NOVA SCOTIA

Environment

GUIDE TO GROUNDWATER ASSESSMENTS FOR SUBDIVISIONS SERVICED BY PRIVATE WELLS

Prepared: July 2011

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1.0 INTRODUCTION

1.1 Background

Access to safe, adequate and reliable water supplies is essential for new residential subdivision developments. In areas that do not have centralized municipal water systems, individual private water wells can usually meet this requirement. However, in order to reduce the risk of water quality and quantity problems with private wells, it is beneficial to have groundwater information available before subdivision developments proceed. If groundwater conditions are considered early during the process of creating a residential subdivision served by private water wells, actions can be taken in advance that will reduce the risk of water quality and quantity problems. These actions could include such things as ensuring adequate distances between water wells to avoid well interferences, or having special well construction requirements to prevent contamination. It is less costly to prevent these types of problems during the planning process than to correct them after they occur.

The purpose of this guide is to provide an approach for conducting groundwater assessments as part of a subdivision approval process in areas to be serviced by individual private wells. The guide is based on similar guidance documents published by the Halifax Regional Municipality (2006), Newfoundland and Labrador Department of Environment and Conservation (2009) and the Ontario Ministry of the Environment (1996).

This guide has two levels of assessment:

> Level 1 assessments are screening level assessments used for small subdivision developments where there is a low risk of potential well water problems. These types of assessments make use of existing information and can be carried out relatively quickly.
>
> Level 2 assessments are used in situations where there is a higher risk of well water problems, such as large subdivision developments or areas with a history of well water problems. Level 2 assessments involve drilling test wells and conducting pumping tests and water quality testing.

1.2 Objectives

The objectives of groundwater assessments for proposed subdivision developments serviced by private wells are as follows:

1. To minimize the risk of potable water quality and quantity problems in new residential subdivisions; and
2. To minimize potential impacts of subdivision developments on existing groundwater users and the environment.

1.3 How to Use this Guide

This guide is intended to be used as part of a residential subdivision approval process in areas to be served by individual private water wells, especially where there may be potable water quality and quantity problems. Municipalities can use this guide to incorporate groundwater assessments into the development agreement process where lots are being created. The use of the guide is at the discretion of the municipality.

The first step in this process is for the municipality to decide if a groundwater assessment is needed. This decision can be made on a case-by-case basis, using the criteria in Table 1. If a groundwater assessment is needed, the developer retains a qualified hydrogeologist (see definition in the paragraph below) to complete the assessment and prepare a report. The municipality reviews the report and determines, based on the report's conclusions and recommendations, if the subdivision can proceed as proposed. If modifications to the proposed subdivision are necessary, the appropriate provisions are incorporated within the development agreement. The municipality may need to retain a third party to assist with the report review if this expertise is not available in-house. A reviewer's checklist is provided in Appendix A to assist with the review process.

Groundwater assessments must be done under the supervision of a qualified hydrogeologist. For the purposes of this document, a qualified hydrogeologist is defined as a person with hydrogeology training and experience, and licenced to practice in Nova Scotia by the Association of Professional Geoscientists of Nova Scotia or the Association of Professional Engineers of Nova Scotia.

Table 1: Guide for Determining Level 1 and Level 2 Assessment Requirements

No. of Lots	Comments	Assessment
<10	A groundwater assessment is not required for subdivisions with less than ten lots, each having a minimum size of 2,787 m^2 (30,000 ft^2), unless the area has known groundwater quality or quantity problems.	**No assessment required**
10 to 25	A proposed subdivision with 10 to 25 lots requires a Level 1 assessment. If the Level 1 assessment report recommends a Level 2 assessment, the municipality may request a Level 2 assessment. A level 2 assessment is recommended for subdivisions with 10 or more lots where open-loop groundwater heat pumps are proposed.	**Level 1 assessment**
>25	A proposed subdivision with greater than 25 lots requires a Level 2 assessment.	**Level 2 assessment**

Where existing lots are already in place, any addition to their number may trigger the above assessments. For example, if a subdivision of five lots was previously approved and five more lots are being added, then a Level 1 assessment would be required because the total number of unserviced lots in the subdivision is equal to ten.

Nova Scotia Environment's (NSE) Regional Hydrogeologists are available to answer questions about local groundwater conditions and can provide assistance finding groundwater information available from NSE and the Nova Scotia Department of Natural Resources (NSDNR). Contact information is provided in Section 4.0 of this guide and a directory of available water data is available in Appendix E.

Although NSE does not regulate groundwater assessments for subdivisions, the department does regulate the following areas related to groundwater and drinking water supplies: well construction (applies to all water wells), water withdrawal approvals (applies to water wells that pump more than 23,000 L/day), and public drinking water supplies (these include municipal drinking water supplies and registered public drinking water supplies). Further information about these regulatory requirements is available from NSE.

2.0 LEVEL 1 ASSESSMENT

A Level 1 assessment consists of a records review, a site visit and reporting. A description of each of these tasks is provided in the following sections.

2.1 Records Review

The objective of the records review is to use existing information to characterize the local hydrogeology, surface water features and land use in the vicinity of the proposed subdivision. Much of this water information can be accessed on-line through Nova Scotia Environment's groundwater webpage (http://www.gov.ns.ca/nse/water/groundwater/) and NSDNR's Interactive Groundwater Map webpage (http://gis4.natr.gov.ns.ca/website/nsgroundwater). A complete directory of relevant databases and websites is provided in Appendix E.

The records review should include, but not be limited to, the following :

- NS Well Logs Database: review and compile local well records from the most recent version of the database;
- NS Pumping Test Database: review and compile local pumping test results from the most recent version of the database for the proposed aquifer source;
- Water quality data: review and summarize available water quality analyses for the proposed aquifer source;
- Groundwater reports: review available groundwater studies and/or literature on the area;
- Geological maps and reports: assess local bedrock and surficial geology, including stratigraphy, depth, thickness, composition, texture, known relevant weathering/alteration/structural features (i.e. joints, fractures, faults, or bedding planes), water bearing potential and lateral continuity based on existing information;
- Watershed information: identify primary, secondary and tertiary sub-watersheds of the proposed development site, and assess surface water features within 500 metres of the site boundaries, including the types of surface water features and the location of the surface water features relative to the site. Providing the information is available, surface water features should also be assessed for water levels, flow rates, seasonal variation, surface water quality, drainage patterns, flood risk and annual precipitation rates; and

- Stormwater Management Plans: if available, review subdivision Stormwater Management Plans with respect to water budget information and the potential for water quality impacts to local aquifers.

During the records review stage it may be helpful to speak with local well contractors and government hydrogeologists (e.g., NSE Regional Hydrogeologists) about the local groundwater conditions. Contact information for NSE is provided in Section 4.0 of this guide.

2.2 Site Visit

Conduct a site visit to verify and supplement the information collected from the records review. In particular, the site visit is used to confirm locations of off-site wells, local land use, surface water body features and obvious sources of potential groundwater contamination (industrial land use, landfills, etc.). The site visit should focus on the area within approximately 500 m from the proposed subdivision site.

2.3 Reporting

A Level 1 report includes the information shown in Table 2 and addresses the conclusions and recommendations identified in Sections 2.3.1 and 2.3.2.

Table 2: Level 1 Reporting Requirements

No.	Task	Description
1	Site Description	Describe the site location and the details of the proposed subdivision (i.e., number of lots, location and size of proposed lots).
		Describe the surrounding land use. Determine if there are current or historical land uses that may cause groundwater contamination (e.g., landfills, gas stations, dry cleaners, other commercial/industrial facilities, etc.).
		Identify existing water users. Describe how many wells are located within at least 500 m of the site and what they are used for (i.e., domestic, commercial, industrial, municipal, agricultural uses).
		Discuss known water quality and quantity concerns in the area (e.g., water shortages, low well yields, high arsenic levels, etc.).
2	Description of Hydrogeology	Describe the hydrogeology, geology and surface water features including: geological mapping, pumping test results, water quality results, and surface water/watershed characteristics.
3	Evaluation of potential effects	Discuss potential well interference effects that the proposed subdivision wells may have on each other and the effects they may have on existing off-site wells.
		Discuss the potential effects that the proposed subdivision wells may have on surface water and the environment.
		Discuss the risk that on-site septic systems may pose to individual wells.
4	Conclusions	See Section 2.3.1 for specific requirements.
5	Recommendations	See Section 2.3.2 for specific requirements.
6	Supporting Figures and Data	Site location map and lot plan with water well locations and septic field locations (well locations must meet regulatory set-back requirements from septic systems).
		Summary of well log information for wells in the area (e.g., well type, depth, yield).
		Summary of pumping tests that have been completed in the area.
		Summary of water quality information from wells in the area.

2.3.1 Conclusions

The conclusions in the report should include, but not necessarily be limited to, the following:

- State the expected range of well yields in the proposed subdivision;
- State whether or not the groundwater source can provide a sustainable water supply to homeowners (each water well serving a four bedroom home should be able to continuously provide at least 1,350 L/day; see Appendix B for further details);
- State the expected effects of groundwater withdrawals associated with the proposed subdivision on any existing water wells and the environment;
- State whether or not water wells in the proposed subdivision are expected to meet the Health Canada *Guidelines for Canadian Drinking Water Quality* (GCDWQ), and whether groundwater quality is expected to change over time; and
- If groundwater quality is not expected to meet the GCDWQ, list the parameters that are expected to exceed the guidelines and discuss water treatment options, including estimates of capital and maintenance costs for each treatment option. For each parameter, clearly indicate if it exceeds a health-based guideline (i.e., Maximum Acceptable Concentration or Interim Maximum Acceptable Concentration) or aesthetic objective.

2.3.2 Recommendations

The report should provide, as a minimum, the following recommendations:

- Indicate whether or not private wells should be used as water supplies in the subdivision;
- If private water wells are not suitable, identify what type of system is recommended;
- Minimum lot sizes to ensure sustainable use of individual private wells;
- Well construction and well type (including well depth, casing length and grouting);
- Well spacing to minimize well interference problems;
- Lot yield (estimated recharge) and sustainable pumping rate;
- Phasing of development, including the necessity and scope of supplemental reports to update hydrogeological information from previous phases;
- If applicable, a description of the recommended water storage system(s) and any special water treatment devices that may be necessary for their proper functioning; and
- Mitigation measures, including contingency plans where applicable, to address identified water quality or quantity concerns. Examples of mitigation measures are provided in Appendix C.

3.0 LEVEL 2 ASSESSMENT

A Level 2 assessment consists of a records review, site visit, field work and reporting. It is similar to a Level 1 assessment, except it includes field work. If a Level 1 report has already been completed for the site, the Level 2 report can make use of the existing information. The field work for a Level 2 assessment involves drilling test wells at the proposed development site, and conducting pumping tests and water quality testing. A description of each of these tasks is provided in the following sections.

3.1 Records Review & Site Visit

The objectives and scope of the records review and site visit tasks in a Level 2 assessment are the same as in a Level 1 assessment. Please see Sections 2.1 and 2.2 for a description of these tasks.

3.2 Field Work

The field program shall include the installation of test wells that will be used for pumping tests and water quality sampling. Further details of these field activities are provided in the following sections. In addition, a well survey may be required (at the discretion of the municipality) if there is potential for the proposed subdivision development to interfere with existing off-site water wells. It is recommended that a well survey be completed if there are off-site wells located within 500 m of the proposed subdivision's site boundaries or if there is a history of well interference problems in the area. The well survey should include water level measurements in at least 10 of the nearest off-site water wells and documentation of the location and well construction details of these wells. This information shall be used to assess the potential for the proposed subdivision to cause well interference effects on existing wells (as required in item 4 of Table 5 below).

3.2.1 Test Well Installation

The objective of this task is to locate and construct test wells for aquifer testing, including pumping tests and water quality sampling. Test wells may be either dug or drilled wells, but should be the same type of well that will be used in the proposed development. The minimum number of test wells depends on the number of proposed lots, as shown in Table 3.

Table 3: Minimum Number of Test Wells for Level 2 Assessments

No. of Lots	Minimum Number of Test Wells
<50	3
50-100	4
101-150	5
>150	5, plus one additional test well for every 50 lots (or portion thereof) above 150

The test wells should be located such that the hydrogeological conditions across the site are adequately represented. Additional test wells may be required depending on the site-specific conditions. Examples of conditions that may trigger the need for additional test wells include: evidence of historical groundwater contamination in the area; a large number of off-site wells within 500 metres of the proposed development site boundaries; the presence of sensitive features such as wetlands or streams that may be impacted by the development; and, evidence of significant hydrogeological variability across the site.

If there are existing water wells located on-site, or within 100 metres of the proposed development site boundaries, they may be used as test wells if the following conditions are met: the well owner agrees to participate in the program; the well construction characteristics are known (e.g. well depth, casing length, geologic formations intercepted); the well is in good condition (i.e., meets well construction regulation requirements and has been properly maintained); and, the well is installed in the same aquifer as the other test wells. At least one new or existing test well should be located on the proposed development site.

The test wells should be located and constructed in a way that permits the prediction of the quality and quantity of groundwater supplies in the proposed development. If past or present land uses on or adjacent to the property are a concern, the test well(s) should be located in a manner that permits a proper assessment of potential land-use impacts. At least two of the test wells should be located within 150 metres of each other to facilitate observation well requirements during the pumping test and to permit the calculation of aquifer properties (see Section 3.2.2).

All test wells must be constructed in accordance with the NS Well Construction Regulations by a person who is licensed to construct wells in Nova Scotia. Test well installation should be supervised by a

qualified hydrogeologist and detailed information on the site geology should be collected and recorded during the test well installation program.

After the groundwater assessment is completed, the test wells may be used as water supply wells on the individual lots, if practical. Test wells that are not intended to be used as water supply wells or long-term monitoring wells must be decommissioned in accordance with the Well Construction Regulations.

3.2.2 Pumping Tests

Pumping tests should be carried out at all of the test wells. Prior to performing the pumping tests, the test wells should be developed until they are free of sand. For sites with drilled test wells, which will be the case in most instances, initial step drawdown pumping tests should be performed in all test wells to estimate well yields, assess well efficiency, and to determine the optimum rate for a constant rate pumping test. The step drawdown pumping tests should include a minimum of four pumping intervals consisting of a minimum period of 30 minutes each. For sites with dug test wells, a short-term pumping test should be performed in all test wells to determine the optimum rate for a longer-term constant rate pumping test.

The constant rate pumping tests should begin with a static water level and should be performed at a fixed pumping rate (±5%) for a minimum of six hours of continuous pumping (no stoppages). Longer duration pumping tests may be required in some cases, such as: sites located adjacent to a significant surface water feature; sites located close to a residential neighbourhood that relies on private wells for its domestic water supply; and, unconfined aquifers. The pumping rate used during the six hour pumping tests should be based on the results of the step drawdown pumping tests (or short- term pumping tests in the case of dug test wells). The test wells should be fully recovered prior to proceeding with the constant rate pumping test. When a constant rate pumping test is being carried out at one well, the other test wells should be used as observation wells.

The pumping tests should include regular water level measurements during and after pumping until 95% recovery occurs, or until sufficient data has been collected to establish a recovery curve. Water levels should be continuously monitored at an appropriate frequency in pumping wells and observation wells. The recommended frequency for water level measurements during pumping tests are shown in Table 4. Surface water bodies within 60 metres of the pumping wells should also be monitored during the

pumping tests in order to assess groundwater-surface water interaction (e.g. stream level measurements relative to a fixed datum).

Table 4: Water Level Measurement Frequency for Pumping Tests (after Driscoll, 1986)

Pumping Well		**Observation Wells**	
Time Since Pumping Began or Stopped (mins)	Time Intervals Between Measurements (mins)	Time Since Pumping Began or Stopped (mins)	Time Intervals Between Measurements (mins)
0-10	0.5-1	0-60 (1 hr)	2
10-15	1	60-120 (2 hr)	5
15-60 (1 hr)	5	120-240 (4 hr)	10
60-360 (6 hr)	30	240-360 (6 hr)	30
360-1440 (24 hr)	60	360-1440 (24 hr)	60

During the pumping tests, the discharge should be diverted an appropriate distance and direction away from the wellhead to prevent artificial recharge. The appropriate discharge location will be site-specific and will depend on the local hydrogeology, pumping test rate and pumping test duration. At a minimum, it is recommended this be achieved by conveying the water to a down-gradient location with a 30 m long pipeline, depending on the location of the monitoring wells. This is likely to be adequate for the low-flow, short-duration pumping tests discussed in this guide, however, the pumping test results should be inspected to confirm that artificial recharge did not occur. The water should be discharged at a location that will not harm aquatic habitat or cause environmental or property damage.

Pumping test data must be plotted, interpreted and analyzed, including a description of the analysis method and the resulting aquifer properties (well yield, specific capacity, transmissivity, storativity). It is not acceptable to provide raw pumping test data without analysis and interpretation.

3.2.3 Water Quality Sampling

Water samples should be collected from all test wells. Samples should be collected at the end of the step drawdown or constant rate pumping test (last hour of pumping test), and analyzed for:

- microbiological quality (total coliform and Escherichia coli (E. coli) bacteria);

- physical and chemical quality (see Appendix D for further details);
- volatile organic compounds (see Appendix D for further details).

Additional parameters may be required depending on the local geology, adjacent land uses and the potential for contaminant impacts.

If a longer duration pumping test is undertaken (e.g., 72-hour pumping test), it is recommended that additional water samples for chemical and bacterial quality should be collected at appropriate intervals (e.g., 1 hour and 36 hours and 72 hours during a 72-hour pumping test) to record any changes in water quality that may occur during the pumping test.

There should be no chlorine residual prior to any testing for water quality. Chlorine residual tests should be performed at the wellhead immediately prior to the collection of bacteriological samples. Chlorine residuals should be reported.

3.3 Reporting

The Level 2 report should include the information shown in Table 5 and address the conclusions and recommendation items in Sections 2.3.1 and 2.3.2.

Table 5: Level 2 Reporting Requirements

No.	Task	Description
1	Site Description	Describe the site location and the details of the proposed subdivision (i.e., number of lots, location and size of proposed lots).
		Describe the surrounding land use. Determine if there are current or historical land uses that may cause groundwater contamination (e.g., landfills, gas stations, dry cleaners, other commercial/industrial facilities, etc.).
		Identify existing water users. Describe how many wells are located within at least 500 m of the site and what they are used for (i.e., domestic, commercial, industrial, municipal, agricultural uses).
		Discuss known water quality and quantity concerns in the area (e.g., water shortages, low well yields, high arsenic levels, etc.).
2	Description of Hydrogeology	Describe the hydrogeology, geology and surface water features including: geological mapping, pumping test results, water quality results, and watershed characteristics.
3	Field Work	Describe the well survey results (if applicable).
		Describe the test well drilling program.
		Describe the pumping test program and present the interpretation and results.
		Describe the water quality sampling program and results. Include sampling protocols.
4	Evaluation of potential effects	Discuss potential well interference effects that the proposed subdivision wells may have on each other and the effects they may have on existing off-site wells.
		Discuss the potential effects of the wells on surface water and the environment.
		Discuss the risk that on-site septic systems may pose to individual wells.
5	Conclusions	See Section 2.3.1 for specific requirements.
6	Recommendations	See Section 2.3.2 for specific requirements.
7	Supporting Figures and Data	Site location map and lot plan with water well locations and septic field locations (well locations must meet regulatory set-back requirements from septic systems).
		Summary of well log information for wells in the area (e.g., well type, depth, yield).
		Summary of pumping tests that have been completed in the area.
		Summary of water quality information from water wells in the area.

4.0 FOR MORE INFORMATION

Please contact Nova Scotia Environment if you have questions about water in Nova Scotia.

Nova Scotia Environment
Phone toll free: 1-877-9ENVIRO or 1-877-936-8476
Website: www.gov.ns.ca/nse/water

Please contact Service Nova Scotia and Municipal Relations if you have questions regarding land use planning in Nova Scotia.

Service Nova Scotia and Municipal Relations
Phone: (902) 424-3872
Website: www.gov.ns.ca/snsmr

Please contact Nova Scotia Department of Natural Resources (NSDNR) if you have questions regarding NSDNR groundwater data.

Nova Scotia Department of Natural Resources
Phone:(902) 424-2035
Website: www.gov.ns.ca/natr

5.0 REFERENCES

Alberta Environment. 2011. Guide to groundwater authorization. http://environment.gov.ab.ca/info/library/8361.pdf

CBCL Limited. 2004. Atlantic Canada guidelines for the supply, treatment, storage, distribution and operation of drinking water supply systems. Prepared by CBCL Limited for the Atlantic Canada Water Works Association (ACWWA) in associated with the four Atlantic Canada provinces.

Driscoll, F.G. 1986. Groundwater and wells (2nd Edition). St. Paul, Minn., Johnson Division.

Farvolden, R.N. 1959. Groundwater supply in Alberta. Alberta Research Council. Unpublished report.

Halifax Regional Municipality. 2006. Guidelines for groundwater assessment and reporting.

Newfoundland and Labrador Department of Environment and Conservation. 2009. Groundwater supply assessment and reporting guidelines for subdivisions serviced by individual private wells.

Nova Scotia Environment and Labour (NSEL). 2005. Guidelines for monitoring public drinking water supplies.

Ontario Ministry of the Environment. 1996. Procedure D-5-5 Technical guideline for private wells: water supply assessment.

van der Kamp, G. and H. Maathuis. 2005. The applicability of Q20 methods for determining sustainable groundwater yields. In Proceedings of the 58th Canadian Geotechnical and 7th Joint IAH-CNC and CGS Groundwater Specialty Conference. Saskatoon, SK, Canada.

APPENDIX A

REVIEWER'S CHECKLIST FOR GROUNDWATER ASSESSMENT REPORTS

Reviewer's Checklist for Groundwater Assessment Reports

Task	Sub-Task	Included in Report? (✔ = Yes)	Report Page No.
Site Description	Describe the site location, surrounding land use and the details of the proposed subdivision.	☐	Page No. ___
	Identify existing water wells.	☐	Page No. ___
	Discuss water quality and quantity concerns in the area.	☐	Page No. ___
Description of Hydrogeology	Describe the hydrogeology, geology and surface water features.	☐	Page No. ___
Field Work	Describe well survey results, if applicable (Level 2 reports only).	☐	Page No. ___
	Describe the test well drilling (Level 2 reports only).	☐	Page No. ___
	Pumping test results (Level 2 reports only).	☐	Page No. ___
	Water quality results (Level 2 reports only).	☐	Page No. ___
Evaluation of Potential Impacts	Discuss well interference effects that the proposed wells may have on each other and to off-site wells.	☐	Page No. ___
	Discuss potential effects of the proposed subdivision wells on surface water and the environment.	☐	Page No. ___
	Discuss the risk that on-site septic systems may pose to individual wells.	☐	Page No. ___
Conclusions & Recommendations	Can groundwater provide a sustainable water supply to the proposed subdivision?	☐	Page No. ___
	Will the proposed subdivision affect existing water wells or the environment?	☐	Page No. ___
	Is groundwater in the proposed subdivision expected to meet drinking water guidelines?	☐	Page No. ___
	Recommended lot size, well spacing and well construction.	☐	Page No. ___
	Mitigation measures for water quality and quantity concerns.	☐	Page No. ___
Supporting Figures and Data	Site location map and lot plan with well locations and septic system locations.	☐	Page No. ___
	Test well logs (Level 2 reports only).	☐	Page No. ___
	Pumping test data and interpretation (Level 2 reports).	☐	Page No. ___
	Laboratory reports (Level 2 reports only).	☐	Page No. ___

APPENDIX B

SUSTAINABLE WATER WELL CALCULATION GUIDE

B.1 Introduction

Water quality and quantity are the two fundamental criteria that should be evaluated when making conclusions about the sustainability of a water supply. The Guidelines for Canadian Drinking Water Quality are used as the benchmark to evaluate water quality. With respect to water quantity, each well serving a single family residential household should be able to continuously provide at least 1,350 L/day (300 gallons) and should be able to provide this amount within a two hour period each day in order to meet peak demands. These water quantity criteria are based on a four bedroom home and are taken from the Atlantic Canada guidelines for water supply systems (CBCL, 2004).

Note that the water quantity requirements discussed above may need to be modified on a case-by-case basis depending on the specific development plans for each subdivision. Water quantity requirements should be adjusted if the building size differs from the four bedroom assumption listed above. In addition, if open loop geothermal systems are planned, the additional pumping requirements associated with the heat pumps should be taken into account. Furthermore, some water treatment units require extra water to operate (e.g., water softeners). If treatment units are needed to meet water quality guidelines, the additional flow associated with these units should be added to the basic flow requirements listed above.

The following three screening level calculations are recommended to evaluate water quantity sustainability:

- safe well yield calculation
- lot water balance calculation
- well interference calculation

These calculations are discussed in further detail in Section B.2 and example calculations are presented in Section B.3. The intent of these calculations is to assess water quantity sustainability at three different scales, including the individual well scale (safe well yield calculation), the individual lot scale (lot water balance calculation), and the subdivision scale (well interference calculation). All three types of calculations should be completed for each subdivision and used towards the evaluation of the sustainability of private well supplies at the proposed subdivision site. To assist with these calculations, a calculator spreadsheet with a summary of aquifer parameters from across the province is available on NSE's groundwater webpage: www.gov.ns.ca/nse/groundwater. Based on site-specific considerations, other methods may be selected to assess water quantity sustainability, such as a numerical groundwater flow model.

If screening level calculations indicate that groundwater quantity may be a concern, the suitability of the proposed subdivision site for private well supplies and/or mitigation measures should be considered. Note that the screening level calculations are not intended to be used as the sole criteria for making decisions, rather they should be used in combination with other lines of evidence.

B.2 Description of Calculations

B.2.1 Safe Well Yield Calculation

The twenty-year safe well yield calculation is used to estimate the long-term safe pumping rate for a well and can be calculated using Equation B.1 (Farvolden 1959), or Equation B.2 (van der Kamp and Maathuis 2005) in cases where large drawdowns associated with turbulent well losses are observed in the pumping well at the beginning of pumping. This approach for estimating long-term well yields is also recommended by Alberta Environment (2011).

$$Q_{20} = 0.683T\ H_A\ S_f \qquad \text{(Equation B.1)}$$

$$Q_{20} = S_f\ H_A\ Q\ /(\ S_{100min} + (S_{20yrs} - S_{100min})_{theor}) \qquad \text{(Equation B.2)}$$

Where:

Q_{20} = 20 year safe pumping rate for the well (m^3/day)
T = Transmissivity (m^2/day)
S_f = Safety factor = 0.7 (no units)
H_A = Available head (m)
Q = Pumping rate used during the pumping test (m^3/day)
S_{100min} = Drawdown observed in well during the pumping test at 100 minutes (m)
$(S_{20yrs} - S_{100min})_{theor}$ = The theoretical drawdown in the well after 20 years of pumping minus the theoretical drawdown in the well at 100 minutes, based on the most appropriate theoretical equation for the aquifer, e.g., Theis, Hantush, etc. (m)

Input data for Equations B.1 and B.2 should be taken from field data collected from the proposed subdivision site. A summary of province-wide aquifer properties from historical pumping test data is available in the calculator spreadsheet to compare with site-specific field data. The summary data includes transmissivity and storativity values for various groundwater regions and hydrostratigraphic units in Nova Scotia.

After the safe yield of a well is calculated using Equations B.1 or B.2, the result can be compared to the minimum well yields in Table B.1 to determine if the well can provide the target water supply of 1,350 L/day. Note that the target water supply can be achieved with a combination of well yield and cold water storage. Furthermore, the storage component can be supplied from both the standing water within the well and/or a storage tank. Wells with higher yields need less storage to meet water quantity requirements compared to lower yield wells. For example, a 20 m deep, 150 mm diameter drilled well

that yields 11 L/minute will meet the 1,350 L/day requirement. However, a 150 mm diameter drilled well that yields only 8 L/minute should be at least 60 m deep to meet this requirement. The additional water stored in the 60 m deep well will make up for the lower yield during peak demand. Table B.1 provides additional examples of well yields and well depths that meet the 1,350 L/day requirement and Table B.2 describes the assumptions used in these calculations.

Table B.1: Examples of Wells That Meet A Water Supply Target of 1,350 L/day

Well Depth (m)	Minimum Well Yield (L/min)
20 (66 ft)	10.6 (2.3 igpm)
40 (131 ft)	9.1 (2.0 igpm)
60 (197 ft)	7.6 (1.7 igpm)
80 (262 ft)	6.1 (1.3 igpm)
100 (328 ft) and deeper	4.6 (1.0 igpm)

Table B.2: Calculations and Assumptions Used to Develop Table B.1

Well Depth (m)	Well Yield (L/min)	Well Storage Volume (L)[3]	2 Hour Well Yield (L)	24 Hour Well Yield (L)	Total Volume Available From Well Storage and 2 Hour Yield (L)[4]
20	10.6	88	1266	15192	1354
40	9.1	265	1092	13104	1357
60	7.6	442	912	10944	1354
80	6.1	618	732	8784	1350
100	4.6	795	558	6696	1353

Notes:
1) The target water supply volume of 1,350 L/day assumes each water well serves a four bedroom home (CBCL, 2004).
2) It is assumed that the entire target water supply volume of 1,350 L/day will need to be supplied during a 2 hour period to meet the peak demand. Furthermore, the well yield must be able to replenish this volume within 24 hours, on an ongoing daily basis. To satisfy these requirements, the last two columns in this table named "24 Hour Well Yield" and "Total Volume Available from Well Storage and 2 Hour Yield" must both meet or exceed the target volume of 1,350 L/day.
3) The "Well Storage Volume" calculation assumes: a) 150 mm diameter well; b) available drawdown in the well is equal to the well depth minus 10 m (i.e., the static water level in the well is 5 m below ground level and the pump is placed at the bottom of the well with a 5 m allowance to keep the pump submerged); c) the available drawdown is reduced by 50% to allow for cumulative well interference effects from other wells in the subdivision.
4) "Total Volume Available from Well Storage and 2 Hour Yield" is calculated as follows (Equation B.3): Total available water (L) = $500\pi\ (D/2000)^2 H_A + 120 Q_{20}$; where D is well diameter (mm), H_A is available head (m) and Q_{20} is the 20 year safe pumping rate (L/min).

B.2.2 Lot Water Balance Calculation

A simplified water balance calculation can be used to estimate whether or not the available groundwater on each lot will meet the target water volume of 1,350 L/day. The calculation assumes that the available groundwater is equal to the groundwater recharge that occurs on the lot, minus the amount of groundwater reserved for ecological use. Ecological use refers to groundwater that helps maintain ecological habitats by discharging as baseflow to surface water bodies. Ecological use is assumed to be 50% of the groundwater recharge, unless there is other information available that indicates this value should be adjusted.

$$Q_{lot} = I\ A_{lot}\ E_{use} / 365 \text{ days} \qquad \text{(Equation B.4)}$$

Where:
Q_{lot} = Available groundwater from each lot (L/day)
I = Groundwater recharge rate (mm/year)
A_{lot} = Area of the lot that contributes to recharge, excludes impermeable areas (m^2)
E_{use} = Percentage of recharge reserved for baseflow and ecological support (%)

A province-wide summary of estimated annual groundwater recharge rates for each primary watershed is available in the calculator spreadsheet.

B.2.3 Well Interference Calculation

In a subdivision with a large number of closely-spaced water wells there is potential for well interference problems. This refers to the cumulative pumping effects from all wells in the subdivision and can result in significant lowering of groundwater levels.

The Theis (1935) equation (see Equation B.5) can be used to estimate cumulative drawdown effects by assuming a worst-case location, such as the centre of a subdivision, and then calculating the amount of drawdown that each proposed well in the subdivision causes at this location. The total drawdown is estimated by summing all drawdowns together. The same approach can be used to predict whether or not the proposed subdivision will cause well interference problems in an existing nearby subdivision.

The Theis equation involves several simplifying assumptions that must be considered when interpreting the calculation results. For example, the equation assumes radial flow in an infinite, homogeneous, isotropic, porous medium, confined aquifer with no recharge. Note that a pumping time must be selected to make drawdown predictions. It is recommended that a time of 365 days be used to represent long-term pumping conditions and account for annual recharge. It is also recommended that the total predicted drawdown for the subdivision not exceed 50% of the available drawdown in each well.

$s = Q(W(u))/4\pi T$ $u = r^2S / 4Tt$ (Equation B.5)

Where: s = Drawdown at a given distance "r" from the pumping well for time "t" after pumping begins (m)
Q = Pumping rate (m^3/day)
W(u) = Well function of "u"
u = Variable of integration (no units)
T = Transmissivity (m^2/day)
r = Radial distance from the center of the pumping well (m)
S = Storativity (no units)
t = Time (days)

B.3 Example Calculations

The following example demonstrates how a hypothetical subdivision can be evaluated using the three equations presented in Section B.2. The subdivision layout details and hydrogeologic information for the site are presented in Table B.3. A spreadsheet calculator to assist with the calculations is available on NSE's groundwater webpage: www.gov.ns.ca/nse/groundwater.

Table B.3: Data for Example Subdivision

Parameter	Value	Comment
Subdivision layout details:		
Total subdivision size	100 ha	
Proposed number of lots	100	Subdivision lot plan shows water wells are spaced 100 m apart.
Lot area ($_{A\ lot}$)	1 ha	Single lot, dimensions are 100 m X 100 m
Test well results:		
Test well depth	80 m	Four test wells were installed to 80 m depth
Test well radius	0.076 m	All test wells were 152 mm diameter
Static groundwater level	5 m, bgs	Deepest static level on-site is 5 m, below ground surface (bgs)
Transmissivity (T)	1.30 m^2/day	This is the lowest value from the four test wells; the value is in the range reported for the Metamorphic Groundwater Region (see calculator spreadsheet)
Storativity (S)	0.000183	This is the lowest value from the four test wells; the value is in the range reported for the Metamorphic Groundwater Region (see calculator spreadshseet)
Groundwater recharge rate (I)	197 mm/year	See calculator spreadsheet

B.3.1 Safe Well Yield Calculation

Based on Equation B.1 and the data provided in Table B.3, the safe yield for the lowest yielding test well is as follows:

$$Q_{20} = 0.683 H_A S_f$$
$$= 0.683(1.30\ m^2/day)(70\ m)0.7$$
$$= 43.5\ m^3/day, \text{ which converts to } 30.2\ L/min$$

Note that the available head of 70 m for this calculation comes from the well depth subtracting the depth to static water level, subtracting 5 m to allow the pump to remain submerged at the bottom of the well (i.e, H_A = 80 m - 5 m - 5 m = 70 m). The calculated safe yield of 30.2 L/min is greater than the minimum acceptable yield for a 80 m well in Table B.1, which is listed as 6.1 L/min and, therefore, it meets the safe well yield criteria.

B.3.2 Lot Water Balance Calculation

Based on Equation B.4 and the data in Table B.3, the lot water balance calculation is as follows: Q_{lot} = I A_{lot} E_{use}/365 days = (197mm/year)(10,000 m^2)(50%)/ 365 days= 2,699 L/day. Since this value is greater than the target water supply volume of 1,350 L/day, it meets the lot water balance criteria.

B.3.3 Well Interference Calculation

Well interference calculations can be carried out based on Equation B.5 and the data provided in Table B.3. The calculations are based on a pumping time of 365 days, as recommended in Section B.2.3.

In order to estimate the cumulative drawdown, the radial distance from the centre of the subdivision to each well is measured from the subdivision layout plan. The drawdown at the centre of the subdivision due to each well is calculated and the results are added together to estimate the cumulative drawdown at the centre of the subdivision. Table B.4 presents a summary of the calculations. Note that one well is assumed to be located at the very centre of the subdivision and this is modeled as a radial distance of 0.076 m, since the diameter of the well is 152 mm. As shown in Table B.4, the total drawdown is predicted to be 33 m.

If the wells in the proposed subdivision are drilled to the same depth as the test wells (i.e., 80 m), they will have approximately 70 m of available head. Note that the available head of 70 m comes from the well depth subtracting the depth to static water level, subtracting 5 m to allow the pump to remain submerged at the bottom of the well (i.e, H_A = 80 m - 5 m - 5 m = 70 m). The predicted drawdown of 33 m is less than 50% of the available head (as recommended in Section B.2.3) and, therefore, it meets the well interference criteria.

Table B.4: Well Interference Calculations

Radial Distance to Centre of Subdivision (m)	Number of Wells Located at Specified Radial Distance	Predicted Drawdown Caused by a Single Well (m)	Drawdown Caused By All Wells at Specified Radial Distance (m)
0.076	1	1.7	1.7
100	3	0.53	1.6
200	12	0.41	4.9
300	20	0.34	6.9
400	28	0.3	8.4
500	36	0.26	9.4
Total =	100	Total =	33

APPENDIX C

EXAMPLES OF MITIGATION MEASURES TO PROTECT PRIVATE WELLS

Examples of potential mitigation measures to protect groundwater quality and quantity in private wells at subdivisions include, but are not limited to, the following:

Groundwater Quantity:

1. Larger lot sizes to reduce the concentration of withdrawals.
2. Smaller total number of lots to reduce the volume of groundwater withdrawals over the proposed development area.
3. Drill a well on each lot prior to building to ensure minimum water requirements can be met.
4. Avoidance of areas that are associated with lower well yields.
5. Development of alternative water sources.
6. Communal water supply.
7. Designation of important recharge areas as green space.
8. Design of subdivision and individual lots to optimize groundwater recharge. This may include minimizing impermeable surface cover and maximizing infiltration of stormwater into the ground.
9. Minimum setback requirement of wells from wetlands, streams, or salt water.
10. Development of short or long-term monitoring plans, including specific ‘triggers' for a contingency plan to prevent well interference, streamflow depletion, sea water intrusion, or other adverse effects.
11. Development of contingency plans to deal with validation and resolution of well interference and other claims. For example, if the development impacts off-site existing wells, corrective action may be required (e.g., replace or deepen wells, lower pump setting, add storage, etc.).
12. Restrictions on non-consumptive water use (e.g., controls on open-loop groundwater heat pumps to minimize well interference effects).
13. Water conservation measures, such as low flow shower heads, ultra low flow toilets, water-efficient appliances (e.g., front loading clothes washers), water metering at homes, etc.
14. Cold storage at each household help meet peak demands.

Groundwater Quality:

1. Additional well casing to prevent shallow, poor quality water from entering the well.
2. Additional well grout to prevent shallow, poor quality water from entering the well.
3. Communal supply with central water treatment.
4. Recommendations for wellhead protection measures.
5. Water treatment systems at each household for treating chemicals that exceed drinking water guidelines.

APPENDIX D

WATER QUALITY SAMPLING PARAMETERS

At a minimum, test wells should be sampled for:

- microbiological quality (total coliform and Escherichia coli (E. coli) bacteria);
- physical and chemical quality*;
- volatile organic compounds**.

*A minimum list of physical and chemical parameters to be tested for is presented in Table D1. The detection limits for these parameters must be sufficiently low to allow the results to be compared to the drinking water guidelines. Note that this list is taken from the "Guidelines for Monitoring Public Drinking Water Supplies" (NSEL, 2005). Additional parameters may be required depending on the local geology, the adjacent land uses and the potential for contaminant impacts.

Table D1: Minimum List of Parameters for Physical and Chemical Quality

Alkalinity	Colour	Potassium
Aluminum	Conductivity	Selenium
Ammonia	Copper	Sodium
Antimony	Fluoride	Sulphate
Arsenic	Hardness	Total Dissolved Solids
Barium	Iron	Total Organic Carbon
Boron	Lead	Turbidity
Cadmium	Magnesium	Uranium
Calcium	Manganese	Zinc
Chloride	Nitrate	
Chromium	pH	

** The volatile organic compound parameters should include all chemicals listed in U.S. EPA Method 624. The detection limits must be sufficiently low to allow the results to be compared to the drinking water guidelines.

APPENDIX E

DIRECTORY OF AVAILABLE WATER DATA

Data Type	Database	Source	Format	Website
Climate	National Climate Data and Information Archive	Environment Canada	Website/Download	http://climate.weatheroffice.gc.ca/climateData/canada_e.html
Hydrometric	HYDAT Archived Hydrometric Data	Water Survey of Canada	Website/Download	http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm
Well Logs				
	Nova Scotia Well Logs Database	Nova Scotia Department of Natural Resources	GIS Download	http://www.gov.ns.ca/natr/meb/download/dp430.asp
	Nova Scotia Well Logs Database	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgroundwater
	Nova Scotia Well Logs Database	Nova Scotia Environment	Online Search	http://www.gov.ns.ca/nse/welldatabase/wellsearch.asp
	Nova Scotia Well Logs Database	Nova Scotia Environment	MS Access Database	http://www.gov.ns.ca/nse/groundwater/docs/NSWellLogs2010.mde
Pumping Tests	Interactive Groundwater Map	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgroundwater
Observation Wells				
	Groundwater Observation Well Network	Nova Scotia Environment	Excel/PDF Download	http://www.gov.ns.ca/nse/groundwater/groundwaternetwork.asp
	Interactive Groundwater Map	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgroundwater
Groundwater Chemistry Data	Interactive Groundwater Map	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgroundwater
Groundwater Reports				
	Water Resource Reports and Maps	Nova Scotia Environment	PDF Download	http://www.gov.ns.ca/nse/groundwater/groundwaterresources.asp
	Interactive Groundwater Map	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgroundwater
Geological Maps				
	Bedrock Geology Digital Products	Nova Scotia Department of Natural Resources	GIS Download	http://www.gov.ns.ca/natr/meb/pubs/pubs3bg.asp
	Surficial Geology Digital Products	Nova Scotia Department of Natural Resources	GIS Download	http://www.gov.ns.ca/natr/meb/pubs/pubs3sg.asp
	Bedrock Geology Maps and Databases	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgeomap/viewer.htm
Groundwater Maps				
	Groundwater Regions Map of Nova Scotia	Nova Scotia Department of Natural Resources	GIS Download	http://www.gov.ns.ca/natr/meb/download/dp428.asp
	Groundwater Regions Map of Nova Scotia	Nova Scotia Department of Natural Resources	PDF Download	http://www.gov.ns.ca/natr/meb/download/mg/ofm/htm/ofm_2008-003.asp
Watersheds				
	Interactive Groundwater Map	Nova Scotia Department of Natural Resources	Online Spatial Search	http://gis4.natr.gov.ns.ca/website/nsgroundwater
	1:10 000 Primary Watersheds of Nova Scotia	Nova Scotia Environment	PDF Download	http://www.gov.ns.ca/nse/water.strategy/docs/WaterStrategy_NSWatershedMap.pdf