaking the work are highly recommended.

A Level 3 investigation should consider additional site investigations involving the following topics and methods:

- Test drilling and completion of monitoring wells.
- Extended aquifer pumping tests to determine aquifer parameters.
- Computer flow modeling and simulation of extended pumping periods.
- Advanced well capture zone analysis.
- Reverse particle-tracking and advanced time of travel determinations.

- Monitoring of water levels and water quality (ground water and surface water) over extended periods of time.
- Particle counting.
- Microscopic particulate analysis (MPA) testing.
- Virus surrogate tracking.
- USEPA Method 1623.1 testing.
- Isotope testing.
- Other advanced techniques including qPCR.

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Table 8-2. lists suggested elements that should be considered for these topics.

Table 8-2: Potential Elements for a Level 3 Investigation

Topic	Elements*
a) Test drilling and completion of monitoring wells	Construction of monitoring 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, aquitards and aquicludes, 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 monitoring 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 well capture zone analysis	Use of water level data from monitoring wells / description of numerical model employed, assumptions and limitations / boundary conditions / simulate ground water equipotential contours and flow directions / sensitivity analysis.
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.

Topic	Elements*
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 indicators of surface water interaction including organisms such as *Giardia* / 1 or more samples at different times of the year including worst case conditions / quality-control procedures in sampling / sampling locations.
i) Virus surrogate tracking	Sampling and testing to track the movement of viral surrogates such as bacteriophage or coliphage. Analysis for *Giardia* and C*ryptosporidium* surrogates, such as bacterial spores *Bacillus subtilis* or *Clostridium perfringens* may be considered as alternative test parameters, at the discretion of the DWO. Sampling should include times of worst case conditions.
j) USEPA Method 1623.1 testing	Sampling and testing for *Cryptosporidium* and *Giardia* in ground water / one or more samples at different times of the year including worst case conditions / quality-control procedures during sampling / sampling locations (USEPA, 2012).
k) 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.
l) Other advanced techniques including qPCR	Sampling and testing for viral DNA/RNA in ground water (Appendix C) / 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.

* 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).

Table 8-2), the design of an adequate program may involve many factors. Samples should be collected during times of the year when the risk is likely to be the highest (e.g., freshet, high summer pumping conditions). 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 MPA testing (Appendix C).

8.3.2 Level 3 Investigation Outcomes

The information collected via a Level 3 investigation should address the uncertainties around specific hazards that were identified in the hazard assessment that could not be resolved through a Level 2 investigation. This should allow the completion of Stage 1 and the overall GARP determination of the ground water source in Stage 2.

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APPENDIX A: GLOSSARY OF TERMS

GLOSSARY REFERENCES (if not a specific literature reference)

CCME	Canadian Council of Ministers of the Environment, 2004
DWPA	*Drinking Water Protection Act*
DWPR	Drinking Water Protection Regulation
FC	Freeze and Cherry, 1979
GWPR	Ground Water Protection Regulation
WSA	*Water Sustainability Act*
WPT	Well Protection Toolkit, 2002

Alter: In relation to a well, means (a) undertake a structural change to a well related to the well's depth, diameter or screen assembly,(b) install a surface seal in a well that does not have one, or (c) hydrofracture a well to enhance groundwater supply from the well. (WSA)

Annular space: an open space between the outside of the casing of a well and the surrounding geological formation, or an open space between 2 or more casings in the same well. (WSA)

Aquifer: a geological formation, a group of geological formations, or a part of one or more geological formations that is groundwater bearing and capable of storing, transmitting and yielding groundwater. (WSA)

Aquitard: less-permeable beds in a stratigraphic sequence, permeable enough to transmit water in quantities that are significant in the study of regional groundwater flow but with permeability insufficient to allow the completion of production wells. (FC)

Aquiclude: saturated geologic unit incapable of transmitting significant quantities of water under ordinary hydraulic gradients (FC)

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

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.

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

Barrier to viral transport: an unconsolidated deposit of low permeability, sufficient thickness, and with an absence of preferential pathways to preclude viruses from an aquifer.

***Cryptosporidium*:** a genus of protozoan parasites potentially found in water and other media; also see *oocysts.* (USEPA, 2012)

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). Typical size of *Cryptosporidium* oocysts is (4 to 6 μm) and shape (round to oval). (USEPA, 2012)

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

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

Engineer: as specified under the *Water Sustainability Act*, except in the definition of "professional" in section 48, means a person designated as an engineer under section 114 (5). (WSA)

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

- Digging in 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 droppings, and naturally in soil. (BCMOE, 2007b)

Floodplain: a lowland area, whether diked, 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, 2012)

***Giardia lamblia*:** a species of the genus *Giardia.* (also called *G. intestinalis* or *G. duodenalis*; found in humans and other mammals). (USEPA, 2012)

Ground water (groundwater): water naturally occurring below the surface of the ground. (WSA)

Ground water source: the raw subsurface water from which a well draws.

Ground water at risk of containing pathogens (GARP): any ground water source that is likely to be contaminated from any sources of human disease-causing microorganisms (pathogens) including various types of bacteria, viruses and protozoa (e.g., *Giardia* and *Cryptosporidium*). Contamination may be continuous or intermittent.

Ground water under direct influence of surface water (GWUDI or GUDI): "any water beneath the surface of the ground with:

(a) significant occurrence of insects or other macro-organisms, algae, organic debris, or large-diameter pathogens such as *Giardia lamblia*, *Cryptosporidium*, or

(b) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions." (USEPA, 1991a)

High-water mark: see natural boundary

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 level: 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 looking at the vegetation and topography.

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, 2012)

Pathogens: disease-causing organisms. (CCME)

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

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.

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

Quantitative polymerase chain reaction (qPCR): is a laboratory technique used to amplify and simultaneously quantify one or more specific sequences in a targeted DNA molecule. The quantity can be either an absolute number of copies or a relative amount when normalized to DNA input. Reverse transcription-quantitative polymerase chain reaction (RT-qPCR) is a variant of qPCR used to detect RNA expression levels.

Professional (in relation to Division 3 of the *Water Sustainability Act)***:** a professional engineer, or a professional geoscientist who is registered or licensed under the *Engineers and Geoscientists Act, or* a holder of a limited licence under the *Engineers and Geoscientists Act* acting within the scope of the limited licence*.* (WSA)

Qualified (in relation to the *Water Sustainability Act)***:** in respect of an activity in relation to a well or well pump; (a) for a well driller, means a well driller who has the qualifications prescribed as required to perform or supervise the activity in relation to the well or well pump; and (b) for a well pump installer, means a well pump installer who has the qualifications prescribed as required to perform or supervise the activity in relation to the well or well pump. (WSA)

Sealant: a sealing material or mixture of sealing materials that is less permeable than the surrounding geological formation to be sealed, appropriate for the particular soil and water conditions, and non-toxic and does not have an adverse impact on the quality of the groundwater in an aquifer or a well. (GWPR);

Small water system: a water supply system that serves up to 500 individuals during any 24 hour period. (DWPR)

Stream: a natural watercourse, including a natural glacier course, or a natural body of water, whether or not the stream channel of the stream has been modified, or a natural source of water supply, including, without limitation, a lake, pond, river, creek, spring, ravine, gulch, wetland or glacier, whether or not usually containing water, including ice, but does not include an aquifer. (WSA)

Stream channel: in relation to a stream, means the bed of the stream and the banks of the stream, both above and below the natural boundary and whether or not the channel has been modified, and includes side channels of the stream. (WSA)

Subsurface or riverbank 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)

Surface water: water which is open to the atmosphere and includes streams, lakes, rivers, creeks and springs. (DWPR) For the purposes of this document it also includes surface runoff.

Surface seal: a sealant that is installed in the annular space around the outside of the outermost casing and between multiple casings, and extends to or just below the surface of the ground. (GWPR)

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 well used or intended to be used for the purpose of exploring for, diverting or using groundwater, and includes a water source well, but does not include a drainage well, dewatering well or remediation well. (GWPR)

Well: an artificial opening in the ground made for:

- Exploring for or diverting groundwater,
- Testing or measuring groundwater,
- Recharging or dewatering an aquifer,
- Groundwater remediation,
- Use as a monitoring well,
- Use as a closed-loop geoexchange well, or
- Use as a geotechnical.

but does not include

- An artificial opening, other than a water source well, to which the *Geothermal Resources Act* or the *Oil and Gas Activities Act* applies, or
- An artificial opening of a prescribed class, made for a prescribed purpose or in prescribed circumstances. (WSA)

NOTE: For the purposes of this document the term 'well' refers to a *water supply well* that is used for the purposes of human consumption as well as domestic uses such as bathing and food preparation.

Well cap: a secure cap or lid that prevents vermin, contaminants, debris or other foreign objects or substances from entering the interior of the production casing, and includes a sanitary well seal. (WSA)

Well capture zone: see 'capture zone'

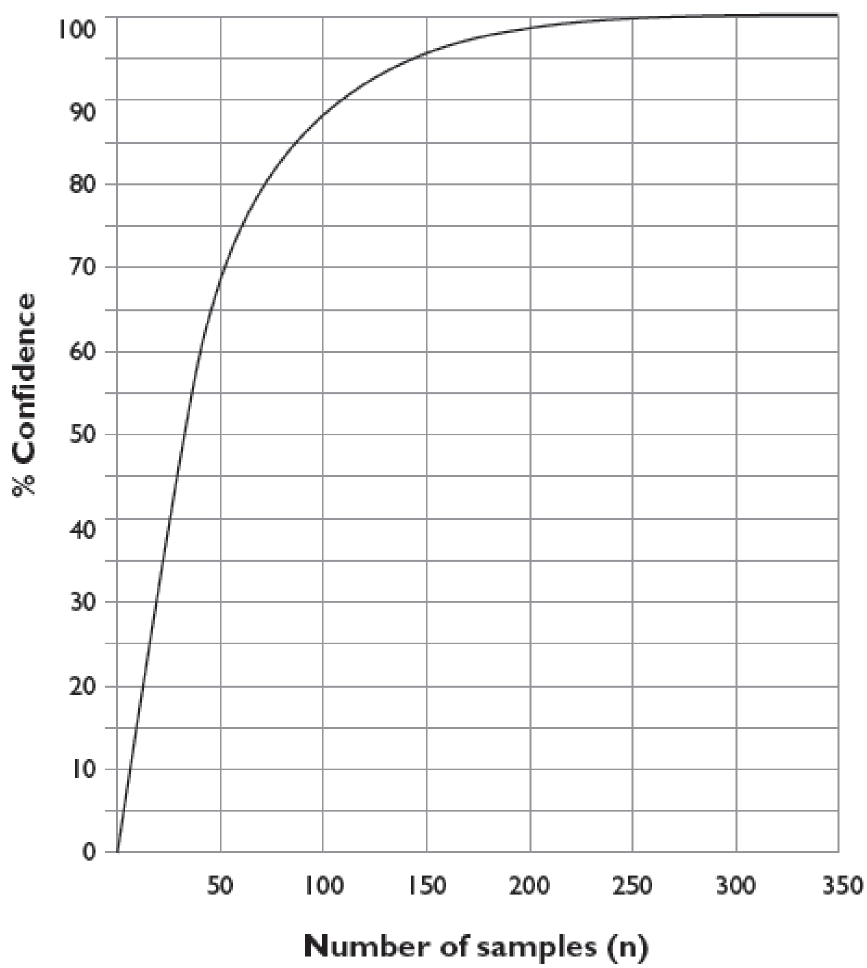
Well cover: means a secure cover, lid or structure that prevents vermin, contaminants, debris or other foreign objects or substances from entering the well. (WSA)

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

APPENDIX B: AUSTRALIAN DRINKING WATER GUIDELINE REFERENCE

"Information Sheet 3.5: Number of Samples Required," contained in the 2011 Australian Drinking Water Guideline (NHMRC, 2011), provides a plot (see below) showing how statistical confidence levels increase as the number of consecutive negative (i.e., no fecal contamination) water samples increases (in this case it is the statistical confidence that 98% of water in a supply is free of fecal contamination).

Figure 5: Levels of confidence versus numbers of negative samples (all samples are free of fecal contamination) to indicate that 98% of the water in a supply is free of fecal contamination (NHMRC, 2011, reprinted with permission).



APPENDIX C: MPA, USEPA METHOD 1623.1 AND QPCR ANALYSES

A water quality sampling program is typically included as part of the Level 3: Detailed Hydrogeological Investigation (section 8.3). Such water quality sampling programs are intended to provide quantitative evidence to support a determination of the risk a ground water source has of containing pathogens. However, water quality sampling results alone are insufficient to determine the risk a well has of containing pathogens and does not replace the need for an understanding of the hydrogeological conditions at the well. The DWO must consider both the qualitative and quantitative information available when making a GARP determination. It is essential that the scope of any water quality sampling program be discussed with a DWO prior to the program commencement.

A water quality sampling program may include microscopic particulate analysis (MPA) and USEPA Method 1623.1 testing for *Giardia* and *Cryptosporidium*. For both tests, the analyzing laboratory typically provides sampling instructions, the sampling equipment, filter media, and transporting containers. 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.

Microscopic Particulate Analysis

Microscopic Particulate Analysis (MPA) is one means of assessing the ground water source for indicators of surface water connection. The MPA test was developed by the USEPA as a quantitative tool to assess the likelihood that ground water is under the direct influence of surface water based on the significant occurrence of primary and secondary surface water indicator organisms such as algae and *Giardia cysts*. The test, including sampling and analysis methodology, is described in detail in the USEPA document *Consensus Method for Determining Groundwaters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (MPA)* (USEPA, 1992). The MPA test provides a relative risk score for a sample collected from the ground water source based on the significant occurrence of primary and secondary surface water indicator organisms such as diatoms and certain other algae, rotifers, coccidia, insect parts, and *Giardia*. 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, 1991).

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 ground water 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). Consequently, MPA test results alone cannot form the basis for a determination on whether a ground water source is GARP or at low risk of containing pathogens.

Due to the high cost of MPA analysis and the long sample collection time required, the collection of a large number of MPA samples is often impractical. At the same time, one or two MPA tests may be insufficient to predict future MPA values (Jacangelo *et al*., 2001). A MPA testing program typically involves 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 (i.e., periods of high recharge) and during high pumping demand periods. Timing of sampling should also consider time of travel delays for MPA analysis to be effective.

MPA sampling involves the filtration of a large volume of water (typically 4,000 L) through a 1 um nominal wound filter. At the lab, the filter is unwound, releasing the particles collected on the filter. Depending on the volume of concentrated particles obtained, either all or a portion of the concentrated particles are then smeared on a series of lab slides and visually inspected under a microscope. The number of *Giardia,* coccidia, diatoms, algae, insects, rotifers, and plant debris are counted. The number of each indicator is then scored on a scale from not significant to extremely heavy based on Table 1 of the USEPA Consensus Method (U.S. EPA, 1992). Since some indicators are more indicative of surface water presence than others, each score is converted to a relative risk factor using Table 2 of the Consensus Method. The sum of the relative risk factors results in a risk ranking for the water sample ranging from 0 to 121.

The MPA risk ranking is then specified based on the following:

- MPA low risk: <=9
- MPA moderate risk: 10-19
- MPA high risk: >=20

These risk rankings should not be confused with the determination of "at risk/at low risk" of containing pathogens made through the GARP procedure. There are a limited number of laboratories in Western Canada that conduct MPA testing. Contact the local health authority staff for details on these laboratories.

USEPA Method 1623.1

In 1999 the USEPA validated a method for simultaneous detection of *Cryptosporidium* and *Giardia* and designated the combined procedure as USEPA Method 1623.1. The latest method was published in January 2012 following a number of revisions (USEPA, 2012). Method 1623.1 is a more sensitive test for *Giardia* compared to the MPA test and especially sensitive for *Cryptosporidium.* Method 1623.1 is a quantification of *Cryptosporidium* and *Giardia* in the sample. While positive results could be considered as an indication that the sampled ground water contains pathogens, a negative result alone does not indicate that the ground water is disconnected from surface water or at low risk of containing pathogens at the time of sample collection, or in the future.

Sampling procedures for Method 1623.1 and options are outlined in the USEPA document entitled *Method 1623.1: Cryptosporidium and Giardia in Water by Filtration/IMS/FA* (USEPA, 2012). The test involves filtering a relatively small volume of water (i.e., 100 to 500 liters).

Method 1623.1 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. Similar to MPA testing, there are a limited number of laboratories in Western Canada that conduct USEPA Method 1623.1 analysis. Contact local health authority staff for details on these laboratories.

Quantitative Polymerase Chain Reaction Testing

If testing for specific viruses is desired, this can be achieved through the use of cell culture or quantitative polymerase chain reaction (qPCR) testing. These two methods vary greatly in their procedures, limitations, and the nature of the results provided. Health Canada (2011) considers cell culture, despite its limitations, to be the best method for determine occurrence of infectious viruses in water. However, given the efficiency and minimization of analyst error, the advanced testing possible with qPCR is rapidly becoming the detection method preferred by researchers (Prystajecky, 2014).

qPCR testing verifies the presence or absence of virus DNA or RNA, but is unable to indicate whether or not the virus is infectious (Bosch, 1998), which is the characteristic of most importance when determining the potential health impact from a ground water source potentially at risk of containing pathogens. Studies where qPCR testing has been conducted in parallel with cell culture tests (which are able to determine infectivity for certain viruses) have found a large proportion of positive qPCR tests did not test positive for infectious viruses by cell culture (Borchardt *et al*., 2012, Bradbury *et al*., 2013 and Abbaszadegan *et al.*, 1999). While this outcome may have been due in part to differences in test sensitivity between qPCR and cell culture, it highlights the need to interpret qPCR results with caution.

The detection of viral DNA/RNA indicates that the ground water is connected to a source of viral contamination (Prystajecky, 2014). Arguably all ground water is connected at some point to surface water, therefore, how long the viruses have been in the ground water and the survivability of an infectious virus become of relevance if qPCR test results are to be used for assessing the risk to public health. These factors are currently unknown. Consequently, both Health Canada (2011) and the USEPA (2012a) cite caution when using qPCR testing to directly address issues of public health.

APPENDIX D: EXAMPLE GARP DETERMINATION FIELD FORM

The following is an example of what a field form might look like for the purposes of the Stage 1 screening and assessment. Actual fields for data collection may vary according to the needs of the health authority office.

WATER SYSTEM NAME: ____________________________________

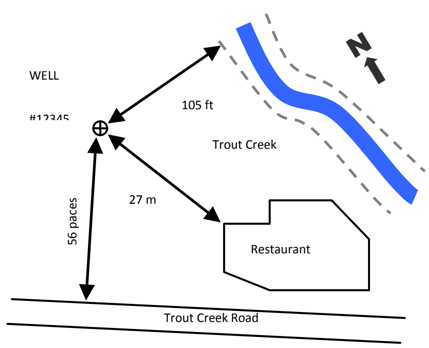
WELL NAME: ________________________

☐ **B.C. MoE Well Identification Plate Number:** ________________________

☐ **B.C. MoE Aquifer:** ☐☐☐ / none / unknown **Local Aquifer Name:** ________________________

			Verbal / Measured
Well Log: ☐ Examined ☐ Attached ☐ NA ☐ Site Sanitary Survey Conducted			
LATitude: ☐☐.☐☐☐☐☐ ° N , **LONG**itude: ☐☐☐.☐☐☐☐☐ ° W			☐ / ☐
Well Depth:	feet *or* metres below ground *or* ☐	unknown	☐ / ☐
Water Level in Well:	feet *or* metres below ground *or* ☐	unknown	☐ / ☐
Well Casing Diameter:	inches *or* mm *or* ☐	unknown	☐ / ☐

Well Location Sketch



Sketch the well location and proximity to roads, buildings, waterways, sources of contamination, etc. Distances may be estimated in feet or metres or paced off.

Stage 1: Hazard Screening and Assessment

HAZARDS Water Supply System Well	SCREENING		ASSESSMENT		NOTES
	NOT PRESENT	PRESENT (Complete Assessment)	AT RISK (Water source potentially GARP)	AT LOW RISK	
A. Water Quality Results					
A1: Exhibits recurring presence of total coliform bacteria, fecal coliform bacteria, or *Escherichia coli* (*E. coli*).					
A2: Has reported intermittent turbidity or has a history of consistent turbidity greater than 1 NTU.					
B. Well Location					
B1: Situated inside setback distances from possible sources of contamination as per section 8 of the HHR.					
B2: Has an intake depth <15 m below ground surface that is located within a natural boundary of surface water or a flood prone area. (Fig 1)					
B3: Has an intake depth between the high-water mark and surface water bottom (or < 15 m below the normal water level), and located within, or less than 150 m from the natural boundary of any surface water. (Fig 2)					
B4: Located within 300 m of a source of probable enteric viral contamination without a barrier to viral transport.					
C. Well Construction					
C1: Does not meet GWPR (Part 3 Div. 3) for surface sealing.					
C2: Does not meet GWPR (Part 4) and WSA (section 54) for well caps and covers					
C3: Does not meet GWPR (section 63) and DWPA (Section 16) for floodproofing.					
C4: Does not meet GWPR (Part 3 and Part 7) for wellhead protection.					
D. Aquifer Type and Setting					
D1: Has an intake depth <15 m below ground surface.					
D2: Is situated in a highly vulnerable, unconfined, unconsolidated or fractured bedrock aquifer.					

D3: Is completed in a karst bedrock aquifer, regardless of depth.					

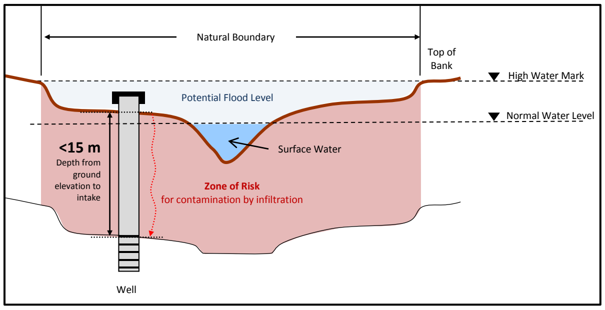


Figure 1: Hazard B2, Flood Risk

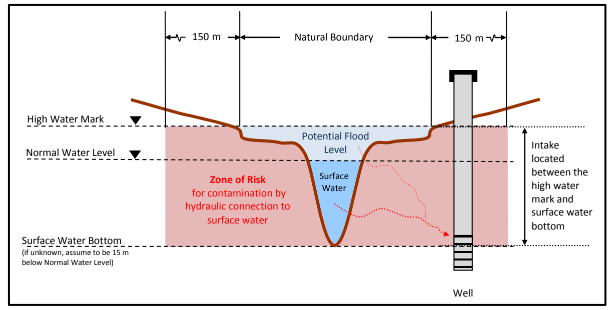


Figure 2: Hazard B3, Connection to Surface Water

Stage 2: GARP Determination

☐ At Risk (GARP) ☐ At Risk (GARP-viruses only) ☐ At Low Risk

- If "at risk" the water supplier should undertake one or more mitigation measures (see options below).
- If "at risk" because information is unavailable or inconclusive for any hazards in the checklist, consider moving to Level 2 or 3 investigation.
- If "at low risk", indicate only "Move to Stage 4: Long-term Monitoring" below.

Stage 3: Risk Mitigation

Recommended options:

- ☐ Treatment to meet provincial drinking water objectives
- ☐ Treatment to meet only the provincial drinking water objectives for viruses
- ☐ Provide alternate source of water
- ☐ Well Alteration / correct significant deficiencies in well construction.[17]
- ☐ Relocate the well
- ☐ Eliminate source(s) of contamination
- ☐ Level 2 or 3 investigation
- ☐ Move to Stage 4 Long-term Monitoring
- ☐ Other

Comments:

Completed by: ______________________________ DATE: _______________________

[17] Deficiencies in well construction related to the Ground Water Protection Regulation must be addressed.