Canadian Council of Ministers of the Environment
Le Conseil canadien des ministres de l'environnement

GROUNDWATER SUSTAINABILITY ASSESSMENT APPROACH: GUIDANCE FOR APPLICATION

PN 1568
ISBN 978-1-77202-038-0 PDF

TABLE OF CONTENTS

1. INTRODUCTION **3**
2. DEFINITIONS **3**
3. THE GROUNDWATER SUSTAINABILITY ASSESSMENT APPROACH (GSAA) FRAMEWORK 5
3.1 Context for GSAA implementation 5
3.1.1 Definition of groundwater sustainability 5
3.1.2 Application of the GSAA 6
3.1.3 Benefits of the GSAA 7
3.1.4 Planning Groundwater Sustainability Assessment Projects 8
3.2 Jurisdictional Assessment and Issue Identification 11
3.3 Driver-Pressure-State-Impact-Response (DPSIR) Conceptual Model 13
3.4. Groundwater Sustainability Indicators 16
3.4.1 Selecting and Developing Indicators 16
3.4.2 Lessons learned from the Pilot Projects 18
3.4.3 Examples of specific indicators 19
3.5 Linkages with other approaches addressing groundwater sustainability 22
4. COMMUNICATIONS AND STAKEHOLDER ENGAGEMENT 23
4.1 Communicating GSAA Results 23
4.2 Engaging Stakeholders 25
5. 'GETTING GOING': PRELIMINARY CHECKLISTS 28
5.1 Jurisdictional Assessment and Issue Identification 29
5.2 DPSIR Conceptual Model 30
5.3 Groundwater Sustainability Indicators 31
5.4 Communications and Stakeholder Engagement 31
6. CHALLENGES 32
6.1 Scientific Challenges and Guidance 32
6.1.1. Data Discovery/Accessibility and Gaps 33
6.1.2. Data Quality Assurance and Control 34
6.2 Governance, Management and Policy Challenges and Guidance 35
6.3 Communication Challenges and Guidance 36
REFERENCES 38

Appendix 1. Groundwater Sustainability Assessment Approach 39
Appendix 2. Suggested Indicators for the Five Groundwater Sustainability Goals (Gordon, 2011) 42
Appendix 3. List of potential indicators for each of the five Groundwater Sustainability Goals 44
Appendix 4. Examples of other approaches addressing groundwater sustainability in Canadian jurisdictions 57

1.0 INTRODUCTION

Groundwater is the main source of water for almost ten million Canadians. It is critical to human health, to important aspects of the economy, and to the viability of many ecosystems.

Canadian Council of Ministers of the Environment (CCME) developed and tested an approach for assessing the sustainability of groundwater resources at a local, regional or Canada-wide scale. The resulting Groundwater Sustainability Assessment Approach (GSAA), (Appendix 1), hereafter referred to as the GSAA, is a high-level framework that can be interpreted for application across various scales, locations and circumstances.

To support the use of the GSAA, CCME has developed this guidance document. The guidance document is meant to assist users to successfully apply the GSAA. It provides a balance of high-level guidance and practical how-to advice while highlighting issues and actions jurisdictions should take into account as they work through the GSAA.

The document is modular. It can be applied linearly, from beginning to end, but also allows users to focus on the specific guidance most appropriate to them. It is comprehensive in scope with specific explanations provided on the GSAA approach, definitions, and principles for reference. Useful background links to past research or reports are also included for easy reference. To help gather and contextualize best practices, interviews were conducted with the leads of all pilot projects.

2.0 DEFINITIONS

The following key definitions and concepts address the need for common "groundwater sustainability" language. All key definitions and concepts are presented in the Gordon Report (2011) and the WESA report (2013) and are summarized below.

The Council of Canadian Academies (CCA) (2009) identifies that groundwater and related surface waters and aquatic ecosystems are elaborately linked. Groundwater provides base flow to streams between storm runoff events, supports aquatic ecosystem health, and maintains many wetlands.

<u>Groundwater sustainability</u> is defined as the maintenance and protection of groundwater and related ecosystems to balance current and future environmental, economic and human (social) requirements." (Gordon, 2011)

<u>Five Goals for Sustainable Groundwater Management</u> (CCA, 2009)

1. Protection of groundwater supplies from depletion (Groundwater Quantity)
2. Protection of groundwater quality from contamination (Groundwater Quality)
3. Protection of ecosystem viability (Ecosystems)
4. Achievement of economic and social wellbeing (Socioeconomic)
5. Application of good governance (Governance)

DPSIR Conceptual Model Framework for Groundwater Sustainability Assessments

The Driving-Force-Pressure-State-Impact-Response Conceptual Model Framework (DPSIR Framework) is an internationally recognized systems analysis approach used for developing and reporting environmental indicators[1]. The DPSIR Framework is used by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2007). The DPSIR Framework (adapted for this groundwater sustainability assessment) is summarized in the Gordon Report and the WESA Report as follows:

- **Driving Force** indicators describe the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns.
- **Pressure** indicators describe the developments by human activities that use groundwater supplies and release contaminants into groundwater.
- **State** indicators describe the groundwater in terms of physical, biological and chemical phenomena in a certain area.
- **Impact** indicators that illustrate the effects of changes in the state of groundwater systems.
- **Response** indicators refer to responses by groups (and individuals) in society, as well as government efforts, to prevent, compensate, ameliorate or adapt to changes in the state of groundwater systems.

Groundwater sustainability indicators are defined as measureable parameters that represent relevant information on trends in groundwater systems in a readily understandable way (based on Steinman, 2007; Gordon, 2011).

Criteria are used as points of reference or standards to help in the selection and evaluation of indicators (based on Steinman, 2007; Gordon, 2011).

Groundwater governance is defined as the decision making process through which groundwater is managed (Gordon, 2011).

Jurisdictions: in this guidance document, the term "jurisdiction" is not limited to federal and provincial governments. It also applies to other decision-making bodies including, but not limited to, municipalities, counties, townships, conservation authorities, and so on.

List of Acronyms:

CCA – Council of Canadian Academies
CCME – Canadian Council of Ministers of the Environment
DPSIR – Driving-Force-Pressure-State-Impact-Response Conceptual Model Framework
GSAA – Groundwater Sustainability Assessment Approach
GGC – Gordon Groundwater Consultancy
PACES – Programme d'Acquisition des Connaissances sur les Eaux Souterraines
UNESCO – United Nations Educational, Scientific and Cultural Organization

[1] More contextual information on the DPSIR Framework and its potential application is provided in section 3.3 of this document.

3.0 THE GROUNDWATER SUSTAINABILITY ASSESSMENT APPROACH (GSAA) FRAMEWORK

3.1 Context for GSAA implementation

The Groundwater Sustainability Assessment Approach (GSAA) Framework was developed by Gordon Groundwater Consultancy (GGC) for CCME in 2011 (referred to as the Gordon Report throughout this Guidance Document). Its purpose was to provide general guidance for groundwater sustainability assessments, including the identification of indicators that could be used as a starting point by jurisdictions wishing to undertake groundwater sustainability assessments. Ultimately, the GSAA aims at informing decision makers and policy developers on the status of groundwater sustainability and on the key data requirements, policy approaches and technical methods required to ensure that sustainable groundwater management practices are implemented across Canada.

The GSAA builds on and complements other existing approaches to address groundwater sustainability (see section 3.5). It also takes into consideration and incorporates the findings from the Council of Canadian Academies (CCA) Expert Panel on Groundwater report (CCA 2009). For example, Figure 1, taken from the CCA report, outlines the scientific and technical building blocks required to be able to evaluate groundwater sustainability.

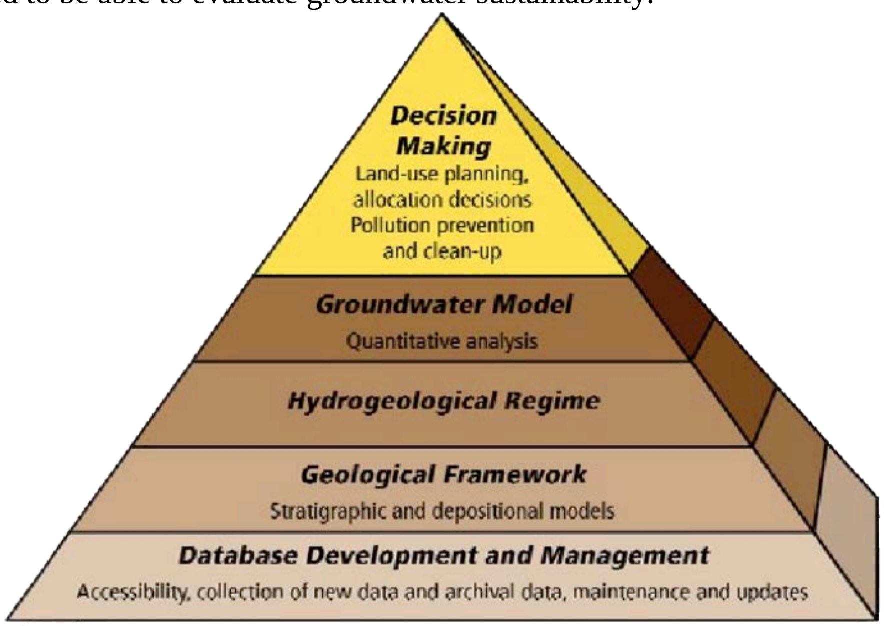

Figure 1. Science requirements for groundwater sustainability (CCA, 2009).

3.1.1 Definition of groundwater sustainability

For the purposes of this assessment approach, groundwater sustainability is defined as "*the maintenance and protection of groundwater and related dependent ecosystems to balance current and future environmental, economic and human (social) requirements*". Groundwater dependent ecosystems may include:

- aquifer and cave ecosystems
- surface water and aquatic ecosystems
- groundwater-related terrestrial ecosystems
- sub-surface biota, involved in groundwater cleaning processes and contaminant degradation.

This definition reflects the integrated nature of the five sustainability goals adopted from CCA 2009.

The Five Goals for Groundwater Sustainability

The GSAA goals, as adopted from the Council of Canadian Academies Expert Panel on Groundwater report (2009), are:

I. *Protection of groundwater supplies from depletion*: Where sustainability requires that withdrawals be maintained indefinitely without creating significant long-term declines in regional water levels.
II. *Protection of groundwater quality from contamination*: Where sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.
III. *Protection of ecosystem viability*: Where sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supply and the support of ecosystem.
IV. *Achievement of economic and social well-being*: Where sustainability requires that allocation of groundwater maximizes its potential contribution to the social well-being (interpreted to reflect both economic and non-economic values).
V. *Application of good governance*: Where sustainability requires that decisions as to groundwater use are made transparently through informed public participation and with the full account of the ecosystem needs, intergenerational equity, and the precautionary principle.

3.1.2 Application of the GSAA

There are a number of components required for a successful implementation of the GSAA. The Gordon Report provided high-level guidance around five steps: 1) Identification of groundwater sustainability issues; 2) Conceptual Model; 3) Indicator Selection criteria; 4) Formulation of indicators; and 5) Communication.

Similarly, this Guidance Document is organized around the following GSAA implementation components:

- Jurisdictional Assessment and Issue Identification
- Driver-Pressure-State-Impact-Response (DPSIR) Conceptual Model
- Groundwater Sustainability Indicators (including indicator selection process, the formulation of indicators and the actual use of indicators to measure various aspects of groundwater sustainability)

- Communications of results (to partners and stakeholders, to decision-makers and policy-makers, and to the general public)
- Stakeholder Engagement (which should happen at all stages of a groundwater sustainability assessment project).

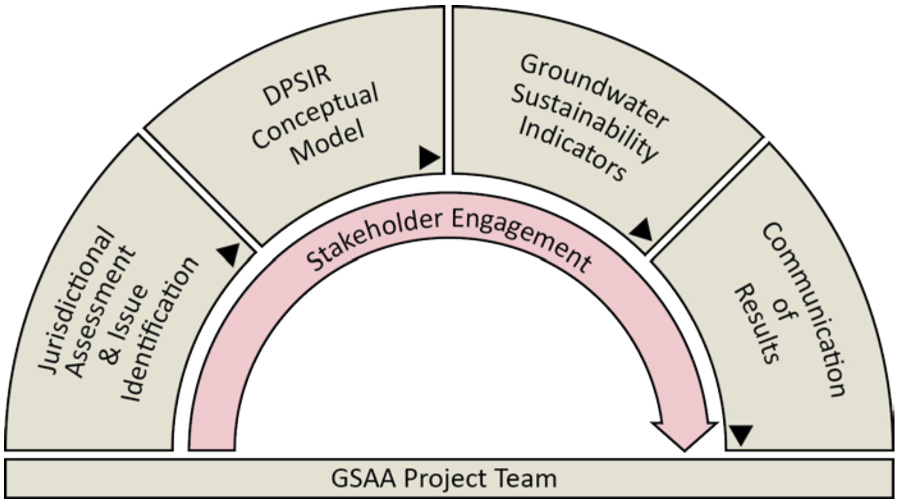

Figure 2. GSAA implementation components.

Figure 2 illustrates that each of the components may be present throughout implementation of the GSAA. This is why they are called "components" and not "steps" as the latter would imply a linear sequence, whereas some components such as stakeholder engagement should be present all along the process. In addition, the process can be iterative as the implementation of a component may lead to repeating the previous component before moving to the next one in certain cases.

3.1.3 Benefits of the GSAA

The purpose of this chapter and the next one is to provide practical advice on why and how to undertake these five components of the GSAA, based on a literature review and on lessons learned from various pilot projects conducted by jurisdictions across Canada. A discussion with one jurisdiction that has not implemented GSAA projects has also been held in order to identify additional guidance needs.

Groundwater sustainability assessment is not a new concept. However, the GSAA framework is still a relatively new and untested methodology in Canada. Consequently, this guidance document is intended to be iterative, and will evolve as our collective practical experience with groundwater sustainability assessment projects across the country becomes more extensive.

For example, groundwater supply assessments have traditionally been done while conducting pumping tests to assess sustainable yield or for regional characterization of aquifers with estimates of available groundwater for municipal wells. However, these assessments are often project-specific and do not address cumulative effects. On the quality side, groundwater quality assessment can be more responsive/reactive, typically implemented following a known or suspected deterioration of the groundwater quality. There is awareness of the bigger picture sustainability but most studies focus on characterization of the state of a specific aquifer. The GSAA framework allows the project team to delve into drivers, pressures, governance and responses, as well as the associated indicators. An added advantage of the DPISR approach is that it allows societies to imagine or define a future state of their environment and help determine the level and nature of development compatible with the predefined future state. This may require a certain level of tradeoff. Through the incorporation of the DPSIR model, the GSAA enables the characterization of broader sustainability challenges and the response function. Basically, the GSAA helps to answer the “why” and the “how” rather than just answering the “what”.

Another reason why the GSAA is such a valuable tool is because it can be successfully applied at different scales and for different issues. This conclusion was reached after several pilot projects were conducted across Canada to test the GSAA under various conditions and at different scales. Not only the scale but also the nature of the groundwater issues varied across projects. Nevertheless, the GSAA proved suitable to all pilot projects conditions (WESA, 2013). It is a tool that is flexible and can be adapted broadly, as long as the project team understands the purpose of the approach and makes the effort to adapt it to the specific conditions of the study area. The very wide range of pilot project conditions supports this conclusion.

List of Pilot Projects conducted with the Groundwater Sustainability Assessment Approach (GSAA) Framework

- Use of Groundwater Sustainability Indicators in Groundwater Outreach and Management for the Town of Gibsons, British Columbia, Canada
- Sustainability Indicator Assessment for the Transboundary Abbotsford-Sumas Aquifer, British Columbia, Canada
- Groundwater Sustainability Assessment for the Lower Athabasca Region, Alberta: A comparative assessment of the Lower Athabasca Groundwater Management Framework and CCME DPSIR Approach, Alberta, Canada
- Groundwater Sustainability in the Montérégie Est Region, Province of Québec, Canada
- Groundwater Sustainability in Prince Edward Island, Canada

3.1.4 Planning Groundwater Sustainability Assessment Projects

Groundwater sustainability management can be proactive or reactive (subsequent to unanticipated degradation of the state of the groundwater). The GSAA flexibility enables its users to apply it in both cases by allowing groundwater managers to enter the cycle at any stage, depending on the situation at hand. No matter the point of entry, GSAA implementation requires planning.

The planning stage of GSAA initiatives is critical. The GSAA provides high-level guidance and principles. However, it is critical for a jurisdiction to initially dedicate the appropriate level of resources towards issue identification and potential consequences.

As a starting point, it is important to clearly describe the current situation:

- Are we responding to an issue that has already occurred (e.g., declining water level in California)? Who/what is impacted? Who needs to be involved?
- Are we anticipating potential future impact (related to expected population growth for example)? What are the potential consequences?

It is critical that in describing the current situation, a causal link be established between the situation at hand and its impact on any of the five groundwater sustainability goals. In other words, there is a need to give operational focus to high-level sustainability goals, at a scale and budget that can be evaluated and tracked.

Living Operational Focus to High-Level Sustainability Goals

I. *Protection of groundwater supplies from depletion*:
- Consider whether and how the state of an aquifer (quality and quantity) may be influenced by anthropogenic factors, climatic conditions and aquifer characteristics (e.g., long transient evolution from one steady state to another).
- Consider defining "groundwater availability" and undertake groundwater studies to determine if groundwater availability is being maintained.

II. *Protection of groundwater quality from contamination*:
- Consider how both natural and anthropogenic factors have the potential to affect groundwater quality, specifically if they are generating contamination.
- Consider specific source contamination problems (e.g., naturally-occurring contamination, agricultural activity, urban sanitation, etc.), and how to monitor groundwater quality parameters to capture them.

III. *Protection of ecosystem viability*:
- Consider how groundwater-dependent ecosystems may be affected by changes in groundwater quality or availability. A critical issue is how much water can be withdrawn from a groundwater body or how much pollutants can be added to it without fundamentally affecting its viability.
- Consider how to collect accurate hydrogeological data over a period of time long enough to show changes in longer-term ecosystem viability, rather than transient periods or with short-term monitoring indicators.

IV. *Achievement of economic and social well-being*:
- Consider how policies and practices surrounding groundwater withdrawals contribute to the economic and social well-being of communities and how these can be balanced between human use and ecosystem and groundwater protection.
- Consider development of indicators that would allow comparisons between groundwater locations and across a number of economic and social well-being parameters fit for the jurisdiction.

V. *Application of good governance:*
- Consider how access to local knowledge can support good governance and allow community resource management decisions to be integrated into more regionalized and provincial planning.
- Consider how shared governance practices involving collaborative bodies of stakeholders including local residents, industry, governments, and other directly affected stakeholders can assist in making ecosystem and groundwater decisions.

In order to translate the high-level guidance of the GSAA into practical recommendations, it is also essential for the project team to engage stakeholders. In the context of a GSAA project, stakeholders can be defined as people and organizations who may be affected by a project or who can influence its implementation. This can include anybody who lives or works in the study area, including project team members such as planners, decision-makers and the public. As explained in section 4.2 of this Guidance Document, engaging stakeholders should be part of all components of a groundwater sustainability assessment project.

The lack of existing hydrogeological characterization and current conditions, as occurs in most jurisdictions at the regional or larger scales, should not be seen as a deterrent to undertake a groundwater sustainability assessment project. For example, where various groundwater parameters such as baseline chemistry or amount of water used are not known yet, applying the GSAA will allow the development of parameters for future use. The development of operational policy with ongoing commitment to fund field activities and their associated reporting is critical, in particular to track the status of groundwater sustainability over time. Successive application of the GSAA will lead to better and more complete assessments.

Groundwater sustainability assessment initiatives can be complex and are often thought to be resource-intensive, both in terms of human and financial resources. It is important to note that good planning may prevent such projects from becoming resource-intensive. For example, GSAA projects may be conducted in tandem with projects already funded through existing programs such as aquifer mapping or regional monitoring. Jurisdictions could also put an operational policy in place that rolls out a GSAA project on a reasonable scale (in space and time) depending on the available budget. It is therefore very important that jurisdictions put in place broader policies to support and encourage the development and implementation of groundwater sustainability assessment projects.

Jurisdictions planning to undertake groundwater sustainability assessment projects should pay attention to the following key factors in order to best use their limited resources:

- a comprehensive and well-resourced planning phase, in particular with clearly articulated sustainability targets
- the continuous enabling and engagement of stakeholders
- the importance of collecting data over a long period of time to support meaningful groundwater sustainability assessments
- the critical importance of effectively communicating the results of the projects.

Lastly, resources dedicated to groundwater sustainability assessment projects could be considered as “wasted” if the results of the assessment cannot be effectively communicated to the public and to the decision-makers. The resources dedicated to such projects should therefore include multi-disciplinary teams allowing the development of a solid communication strategy as an integral part of the project.

Designing a groundwater sustainability assessment project

- Identify issues.
- Describe potential consequences (perceived and/or real).
- Provide operational focus and smaller scale management targets to high-level groundwater sustainability goals.
- Develop short, medium and long term goals.
- Dedicate enough resources to the planning stage of the project.
- Identify existing information and establish a long-term field survey, data management protocols and a GIS system to collect and articulate new information in order to monitor groundwater parameters and recognize local and regional trends.
- Identify and engage with key local and regional stakeholders.
- Secure long-term commitment from participating organizations.
- Build a multi-disciplinary team.
- Link and integrate GSAA projects into existing programs when possible.
- Make sure that broader policies support the development and implementation of groundwater sustainability assessment projects.

3.2 Jurisdictional Assessment and Issue Identification

This component sets the purpose and focus of the GSAA to follow. Its primary value is in establishing clear goals for the GSAA. Jurisdictions can utilize the two steps in this component to undertake the most effective approach to the groundwater issues it considers most relevant. A broad, initial jurisdictional assessment can usefully place groundwater concerns into larger sustainability, environmental protection plans and economic development policies of the jurisdiction. From there, specific issue identification follows aimed at keying in on the priority groundwater concerns suitable for GSAA application. Together, these two steps within this GSAA component can ensure sufficient capacity, resources, and time are available to carry out the actual GSAA.

A description of each follows below.

Jurisdictional Assessment

Jurisdictional assessment is helpful in determining the state of the groundwater environment and identifying risk and/or priority. It provides an opportunity to link with other policy priorities such as climate change, water quality, land use, economic development issues and others of companion importance to the jurisdiction. Certain issues will emerge naturally through this process where a convergence of policy drivers will help clarify and facilitate groundwater sustainability assessment. It will also provide an opportunity to mobilize departmental, ministerial and agency representatives and stakeholders in the important early stages of the GSAA process.

The five goals for groundwater sustainability described above should provide the starting point for this exercise. As stated above, the project team will first need to consider how these high-level sustainability goals can be given an operational management focus at a scale that is both manageable and relevant for the jurisdiction.

As these goals cover a variety of groundwater issues, namely availability or quantity, quality, ecosystem viability, economic and social well-being, and governance, the jurisdictional assessment should be conducted by a multidisciplinary team. The most effective teams are comprised of hydrogeologists, ecologists, and other technical or scientific resources, complemented with expertise in other areas, such as land-use planning, economic development, intergovernmental affairs, public liaison, communications, and so on. The nature of the assessment – broad or narrow – and the issues being examined will inform the make-up of the team. Ideally, it is better to consider a broader, more holistic assessment in the first instance.

The multidisciplinary core project team needs to engage key stakeholders, i.e., individuals or organizations having an interest in the study area. This may include municipalities and other regional governments, First Nations, industry groups, environmental groups, fish, wildlife, and game associations, tourism corporations, chambers of commerce, individual land owners, etc. There are various ways of engaging stakeholders in the jurisdictional assessment. The project team will decide how to do it best, based on their knowledge of stakeholders, their previous engagement in similar projects, and the scope and focus of the assessment itself. Chapter 4 provides more information about stakeholder engagement during the various components of a groundwater sustainability assessment project.

A groundwater sustainability assessment project does not need to cover all five groundwater sustainability goals. These are guidance only for consideration. There are several reasons why a project team may want to focus its efforts on a subset of the goals including resources and time. This determination should be made for every project, based on the most important issues at stake and the available resources. A groundwater sustainability assessment initiative is an iterative process by nature, as such a project focusing only on a subset of the five goals can still produce relevant and useful information for conducting a GSAA. Additional projects can then aim at completing the assessment by focusing on the other goals. Consequently, a jurisdiction should not wait until it feels comfortable to address all five goals before undertaking groundwater sustainability assessments.

Issue Identification

The purpose of this step is to identify the key issue or issues that will form the focus of the actual GSAA. In doing so, it sets the parameters for the actual study. It begins with identifying what we know about the state of groundwater and the groundwater issues specific to the study area. This should include developing a baseline picture of what data are available on the state of groundwater and water uses. This will help the project team to determine the scope of GSAA project that should be undertaken at this time and will allow the communication of realistic expectations for results early on. For example, this initial step will help determine whether the GSAA should be a detailed study that will result in meaningful long term metrics, or a high level study that will allow the determination of what should be monitored or measured first. The latter would eventually lead to a more meaningful assessment and set of metrics. Together with the jurisdictional assessment step, issue identification aims at identifying all useful data, monitoring infrastructure, evaluation tools and resources.

One of the biggest challenges identified by the pilot projects was the availability of data and information to support the GSAA. It is therefore critical that, in identifying issues, the project team includes a comprehensive data inventory, both current data and historical sources of information. Engaging stakeholders at this stage may help identify various sources of data, both from the private sector (utilities, resource companies, etc.), the public sector (other provincial ministries, federal departments, municipalities, etc.) and traditional sources (First Nations traditional knowledge). There are several challenges with data availability and data quality, as discussed in Chapter 5. At this initial stage of a groundwater sustainability assessment project, the most important data-related action is to identify all sources of information and to discuss and negotiate data-sharing agreements when appropriate. An assessment of the data quality, availability and limitations should also be conducted.

Jurisdictional Assessment and Issue Identification – In Summary

- Keep in mind the five goals for Groundwater Sustainability.
- Put in place a multi-disciplinary project team (ideally a multi-agency team).
- Engage local stakeholders.
- Conduct a comprehensive data inventory, including an assessment of data quality, availability and limitations.
- Secure data availability through formal data-sharing agreements.

3.3 Driver-Pressure-State-Impact-Response (DPSIR) Conceptual Model

The Gordon Report recommends the use of the Driver-Pressure-State-Impact-Response (DPSIR) framework to develop a conceptual model for groundwater sustainability assessments. DPSIR is an internationally recognized systems analysis approach used by several government agencies around the world, including some Canadian jurisdictions. When applied to groundwater, it is a method that facilitates the wide assessment of issues covering aspects of human activity that have an impact on groundwater resources, and of the impacts that are caused by these activities. It also helps determine whether there are measures in place to guard against further impacts or to restore damages that have taken place.

DPSIR Conceptual Model Framework for Groundwater Sustainability Assessments

The Driving-Force-Pressure-State-Impact-Response Conceptual Model Framework (DPSIR Framework) is an internationally recognized systems analysis approach used for developing and reporting environmental indicators. The DPSIR Framework is used by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2007). The DPSIR Framework (adapted for groundwater sustainability assessments) is summarized in the Gordon Report as follows:

- **Driving Force** indicators describe the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns.
- **Pressure** indicators describe the developments by human activities that use groundwater supplies and release contaminants into groundwater.
- **State** indicators describe the groundwater in terms of physical, biological and chemical phenomena in a certain area.
- **Impact** indicators that illustrate the effects of changes in the state of groundwater systems.
- **Response** indicators refer to responses by groups (and individuals) in society, as well as government efforts, to prevent, compensate, ameliorate or adapt to changes in the state of groundwater systems.

While DPSIR is a useful framework to organize information in a way that describes the relationships between causes and consequences of sustainable groundwater management challenges, using it in combination with the five groundwater sustainability goals proved challenging in the pilot projects that were undertaken to apply the GSAA to actual groundwater assessment projects.

The pilot projects noted that framing the groundwater issues and the indicators into the DPSIR framework can increase the complexity of the assessment. For example, more than one indicator can be used for more than one DPSIR element and some indicators do not seem to always belong where they may be intuitively assigned. One pilot project concluded that taking into account the sustainability goals, the DPSIR Framework and the indicators altogether seemed to complicate the approach. While this may be true, the DPSIR Framework provides key insights into the development of relevant indicators and can improve the overall quality and usefulness of groundwater sustainability assessment projects.

Benefits of using the DPSIR Conceptual Model in GSAA projects

The Driving-Force-Pressure-State-Impact-Response Conceptual Model Framework (DPSIR Framework) allows for the identification of key linkages between pressures on groundwater and potential responses from jurisdictions. It adds a practical component to groundwater sustainability assessment projects, allowing the evaluation to go beyond the assessment of the current state of aquifers.

The five groundwater sustainability goals provide strong objectives and overall guidance for the identification of what should be considered in groundwater sustainability assessment projects. They do not, however, provide specific direction on implementation. This may be a problem since most groundwater studies aim to characterize the state of aquifer conditions but don’t often address the pressures and the potential responses that are key elements of managing groundwater in a sustainable manner. The DPSIR model provides for a more structured approach to identifying broad aquifer sustainability issues across a range of scales and regional contexts. The GSAA pilot projects showed that the DPSIR model can be applied to a broad range of circumstances, allowing for a structured approach as well as creativity in the development of specific indicators.

The DPSIR framework allows the identification and monitoring of specific issues over time. It also allows the five sustainability goals to be further compartmentalized according to the driving forces, the current state and the potential responses (government actions). This facilitates the development of appropriate response mechanisms, which typically include:

- identification of indicators that go beyond merely characterizing the state of the aquifer
- policy, regulatory or non-regulatory instruments
- corrective action
- education
- knowledge development.

It adds complexity to the assessment, but it also helps in adopting appropriate tools upon which the management response can be evaluated.

The DPSIR Framework allows for the identification of key linkages between regional conditions and the groundwater sustainability goals, which facilitates the development of appropriate response mechanisms relevant to various regional contexts. It also provides a method to communicate the issues around groundwater sustainability. However, it has the potential to generate some confusion while communicating the result of a groundwater sustainability assessment, especially if the project team does not fully understand the DPSIR approach or wants to use it as a tool for the identification of specific issues rather than as a conceptual framework showing key linkages, therefore supporting a better-informed decision-making process.

Because it provides a logical and replicable way of organizing the information, <u>the DPSIR Framework should be used as a consistent method to prepare for groundwater sustainability</u>

assessment projects. But in order to keep the analysis less complex and easier to communicate, DPSIR should not be used as the only means to management responses. A groundwater sustainability assessment project should also rely on the five groundwater sustainability goals with indicators developed for each of these goals.

As stated in the Gordon report, determining which of the DPSIR elements has the most relevance depends on the stage of policy in a given jurisdiction. Groundwater sustainability policy in Canada is still at the stage of problem identification, whereby indicators of the state of groundwater and those assessing the impacts on groundwater play a major role in groundwater sustainability assessments. Initially they will be mainly descriptive indicators, which will identify trends in the state of the situation. If any identified issue becomes the subject of new policy measures, then it is anticipated that the attention will shift to "pressure" and "driving force" indicators. Over time, it will also become possible to assess the effectiveness of the "response" component of the DPSIR framework.

Driver-Pressure-State-Impact-Response (DPSIR) Conceptual Model:
In Summary

- The DPSIR Framework is a useful framework providing a logical model to organize the information while preparing and implementing groundwater sustainability assessment projects.
- The DPSIR Framework allows for the monitoring of groundwater sustainability issues over time.
- It provides a structured approach to identifying broad aquifer sustainability issues across a range of scales and regional contexts and facilitates the development of indicators that are relevant to specific regional conditions.
- DPSIR will improve the practicality and usefulness of a groundwater sustainability assessment if it is used in conjunction with the five groundwater sustainability goals.

3.4. Groundwater Sustainability Indicators

3.4.1 Selecting and Developing Indicators

Once the groundwater sustainability issues have been identified, the indicators that best allow the assessment and monitoring of the issue should be selected and developed. Indicators help describe relevant information on trends in groundwater systems in a clear and simplified way. Without indicators, it would be difficult to organize and present the information in an accessible manner. It is also worth noting that there could be indicators specific to each component of the DPSIR framework, for example "pressure" indicators may not be the same as "impact" or "response" indicators.

The criteria needed to develop and design groundwater sustainability indicators need to be sensitive, scientifically robust, measurable and representative. Indicators need to be created from available or obtainable information, be consistent and reproducible. Ideally, groundwater indicators should be reliable and appropriate at different scales, plus comparable between different hydrogeological regimes (based on Li, 2013). Strong consideration should be given to selecting already established indicators from internationally recognized organizations. For example, we recommend the use of a few indicators from UNESCO (2007) in Appendix 2. Using already established indicators has the following benefits:

- It saves time and resources;
- It provides a basis for comparison with other studies and geographic areas;
- It gives some confidence that the indicators are relevant as they have already been subject to scrutiny and analysis.

Despite these benefits, there are good reasons for a team undertaking groundwater sustainability assessment projects to develop their own set of indicators. Established indicators from recognized organizations can be used as a starting point and as references, but the most useful indicators are often those designed and customized based on local issues and the historical indicators used in the study area.

Although information should be available when developing indicators, the selection of groundwater indicators based primarily on data availability would be detrimental because it reinforces the collection of the same data rather than probing whether key data are missing (UNESCO, 2007).

Project teams need to be aware of indicators' limitations due to data bias and inaccuracy. For example, some critical indicators in the Prince Edward Island Pilot Project could only apply in a small part of the study area or for a period of time due to data limitations, but developing these indicators proved to be very helpful for the overall groundwater sustainability assessment.

Care should be taken to find the balance between available data and obtainable data when developing indicators. The development of indicators often requires agencies to collaborate with other data/information holders. This will likely involve communication of project goals, objectives and end-products and may require formal data sharing agreements.

While developing indicators, it might be useful to apply them to the DPSIR Framework by answering a set of questions: What is happening to the state of groundwater? Why is this happening? What are we going to do about it? Impact and state indicators help answer the first question, driving force and pressure indicators help answer the second, and response indicators answer the last question (based on Gordon, 2011). As explained earlier, some of the pilot projects found that using the DPSIR Framework in conjunction with the five sustainability goals may sometimes be challenging. Even if this may be due to how the indicators were used by the pilot project teams, it is recommended to simply formulate the indicators around the sustainability goals when it is unclear where the indicators would fit into the DPSIR Framework.

Indicators should be used in a flexible and lenient way, allowing for innovation. The Abbotsford-Sumas Aquifer pilot study did not necessarily compare their indicators against the DPSIR Framework or the sustainability goals, but instead evaluated their indicators against a suite of factors including statistical properties, management and reporting needs and data considerations. Several indicators were used to communicate more than one DPSIR element or sustainability goal, such as the indicator "Groundwater Quality Impacts on base flow" being used as an indicator for the State and Impact components of DPSIR and also as an indicator for the Ecosystems and Socioeconomic sustainability goals. Pilot projects also noted that every single component of the DPSIR Framework needed a complementary approach (i.e., framing the indicator around the sustainability goals) that took into consideration stakeholder engagement and scientific facts to help select appropriate indicators. One pilot project suggested including statistical tools to differentiate between variation deriving from common causes and variation deriving from special causes (i.e., control charting) (Bayegnak, 2013). The Lower Athabasca project chose the "SMART"[2] criteria to evaluate the indicators in conjunction with the DPSIR Framework.

Selecting and Developing Indicators: In Summary

- Indicators can be very useful tools to measure and evaluate the sustainability of natural resources.
- Scaling is very important in developing indicators. Indicators developed for specific spatial scales may not be useful at another scale.
- Indicator development should help inform discussions about the sustainable management of groundwater.
- Indicators should be limited in number, and be clear and straightforward for all parties involved.
- An indicator is used for problem identification and for monitoring the evolution of the problem over time; it is not used for solving problems. However, it can be used to monitor the effectiveness of the public or government response to the problem..
- When selecting or developing an indicator, it is important to keep in mind that it will have to be communicated.
- When initiating a groundwater sustainability assessment project, the team could:
    - Identify existing indicators developed by recognized organizations and assess whether they could be applied to their specific context.
    - Modify existing indicators or develop new ones to fit their needs.
    - In the absence of data, the team should still develop an indicator that is deemed relevant to the situation and start collecting data to support its implementation.

3.4.2 Lessons learned from the Pilot Projects

The Gordon Report suggested, as examples, a total of twelve preliminary indicators covering the five sustainability goals. Ten of these indicators were based on groundwater sustainability indicators developed by UNESCO (2007) and the State of Michigan (MGCAC, 2006), and were selected for the quantity, quality, aquatic ecosystems and socioeconomic goals. The report also formulated two indicators related to the governance goal. All of these indicators can be found in a table in Appendix 2, which is replicated from the Gordon Report (2011). It should also be noted that all of these indicators could and should be modified to better fit the specific issues that the project teams are trying to address in each jurisdiction. The Lower Athabasca Region pilot project did not directly use any of the indicators proposed in the Gordon Report; they instead developed variations of the suggested indicators to fit their needs.

All of the pilot projects developed their own indicators. They all agreed that the indicators suggested by the Gordon Report were helpful starting points, but each project team created indicators to better assess the different sustainability issues in the respective jurisdictions. This

[2] SMART is an acronym standing for : Specific, Measurable, Attainable, Relevant, Time-Bound

demonstrates the flexibility provided by the GSAA for indicators development. Appendix 3 shows all of the indicators developed by the pilot projects teams and provides some context around the selection of these indicators. This is discussed in more detail in section 3.4.3 below.

There were some issues with indicator and data gaps, but these can be filled by narrative descriptions and supplementary data, as described in the Abbotsford-Sumas Aquifer pilot project (Aldridge *et al,* 2013). Pilot projects also commented on the need and importance of continued data availability in order to monitor indicators over time. It is easier to detect and understand data trends when data are collected over time, and the value of the indicator increases. Long-term data acquisition also helps in deciphering whether variations fall outside the "normal" range of components of the environment. Aldridge *et al* (2013) suggested that the state and impact of indicators with respect to areas experiencing groundwater depletion should be evaluated using long-term monitoring data, ensuring that temporal and climatic variability is accounted for. Most pilot projects created indicators based on available data, instead of developing indicators without readily available data, with the exception of the Town of Gibsons project, which developed indicators for future population based on the Town's communication needs. It is recommended to create indicators, even in the absence of data, and then collect the necessary data, as this will help establish a data collection system allowing long term monitoring of the indicators.

In summary, the pilot projects demonstrated that the GSAA, as described in the Gordon Report, is a flexible approach that can be used to develop indicators in various contexts and scales.

3.4.3 Examples of specific indicators

This section summarizes how the pilot projects used the DPSIR framework to develop indicators around the five Groundwater Sustainability Goals. A complete list of all indicators used by the pilot projects, organized around the five goals, is provided in Appendix 3.

<u>Groundwater Quantity</u>

Pilot projects had a good grasp of what indicators to develop and use to measure groundwater quantity. Many pilots used indicators for both quality and quantity, such as PEI and the Town of Gibsons. It was the general consensus that available data were easy to find for indicators measuring this sustainability goal, such as assessment of water levels and water use.

<u>Groundwater Quality</u>

Out of the twelve indicators recommended by the Gordon Report, the only one that was used by all of the pilot projects was an indicator to describe the status of groundwater quality (the assessment of groundwater quality problem relative to the total studied area). The Pressure Indicator ((Σ Areas with a specific class of groundwater vulnerability/ Total studied area) x 100) provides a good communication tool to better advise the public about protecting the aquifer. The State and Impact Indicator ((Σ Areas with groundwater quality problem/ Total studied area) x 100) is often easily understood by various groups of people (such as the public and government) and can create public awareness (Li, 2013).

<u>Ecosystems</u>

The State Indicator (Groundwater contribution to baseflow) is an important indicator of ecosystem health and should be used if the data are available, because baseflow is critically important to species that rely on it in groundwater fed streams (Aldridge *et al*, 2013; Gordon, 2013). The Montérégie Est Region pilot project found that limitations exist with the availability of the data, and could be presented as an average of the total flow if needed. This allows comparisons to be made. The Abbotsford-Sumas Aquifer project developed a Pressure/Impact Indicator, Number of species at risk associated with streams/riparian habitat, as changes to the number of identified species at risk and their status may provide some indicator of ecosystem health, although there is currently insufficient data to comment on temporal changes. It can also be pointed out that many quantity indicators and quality indicators are also good indicators for ecosystems health.

Socioeconomic

Most pilot projects faced some difficulty while developing indicators for this sustainability goal. The Abbotsford-Sumas Aquifer project assessed this sustainability goal in terms of: dependence on groundwater, agricultural reliance, price of groundwater and restricted groundwater access. An indicator assessing the importance of groundwater to the local population was developed by the Abbotsford-Sumas Aquifer pilot project called 'Dependence on groundwater', which assesses groundwater use as a percentage of total water use within the community. The NAOS Alberta pilot project developed a 'Water Level' indicator, which is a good indicator to pursue, as continuous monitoring will help improve the data over many years. Typically there will be a delay between the extraction of groundwater and the occurrence of lowered groundwater levels, so measuring the levels now will help in the future (Bayegnak, 2013). The Town of Gibsons pilot project also developed socio-economic indicators, as described in Table 3.4 in Appendix 3. Table 3.4 also suggests some new socio-economic indicators, based on UNESCO (2007).

Good Governance

Some of the pilot projects found it somewhat difficult to find available data and develop appropriate indicators for Good Governance. Three of them, however, developed at least one governance indicator, as presented in Table 3.5 in Appendix 3. Many pilot projects expressed the need for follow-up indicators, which could test, for example, if the implementation of outreach programs as suggested in the Town of Gibsons pilot project, is achieving their stated goals (Gordon, 2013). The Abbotsford-Sumas Aquifer suggested in their indicator "Government Action", that a government action score would be a good way to assess government involvement. As a follow up indicator, "Levels of Government with Interest in the Aquifer" would be helpful as good governance includes engagement from multiple levels of government. Table 3.5 also suggests four new Governance indicators, which are adapted from Ehler (2003).

In a discussion intended to identify indicators for good governance, it is worth noting that a recent report from the Forum for Leadership on Water (FLOW) (Wilson, 2013) looked at water co-governance and identified a set of eight principles for good governance. These principles, listed in the text box below, could be used as a starting point for developing additional governance indicators.

8 Principles for Good Governance

(Wilson, 2013)

1. **Accountability**: To be accountable is to be "both responsible for something and liable for the failure to produce agreed upon and expected outcomes."(Furlong, 2005).
2. **Fairness and equity**: These are essential elements of social harmony and peaceful co- existence. Including multiple perspectives in governance regimes implies fairness because it gives voice to a various rights holders and enables policy adjustment to account for their needs (Furlong, 2005).
3. **Coordinated leadership**; Given the cumulative effects of human activity on water resources and the division of responsibility across multiple levels of government, avenues for effective communication, joint action and decision making across and within governments are critical to good water governance (Furlong, 2005; IUCN, 2009).
4. **Sound capacity** in water management practices and techniques is essential to ensure the safe operation of water supply and disposal systems (O'Connor, 2007).
5. **Resilient institutions**: Building resiliency into our water governance and management system is prudent to allow the socio-ecological system to adjust smoothly to large disturbances (Homer-Dixon, 2006; Brandes and Maas, 2006).
6. **Coherent and effective regulation and enforcement**; Regulation and enforcement are primary tools of formal institutions to govern behaviour and these must be coherent and effective in achieving their anticipated objective (IUCN, 2009).
7. **Integrative approach** to water governance and water resources management "is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."(UNEP-DHI Centre for Water and Environment. 2009).
8. **Respect Indigenous rights**; In the Canadian context this is a condition precedent to achieving the other conditions described above.

Most pilot studies expressed difficulty in developing indicators to assess the application of good governance as it pertains to groundwater sustainability. One cited constraint was the scientific composition of project team memberships, and another the lack of guidance with respect to what defines good governance. The eight principles identified above provide good insights into the meaning of good governance and could facilitate the analysis of governance for project teams.

Presence of these eight principles facilitates a foundation for sound management and a framework in which to develop appropriate indicators. It is recommended to keep these principles in mind when developing governance indicators. However, much like sustainability assessment, governance indicator development is subject to various factors, or conditions. A pilot project cannot ascertain an ideal set of governance indicators without first understanding, and ensuring, that its greater political climate is pursuant to the eight prescribed principles.

The transboundary nature of groundwater creates overlapping structures at all governance levels, each with specific needs and mandates. For example, aquifers usually expand over watershed boundaries and may cover areas within several administrative entities (municipalities, provinces, conservation authorities, etc.). Although sustainability issues in groundwater quality and quantity are mostly regulated by provincial governments, significant information rests outside of the government realm. For example, the oil and gas sector in Alberta reports a great deal in-house, and many provinces' leading industries (e.g., agriculture) have monitoring systems in place. A mechanism is needed to engage these various entities and tap into their data and information inventories.

Effective groundwater management requires the involvement of a range of federal, provincial, and municipal governments, in addition to various stakeholder groups. The key benefit in an interdisciplinary and cross-jurisdictional team is its ability to address a wide range of issues with a complementary suite of skills. For example, hydrogeologists can help identify governance issues requiring attention, but need policy individuals to implement and plan them. This rings true beyond the confines of project teams and into groundwater management as a system of governing water resources.

The following textbox intends to provide guidance with respect to ascertaining the state of groundwater governance in a particular jurisdiction, which should be the first step towards preparing a project team to develop governance indicators.

1. Develop a case for groundwater sustainability specific to the jurisdiction – good idea to balance fundamental scientific and other public interests.

2. Assemble a directory of all entities with interest in groundwater.

3. Determine the groundwater jurisdictional framework specific to the study area (e.g., aboriginal water rights, federal/provincial/local jurisdictions, private sector, industry, public, etc.).

4. Conduct assessment of where stakeholders – or audiences – stand. The focus should be on issue-based engagement specific to groundwater sustainability issues in that particular jurisdiction.

5. Assess the current state of groundwater water protection tools (e.g., regional growth strategy policies, zoning bylaw provisions, development permit approvals processes, tools to limit and measure extraction, etc.).

3.5 Linkages with other approaches addressing groundwater sustainability

The GSAA is an innovative approach put forward by CCME, providing common terminology and identifying steps that could be taken by jurisdictions wanting to initiate groundwater sustainability assessment projects. It is intended to complement existing approaches already implemented by jurisdictions across Canada, not to replace them.

For example, Ontario has been implementing its *Source Water Protection Program* for a number of years and has already made tremendous progress in its knowledge and good management of groundwater resources. Other programs, such as Alberta's *Water for Life* and Québec's *PACES*

(Programme d'acquisition de connaissances sur les eaux souterraines), also address groundwater sustainability and provide useful context for the implementation of the GSAA. More information on these programs can be found in Appendix 4.

As stated earlier in this document, the implementation of groundwater sustainability assessment projects should be supported by broader policies and programs. These are examples of existing initiatives that have the potential to facilitate the planning, funding, and implementation of the Groundwater Sustainability Assessment Approach.

4.0 COMMUNICATIONS AND STAKEHOLDER ENGAGEMENT

4.1 Communicating GSAA Results

The GSAA is a tool that can guide the planning and conduct of groundwater sustainability assessment projects. In order for the GSAA to be an effective tool supporting decision-making and policy-making, communicating the results of the projects must be recognized as an integral and critical component of the GSAA framework. Therefore, a communications strategy should be developed for every such project.

The Gordon Report briefly discusses the communication aspects of the approach, with a focus on communicating with stakeholders. There are three major audiences that groundwater sustainability assessment project teams must keep in mind: (1) stakeholders (2) project partners, and (3) decision-makers and policy-makers. These categories are not mutually exclusive, as some individuals or organizations may belong to more than one category of audience. This is the case, for example, with industry officials, consultants or academics. Each type of audience will have different levels of knowledge about the project and accordingly, different information needs to perform their roles. Ongoing engagement throughout the project will help the project team identify the most appropriate communication tools and methods for each part of the target audience.

Lessons learned from the pilot projects in terms of communications are limited at this stage, as this was not identified as a key component of their studies. In most cases, the project team prepared a report intended to provide a summary of their project to the CCME. Efforts to communicate the results of the GSAA pilot projects to decision-makers have been limited. It is worth nothing, however, that in some cases, certain pilot project team members were also decision-makers.

While there are several other communication tools worth exploring for the purpose of communicating the result of a groundwater sustainability assessment project, the following three tools should be considered:

Weight-of-evidence approach: In one of the pilot projects, the project team completed a weight-of-evidence assessment for each of the sustainability goals, following the indicators evaluation. This approach was used to provide a summary of the goals, the DPSIR elements, and the indicators that were used. The weight-of-evidence approach provided a synthesis of the indicators within the assessment approach, almost like a ground-truthing or a verification exercise, which made it easier to communicate the results of the study in a concise manner. It used the indicators as specific lines of evidence to prove an overall statement of sustainability for the study area.

Maps, graphics and models: Another pilot project used a series of maps to illustrate the status of the various indicators throughout the study area. Such a visual geographic illustration may be of interest to stakeholders, as well as to policy-makers, as it can convey a lot of information on a single page. It is also easy to add time-series to such mapping over years, as sustainability assessment projects are conducted on the same study area. The same is true for other visual tools such as graphics and models.

Storyline: The Gordon Report recommends the use of a storyline as an effective communication tool, in particular when the audience is likely to include people with no technical or scientific background. The steps in the development of a storyline are described below, as taken from the Gordon Report (adapted from Gabrielsen and Bosch, 2003).

1. Develop the preliminary story: a description of the problem and its potential solutions;
2. List the most important policy questions that arise from the problem description;
3. Select preliminary indicators that are expected to communicate the problem and potential policy response;
4. Determine the appropriate criteria (standards, references) and the appropriate time period and spatial scale;
5. Develop the key messages and the approach that will be used to communicate the interpretation of the indicators and criteria (and modify, adapt, update and iterate).

Whatever communication tools are used, it is important to clearly link the result of a groundwater sustainability assessment project to the five sustainability goals. The focus of the communication should be adapted depending on which goals are most important to the target audience. For example, it is important, when communicating with decision-makers, to clearly outline linkages of the results with land-use planning and economic development.

In addition, the level of certainty associated with the results of the GSAA, as well as the data limitations, should be clearly described. Technical and scientific information frequently gets used improperly in the policy world because the limitations of the data have not been adequately communicated. Significant efforts must be dedicated to clearly spell out what can be (and what cannot be) concluded from the results of a groundwater sustainability assessment project.

Communicating GSAA Results: In Summary

- Communicating the results of a groundwater sustainability assessment project is as important as conducting the assessment itself.
- Local stakeholders, project partners and policy and decision-makers should all be part of your communications efforts.
- There is a broad range of potential communication tools that jurisdictions should experiment, alone or in combination.
- The certainty/uncertainty of the results and limitations of the data should be clearly stated in the communications materials.
- Communication efforts should focus on the groundwater sustainability goals and the associated indicators, using plain and non-technical language as much as possible.

4.2 Engaging Stakeholders

Groundwater sustainability assessment projects should rely on the best available scientific data related to the five groundwater sustainability goals, but they also benefit from the knowledge and input of stakeholders (people and organizations living and/or working within the geographic boundaries of the study area). This has been recognized in various locations around the world and also in the pilot projects conducted by a number of Canadian jurisdictions to “ground-test” the implementation of the GSAA framework. This section of the guidance document explains why stakeholder engagement is critical to the successful implementation of the GSAA and when it should happen throughout the project. Jurisdictions undertaking groundwater sustainability assessment projects should report back on how they engaged stakeholders and what were the outcomes of such engagement. This will help build a “how-to” section based on Canadian experience for future iterations of this guidance document.

Some of the pilot projects highlighted the importance of stakeholder engagement, in particular as it relates to the selection of indicators. In reality, stakeholder engagement was not a major component of the pilot projects, with the exception of the Town of Gibsons project in British Columbia and the Montérégie-Est project in Québec. The Québec project was conducted under an existing provincial program intended to gather information on groundwater resources (PACES: Programme d’Acquisition des Connaissances sur les Eaux Souterraines). One particular characteristic of this program is that it requires stakeholder engagement and partnerships. The project team therefore had an obligation to engage local actors and benefited from it.

What is stakeholder engagement?

Stakeholder engagement is the process by which an organization involves people who may be affected by the decisions it makes or can influence the implementation of its decisions.

Stakeholder engagement is actually a continuum, as there may be various levels of engagement. A widely-accepted public engagement continuum model, developed by the *International Association for Public Participation* (http://www.iap2.org/), identifies the following goals which require an increasing level of stakeholder engagement as you move along this continuum:

INFORM ⟶ CONSULT ⟶ INVOLVE ⟶ COLLABORATE ⟶ EMPOWER

While it can be said that engaging stakeholders requires significant human and financial resources, the involvement of stakeholders in a decision-making process will generally lead to better outcomes.

Stakeholders are defined as people who may be affected by a project or who can influence its implementation. For a groundwater sustainability assessment project, this literally means anybody who lives or works in the study area. This may include municipalities and other regional governments, First Nations, industry groups, environmental groups, fishermen associations, tourism corporations, chambers of commerce, individual land owners, etc. Experience from the pilot projects has shown that engaging municipalities and townships is critical as these local or regional government organizations usually have some financial and technical capacity and they also have a legal mandate and the authority to make decisions around land-use issues.

Jurisdictions who decide to pursue groundwater sustainability assessment projects should make sure that they engage local and regional stakeholders at every step of their projects. Table 2 illustrates some of the reasons and benefits for such engagement throughout the life-cycle of a project.

Table 2: Rationale for engaging stakeholders throughout the implementation of the GSAA

Component of the GSAA	Benefits of engaging stakeholders
Jurisdictional Assessment and Issue Identification	Stakeholders can bring to the table a personal and sometimes life-long direct experience with and knowledge of the study area. This will greatly help the issue identification and may be particularly beneficial in certain parts of the study area where few scientific data exist. Some stakeholders may be aware of the existence of historical data that will contribute to the jurisdictional assessment.
DPSIR Conceptual Model	Engaging stakeholders in the development of the DPSIR framework for their area will raise their awareness about the complexity of groundwater sustainability and improve their understanding of the issues. This, in turn, may help government agencies get support from the communities when developing management responses.
Indicators	A discussion of groundwater management issues with stakeholders and the public often allows for a clear description of which indicators could be selected with a specific set of reference conditions and targets in mind, and what can be achieved with these indicators.
Communications	Engaging stakeholders in the development of a communication plan will lead to a better understanding of their needs, their expectations and their capacity to digest complex information. The project team will therefore be in a position to develop communication products better adapted to the stakeholders.
Throughout (all components)	Groundwater sustainability assessment is not only about scientific data. It also involves trade-off decisions with respect to water use and land-use planning. It therefore brings the question of what is acceptable for a community in a given watershed. In areas such as these, where science does not provide all the answers and value judgments are needed, input from stakeholders is critical. Engaging local stakeholders in groundwater sustainability assessments will help secure long-term buy-in from them when water management decisions are made based on the assessment projects. Engaging stakeholders up front in the project planning phase will help make clear what can be gained from the study and what the limitations can be. It often prevents people from being disappointed by the outcomes. Engaging stakeholders through community monitoring will lead to strong engagement from local actors because they become responsible for measurements.

How to most effectively engage stakeholders depends on a number of factors and should be decided according to each project's characteristics. What works well for one project may not be suitable for another. It is likely that a combination of engagement activities will be necessary to achieve the project's objectives. There exists a variety of traditional (in person or through written documents) and online engagement techniques that may be used.

Examples of potential engagement techniques

Jurisdictions should consult the very large literature available on the topic of stakeholder and public engagement; in order to determine what level of engagement and which engagement techniques are most suited to their needs when conducting groundwater sustainability assessment projects. Communications specialists, within or outside the organization, may also have this knowledge and should be consulted if resources are available.

To illustrate the diversity of engagement techniques available, the following list is offered as a starting point:

Traditional in-person engagement techniques:
Television/Radio; Open Houses; Tours and Field Trips; Interviews; Information Kiosks; Fairs and Events; Telephone Hotlines; Town Hall and Public meetings; Public Information Centers; Symposium; Advisory Groups or Committees; Focus Groups; Voting pads during public meetings; Task Forces; Workshops; Public Hearings; Charrettes; World Cafés; Citizen Panels.

Engagement techniques through documents:
Posters; Newspaper advertisements; Road signs; News Releases; Fact Sheets and FAQs; Surveys; Comment Forms.

Online engagement techniques:
Information on website; Digital screens; Email distribution; Twitter; Facebook; Online Idea Forum.

These are examples only of potential stakeholder engagement techniques. Jurisdictions undertaking groundwater sustainability assessment projects should report back on how they engaged stakeholders and what were the outcomes of such engagement. This will help build a "how-to" section based on Canadian experience for future iterations of this Guidance Document.

5.0 'GETTING GOING': PRELIMINARY CHECKLISTS

This section intends to give practical and systematic guidance for a jurisdiction undertaking groundwater sustainability assessment. It is by no means comprehensive or exhaustive, but offers an insight into the main pillars required for each component of the GSAA.

5.1 Jurisdictional Assessment and Issue Identification

<u>Jurisdictional Assessment</u>

- ☐ Identify potential GSAA study sites for assessment. These could be based on relevant criteria drawn up by the jurisdiction for selection if resources and capacity limit candidates. Initial criteria could include:
    - Environmental pressure
    - Economic impact
    - Community concern and impact
    - Data and information availability
    - Capacity to implement and learn for future application and expertise development
    - Stakeholder support
    - Ability to apply solutions and remedies

- ☐ Create multi-disciplinary team across government departments, agencies, and experts to guide and support the GSAA process. Ensure a lead department or agency is identified with appropriate internal responsibility and accountability to drive the process

- ☐ Establish clear goals for the GSAA process with specific outcomes. These should include high-level policy and program goals as well as specific groundwater sustainability goals. Use the five CCA groundwater sustainability goals as the basis

- ☐ Create initial inventory of data and information available, how this could be utilized or leveraged, while identifying gaps to be filled. Determine which data and information can be utilized immediately to commence process. Seek corollary and proxy data and information to buttress the GSAA process

- ☐ Establish initial timeframes, budget and resource requirements for the GSAA process

- ☐ If possible, identify linkages and alignment with existing programs or policies in order to facilitate senior management support and funding

<u>Issue Identification</u>

- ☐ Why is this project being initiated?
    - Because we were told to do so
    - We have an issue at hand:
        - Groundwater quality degradation
        - Anticipated major project which could potentially impact groundwater
        - Anticipated population growth ➔ need to ensure better management and allocation practices (in AB for examples some basins are closed to surface water allocation. Prior issue identification and planning could have avoided this)
    - Concerns that we do not know more about our groundwater
    - Etc.

- ☐ Who is/could be impacted?
- ☐ What ecosystem is/could be impacted?

☐ Who is at the table? Who should be at the table? How do we get them to the table?

☐ How do we imagine the future state of the groundwater following this project?

- o This is where the society can decide if they want to accept some tradeoff and allow project to proceed.
- o What level of tradeoff? 10% of groundwater level decline? Remove the perched aquifer and implement an aquifer storage and recovery scheme?
- o Do not allow project to proceed and keep pristine aquifer?

☐ Set potential end goals.

5.2 DPSIR Conceptual Model

☐ Using the DPSIR Framework, fill out each section based on its applicability and relevance to (a) the jurisdiction (b) its internal understanding of the state of groundwater sustainability (c) its integrated application to determining and launching individual GSAA assessments

☐ In particular, use the DPSIR framework to identify candidates for GSAA assessment based on each element of the framework

☐ Drivers: determine what factors are most important in driving groundwater sustainability in the jurisdiction and where and how these are converging on specific groundwater sites in raising concerns

☐ Pressures: identify key human and environmental factors impacting sustainability that will need to be measured and ultimately addressed

☐ State: identify initial broad and relevant indicators that will be incorporated into the GSAA planning and implementation process with more specific relevance to stakeholders and decision-makers

☐ Impacts: consider major or most important impacts from an environmental, economic, and social perspective that guide development of individual GSAA assessments

☐ Response: consider categories or types of response indicators for consideration and application in individual GSAA assessments

5.3 Groundwater Sustainability Indicators

- ☐ Ensure clear link between GSAA goals and indicators. Choose goals based, in part, on ability to measure and report on performance and progress towards the goals

- ☐ Consider indicators from range of perspectives:
  - Meaningful – to stakeholders and decision-makers
  - Measureable – by data available now or obtainable during the process
  - Actionable – can be tied to ameliorative actions to justify investments, attention, and commitment
  - Relevant – over short and longer-term timeframes
  - Communicable – can be easily presented and understood by public, stakeholders, and decision-makers
  - Priority – for action, for investment, for importance
  - Accountable – to responsible government departments and agencies
  - Supported – by appropriate governance system and process internally
  - Coherent – support overall GSAA effort collectively

- ☐ Match initial desired indicators to data and information availability. If mismatched, drop indicator or invest in data and information acquisition to support it

- ☐ Draw up initial list of indicators via DPSIR for consideration by multi-disciplinary governance process; add, drop, modify as necessary. As first step, use categories (e.g., policy, governance, quality, etc.) to group potential indicators and determine their eventual utility, relevance, and coherence

- ☐ Examine other jurisdictions for ideas and examples of possible indicators. Consider best practice literature and approaches for determining and applying indicators

5.4 Communications and Stakeholder Engagement

- ☐ Establish likely communications issues UP (to policy makers and politicians) who will decide outcomes of the GSAA process, and DOWN (to stakeholders and local interests) who are interested in, will be affected by, or can contribute to the GSAA process

- ☐ Identify stakeholders for each stage of the process who are interested in or will be affected by a GSAA process

- ☐ Plot stakeholders and issues along a continuum that matches key steps of the GSAA process, from identification of candidates for assessment through to communicating results and next steps at close of process. Communicate throughout the process. Do not wait till the end

- ☐ Establish OPEN, TRANSPARENT, and REGULAR communications processes, channels, or forums with identified stakeholders including updates. Use range of tools depending on steps in the process, issue(s) under consultation and engagement, and what is best suited to stakeholders and decision-makers

- ☐ Use the DPSIR tool and process as high-level engagement mechanism of relatively low-risk to shape the GSAA process
- ☐ Determine each stakeholder’s specific or desired information needs and preferred communications method to ensure they remain informed, engaged, and positive throughout the GSAA process
- ☐ Clearly communicate goals and desired outcomes of the process at onset of process so stakeholders ‘buy-in’ and support throughout. If material changes occur in goals or process, communicate these following the OPEN, TRANSPARENT, and REGULAR communications channels
- ☐ Set-aside sufficient resources and budget for communications and stakeholder engagement. Partner with local or provincial organizations to share costs for activities, such as community forums, or micro-engagement with diffuse stakeholders not having access to broader representation

6.0 CHALLENGES

The GSAA is a powerful and dynamic tool, offering jurisdictions the inherent ability to assess groundwater sustainability according to specific context and parameters. Pilot studies have illustrated its effectiveness across numerous geographic landscapes and political structures. These same pilot studies have highlighted a need to refine or direct the level of subjectivity in application of the GSAA. A main challenge to this document has been to balance prescriptive with flexible guidance.

To some degree, groundwater sustainability efforts were underway in each jurisdiction prior to the pilot studies. Jurisdictions had many of the critical contextual elements necessary for assessment (data, monitoring infrastructure, tools, resources, etc.). The pilot studies were a first effort at developing a coordinated and comprehensive indicator and assessment framework. Despite ongoing discussions within and between jurisdictions, there was no written guidance available to provide a basis for collaboration, knowledge sharing and comparison across jurisdictions. Challenges arose when trying to identify and share data and resources at various institutional levels, including published and grey literature, long-term data sets not entirely in the public domain, and contemporary data still being collected and analyzed. Finally, there was no clear goal preparation and dissemination of assessment outputs for each of the three main constituencies: stakeholders, project partners, and decision makers.

6.1 Scientific Challenges and Guidance

There are a number of challenges that arise from the complexity of groundwater sustainability assessment, as explained below.

6.1.1. Data Discovery/Accessibility and Gaps

Groundwater stakeholders include all tiers of government, private sector and the public. Each entity approaches groundwater sustainability through a different lens. Supporting partnerships (research, industry, etc.), governance structures, developmental priorities, public salience on groundwater sustainability, etc. contribute to the set of constraints each jurisdiction is faced with.

Some of the pilot project teams have identified the inadequacy of data to support indicators as an issue. Numerous jurisdictions have expressed that the type of indicators can be envisaged or developed, but difficulty arises with having adequate data unless reasonable scales and timelines for projects match the resources. The methodology for indicator development has sometimes been counter intuitive. In some instances, project teams assess the accessible data, and then develop indicators that best fit what is available. By trying to fit the data to indicators, the outcomes represent an assessment of the state of the environment according to indicators that have been selected on the merits of available data. The core purpose of developing indicators as they relate to the GSAA goals for groundwater sustainability is no longer the key driver. At least two pilot projects avoided this problem. In the Town of Gibson pilot project, the project lead felt that having the GSAA framework and process in place to support project implementation was in fact more important than having the data. The Athabasca pilot project used the logical succession of the DPSIR elements to develop its indicators. Proxy data such as the amount of development projects approved were used to estimate pressure.

UNESCO (2007) states that the dependence of indicator development on data can lead to a situation in which data availability drives the selection of indicators, which, in turn, reinforces the collection of that same data. The interviews with the pilot project teams supported this statement, as one key lesson highlighted that indicator development can, and should proceed with incomplete or qualitative data. Project teams are often inclined to dive straight into the data without first considering high-level objectives, governance structures, operational policy, and local stakeholders for issue-based engagement. Project teams need to engage stakeholders and incubate collaboration to avoid a silo, or internalized process. Beyond government, key stakeholders such as industry, academia and consultants also collect groundwater information (community monitoring networks can also provide useful data provided they have a sufficient level of expertise). This will facilitate more effective scoping and the translation of project outputs into useful packages for stakeholders.

No single agency collects data for all indicators, and the pilot studies represent a first effort at compiling these data for reporting. Experience from the pilot projects highlight that a lot of data for groundwater exist, but from various sources and time periods. Datasets are incomplete (i.e., specific to sub-areas, or time periods) and the challenge is in reconciling data that are not necessarily comparable or comprehensive. In addition, GSAA projects require data from several disciplines, which calls for multi-disciplinary teams in order to secure the capacity to collect, sort and interpret all relevant data. Pilot project teams have lacked the resources necessary to reconcile all available data and render it useful for their specific uses. This sort of work would include identifying all data sources, organizing them into a consolidated space (e.g., spreadsheet database), negotiating agreements with data owners, and beginning to identify commonalities across datasets that can support robust indicator development. Technical and financial capacity of project teams must be considered. Most interviews revealed an undertone that outputs were limited by resource allocation and cooperation from partnering entities.

6.1.2. Data Quality Assurance and Control

As previously mentioned, numerous indicators have been used to provide a snapshot in time of the existing circumstances, or when data quantity and/or quality are best. A snapshot of the current situation at a given time may be very useful as convincing evidence to respond to groundwater status degradation. However, snapshots may have limited communication value unless they relate to indicators, which are measured over time. For example, the Abbotsford-Sumas Aquifer pilot study utilized the number of contaminated groundwater sites as one indicator for assessing the protection of groundwater quality from contamination. However, it was not noted that the indicator development was in its infancy and requires future considerations of the adequate study area and frequency of measurements. This example illustrates the challenges in populating an indicator too early or over too large an area.

Long-term hydrogeologic characterization and monitoring tailored to the groundwater sustainability issues are essential to ensure data are collected through an appropriate spatiotemporal monitoring design, facilitating distinctions between anthropogenic influences and natural environmental variability (WSAS, 2012). This will transition indicators from acting as assessors of the current state of the environment into robust tools that can track the status of groundwater over time. It will ensure that temporal and climatic variability can be distinguished from regional depletions (e.g., El Niño-Southern Oscillation driven climate variability). If indicators are developed utilizing only data from current datasets, this will perpetuate collection of the same data. The Project Team must develop indicators that will identify precisely what sort of data are needed and how to facilitate its collection. Interviews revealed that implementation of field programs would be an effective and hands-on approach for projects teams to develop new and more adequate indicators, ideally with input from relevant stakeholders.

Another crucial area is the recognition of the importance of appropriate monitoring systems that allow for the integrative analysis of surface water and groundwater. Project teams must be aware of ecosystem dynamics and data limitations, however, when utilizing the data and indicators to guide the integrated assessment of sustainability. For example, groundwater and surface water changes are usually observed at different timescales. Groundwater issues build slowly and resultant data collection lags behind surface water, given the more complex nature of groundwater.

The consideration of surface water data in GSAA projects may have additional benefits, in terms of lessons learned. Surface water monitoring systems have been developed and operated for decades in Canada. This long term experience with water data collection and analysis may offer insights into data reliability, mutual comparability, sampling procedures and standardization of data reporting (NRTEE, 2011) that could be applied to groundwater.

Scientific Challenges: In Summary

- Recurring trend across interviews with jurisdictions has been the inadequacy of data to support indicators. This may lead to selection of indicators on the merits of available comprehensive data, and not as they relate to the GSAA goals.
- Key lesson: indicator development can, and should proceed with incomplete or qualitative data.
- Project outputs were limited by resource allocation and cooperation from partnering entities.
- Indicators have been assessed for current circumstances, and may lead to misinterpretation where temporal or spatial data may not be appropriate.
- Long term monitoring will transition indicators from acting as assessors of the current state of the environment into robust tools that can track the status of groundwater over time.

6.2 Governance, Management and Policy Challenges and Guidance

From the onset, the transboundary nature of groundwater reflects a diverse set of stakeholders, each with different data needs and dissemination targets. Collection methods of each entity are based on specific interests, geographical scope and resource capacity. Each jurisdiction also sets priorities according to its specific conditions and pressures. These numerous interests, methods, conditions, pressures and targets require a complex regime for data collection.

Depending on the available resources and the scale of the GSAA project, it may be challenging for any single government department, ministry, agency or external organization to collect, analyze, and maintain the data necessary for the completion of a scientific analysis. Furthermore, indicator placement within the DPSIR framework is subjective, and is highly dependent on how the leading body defines what is pertinent (i.e., salient), available (i.e., data), and acceptable (i.e., scope). Experience from the State of California reveals the need to enhance local management of groundwater resources (ACWA, 2014). This is well in line with the increasing trend for provinces to delegate some specific groundwater management responsibilities to local governments and multi-stakeholder bodies (CCA, 2009). Moreover, the WESA document emphasizes the importance of framing future projects with the goals and issues of the local community or watershed in mind. Local capacity building and agency involvement with input from stakeholders reiterates the need to improve linkages across monitoring, education and outreach, and regulation. This is a first step in the right direction to produce more meaningful and easier to communicate results.

Another important consideration is evaluation of positive sustainability efforts. There must be pre-established objectives with targets, rather than a simple intent to minimize negative changes. The importance of performance metrics was recognized by the pilot project teams. For example, water level change over time does not provide a bar or measure to compare against. As such, there must be an established and measurable objective to provide a more effective and meaningful, assessment of indicators. Measurable objectives are crucial in determining the intensity, magnitude, scale, extent, duration or frequency of a desired change. Indicators are commonly assessed against existing guidelines (e.g., Canadian Guidelines for Drinking Water or Alberta Tier 1 Soil and Groundwater Remediation Guidelines), which tend to be perceived as ‘pollute up to levels’. As such, involved parties tend to wait until those levels are reached before taking action. Assessments must outline specific, and measurable, objectives to encourage decision makers in taking action on groundwater sustainability (WESA, 2013).

Project teams must realize that each level of government that legislates within a study area has a different set of needs and mandates. The sustainability goals put forth in the GSAA are lofty and difficult to quantify at onset. There tends to be a disconnect between the data needed to make assessment a reality at a regional or operational level, and the stated management objectives. These objectives require consensus and cohesion amongst partners. The utility of a multidisciplinary and multi-agency team is that each tier is represented at the table. The scoping stage of the project must incubate a collaborative process, one in which each party understands the overarching policy objectives. Moreover, the shelf life of projects tends to correlate to their level of funding. Ongoing funding must exist to turn short-term excitement into a long-term agenda item. Although the pilot studies were designed as finite exercises, each project report and interview clearly indicated that long-term datasets and commitment were crucial to effective groundwater sustainability assessment.

It is important to understand that a groundwater sustainability assessment project in and of itself is only the beginning of a much larger undertaking. The pilot studies have provided a snap shot in time, or a current state of the environment. They should be treated as scoping exercises for longer-term commitment of resources. Decision makers need to understand that groundwater issues build slowly, and require long term monitoring. Crisis issues most often receive attention with respect to the environment, and this status quo needs to be reevaluated in light of groundwater sustainability.

Governance, Management and Policy Challenges: In Summary

- Evaluation of positive sustainability efforts requires pre-established objectives, rather than a simple intent to minimize negative changes.
- There must be established and measurable objectives to provide a more effective, and meaningful, assessment of indicators.
- Important to understand that a groundwater sustainability assessment project in and of itself is only the beginning of a much larger undertaking to support better-informed decisions around societal issues having the potential to affect the sustainability of groundwater and related ecosystems.

6.3 Communication Challenges and Guidance

Consensus from pilot study reports and interviews indicated that the CCME was the target audience, with a great deal of documentation being referred to as draft. Project teams were skewed to a scientific - or hydrogeological – composition, resulting in technical reports. Members of pilot project teams concluded that although communication was not a focus of their project, communication strategy development should be a key issue moving forward.

The major audiences in terms of communication needs include: stakeholders, project partners, as well as decision-makers and policy-makers. Engaging with these audiences throughout the process of groundwater sustainability assessment is the ideal way to not only gauge their understanding and perspective on particular issues, but to prepare a comprehensive communication strategy. Consultation with each entity at project onset will reveal a hierarchy of needs for each audience. Building in communication needs at onset and visualizing how they will affect the structure of project outputs is essential. Engaging earlier will result in stakeholders owning the process and will help ensure their information needs are satisfied upon project completion.

Communicating the results of groundwater sustainability assessment projects to elected officials and other decision-makers may be particularly challenging. Government officials typically involved in such projects may not have the necessary skills to communicate highly technical information in laymen terms, which often results in lost opportunities when the decision-makers cannot make sense of the results presented to them or cannot relate them to specific management actions.

At the core of improving communication is the need for project teams to conduct a strategic analysis of end uses for their data (NRTEE, 2011). They must also assess what aspects of data are appropriate, or useful, for public dissemination. A communication plan will clearly outline each constituency's information needs according to their purpose, complexity, level of detail and involvement. Necessary components to a communication plan include: representativeness, a good facilitator, oversight, clear articulation of the issue and expected outcomes, empowerment of participants, and recognition in the value of anecdotal and traditional knowledge. Groundwater sustainability assessment projects should not proceed without first establishing clear objectives for communicating results to relevant stakeholders, with emphasis on decision-makers. The intent is not to focus on the scientific or technical aspects of the project, but rather on linkages with land-use planning and economic development, positioning the GSAA as an essential framework supporting decision-making.

Components of a Communication Plan: In Summary

Representativeness – each stakeholder group with a vested interest should be considered in the development of the plan.

Good facilitator – an experienced individual should be tasked with development and completion of the communication plan. Not necessarily from the same institution's communications department, as there can be challenges and sensitivities in terms of portraying implications.

Oversight – internal project progress discussions and review, with recommendations in hydrogeology, geology, biology, policy, etc. will allow for ongoing input from stakeholders. For example, tap into industry and disciplinary knowledge by way of expert panels or advisors.

Clear articulation of the issue and expected outcomes – the overarching targets and objectives need to be articulated in plain language, avoiding overly technical and complex language.

Empowerment of participants – stakeholders must own the process and be involved in the development of the communication plan.

Recognition in the value of anecdotal and traditional knowledge – scientific data are not the only driver, as local stakeholder input can provide valuable primary data.

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Appendix 1. Groundwater Sustainability Assessment Approach Framework

1.0 Definition

Groundwater sustainability is the maintenance and protection of groundwater and groundwater dependant ecosystems to balance current and future environmental, economic and human (social) requirements.

2.0 The Five Goals for Groundwater Sustainability

The Groundwater Sustainability Assessment Approach goals (Figure 3) as adopted from the CCA Expert Panel on Groundwater 2009 report, are:

I. *Protection of groundwater supplies from depletion:* Where sustainability requires that withdrawals be maintained indefinitely without creating significant long-term declines in regional water levels.

II. *Protection of groundwater quality from contamination:* Where sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.

III. *Protection of ecosystem viability:* Where sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supply and the support of ecosystem.

IV. *Achievement of economic and social well-being:* Where sustainability requires that allocation of groundwater maximizes its' potential contribution to the social well-being (interpreted to reflect both economic and non-economic values).

V. *Application of good governance:* Where sustainability requires that decisions as to groundwater use are made transparently through informed public participation and with the full account of the ecosystem needs, intergenerational equity, and the precautionary principle.

Figure 3: Integrated Goals for Sustainable Groundwater Management
(Adopted from the Council of Canadian Academies 2009)

3.0 DPSIR Conceptual Model for Assessment of Groundwater Sustainability

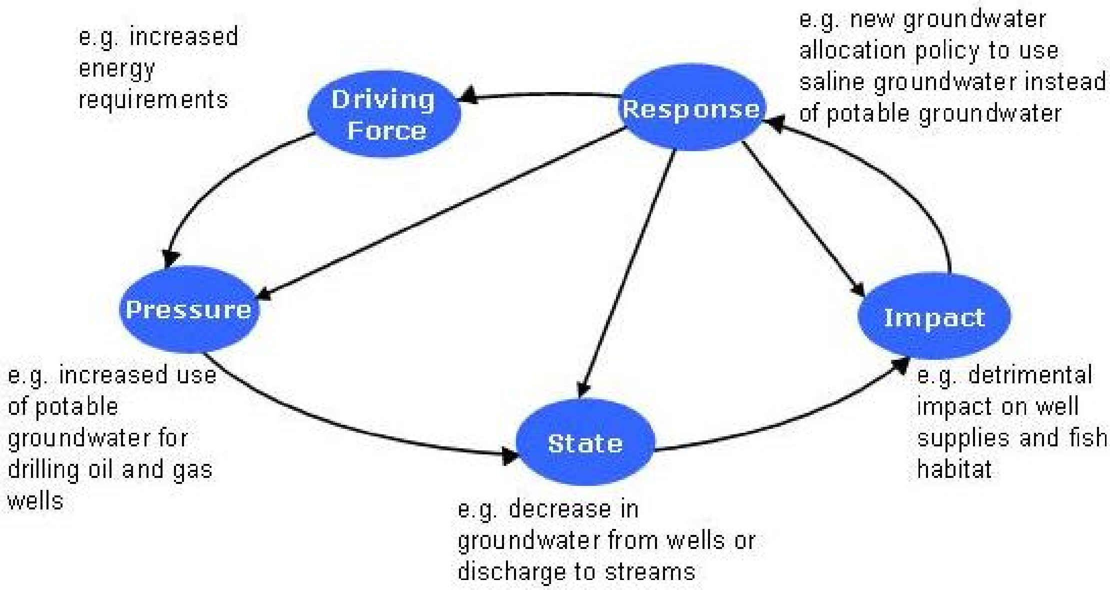

Figure 4: DPSIR Conceptual Model for Assessment of Groundwater Sustainability

- Driving force indicators describe the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns.
- Pressure indicators describe the developments by human activities that use groundwater supplies and release contaminants into groundwater.
- State indicators describe the groundwater in terms of physical phenomena (such as reduced flows), biological phenomena (such as changes in fish stocks) and chemical phenomena (such as nitrate concentrations) in a certain area.
- Impact indictors illustrate the effects of changes in the state of groundwater systems. They are typically expressed as changes in functions such as human and ecosystem health or water resource availability, or indirect ones such as loss of agricultural production due to declining groundwater levels, increased taxes to support water treatment processes, or reduction in tourist dollars from loss of fish stocks.
- Response indicators refer to responses by groups (and individuals) in society, as well as government efforts to prevent, compensate, ameliorate or adapt to changes in the state of groundwater systems. Some societal responses may be regarded as negative driving forces, since they aim at redirecting prevailing trends in consumption and production patterns. Other responses aim at raising the efficiency of products and processes, through stimulating the development and penetration of more effective water saving, treatment and remediation technologies.

Example indicators for the DPSIR indicator elements:

- Driving Force indicators: population increasing; attitudes towards water sustainability activities.
- Pressure indicators: groundwater use by agriculture; contaminated releases from septic systems; amount of land covered by roads.
- State indicators: declining groundwater levels; changes in fish stocks; changes in nitrate concentrations.
- Impact indicators: human and ecosystem health; water resource availability (quantity and quality); losses of manufactured and natural capital, losses of and biodiversity.
- Response indicators: the relative amount of municipal supply wells with treatment; policies related to alternative sources of groundwater; the drilling of geothermal wells; expenditures supporting groundwater programs.

Appendix 2. Suggested Indicators for the Five Groundwater Sustainability Goals (Gordon, 2011)

Goal	Indicator (Reference)	Examples of Measurements/Estimates[1]	Comments on Criteria[2]	DPSIR Element: Comments on Policy Relevance
I. **Quantity** **(Protection from depletion)**	I-i. Renewable groundwater resources per capita m^3/yr (UNESCO 2007)	- Water budget components	- Greater values are desirable - Used for comparison between study areas	Driving force indicator: - e.g., Adaption to climate change, population growth
	I-ii. (Total groundwater abstraction/Recharge) x 100 (UNESCO, 2007)	- Allocations/licensed withdrawals - Recharge estimates	- If data limited e.g.,: - Scenario 1: abstraction ≤ recharge; i.e., <90% - Scenario 2: abstraction = recharge; i.e., = 100% - Scenario 3: abstraction > recharge; i.e., > 100%	State indicator: - Status of resource development
	I-iii. (Σ Areas with a groundwater depletion problem / Total studied area) x 100 (UNESCO 2007)	- Water levels evaluated with other factors, e.g., seasonality, density of production wells, change in base flow/land use/well performance	- Evaluate trend over time and space to determine if aquifer at steady state, i.e., decrease may not represent a problem of unsustainable exploitation	State and impact indicators: - Illustrates the consequences on supplies and base flow - Revise allocations and monitoring requirements
II. Quality **(Protection from contamination)**	II-i. (Σ Areas with groundwater-quality problem / Total studied area) x 100	- Chemicals selected to best fit the problem statement - Concentration changes over space and time	- Relative to a standard or background concentrations - Naturally occurring chemicals such as arsenic can be health concern - Anthropogenic contamination occurs from multiple sources	State and impact indicators: - Supports effective groundwater protection policy - Requirements for groundwater quality monitoring networks
	II-ii. Groundwater Vulnerability = (Σ Areas with a specific class of groundwater vulnerability / Total studied area) x 100 (UNESCO, 2007)	- Dependent on data availability - Basic data from regional geology and climate maps - More complex classifications i.e., including groundwater use	- Small % of areas ranked as high (to medium) vulnerability - Above % decreases with time	Pressure and state indicators: - Useful for planners and decision makers in prioritizing locations for comprehensive protection and conservation policy
	II-iii. Number of contaminated sites (Steinman, 2007)	Number of sites with contaminated groundwater	- Stabilize, then decrease	Response indicator: - For decision makers in determining effectiveness of remediation and enforcement policies and regulations

III. Ecosystems **(Protection of ecosystem viability)**	III-i. Groundwater contribution to base flow (Steinman, 2007)	- Change in base flow over time	- Relative to in-stream flow needs - Adequate temperature and oxygen regimes	State indicator: - For conjunctive use policies and allocations
IV. Socioeconomic **(Achievement of economic and social well-being)**	IV-i. Example - Dependence of agricultural population on groundwater = (# farmers, etc. / population) x 100 - Could be formulated for other sectors (UNESCO, 2007)	- Population of the study area - Number of people engaged in agriculture - Number of agriculture groundwater users	- Relative to other jurisdictions	Driving force indicator: - For developing long term growth strategies to illustrate economic link to groundwater
	IV-ii. Efficiency of groundwater usage (Steinman, 2007)	- Product-output / Unit Groundwater / Sector	- Increase	Response indicator: - Effectiveness of policies restricting groundwater use in a specific sector
	IV-iii. Restricted groundwater access (Steinman, 2007)	- Use restrictions due to water use conflicts or contamination	- Decrease	Pressure and response indicators: - Policies and monitoring developed to resolve problems
V. Governance: **(Application of good governance)**	V-i. Public education on groundwater sustainability	-Public knowledge of groundwater resources - Water resource education in schools - Local government training	- Increase	Response indicator: - Programs and funding recognize the importance of this component
	V-ii. Groundwater Program Resources	- Staffing, infrastructure, budgeting	- Increase	Response indicator: - Decision makers recognize the importance of this component

Notes:
1. The measurements/estimates should be taken as broad guides only. UNESCO (2007) and Steinman, (2007) provide additional details. Each jurisdiction should develop the appropriate methods based on their own requirements.
2. The criteria provided should only be used as examples. These references or standards are dependent on the specific groundwater sustainability issue that the jurisdiction is looking at.

Appendix 3: List of potential indicators for each of the five Groundwater Sustainability Goals

Note: An asterisk in the indicator column (e.g., potato crop trend/potato crop acreage*) denotes that this particular indicator can also be used for another sustainability goal. The other goal is identified in italics at the end of the associated notes column. Indicators that are new and proposed by Innovolve are denoted as 'Proposed Indicator (NEW)' in the pilot project column.

Table 3.1: Indicators for Groundwater Quantity

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Global Population Growth	Driver	With the world population increasing, there is a higher demand for energy (including oil).	NAOS Alberta (Bayegnak, 2013)
Global Energy Demand	Driver	The global energy demand keeps increasing.	NAOS Alberta (Bayegnak, 2013)
Oil Prices	Driver	With the global energy demand increasing, oil prices are subsequently increasing as well.	NAOS Alberta (Bayegnak, 2013)
Renewable groundwater resources per capita	Driver	Very useful to communicate an important groundwater concern for decision makers and some community members. Also useful as a planning tool for future growth.	Town of Gibsons (Gordon, 2013)
Population Increase	Driver	Increases in population - coupled with economic development - increase water demand.	PEI (Li, 2013)
Potato crop trend/Potato crop acreage*	Driver	Tracking potato acreage is representative of pressures on the groundwater environment. *Indicator also applies to groundwater quality.*	PEI (Li, 2013)
Overall authorized groundwater extraction	Pressure	It is useful to see how much groundwater in an aquifer is allocated for extraction.	NAOS Alberta (Bayegnak, 2013)
Water use per capita	Pressure	This indicator helps determine water use between different jurisdictions.	PEI (Li, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
([Total groundwater abstraction/ recharge] x 100)	State	Useful indicator for communication about the need to conserve groundwater. Also useful for decision makers when planning for any additional development.	Town of Gibsons (Gordon, 2013)
Groundwater elevation	State	Water level measurements are direct ways to assess the available head and drawdown extent; whereas hydraulic gradient will provide a good indication of the flow direction.	NAOS Alberta (Bayegnak, 2013)
Regional Transmissivity	State	Once baseline aquifer transmissivity has been established subsequent deviation of transmissivity from established baseline values would be an indication of change in the aquifer's ability to store or transmit groundwater, as well as its potential for water well supply.	NAOS Alberta (Bayegnak, 2013)
Water level trend/change	State	Used observation wells across the province to see if there were any long-term trends that suggested sustainable water resource usage.	PEI (Li, 2013)
Percentage of available water utilized	State	Using a low percentage of water deemed available indicates that the state of the resource is both in excellent condition and that increased usage will not cause that status to deteriorate.	PEI (Li, 2013)
Renewable groundwater resources	State	Objective of indicator is to estimate the quantity of groundwater that is renewed on an annual basis. Indicator is defined as the total renewable groundwater resources without considering groundwater quality but excluding brackish and saline waters.	PEI (Li, 2013)
Drinking Water and Wastewater Facility Operating Regulations*	State	Indicator also applies to groundwater quality.	PEI (Li, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
([Σ Areas with groundwater depletion problem/Total studied area] x 100)	Impact	This indicator can be used to promote the jurisdiction's supply when compared to other municipalities or regions, if possible.	Town of Gibsons (Gordon, 2013)
Cost of pumping water	Impact	The impact of a reduction in groundwater discharge could result in higher pumping costs.	NAOS Alberta (Bayegnak, 2013)
Number of well damaged/reclaimed/recompleted due to water level decline	Impact	The impact of a reduction in groundwater discharge could result in well damages.	NAOS Alberta (Bayegnak, 2013)
Aquifer compaction	Impact	Lowering the groundwater level may alter groundwater flow pattern and result in reduced discharge to surface water bodies including river, lakes, wetland, or dry springs.	NAOS Alberta (Bayegnak, 2013)
Land subsidence	Impact	See "Aquifer compaction".	NAOS Alberta (Bayegnak, 2013)
Change in groundwater gradient	Impact	See "Aquifer compaction".	NAOS Alberta (Bayegnak, 2013)
Resource for Water Infrastructure Upgrades*	Response	Used because of data available. Data included amount spent on infrastructure planning, ability to track water losses, data which indicate if drinking water quality parameters are exceeded. *Indicator also applies to groundwater quality.*	Town of Gibsons (Gordon, 2013)
Conservation fixtures/procedures	Response	The use of conservation fixtures and other water saving techniques can reduce the amount of water utilized individually and collectively reduce the impact of water extraction on the environment.	PEI (Li, 2013)
Regulations on water use/disposal	Response	Indicator measures how active and ongoing a regime of protection for groundwater is.	PEI (Li, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Maximum Development Density*	Response	Assesses the density of residential development. This indicator could look at the relationship between the maximum density and current density of an area. *Indicator also applies to groundwater quality.*	Montérégie Est Region (Martin *et al*, 2013)
Influence of climate change on groundwater*	Response	An indicator should be developed to flag the effects of long-term climate change on the quality and availability of groundwater. *Indicator also applies to groundwater quality.*	Montérégie Est Region (Martin *et al*, 2013)

Table 3.2: Indicators for Groundwater Quality

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Potato crop trend/Potato crop acreage*	Driver	Tracking potato acreage is representative of pressures on the groundwater environment. *Indicator also applies to groundwater quantity.*	PEI (Department of Environment, Labour and Justice, 2013)
Number of ongoing development projects	Pressure	Every single project increases pressure on groundwater quality, availability and flow.	NAOS Alberta (Bayegnak, 2013)
Number of approved development projects	Pressure	This indicator may be used as a surrogate or indirect indication of the pressure intensity on groundwater resources.	NAOS Alberta (Bayegnak, 2013)
Groundwater vulnerability	Pressure	([Σ Areas with a specific class of groundwater vulnerability/Total studied area] x 100). This indicator is useful as it provides communication tools to inform the community and businesses about their role in protecting the aquifer.	Town of Gibsons (Gordon, 2013)
Fertilizer use per acre	Pressure	The higher the amount of fertilizer used per acre, the more chance there is that the fertilizer will contaminate an aquifer.	PEI (Department of Environment, Labour and Justice, 2013)
Redox Potential	State	Changing chemical conditions may lead to the mobilization of metals incorporated in the bitumen structure or forming part of the mineral matrix.	NAOS Alberta (Bayegnak, 2013)
Heteroaromatic compounds	State	See ‘Redox Potential’ explanation.	NAOS Alberta (Bayegnak, 2013)
Hydrocarbon compounds	State	See ‘Redox Potential’ explanation.	NAOS Alberta (Bayegnak, 2013)
Metals	State	See ‘Redox Potential’ explanation.	NAOS Alberta (Bayegnak, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Free gas	State	See ‘Redox Potential’ explanation.	NAOS Alberta (Bayegnak, 2013)
Average Nitrate Concentration	State	Pristine water conditions for nitrate concentration are in the range of 0.501 m N/L. Watersheds with an average nitrate concentration of 1-2 mg N/L are considered to have minor concentrations, while watersheds with an average nitrate concentration of 2 mg N/L or above are seen to have groundwater quality that is degraded and heavily contaminated.	PEI (Department of Environment, Labour and Justice, 2013)
Drinking Water and Wastewater Facility Operating Regulations*	State	*Indicator also applies to groundwater quantity.*	PEI (Department of Environment, Labour and Justice, 2013)
Salt concentration in stream base flow	State		PEI (Department of Environment, Labour and Justice, 2013)
([Σ Areas with groundwater quality problem/Total studied area] x 100)	Impact	This is a useful indicator as long as water quality results does not indicate any problems. It appears that this indicator is well suited for regional water quality issues or contaminated sites of a relatively large scale compared to the overall study area.	Town of Gibsons (Gordon, 2013)
Suitability of water quality for its intended purposes	Impact	Releases of deleterious substances in sources may result in the inability of groundwater to provide its social and economical services.	NAOS Alberta (Bayegnak, 2013)
Inventory of hypogean community structure	Impact	Hypogean invertebrates directly or indirectly respond to changes in the properties of the different constituent of the subsurface and they integrate the effect of contamination over various periods of time.	NAOS Alberta (Bayegnak, 2013)
Changes in structure of invertebrates communities	Impact	The assessment of the quality of groundwater ecosystems relies on the presence or absence of previously defined sensitive species or on the examination of contaminant levels accumulated within the food web.	NAOS Alberta (Bayegnak, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Decline in groundwater dwelling organism populations	Impact	See 'Changes in structure of invertebrates communities'.	NAOS Alberta (Bayegnak, 2013)
Penetration of alien cosmopolitan epigean species	Impact	See 'Changes in structure of invertebrates communities'.	NAOS Alberta (Bayegnak, 2013)
Percentage of Wells with Nitrate Concentration above 10 mg N/L	Impact	The percentage of private wells with a nitrate concentration above 10 mg/L shows the number of households that potentially would have had to react to the poor status of their well water.	PEI (Department of Environment, Labour and Justice, 2013)
Number of contaminated sites	Response	Information could possibly be found in Town and Provincial records.	Town of Gibsons (Gordon, 2013)
Resource for Water Infrastructure Upgrades*	Response	Used because of data available. Data included amount spent on infrastructure planning, ability to track water losses, data which indicate if drinking water quality parameters are exceeded. *Indicator also applies to groundwater quantity.*	Town of Gibsons (Gordon, 2013)
Use of Nutrient Management	Response	Nutrient management has a goal of ensuring that crop nutrient needs are met while not having these nutrients in excess. Too many nutrients in the soil will cause contamination of ground and surface water.	PEI (Department of Environment, Labour and Justice, 2013)
Regulations on Crop Rotation	Response	Regulations should include provisions that protect groundwater from siltation, yet most only protect surface water.	PEI (Department of Environment, Labour and Justice, 2013)
Maximum Development Density*	Response	Assesses the density of residential development. This indicator could look at the relationship between the maximum density and current density of an area. *Indicator also applies to groundwater quantity.*	Montérégie Est Region (Martin *et al*, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Wetlands and groundwater relationship*	Impact	Indicator would highlight impacts from development activities on wetlands. *Indicator also applies to ecosystems.*	Montérégie Est Region (Martin *et al*, 2013)
Influence of climate change on groundwater*	Response	An indicator should be developed to flag the effects of long-term climate change on the quality and availability of groundwater. *Indicator also applies to groundwater quantity.*	Montérégie Est Region (Martin *et al*, 2013)
E.coli (percentage wells detection)	Response	The presence of E. coli in well water shows that a pathway of fecal contamination and a subsequent health risk is present.	PEI (Li, 2013)
Pesticide - Percentage Detection	Response	Pesticide detection rate in private wells is considered as a response indicator because it measures how well people prevent pesticides from entering groundwater and how reliable the private wells are protected from agricultural contamination.	PEI (Li, 2013)

Table 3.3: Indicators for Ecosystems

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Groundwater contribution to base flow	State	Important to species feeding on groundwater (e.g., salmon).	Town of Gibsons (Gordon, 2013)
Groundwater Quality Impacts on base flow*	State/ Impact	Local surface water quality degradation may be due to groundwater. Surface water quality does not meet applicable guidelines for freshwater aquatic life. *Indicator also applies to socioeconomic.*	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
Number of species at risk associated with streams/riparian habitat	Impact	Changes to the number of identified species at risk and their status may provide some indicator of ecosystem health. Currently insufficient data to comment on temporal changes.	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
Ecosystem dependence on groundwater	Impact	The assessment of the quality of groundwater ecosystems relies on the presence or absence of previously defined sensitive species or on the examination of contaminant levels accumulated within the food web.	NAOS Alberta (Bayegnak, 2013)
Wetlands and groundwater relationship*	Impact	Indicator would highlight impacts from development activities on wetlands. *Indicator also applies to groundwater quality.*	Montérégie Est Region (Martin *et al*, 2013)

Table 3.4: Indicators for Socioeconomic

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Restricted groundwater access: Percentage population supplied by groundwater wells	Pressure	If possible, jurisdiction should try and be the sole user of the aquifer in order to ensure proper maintenance.	Town of Gibsons (Gordon, 2013)
Agricultural Reliance	Pressure	Indicator provides a measure of the aquifer area used for agricultural production.	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
Groundwater Quality Impacts on base flow*	State/ Impact	Local surface water quality degradation may be due to groundwater. Surface water quality does not meet applicable guidelines for freshwater aquatic life. *Indicator also applies to ecosystems.*	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
Lower water levels	Impact	Lower water levels can indicate that the aquifer is being overused.	NAOS Alberta (Bayegnak, 2013)
Efficiency of groundwater usage and quantity	Response	Different types of users reduce water use by set amount. This indicator could be used in the development and implementation of a Water Conservation Plan.	Town of Gibsons (Gordon, 2013)
Price of Groundwater	Response	Access to groundwater from the aquifer with no associated metered costs has implications for aquifer sustainability.	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
Total groundwater abstraction/Exploitable groundwater resources (UNESCO, 2007)	Driver	It is crucial that as the sum of licensed, unlicensed and natural abstraction, groundwater abstraction needs to be broken down to its components, to provide transparent information for policy-making purposes. The second issue in relation to the ‘exploitable groundwater resources’ is to specify clearly for a given aquifer the current social and economic constraints, ecological conditions and political priorities under which the competent authorities are operating.	Proposed Indicator (NEW)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Groundwater as a percentage of total use of drinking water at national level (UNESCO, 2007)	Pressure	This indicator is of particular social importance since it highlights the importance of groundwater for drinking purposes on a national basis, i.e., the population dependency on groundwater and therefore, its key role in public and domestic water supply.	Proposed Indicator (NEW)
Groundwater treatment requirements (UNESCO, 2007)	Response	This indicator can help with planning for capacity building e.g., in developing the knowledge and maintenance expertise needed. Since the indicator would provide information on groundwater which is potable (drinking water), or usable for other purposes with respect to the level of complexity of the treatment required, it can therefore help with investment planning not only on treatment options but on the beneficial use for which groundwater can best e used, in the context of its current quality.	Proposed Indicator (NEW)

Table 3.5: Indicators for good governance

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Government pressure to implement measures to alleviate pressure on groundwater resources	Pressure	Knowledge development, education and outreach, policy measures, planning actions and market instruments can be used in isolation or in combination to address human induced pressures.	NAOS Alberta (Bayegnak, 2013)
Mandatory Monitoring	State	Governments should have the tools and authority to mandate the monitoring, evaluation and reporting of groundwater/aquifer status prior, during and after development.	NAOS Alberta (Bayegnak, 2013)
Public outreach on groundwater sustainability	Response	A recommended additional indicator is to test whether outreach outputs are on track to achieve their stated goals.	Town of Gibsons (Gordon, 2013)
Government Action	Response	Good governance requires leadership, collaborative participation by decision makers with an interest in the aquifer. A government action score is suggested to assess government involvement.	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
Levels of Government with Interest in the Aquifer (Golder, 2011)	Response	Good governance includes engagement from multiple levels of government.	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)
# Municipal supply wells / # of monitoring wells	Response	Monitoring within or upgrading well capture zones can provide warning of groundwater exceedances of guidelines prior to use. This indicator could be used to assess the response of a governance framework to aquifer protection requirements.	Abbotsford-Sumas Aquifer (Aldridge *et al*, 2013)

Indicator	DPSIR Framework Element Considered	Notes	Pilot Project
Effectiveness of resource management structures and strategies (Adapted from Ehler, 2003)	Response	This indicator will measure for: effective and implemented management planning, socially acceptable and clearly defined rules for resource access and use, presence of effective and accountable decision-making and management bodies, sufficient human and financial resources used efficiently and effectively, recognition and incorporation of traditional/local/informal governance in management planning, periodic effective monitoring, evaluation and adaptation of the management plan ensured.	Proposed indicator (NEW)
Effectiveness of legal structures and strategies for management (Adapted from Ehler, 2003)	Response	This indicator will measure for: the existence of adequate legislation, compatibility between formal legal arrangements and traditional local arrangement, national/local legislation incorporates rights and obligations set out in international legal instrument, compatibility of international, national, state and local rights and obligations and enforceability	Proposed indicator (NEW)
Effective and equitable representation and participation of groundwater resource stakeholders in management (Adapted from Ehler, 2003)	Response	Representative and effective systems of co-management, building resource users capacity to participate in co-management and strengthen and enhance community organizing.	Proposed indicator (NEW)
Compliance by resource users with management plans (Adapted from Ehler, 2003)	Response	Improve the willingness and acceptance of people to behave in ways that allow for sustainable groundwater management, build the local ability (capacity) to use resources sustainably, increase user participation in surveillance, monitoring and enforcement, adequate applications of law and regulations, and ensure transparency and simplicity of, and access to, management plan to foster compliance.	Proposed indicator (NEW)

Appendix 4. Examples of other approaches addressing groundwater sustainability in Canadian jurisdictions

Ontario Source Water Protection Program

The Ontario Source Water Protection Program was created in the wake of the Walkerton tragedy of 2000. Public salience of the high profile incident has been the catalyst for development of a multi-barrier approach to source water protection. It relies on adequate water treatment and distribution systems, water testing and training of water managers. With it came an understanding that effective source water protection is conducted on a watershed basis. Traditional municipal boundaries (i.e., city, town or village) do not match those of lakes, rivers, streams, or aquifers.

Ontario has created 36 Conservation Authorities, which operate as resource management agencies at a watershed level. They have been grouped into 19 Source Protection Areas and Regions. Numerous technical expertise, advisory, implementation and source protection committees over the years have informed development of comprehensive legislation. The Clean Water Act - http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_06c22_e.htm - is the flagship, setting the standard on source water protection. It requires communities in Ontario to develop localized Source Protection Plans.

These plans are informed by Assessment Reports consisting of six technical components: 1) watershed characterization, 2) water budget, 3) water quantity threats assessment, 4) surface water vulnerability analysis, 5) groundwater vulnerability analysis; and, 6) drinking water quality threats analysis. Of particular relevance to this guidance document is the groundwater vulnerability analysis, which assesses: wellhead protection areas, highly vulnerable aquifers, and significant recharge areas. It identifies and maps vulnerable areas, assigning vulnerability scores. Finally, uncertainty assessment is conducted to inform improvement of future source protection planning.

Helpful tools and resources:

http://www.waterprotection.ca/download/swp_background_technical.pdf

- Science-based decision-making for protecting Ontario's drinking water resources. A technical expert committee publication focusing on two key topics: areas where highest risk perceived to be present or anticipated, and technical components of the threats assessment framework. Significant attention is paid to groundwater.

Alberta Water for Life

The Alberta Water for Life action plan and strategy act as guidance tools for management of the province's water resources. Much like Ontario's program, its origin can be traced to an issue of high public salience, serving as a catalyst for change. The multi-year drought at the turn of the millennium raised serious water management concerns province wide. A public consultation process was initiated, and the result was the first iteration of the Water for Life: Alberta's Strategy for Sustainability (November, 2003).

A renewed strategy and action plan (November, 2009) identify three goals: safe, secure drinking water supply; healthy aquatic ecosystems; and, reliable, quality water supplies for a sustainable economy. These are supported by prioritized actions in three key areas: knowledge and research; partnerships for watershed management and stewardship; and, water conservation.

Surface and groundwater resources receive what appears to be equal attention in the renewed strategy. Groundwater has also been acknowledged as increasingly important with limits on surface water allocations in Southern Alberta. Priority has been placed on access to comprehensive information on groundwater, with action items to develop and implement an education framework. Specifically, print- and web-based public information resources are to be produced on watershed management, wetlands, groundwater, and water conservation. Teacher resources and programs, as well as facilitation of partnerships on education programs are to support the education framework on the same topics.

A report on implementation progress of Albert's Water for Life (October, 2005) provides an overview of implementation initiatives and identifies responsible ministries. Assessing the state of quality and quantity of groundwater supplies was assigned to Alberta Environment and Sustainable Resource Development. Collection and interpretation of groundwater data were identified as costly and resource-intense. As such, knowledge enhancement was conducted on a watershed scale, with one or two watersheds evaluated every two years. Potential opportunity arose from linking this with the development of water management plans in each watershed. Groundwater modeling was completed for the Cold Lake-Beaver River watershed as part of an upgrade to the watershed management plan (2004-2005). Finally, a major project proposal set out to determine delineation of the depth of useable groundwater in Alberta (i.e., water with total dissolved solids concentration < 4,000 mg/L, as anything more is considered saline).

Principal outcomes of the Water for Life program are tied to promotion of development of a generic numeric model that will enable continuous evaluation of groundwater systems, as well as policies and tools to support management and protection of groundwater resources.

Helpful tools and resources:

http://www.waterforlife.alberta.ca

- Report on implementation progress of Water for Life. Provides summary of initiatives implemented in 2004-2005 and identifies the key ministries responsible for implementation.

Québec's Programme d'acquisition de connaissances sur les eaux souterraines (PACES)

Following up on a commitment from Québec's *National Water Policy*, the Québec Government created in 2008 the *Programme d'acquisition de connaissances sur les eaux souterraines (PACES)*. This program aimed at developing a practical and realistic picture of groundwater resources in southern Québec, in order to protect groundwater and ensure its long term sustainability.

Specific objectives of the program included:

- To develop an assessment of groundwater resources at the watershed scale or at the Regional Municipality scale, in order to support information needs on groundwater.
- To complete the coverage of the lands targeted by the shale gas industry.
- To develop partnerships between water stakeholders and land managers for the collection of groundwater information.

The program, which was originally planned to end in 2013, was extended until March 31, 2015. Through this program, university research centers applied for funding. To be eligible, projects must have had as one of their objectives, the determination of the state of groundwater, including quality, quantity, human use and other pressures. Projects were to aim at assessing sustainable levels for human use, contamination risks and overuse risks. In addition, projects had to be conducted in partnership with a watershed-based organization, a municipality or another organization with recognized water expertise.