GUIDANCE DOCUMENT FOR GROUNDWATER INFORMATION FOR AN ENVIRONMENTAL ASSESSMENT OF DEEP SALINE GROUNDWATER EXTRACTION IN THE HORN RIVER BASIN

Submitted To:

BC Ministry of Environment

Submitted By:

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Nanaimo, British Columbia

December 18, 2012

ACKNOWLEDGEMENTS

Guidance Document for Groundwater Information for an Environmental Assessment of Deep, Saline Groundwater Extraction in the Horn River Basin has been authored by: Darren David and Shelley Bayne of Waterline Resources Inc., and Sue Gordon of Gordon Groundwater Consulting. Vicki Carmichael and Klaus Rathfelder of Ministry of Environment were the project facilitators/co-ordinators and senior editors for the document.

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Technical input during the guidance document development was gratefully received from Mike Wei (Ministry of Environment), Teresa Morris (Environmental Assessment Office), Elizabeth Johnson (Ministry of Energy and Mines), Adrian Hicken (Ministry of Energy and Mines), Allan Chapman and Kevin Parsonage (Oil and Gas Commission), Stuart Lunn (Imperial Oil), Scott Hillier (Conoco Phillips), Scott Wagner and Shad Watts (Nexen Inc.), John Horgan, Kevin Beneteau, James Armstrong, Kellen Foreman (Encana Corp.), Colin Harfman and Geoff Eerkes (EOG Resources Inc.)

Funding of this document was provided by the Climate Action and Clean Energy Fund through the BC Ministry of Environment.

PREFACE

In British Columbia, groundwater extraction projects that exceed 75 L/s fall under the Reviewable Project Regulation under the BC *Environmental Assessment Act* (*EA Act*). Saline groundwater projects that meet or exceed this rate of extraction and will be operated either intermittently or continuously for a period of one year or more, are considered a reviewable project requiring an environmental assessment certificate (EA certificate) before the project may proceed with construction[1] or operation. The environmental assessment process is managed by the BC Environmental Assessment Office (EAO) and is designed to assess the potential for significant adverse environmental, social, economic, health and heritage effects, as well as ensure Crown obligations to First Nations are met. Under the *EA Act*, reviewable projects may be exempted from the requirement for an EA certificate if "the executive director considers that a reviewable project will not have a significant adverse environmental, economic, social, heritage or health effect, taking into account practical means of preventing or reducing to an acceptable level any potential adverse effects of the project".

Energy companies who wish to extract groundwater from deep, saline aquifers/reservoirs in the Horn River Basin area (e.g., Debolt Formation, or deeper formation) must contact the EAO regarding a complete list of information required for an environmental assessment.

This guidance document clarifies the groundwater related information requirements that proponents should prepare and is focused on the type of hydrogeological data that must be provided to demonstrate the hydraulic separation between the formation where saline groundwater is being extracted and the shallow groundwater and surface water systems. Detailed information regarding an appropriate monitoring plan to be put into place by the proponent to address any unpredicted impacts that may occur is also covered in this guidance document. The guidance document's intent is also to facilitate a more streamlined and efficient review process by bridging the gap between the reservoir engineering data and hydrogeological data. The information requirements identified in this document focus largely on data that already exists at the stage where energy companies are considering groundwater extraction in excess of the 75 L/s threshold. Although this guidance document is focussed on saline groundwater extraction projects in the Horn River Basin, the technical information requirements for similar projects in other areas of the province will be comparable.

For saline groundwater projects that fall below the extraction threshold of 75 L/s, proponents should contact the Oil and Gas Commission regarding permit information requirements.

[1] A test well can be constructed prior to receiving an environmental assessment certificate to provide groundwater data for an application for an environmental assessment certificate and the well can be tested if the testing is conducted by or under the supervision of a person registered as a member of the Association of Professional Engineers and Geoscientists of British Columbia with competency in the field of hydrogeology.

TABLE OF CONTENTS

PAGE

LIST OF FIGURES

1.0 INTRODUCTION

In British Columbia, groundwater extraction in excess of 75 L/s triggers the Reviewable Project Regulation (BC EAOa, 2002) under British Columbia's *Environmental Assessment Act* (*EA Act*) (BC EAOb, 2002). Saline groundwater projects that meet this extraction trigger require an environmental assessment certificate (EA Certificate) or a certificate exemption, prior to initiating construction[2] or operation of a project. Where this extraction occurs from deep, saline aquifers/reservoirs in the Horn River Basin area in northeastern British Columbia, and an environmental assessment is required, proponents should refer to this guidance document designed to clarify the groundwater information requirements. Proponents must contact the Environmental Assessment Office (EAO) regarding a complete list of information required for an environmental assessment.

For saline groundwater projects that fall below the extraction threshold of 75 L/s, proponents should contact the Oil and Gas Commission regarding permit information requirements.

1.1 BACKGROUND

Large deposits of natural gas have been identified in deep shale-bearing formations within the Horn River Basin located north of Fort Nelson, British Columbia (Figure 1-1). To produce natural gas from these formations, hydraulic fracture stimulation (hydrofracturing) methods are utilized. Hydrofracturing operations require large quantities of water injected at high pressure to fracture the shale formation. Adequate water sources to meet the demand are necessary for the development of the unconventional gas industry in this area. Several water sources have been identified to meet the current demand including surface water, shallow fresh to saline groundwater, and deep saline groundwater.

In 2010, Petrel Robertson Consulting Ltd (Petrel) completed a hydrogeological assessment of the Horn River Basin to evaluate potential deep-basin, saline groundwater supply sources. Three regional formations were identified as capable of supplying water for hydrofracturing operations (Figure 1-2) as follows:

- Mississippian Debolt-Rundle carbonate platform
- Upper Mississippian Mattson sandstones
- Basal Cretaceous sandstones

[2] A test well can be constructed prior to receiving an environmental assessment certificate to provide groundwater data for an application for an environmental assessment certificate and the well can be tested if the testing is conducted by or under the supervision of a person registered as a member of the Association of Professional Engineers and Geoscientists of British Columbia with competency in the field of hydrogeology.

Figure 1-1: Horn River Basin Location Map

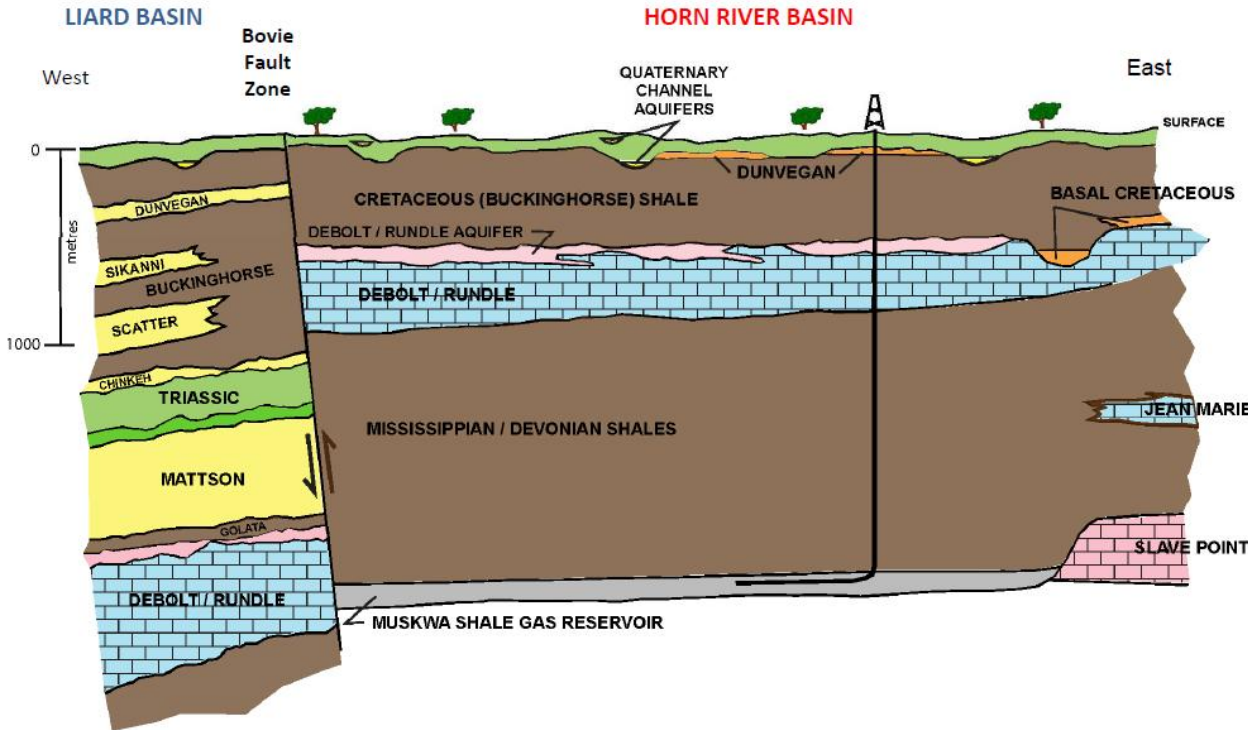
(Source: Ministry of Environment)

Of these, the Debolt-Rundle platform was identified as the best target zone for saline groundwater sources. It is the most regionally extensive of the three zones exhibiting good aquifer/reservoir potential, primarily at the top of the platform. The Mattson sandstones were also found to offer significant aquifer/reservoir potential, but are isolated to the west. Similarly, the Basal Cretaceous sandstones have good reservoir quality, but are thin and isolated (Petrel Robertson Consulting, 2010).

Figure 1-2 presents a conceptual cross-section across the Horn River Basin, looking north and showing the main bedrock formations and a representative directional gas well.

The Debolt Formation is a confined karstic limestone aquifer situated approximately 600 to 900 metres below ground level. It is regionally isolated from surficial aquifers by thick Cretaeous shale deposits. The total dissolved solids (TDS) concentration ranges from >15,000 mg/L to <40,000 mg/L and may contain H_2S in excess of 100 mg/L. Estimates indicate that there may be upwards to 10 billion cubic metres (m^3) of groundwater in the Debolt Formation Aquifer/Reservoir. Water source wells drilled into the Debolt Formation indicate highly variable yield. However, long-term yield estimates in some areas are in excess of 20,000 m^3/day (Petrel Robertson Consulting, 2010).

Figure 1-2: Horn River Basin Conceptual Cross-Section



(Source: Petrel Robertson Consulting, 2010)

Since the Debolt Formation is deep, and the salinity of groundwater is comparable to seawater, it is likely that this highly mineralized water is not in hydraulic communication with potentially higher quality, shallow groundwater aquifers or surface water that may be used for other purposes. As such, extraction of significant amounts of saline groundwater from the Debolt Formation Aquifer is expected to exhibit a low potential to adversely impact shallower groundwater and surface water resources in the region.

1.2 REGULATORY OVERVIEW

In British Columbia, water, including groundwater, is owned by the Crown and is managed and protected in various ways through various provincial agencies. The Oil and Gas Commission (OGC), under the *Oil and Gas Activities Act* (OGAA) regulate the construction and operation of water source wells used to obtain water for injection into an underground formation used in the production of petroleum or natural gas (BC OGC, 2010).

Water wells used for drinking water supply, or other non-oil and gas related uses, must comply with the *Water Act* (BC MoE, 1996) and the *Drinking Water Protection Act* (BC MoH, 2001).

Section 5.0 of the Reviewable Projects Regulation (B.C. Reg. 370/02) under the *EA Act* gives the EAO authority to regulate large groundwater extractions. The development of a new facility

is reviewable if it consists of one or more wells, operated either periodically or continuously for one year or more, designed to be operated to extract ground water at the rate of 75 litres or more per second.

The *EA Act* does not distinguish between saline or non-saline groundwater and therefore any groundwater extraction activity exceeding the threshold limit is subject to review (BC EAOa, 2002). In the Horn River Basin, a description of the project (i.e., extraction of saline groundwater from the Debolt or deeper formations) will allow the EAO to determine if exemption is warranted or not.

The EAO should be contacted if there is any uncertainty whether a project requires an EA Certificate or not.

The environmental assessment process is the responsibility of the EAO and is initiated by submission of a project description prepared by the proponent.

1.3 PURPOSE OF GUIDANCE DOCUMENT

This guidance document applies to groundwater information requirements related to saline groundwater extraction from the Debolt Formation or other deeper formations within the Horn River Basin that trigger the EA thresholds defined above in Section 1.2. Although this guidance document is focussed on saline groundwater extraction projects in the Horn River Basin, the technical information requirements for similar projects in other areas of the province will be comparable.

The guidance is focused on the type of hydrogeological or groundwater data and information that must be provided to demonstrate the hydraulic separation between the formation where saline groundwater is being extracted and the shallow groundwater and surface water systems. Detailed information regarding an appropriate monitoring plan to be put into place by the proponent to address any unpredicted impacts that are inherent when dealing with subsurface resources that may occur is also covered in this guidance document.

Although outside of the scope of this guidance document, during an environmental assessment, the proponent will be required to assess whether a proposed project has adverse effects to other environmental values, as well as adverse effects to heritage, health, economic and social valued components. Consideration of effects on Treaty Rights must also be taken into account. EAO will advise proponents of additional information requirements and the need to identify mitigation measures and strategies to prevent or reduce any potential adverse effects of the project. Proponents are advised to contact the EAO office prior to submitting a project description.

The supporting information should demonstrate the following key issues (see Section 3.0):

- The hydraulic isolation of the Debolt Formation from shallower aquifers and surface water resources;

- The capacity of the Debolt Formation to supply the proposed extraction volumes and rates with the intent to understand the effects on resource sustainability; and,
- Potential effects of the proposed project associated with extraction and disposal activities on existing users of saline groundwater from the Debolt Formation.

This guidance document also outlines potential monitoring and reporting requirements (Section 4.0 of the guidance), and adaptive management measures (Section 5.0) that should be included in the information provided to the EAO. Often the proponent is already undertaking these measures as part of the day to day management of their operations.

The guidance document only addresses aspects relevant to the groundwater component of the project, such as:

- The extraction of the saline groundwater from the deep, saline aquifer/reservoir, and,
- The injection of the spent water from hydrofracturing activities into the deep, saline aquifer/reservoir.

It does not address other aspects of the project, including:

- The conveyance (e.g., pipelines) and storage (e.g., burrow pits, storage ponds, dugouts, etc.) of the saline water on the land surface;
- The gas production wells where saline water is injected to hydraulically fracture the shale formations;
- Social, economic, health or heritage potential effects of the project;
- First Nation consultation and consideration of treaty rights;
- Other project effects not directly associated with the use of groundwater such as the potential project effects on valued components (e.g., wildlife) associated with surface disturbance and location of project infrastructure; and,
- Other information requirements that may be identified by the EAO.

This guidance document does not provide information on groundwater modeling that may be relevant for groundwater projects. The Ministry of Environment has prepared a separate guidance document on groundwater modelling - Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities.

2.0 SUBMISSION OF A PROJECT DESCRIPTION

The environmental assessment process in British Columbia has been implemented to identify and evaluate the potential for a proposed project to have significant adverse environmental, social, economic, health, and heritage effects and to identify mitigation measures that could avoid or reduce these effects. The environmental assessment process is managed by the EAO and is initiated by submission of a project description.

The EAO uses the project description to determine whether the project, or a component of the project:

(1) falls within a category of projects that is "reviewable" under the Reviewable Projects Regulation, and
(2) meets the environmental assessment review threshold for that category.

If the answer to both (1) and (2) is yes, then the project qualifies as "reviewable" under the *Environmental Assessment Act* (the "Act").

However, even though a project qualifies as "reviewable", the EAO may not necessarily require the project to undergo an environmental assessment. To decide whether the project warrants an environmental assessment, the EAO determines whether the project:

> "…*may have a significant adverse environmental, economic, social, heritage or health effect, taking into account practical means of preventing or reducing to an acceptable level any potential adverse effects of the project*…" (section 10 (1)(b) of the Act).

The project description is the basis for the EAO's decision under section 10 of the Act as to whether to proceed with a review. Consequently, it is important that the project description contains sufficient information to permit such a determination to be made about the potential effects of a project. This guidance document addresses the groundwater information that should be contained in the project description. The proponent should discuss other information requirements that will be required in the project description with EAO and the environmental assessment process that may be followed. Proponents may refer to the Guidelines for Preparing a Project Description for an Environmental Assessment in British Columbia for guidance on writing general project descriptions (BC EAO, Updated 2010).

2.1 Environmental Assessment Process – Section 10

Once the EAO has received an acceptable project description, it will use the project description and any supporting documentation to make a determination on whether the project requires an EA Certificate in which case, an order will be issued that directs the proponent to the environmental assessment process under Section 10(1)(c) of the *EA Act* (BC EAOb, 2002) and the proposed project will enter the pre-application phase of an environmental assessment.

2.2 Provincial Government Technical Staff Review and Comment of Groundwater Information

The EAO typically seeks the review and advice from the First Nations and provincial government technical staff for reviewable groundwater extraction projects. This guidance document has been developed to facilitate the provincial government technical staff review for hydrogeology information required for reviewable groundwater extraction projects from the Debolt Formation or other deeper saline aquifer in the Horn River Basin. However, the EAO office, nevertheless, may request further information to meet their requirements or based on information requests from the provincial government technical staff.

Based on the information provided by the proponent, the provincial government technical staff will provide advice or comments to the EAO including the potential for adverse effects to the quantity and quality of shallow water resources, to the deep, saline groundwater source, and regarding existing extraction and use by other oil and gas companies in the area. The review process is iterative and the EAO may request additional information from the proponent for review by government technical staff.

Project Description – GROUNDWATER COMPONENT
The groundwater-related information submitted within the project description should be sufficient to allow the EAO/ provincial government technical staff to assess:

- If a hydraulic connection exists between the deep and shallow groundwater/surface water zones;
- Whether existing users extracting groundwater from a deep, saline aquifer/reservoir (e.g., Debolt Formation) are likely to be adversely impacted by the proposed proponent's groundwater extraction project;
- If the deep, saline aquifer/reservoir water quality is likely to be impacted where it becomes unusable for the intended purpose (e.g., water quality changes from injection activities);
- Where inherent uncertainties exist and how the proponent proposes to monitor the environment to address any data gaps and verify the predicted groundwater system response to extraction activities; and,
- Mitigative or adaptive management measures proposed.

The following sub-sections provide guidance for proponents regarding groundwater related information that should be included in the project description document. Note that the groundwater related information should be prepared by a qualified hydrogeologist or groundwater specialist, who is a member of the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC).

2.3 INFORMATION REQUIREMENTS

The proponent is responsible to submit the supporting groundwater-related information in a hydrogeological format using the metric system of measurement to ensure efficiency and consistency for the review process.

Proponents should account for density differences in hydraulic head between groundwater of varying salinity between the different hydrostratigraphic units being considered. The standard is to normalize to a fresh water head i.e., the density of 1.0 g/cm^3.

2.4 PROJECT DESCRIPTION OVERVIEW – GROUNDWATER REQUIREMENTS

2.4.1 Shale Gas Development Plan

The project description overview should include a high level description of the overall shale gas development plan. It should describe the project location, size and the anticipated project life.

2.4.2 Water Development Plan

The water development plan establishes the context for the proposed groundwater extraction project within the proponent's overall shale gas development plan.

It should include an overview related to the project's water use and disposal needs. This should include, but not be limited to; the following:

- The location of existing or proposed source wells;
- The location of existing or proposed disposal wells;
- Anticipated groundwater extraction and injection volumes and the duration of operation of each well; and
- Proposed saline groundwater storage, treatment, and transport at the surface, including any plans for reuse, recycle, and disposal.

2.5 REGIONAL HYDROGEOLOGIC SETTING

2.5.1 Geological, Hydrogeological and Hydrological Overview

Regional geological and hydrogeological information from available sources should be summarized with reference to known hydrostratigraphic units in the area extending from ground surface to the saline aquifer/reservoir which is being proposed for use. Surface water bodies and known shallow aquifers within a 5 km radius of the proposed Debolt wells should also be identified.

The information should include lithological and physical characteristics (e.g., formation thicknesses, known boundaries, etc.), and where known; aquifer transmissivity/hydraulic conductivity, hydraulic head, hydraulic gradient, inferred ambient groundwater flow directions, and water quality characteristics.

2.5.2 Existing Users of Saline and Non-Saline Groundwater

Available data from existing saline and non-saline groundwater monitoring activities can provide valuable information to assess the potential for interference drawdown from proposed extraction activities at the project site on other existing groundwater extraction wells in the region. This information may be available through sources such as the OGC, Accumap, GeoScout, the BC

Water Resources Atlas website or the BC MOE WELLS database (water supply wells), and the EAO that will have existing project summaries and groundwater monitoring data.

At a minimum, a plan should be provided that shows the ownership and locations of existing wells within a 5 km radius. This should include water source wells, disposal wells, observation/monitoring wells, or water supply wells that may be completed in shallower aquifers using different symbols. Gas well information is only required where it helps to better define the proponents water management plan and the lithological environment. For instance, geophysical logs extending from ground surface to the Debolt Formation helps to show the existence of aquitard (e.g., clay, shale) and aquifer (e.g., sand and gravel overburden, sandstone, limestone) zones and the possible connections or disconnections vertically across the system. These data should be presented in conjunction with piezometric/pressure data (in meters) to illustrate the hydraulic disconnect that is expected to exist between the shallow non-saline and deep saline zones.

Where the information is available, tabulated information should be presented that may include, but not be limited to the following:

- owner name,
- well identifier,
- location coordinates,
- elevation,
- well use,
- well completion details,
- hydrostratigraphic unit(s) in which the well is screened/completed,
- static water level,
- pumping water level,
- flow rates and usage, and
- water quality.

2.6 DESCRIPTION OF LOCAL SETTING

2.6.1 Interpreted Site Geology

The interpreted site geology provides key information related to the possible hydraulic connection, or isolation between the shallow and deep aquifer/reservoir zones. Energy or water source well drilling records, geophysical logs extending to surface (natural gamma as a minimum, which can penetrate through steel casing), ground or airborne geophysical (EM/Seismic), or and other existing geological maps and reports should be considered in the assessment.

It is understood that companies may not want to share shale gas reservoir data, therefore energy logs can be truncated at the base of the Debolt Formation Aquifer, or other targeted, deep, saline aquifer/reservoir. The information should be presented at a scale that all hydrostratigraphic units from Quaternary deposits down through to the Debolt Formation can be clearly identified. Presentation of a cross-section(s) is recommended as a preferred method to

present this information visually and in a more readily understandable manner. Cross-sections should be annotated wherever possible.

Water levels or reservoir pressure measurements converted to equivalent groundwater elevation in metres above sea level, where available, should also be depicted to show the hydraulic relationships and inferred direction of groundwater flow between the hydrostratigraphic units or formations.

2.6.2 Source/Disposal Well Completion and Integrity Testing

Standard integrity testing also may provide key information to demonstrate hydraulic isolation between the deep and shallow systems. The following sub-sections include typical data that may be collected by energy companies as part of the exploration and testing of disposal zones. Where the data is available, the EAO encourages proponents to include the information that helps to provide scientifically defensible data in the project description.

2.6.2.1 Loss of Circulation Incidents

A loss of circulation incident describes a subsurface zone where drilling fluid was lost to the formation. In a low permeability formation, significant mud losses typically do not occur. However, in high permeability, coarse granular sediments, or in fractured or karstic bedrock materials, significant volumes of drilling mud may be lost to the formation. As such, loss of circulation zones can be indicative of potential hydraulically active or aquifer zones. Loss of circulation incidents are typically recorded on the driller's report.

This information (if available) should be summarized in a table format to indicate where intervals were encountered in the subsurface and drilling fluid loss was observed. Where available, the proponent is encouraged to annotate well logs or cross-sections submitted as part of the environmental assessment requirements to indicate where hydrostratigraphic zones of higher permeability may be indicated.

2.6.2.2 Cement Returns

The Drilling and Production Regulation requires that surface casing be set below the deepest useable groundwater zone, and that the casing be cemented to surface. Hydraulic isolation should be established between all porous zones (BC OGC, 2010) by cementing the annular space between the casing and the adjacent geologic formation.

In order to accomplish this, the driller pumps cement down the surface or production casing forcing it to return to surface along the wellbore annulus. The cement volume is tracked by the driller cementing during the procedure. Typically, the cement volume will be the anticipated volume based on casing size and probable annular space plus 20%. The driller monitors fluid displacement and the amount of cement that returns to surface as a qualitative measure of the success of the casing cement seal (K. Parsonage, BCOGC, 2012).

If cement does not return to surface, then cement has been lost to a porous zone in the formation (typically fractured). Where this occurs, the top of the cement should be confirmed through a cement bond log. The cement returns are reported on the drilling report to the OGC (K. Parsonage, BC OGC, 2012). As part of the information submitted to EAO, the proponent should include the applicable drilling report and explain how it either demonstrates or fails to demonstrate cementing integrity along the casing length.

2.6.2.3 Cement Bond Logs

A cement bond long shows channels or holes between the casing and the formation. A successful log should show adequate coverage with 100 percent bond. A geophysicist typically completes the interpretation and may identify a good cement bond, partial cement bond or no cement bond present from the log. Whether a partial bond is sufficient to ensure cement seal integrity may be a subjective decision by the geophysicist.

Once the casing is installed and cemented, a geophysical cement bond log survey may be completed if the cement did not return to surface, or there is question about the seal integrity. Cement bond logs are most commonly completed for disposal or injection wells that are to be subjected to injection pressure. However, under the OGC's Drilling and Production Regulation, if the surface casing is not cemented to surface, the well permit holder should conduct adequate logging to demonstrate hydraulic isolation of the zone (BC OGC, 2010). Where available, cement bond logs and appropriate interpretation to explain the findings in terms of cement integrity should be summarized in table format as part of information submitted to EAO.

2.6.2.4 Pressure Integrity and Leakoff Testing

Disposal/injection wells must undergo pressure integrity testing prior to operation. Pressure integrity testing requires that the well casing annulus be pressure tested to a minimum pressure of 7,000 kPa for 15 minutes duration. If the pressure does not vary by more than 3% the test is considered successful (BC OGC, 2011). The record(s) should tabulate for each disposal well available for the study area and provide appropriate interpretation to explain the findings as they relate to well integrity.

Disposal/injection wells may also undergo formation fracture testing or a procedure referred to as leak-off testing. A leak off test is completed in the open wellbore below the drill shoe to establish the pressure at which the formation starts to fracture. The wellhead is sealed and the well casing and open bore is filled with fluid. At some pressure, the fluid will begin to enter the formation. This is used to establish the maximum mud/fluid pressure permitted when constructing injection wells. It can also be used to obtain an estimate of the matrix permeability, which can then be interpreted to show hydraulic isolation between formations (K. Parsonage, BC OGC, 2012).

If any of these tests are completed for the water source wells or injection wells, the proponent is encouraged to provide documentation of the methodology, assumptions and limitations with the data interpretation within the context of confirming well integrity and probable hydraulic isolation

between the formations. All data presented to EAO must be in a hydrogeological format to facilitate review by provincial government technical staff (typically a hydrogeologist).

2.6.2.5 Casing Vent Monitoring

A casing vent flow is defined as the flow of gas and/or liquid or any combination from the surface casing/casing annulus (BC OGC, 2012). Monitoring of casing vent flows is conducted as a standard practice in oil and gas operations. These data can be helpful to verify casing seals. If there is a leak along the annulus of a casing or within an improper cement seal, gas or fluid is able to enter into the casing vent located near the ground surface. Monitoring the casing vent can indicate a leaky casing or a faulty cement seal. Since the Debolt Formation is known to contain H_2S gas, a positive result (gas present) may indicate a problem and should be investigated (K. Parsonage, BC OGC, 2012).

If available, the proponent is encouraged to summarize casing vent monitoring data in table format and to provide interpretation, where possible. These data help confirm the quality control and quality assurance measures taken by the energy companies and verify well casing/seal integrity. If any leaks are identified through surface casing vent flows, appropriate remedial measures must be conducted (K. Parsonage, BC OGC, 2012). These data, if available, should also be presented as part of the enclosed submission.

2.6.3 Hydrogeological Testing to Assess Potential Impacts and Hydraulic Connectivity to Shallow Aquifers

Hydrogeological tests and long-term groundwater monitoring data, that may be available as part of on-going operations, would provide insight into the hydrogeologic characteristics in the area of interest. Various hydrogeological tests may be used to estimate hydraulic properties of an aquifer/reservoir (hydraulic conductivity, transmissity, storativity, etc.). Various testing procedures may be used in the shallow versus deep aquifers/reservoirs depending on the cost of equipment and logistical challenges presented.

The intent is for energy companies to provide as much interpreted data as possible as part of the environmental assessment. It is recognized that some of the data sources described below may not be available for all project sites. Aquifer testing data, for instance, may only be available to those projects that have an existing Debolt well where groundwater has been extracted below the 75 L/s *EA Act* threshold. It is understood that energy companies collect groundwater extraction and water level/reservoir pressure data from operating wells as a standard practice. Where these data are available, the proponent should include the data as part of the hydrogeological context.

2.6.3.1 Drill Stem Test or Swab Tests

Drill stem tests (DST) may be performed during drilling of oil, gas or water source wells to assess the reservoir pressure or shut-in water level and permeability variations within different formations. The basic drill stem test tool consists of a packer or packers, valves or ports that

may be opened and closed from the surface, and two or more pressure (water level)-recording devices. During the test, the formation fluid is recovered through the drill stem, while pressure/level is measured and recorded. The data is used to assess formation permeability.

If DST data is available and used to derive aquifer/reservoir parameters, the data should be interpreted and summarized in a hydrogeological context and included in information provided to the EAO and reviewed by provincial government technical staff. Typically, interpreted permeability estimates from DST's are reported in darcy or milli-darcy units, but should be converted to equivalent hydraulic conductivity values in metric units (centimetre per second, or meters per second).

A swabbing tool can be used to extract drilling and reservoir fluids from a wellbore in the same way water wells may be developed using a bailer system. The swabbing string is much more complex due to the greater depths and gas content in deeper formations but it does provide some information about the capacity of the zone being tested. The swabbing tool incorporates a weighted bar and swab cup assembly that are run in the wellbore on a wireline. When the assembly is retrieved, the specially shaped swab cups expand to seal against the tubing wall and carry the liquids from deep in the wellbore. Swabbing data, including volumes of water extracted and fluid levels recorded, can be used to estimate hydraulic characteristics of the Debolt Formation. In the absence of more quantitative data, swabbing data can be useful.. Although standard oilfield methods may be used to interpret the DST and swab data (e.g., Horner Plots), all results should be converted into standard metric hydrogeological units to equivalent hydraulic conductivity values.

2.6.3.2 Injection Tests

Under OGC guidelines, injection wells undergo injection testing to confirm the long-term rate at which produced saline water can be disposed into a disposal zone such as the Debolt Formation. During the test, the pressure or equivalent water level change over time is monitored along with the injection. This data can be interpreted to obtain an estimate of formation permeability or hydraulic conductivity.

2.6.3.3 PumpingTests

For those energy companies that have existing wells completed in the Debolt Formation and that may be pumping saline groundwater below the 75 L/s reviewable project threshold, longer-term aquifer testing data may be available. Aquifer test data may also be available for shallow(er) aquifers from water supply wells or source water wells. Where available, these data should be made available in the environmental assessment.

Aquifer/reservoir tests (pumping) to quantify hydraulic properties of the Debolt Formation are not routinely conducted. Such aquifer tests pose numerous challenges due to equipment constraints and the need extract groundwater at depths >200 m in a highly productive aquifer/reservoir. In addition, the management and disposal of the extracted saline, H_2S-bearing, groundwater may pose a significant challenge. As such, energy companies are not

required to conduct aquifer/reservoir tests in the Debolt Formation for the environmental assessment. Companies can rely on both local and regional information and shorter term tests (DST, swab tests, injection test, etc.) to support an environmental assessment. It should be noted, however, that a more quantitative assessment will provide greater support to the environmental assessment process and establishment of any subsequent monitoring requirements as a result of more direct testing.

During an aquifer test, groundwater is typically extracted at a constant or variable, but controlled, flow rate for a specified period of time. The flow rate and bottom hole pressure (or water level) changes in the aquifer/reservoir are monitored. This data may be interpreted by various methods to obtain aquifer/reservoir parameter estimates. Notwithstanding that the tests are interpreted using oil and gas/reservoir engineering methods, all results should be converted into standard metric hydrogeological units, interpreted and summarized for EAO/ provincial government technical staff review. For example, the method and any assumptions used in the analysis should be clearly presented to facilitate independent review.

Depending on the flow rate and duration of injection or pumping tests, a hydraulic response could be observed further away in the same aquifer/reservoir, or potentially in an overlying aquifer if it were hydraulically connected to the tested aquifer. As such, any long-term testing in the deep, saline aquifer/reservoir should involve monitoring other available Debolt wells and any shallow aquifer wells to assess the degree of hydraulic connection.

2.6.3.4 Other Data (temperature, tracer, etc.)

Proponents may have performed other testing studies or monitoring as part of the day-to-day operation to evaluate or operate a shale gas area/pool. These tests should be documented, interpreted and summarized if it helps to develop a better understanding of the linkages between the shallow and the deep aquifers/reservoirs or well to well interference within the Debolt Formation. All relevant data should be included in the project description.

2.6.3.5 Aquifer/Reservoir Monitoring Data

Local shallow groundwater resources may be developed for on-site camp water supply wells, shallow source water wells and/or monitoring wells for environmental management purposes. Provincial observation wells may also be available in the Horn River at some point in the future. If these wells are appropriately located relative to the proposed groundwater extraction project area (i.e., within 5 km), information may be gathered to characterize the shallow groundwater system in terms of water levels and water chemistry to assess the existence of any hydraulic connection between aquifers.

In some cases, the proponent may complete a water source or disposal well within the deep, saline aquifer/reservoir without triggering the reviewable project threshold. Where early water extraction or disposal occurs, continuous water level/bottom hole pressure monitoring data may be used to assess aquifer/reservoir response. The aquifer/reservoir response to both pumping/extraction and/or injection/disposal in the area provides valuable information to

evaluate the long-term injection and withdrawal response of the Debolt reservoir/aquifer. This data also allows for an evaluation of the degree of hydraulic isolation from the shallow regime if shallow monitoring data is also available for comparison. All monitoring data should be reported as water levels or groundwater elevations.

Groundwater volumes diverted from shallow and deep aquifer systems, or injected into deep aquifer systems are generally tracked by energy companies for operational purposes and is also required by the OGC. This data, if available, will help correlate temporal water level changes observed in shallow groundwater zones which can be compared to monitoring of deep, saline groundwater zones to illustrate and quantify the hydraulic connection/disconnection between units. Existing water level data from various hydrostratigraphic zones should be presented graphically and submitted as part of the environmental assessment.

2.6.3.6 Groundwater Flow/Reservoir Modeling

It is understood that energy companies using the Debolt Formation, or other saline groundwater reservoirs, often complete analytical or numerical flow simulations as part of long-term water management planning. If available, such models can be used to predict aquifer capacity, potential interference with neighbouring wells, and long-term yield from the aquifer/reservoir. If modeling has been completed, a description of the model including methods, results, assumptions and limitations should be included. The Ministry of Environment has prepared a more detailed guidance document on groundwater modelling - Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities.

2.6.4 Groundwater Quality Assessment

Regional water quality monitoring from the Debolt Formation aquifer/reservoir has shown it to be saline and containing hydrogen sulphide gas. All readily available water quality information from the Debolt Formation and shallower formations are required.. The data should be tabulated to confirm salinity and to help demonstrate the hydraulic connection between shallow and deep groundwater zones and to establish baseline conditions.

2.7 POTENTIAL ADVERSE EFFECTS ASSESSMENT FROM GROUNDWATER EXTRACTION

This section provides guidance to the proponent on submission requirements to the EAO/ provincial government technical staff with regard to potential adverse effects from the proposed groundwater extraction project.

2.7.1 Potential Hydraulic Connection with Shallow Water Resources

The proponent should present the interpreted evidence to demonstrate the presence or absence of a hydraulic connection between the deep, saline aquifer/reservoir and the shallow groundwater aquifer(s) and/or surface water resources. It is expected that the evidence would be derived from one or more sources including:

- Geological evidence of aquitard/aquiclude between shallow and deep zones;

- Pressure head/water level differences between the shallow and deep zones;
- Water quality differences between the shallow and deep zones;
- Evidence to demonstrate well integrity and the isolation between the porous zones; and,
- Evidence from monitoring of shallow and deep aquifers during testing or from operational data.

2.7.2 Water Source Well Capacity and Potential Impact Analysis

A management option for a deep, saline aquifer like the Debolt Formation could be similar to that of a hydrocarbon reservoir, i.e., it is a resource that can be depleted. Current predictions for the long-term well capacity of the Debolt Formation are limited by available data; however, the existing limited baseline data can be used to provide interference thresholds at this time. This guidance document is intended to allow for the compilation and interpretation of existing and future baseline and operational data so that energy companies and regulatory officials can make informed decisions should disputes over groundwater occur.

To facilitate responsible and equitable use of saline groundwater in the Debolt Formation, the proponent should include an assessment of potential impacts within the deep, saline aquifer. This analysis should include, but not be limited to:

- A source well and aquifer/reservoir capacity assessment based on available information. The intent is not to provide a detailed aquifer/sustainability assessment of the saline source, but rather to provide a clear indication that the aquifer would be able to support the water supply demand over the life of the project. If the reservoir is managed as a non-renewable resource, as is common practice in the oil and gas industry, the proponent should assess the timeframe over which the saline aquifer/reservoir would no longer support the existing demand for water. This assessment should document all assumptions, findings and limitations.
- Potential well interference and offset analysis using the information related to the modeling described under Section 3.4.3.6, if available. Specifically, provide estimates of how the proposed saline groundwater extraction activity will impact the aquifer/reservoir in the vicinity of the project as well as estimates of predicted drawdown effects to adjacent users within 5 km radius of the site. As noted previously, the Ministry of Environment has prepared a more detailed guidance document on groundwater modeling - Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities.
- The effects of mixing on water quality over the life of the project and whether the proposed project disposal activities, if applicable, are likely to cause significant deterioration of the water quality, such that it could adversely impact other users.

2.8 MONITORING PROGRAM

2.8.1 Approach and Objectives

Groundwater monitoring is routinely conducted by most companies as part of their due diligence program and standard operational practices. Based on the hydrogeological assessment findings described in sections 3.2 through 3.5, gaps or uncertainties may be recognized, upon which the predictive assessments are based. It is recommended that the proponent identify these data gaps and describe how additional data will be gathered to confirm predictions and decrease uncertainties or risks.

The key monitoring program objective is to obtain additional data to verify the performance of the aquifer/reservoir and to confirm the lack of hydraulic connection with overlying shallow aquifers, lack of impacts to other users.

An environmental assessment may specify terms and conditions related to monitoring. Reporting of monitoring data to the EAO may be required and will be consistent with EAO's compliance management program.

The following sections describe recommended monitoring practices that may be adopted by the proponent. The proponent should not limit monitoring activities to these recommendations and should tailor monitoring programs to site specific conditions.

2.8.2 Deep, Saline Source Aquifer/Reservoir (i.e., Debolt or Deeper Formations)

2.8.2.1 Monitoring Well(s)

Monitoring well(s) within the deep, saline source aquifer/reservoir should include existing production wells, observations wells, and disposal wells, where appropriate. The intent is to monitor changes in aquifer/reservoir response over time resulting from groundwater extraction activities.

2.8.2.2 Water Extraction and Levels

Automated pressure transducers with data loggers should be installed at each deep, saline water source well. As a minimum, the reading interval should be set to hourly but more frequent readings are also acceptable (e.g., 1 min, 15 min) and will largely depend on the memory storage of the data logger and the nature of pumping activities being carried out.

Groundwater extraction or injection rate data should also be collected and should include instantaneous and total volumes.

The collected data should be downloaded, processed and/or compiled on a monthly basis. The water pressure data should be converted to equivalent groundwater level or elevation. Hydrographs should be developed to show a continuous record for each monitoring well. Extraction or injection rates and/or volumes can be plotted on the same hydrograph to show the

cause and effect relationship between pumping or injection and water level response in the aquifer/reservoir. These data can be compared to shallow groundwater monitoring well data to allow for an analysis of the vertical hydraulic communication between shallow and deep reservoirs/aquifers at the groundwater extraction site.

2.8.2.3 Water Quality

On-going water quality monitoring of Debolt Formation groundwater is currently being conducted by energy companies to determine treatment requirements. This data can be used to help assess possible water quality degradation effects resulting from the disposal of spent water into the Debolt Formation, or water quality changes over time resulting from continued pumping. Water quality samples should be collected a minimum of two times per year following standard sampling practices for deep reservoir that contain hydrogen sulphide gas. Field parameters such as electrical conductivity may be measured on a more frequent basis, if appropriate.

For environmental monitoring purposes, chemical analysis from an accredited lab should include major anions and cations, trace total metals, and hydrocarbon parameters. As Debolt Formation groundwater contains H_2S gas, analysis of dissolved hydrogen sulphide species is also recommended.

2.8.3 Shallow Aquifer Monitoring

2.8.3.1 Monitoring Well(s)

Water level monitoring in the shallow aquifer will provide evidence of its hydraulic isolation from, or connection with the deeper saline source aquifer. If appropriately located, existing water wells or monitoring wells completed in a shallow aquifer zone can be monitored to allow for evaluation of the vertical hydraulic connection with the saline aquifer/reservoir well that is being pumped. A regional shallow groundwater monitoring network is under development through the Ministry of Environment with collaboration from industry participants. If one or more of these observation wells are appropriately located, the groundwater monitoring data collected could provide the required information to determine the baseline and natural variability of groundwater levels and water quality in the region.

If a suitable monitoring well(s) is not available at the site, then the proponent should plan to install a single shallow monitoring well, ideally located in the vicinity of the saline source well field area. The monitoring program presented as part of the environmental assessment requirements should include the identification of proposed monitoring wells. The EAO will consider the need for additional monitoring.

2.8.3.2 Water Levels

The purpose of monitoring water levels in a shallow well(s) is to evaluate if there are any potential drawdown effects from the extraction of deep, saline groundwater.

An automated pressure transducer with data logger should be installed at each deep, saline and at least one shallow monitoring well. It is understood that the data logger required for the saline groundwater source well will have different requirements than the data logger used in the shallow wells. The data logger selected for the shallow well should also be capable to measuring both water pressure/level and electrical conductivity. The logger clocks should be synchronized and set to the same reading interval (if possible). The frequency of the reading interval should be set in accordance with the available memory storage of the data logger and the nature of the pumping activities. An hourly or more frequent interval is recommended during pumping periods.

The collected data should be downloaded, corrected as required and compiled graphically on a monthly basis. Any water pressure data should be converted to equivalent groundwater elevations. Water level hydrographs from the shallow well should be plotted at the same scale as those collected from the saline source well. If groundwater extraction is occurring in the shallow aquifer, this information should be included.

Water level fluctuations can be tracked over time and a comparative analysis of the hydrographs should be completed to determine if hydraulic communication exists. Groundwater elevations for both the deep and shallow groundwater wells at the same location will also allow for documentation of the vertical hydraulic gradient between the two wells over time. This will help to verify the degree of hydraulic communication between the deep Debolt aquifer/reservoir and the shallow aquifer(s).

2.8.3.3 Water Quality

On-going water quality monitoring of shallow groundwater must be conducted by energy companies to help assess possible water quality effects resulting from pumping saline groundwater to surface from deeper formations.

The electrical conductivity data, when downloaded, should be reviewed to assess temporal changes to water quality.

As with the saline groundwater sampling program, water quality samples from the shallow aquifer should be collected a minimum of two times per year using accepted standard sampling practices outlined in the British Columbia Field Sampling Manual (BC MWLAP, 2003). Chemical analysis should include major anions and cations, trace total metals, and hydrocarbon parameters. Analysis for dissolved hydrogen sulphide species is also recommended.

The proponent should compare the recent water quality sample results with the historical groundwater chemistry record for the same well to determine if water quality changes are occurring over time. These data should further confirm the hydraulic disconnection that is expected between shallow aquifer zones and the deeper saline Debolt Formation aquifer.

2.8.4 Reporting Requirements

The proposed monitoring program submitted with the project description should include proposed monitoring reporting. The EAO may consult with the provincial technical staff on the appropriate reporting requirements and frequency on a case by case basis. The reporting components are expected for both the shallow aquifer and the saline source aquifer. The frequency of reporting is anticipated to decrease as more data is accumulated and environmental risks are determined to low.

The following provides some suggested content for monitoring reports that the proponent may wish to consider.

- Objective(s) or purpose(s) of the monitoring.
- A description and rationale for the location, and completion of the monitoring well(s) to monitor the relevant potential adverse effect in the two aquifers.
- Description of methods used to collect and present the groundwater flow, water level and EC measurements and water samples, as appropriate.
- Daily extracted and/or injected groundwater volumes plotted over the month and cumulative extractions/injections to-date
- Hydrograph(s) of the water levels over the month plotted at the required scales to allow for clear presentation of trends or fluctuations.
- Electrical conductivity results over the month plotted at the required scales to allow for clear presentation of trends or fluctuations.
- Discussion related to the interpretation of the groundwater flows, water levels and EC measurements and water chemistry.
- Updates on the status or problems with the monitoring program.
- Characterization and description of the data variability using trend graphs and documenting any water quality sampling results obtained.
- A review of the adequacy of the monitoring requirements. This may include recommending changes to the monitoring requirements as the additional baseline understanding of conditions develops, or alerting EAO that conditions are changing.

The monitoring reports must be prepared by a qualified hydrogeologist or groundwater specialist, who is a member of the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC).

2.9 ADAPTIVE MANAGEMENT AND MITIGATION PLANNING

Adaptive management programs typically provide early warning of adverse effects. Threshold exceedances will trigger a set of contingency actions sometimes leading to mitigation, or to shutting down the project operation. Results of the monitoring program provide the data used to

establish baseline or reference values. Threshold-based triggers most often are developed as a percentage or are statistically related to the baseline or reference value.

US Environmental Protection Agency (2009) notes that it may take several years of regular monitoring to fully characterize the extent of variability in the data. Currently, there is little to no baseline groundwater data in the Horn River Basin that can be used to develop reasonable quantitative threshold trigger values for use in developing an adaptive management program. Once the variability of the water levels and water quality is established through the early operational phase monitoring, threshold-based triggers can be developed in discussion with the EAO, or provincial government technical staff should it be required. A review and possible revisions of the approach is recommended as more data is collected.

- The adaptive management program should address monitoring evidence that suggests that the water level or water quality in either the shallow or deep aquifers are not responding in accordance with the predictions presented in the environmental assessment. For example, the main triggers that should be tracked include:Monitoring responses or trends that reveal a hydraulic connection between the shallow aquifers and the Debolt Formation or deeper sources of saline groundwater; and,
- Monitoring evidence that shows water level or water quality changes in the Debolt aquifer/reservoir are greater than predicted and could result in adverse effects for existing users.

Where these thresholds are identified, it may be appropriate to initiate additional assessment or data collection to evaluate if an adverse effect(s) is anticipated and whether mitigative measures should be triggered.

If adverse effects are occurring then mitigation may be required. The proponent is encouraged to provide a mitigation plan that recommends operational changes or mitigative actions that could be undertaken based on the anticipated risks for an adverse effect that was not predicted (e.g., possible operational solutions for dispute resolution between Debolt users, changes to treatment measures where water quality effects are identified, etc.).

The proponent should expect to notify the EAO if any complaints or disputes are received.

3.0 DISCLAIMER

This document is intended to provide clarification and guidance to proponents regarding environmental assessment groundwater related information. It provides information only and should not be used as a substitute for the *Environmental Assessment Act*, regulations or direction from the EAO or any other regulatory body, Act, regulation, or guidance document. In the event of a discrepancy, the EAO should be contacted. Portions of the *Environmental Assessment Act* have been paraphrased in the enclosed guidance document and should not be relied upon for accuracy. The enclosed document does not have legal authority and is not intended to provide legal advice or direction. The procedures described in this guidance may be modified in discussion with the EAO to meet specific project circumstances. Early and ongoing consultation with the EAO is recommended regarding project description requirements.

4.0 REFERENCES

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