ASSESSMENT OF WATER RESOURCES TO SUPPORT A REVIEW OF ONTARIO'S WATER QUANTITY

MANAGEMENT FRAMEWORK: SCIENCE REVIEW REPORT

Submitted to:

Government of Ontario
Ministry of the Environment, Conservation and Parks
Standards Development Branch
7th Floor, 40 St Clair Avenue West
Toronto, ON M4V 1M2

Prepared by:

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Project Number: 180107
Submission Date: 31 October 2018

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TABLE OF CONTENTS

1. INTRODUCTION 1
2. METHODOLOGY 1
2.1 LITERATURE SELECTION 1
2.2 LITERATURE ORGANIZATION 2
2.3 LITERATURE REVIEW 3
2.4 ANALYSIS AND EVALUATION MATRIX 6
3. RESULTS OF THE ANALYSIS OF THE SCIENCE AND BEST SCIENTIFIC PRACTICES REVIEW 7
4. SUMMARY AND CONCLUSIONS 8
5. REFERENCES 9

LIST OF TABLES

Table 1: Attributes Assigned to Selected Publications 3
Table 2: Number of Publications Reviewed for the Selected Topics 4

LIST OF FIGURES

Figure 1: Template used for literature reviews 5

LIST OF APPENDICES

Appendix A : Glossary
Appendix B: Task 1 Analysis Matrices

1. INTRODUCTION

The materials included in this report provide an analysis in tabular format of the finding of the Science and Best Scientific Practice Review. The methodology describe herein therefore includes the methodology of the original review as well as the subsequent analysis of the results.

The purpose of completing the analysis of the outcome of the Science and Best Scientific Practices review is to present the material in a quick reference format such that it can be used to evaluate different approaches as it might relate to Ontario's conditions and water quantity management and policy framework.

This analysis considers the information gathered on the topics of the review including water quantity assessments, scientific data needs; evaluation of sustainability, water permitting and allocation, assessment of water security, existing and anticipated effects of climate change, population growth, and changing land uses, cumulative effects on a water resource and assessment of environmental flow needs, use of numerical models (groundwater, surface water and integrated), and assessment of the effects of takings by water bottlers.

2. METHODOLOGY

2.1 LITERATURE SELECTION

The overarching goal of the Science Review was to evaluate the extent of scientific consensus concerning the science tools and methodologies that may be needed to improve management of water quantity in Ontario, taking into consideration climate change, population growth, ecological impacts and cumulative effects. The literature search was conducted using key words or search terms consistent with the main topics of study. Accessible sources included academic databases and search engines that provided comprehensive coverage of peer-reviewed publications, reports and books. The sources included restricted-access (reserved access) online scientific libraries, such as Université Laval https://www.bibl.ulaval.ca/ and University of Waterloo http://www.lib.uwaterloo.ca/, Google Scholar, open access publications and journals, and finally social research networks such as ResearchGate. For each topic considered in this study, the aforementioned scientific databases were first searched for publications and books published from 2010 through 2018 and then from 2000 to 2018 for review papers or those with important citation rates.

The search process was based on the use of various permutations of keywords or search terms either in the ***title***, the ***abstract*** and/or the ***body***. Publications were retained if they addressed the questions, criteria and topics of study identified by the Ministry of the Environment, Conservation and Parks (MECP), i.e. the science tools to manage water quantity, water permitting and allocation, environmental flow needs, cumulative effects on water resources, water security and sustainability of water resources in Ontario. It should be noted that the impact of climate change, population growth, ecological flows and water taking on the sustainability of water resources was included in the discussion on cumulative effects.

The search began with the keywords included above and then continued with complementary target terms such as "groundwater", "surface water", "indicators", "field method", "modelling", "case study", "geophysical methods", etc. For topics where the main and complementary terms did not result in an acceptable number of relevant articles, more scientific publications were found by data mining of the articles selected in the initial searches; for example by using the keywords of the relevant papers or targeting the articles cited in these articles.

Articles prioritized for use in the review had to have at least some information that fulfilled each of the following criteria: 1) a qualitative or quantitative model or approach; 2) a field method; and 3) a case study. Temporal and spatial scales of assessment were excluded from the criteria of selection. No filter was applied to the number of times that a single approach could be used or presented in different selected publications. This strategy was adopted to highlight the methods mostly used by different researchers, professionals and agencies.

2.2 LITERATURE ORGANIZATION

To accomplish our primary objective of synthesizing the science tools that could be used to improve management of water quantity in Ontario, the pre-selected papers were stored in the reference-managing Excel spreadsheet database and assigned qualitative attributes for efficient identification. Each publication was attributed multiple tags representing different qualitative attributes, which were systematically assigned according to the parameters in Table 1. These attributes were then used to identify relevant publications for each topic studied.

Table 1: Attributes Assigned to Selected Publications

<table>
<tr><th>Section</th><th>Description</th></tr>
<tr><td>No.</td><td>Unique identification number at the beginning of each document, divided into the following subsections
<table>
<tr><th>Subsection</th><th>Identification Number Start</th></tr>
<tr><td>Assessment of Water Quantity</td><td>1000</td></tr>
<tr><td>Ecological Flow Needs</td><td>2000</td></tr>
<tr><td>Cumulative Effects of Water Taking</td><td>3000</td></tr>
<tr><td>Climate Change and Population Growth</td><td>4000</td></tr>
<tr><td>Books</td><td>5000</td></tr>
</table></td></tr>
<tr><td>Type of Document</td><td>Description of document format, such as report, manual, article</td></tr>
<tr><td>Title</td><td>Title of Document</td></tr>
<tr><td>Author</td><td>Prepared by</td></tr>
<tr><td>Year of Publication</td><td>Year of publication</td></tr>
<tr><td>Qualitative Attributes</td><td>Descriptive tags given to easily identify material covered in the document.
For example: water budget, watershed management plans, climate change models</td></tr>
<tr><td>Georeference</td><td>Geographical area which research, report, or examples take place</td></tr>
</table>

2.3 LITERATURE REVIEW

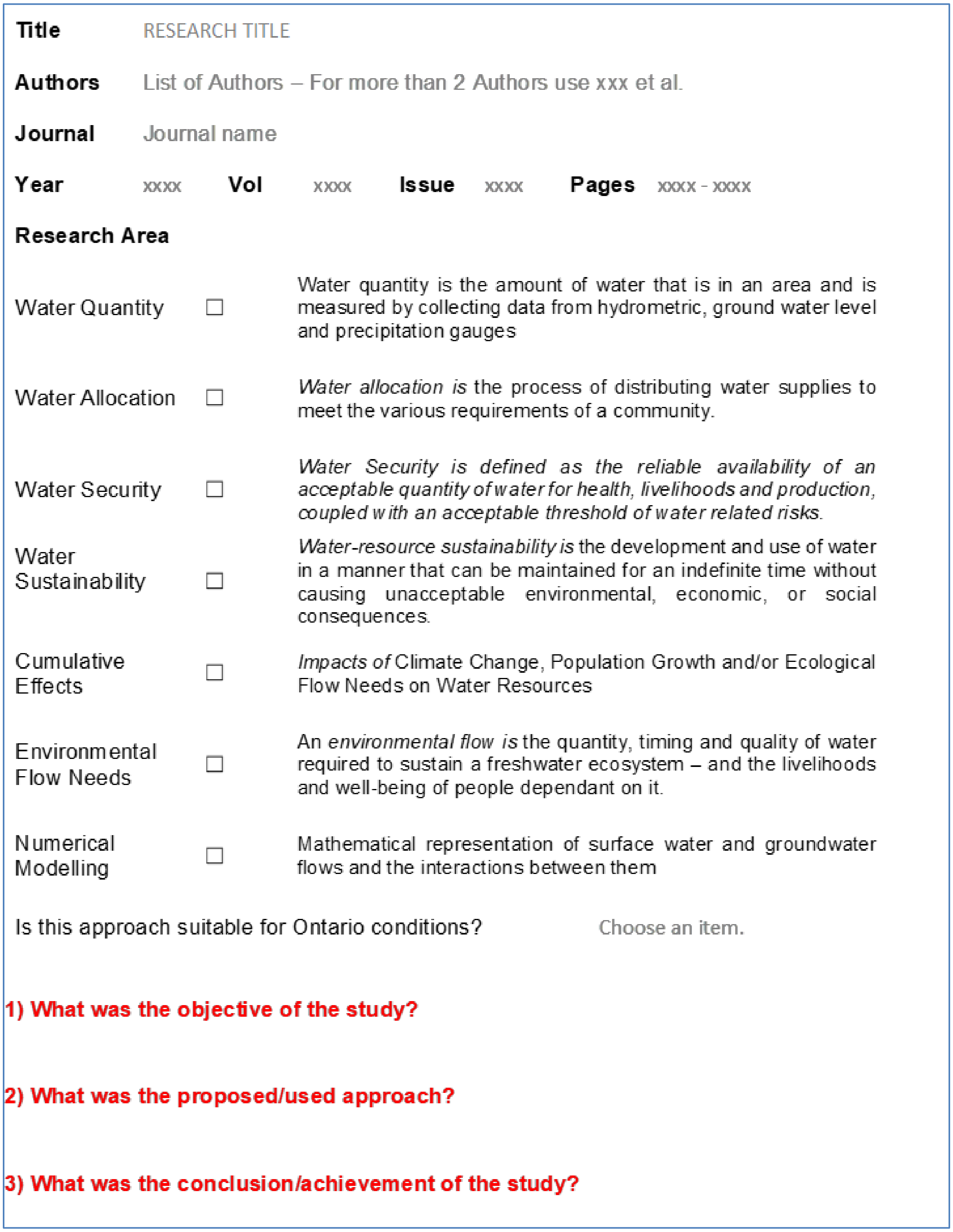
We defined a set of questions for conducting systematic detailed reviews for each prioritized document. The questions were:

- What was the objective of the study?
- What was the proposed approach?
- What were the conclusions and/or achievements of the study?

The template used during the review process is presented in Figure 1. Prioritized articles in each of the topics of study were reviewed by several reviewers in order to improve the discussion on the relevance of a specific approach under hydrological and hydrogeological conditions of Ontario. The approach to the reviews allowed reviewers to concurrently cover several topics at the same time and help to identify publications that covered multiple topics of study suggesting a high degree of relevance. The results and findings of the publications reviewed were presented in different matrices of the main report. Table 2 shows the number of publications reviewed for each of the topics of study. It should be noted that some of the reviewed materials cover several topics and some of the reviewed materials noted cover specific topics including water bottlers and climate change, population and land use.

Table 2: Number of Publications Reviewed for the Selected Topics

Topic	Number of reviewed publications
Water quantity	59
Water permitting and allocation	34
Environmental Flow Needs	17
Cumulative effects on water resources	29
Water security	33
Sustainability of water resources	30
Water bottlers	5
Climate change, population and land use	7



Title RESEARCH TITLE

Authors List of Authors – For more than 2 Authors use xxx et al.

Journal Journal name

Year xxxx **Vol** xxxx **Issue** xxxx **Pages** xxxx - xxxx

Research Area

Water Quantity	☐	Water quantity is the amount of water that is in an area and is measured by collecting data from hydrometric, ground water level and precipitation gauges
Water Allocation	☐	*Water allocation is* the process of distributing water supplies to meet the various requirements of a community.
Water Security	☐	*Water Security is defined as the reliable availability of an acceptable quantity of water for health, livelihoods and production, coupled with an acceptable threshold of water related risks.*
Water Sustainability	☐	*Water-resource sustainability is* the development and use of water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.
Cumulative Effects	☐	*Impacts of* Climate Change, Population Growth and/or Ecological Flow Needs on Water Resources
Environmental Flow Needs	☐	An *environmental flow is* the quantity, timing and quality of water required to sustain a freshwater ecosystem – and the livelihoods and well-being of people dependant on it.
Numerical Modelling	☐	Mathematical representation of surface water and groundwater flows and the interactions between them

Is this approach suitable for Ontario conditions? Choose an item.

1) What was the objective of the study?

2) What was the proposed/used approach?

3) What was the conclusion/achievement of the study?

Figure 1: Template used for literature reviews

2.4 ANALYSIS AND EVALUATION MATRIX

A template for the matrices was developed in consultation with the MECP. The template was further refined in a workshop with the MECP on September 6, 2018. The final template for the matrices consisted of twelve columns. These columns include:

1) Approach: a reference column identifying the title and general information about the approach being presented;
2) Purpose: describing the types of assessments applicable to the approach, as well as the approach's applicability to surface water and/or groundwater assessments;
3) Setting: the type(s) of environmental settings (see Glossary in Appendix A) to which the approach is applicable;
4) Risks of concern: the types of activities (e.g. individual water takings, planning, source protection) to which the approach is applicable;
5) Spatial and temporal scales: the appropriate scales of assessment for implementing the approach;
6) Data needs: the types and availability of data required by the approach, and requirements for monitoring;
7) Tool needs: the types of analytical programs, models, science tools, etc. required by the approach to predict impacts and establish triggers for assessment and management activities;
8) Strengths/benefits: the reasons for shortlisting the approach for inclusion in the analysis and evaluation matrix;
9) Limitations/challenges: conditions under which the approach may not function as intended or not be feasible;
10) Jurisdictions using: examples of jurisdictions using the approach;
11) Linkages: relevance to the other topics of study (sustainability, security, climate change, etc.)
12) Considerations for use in Ontario: the potential applicability and suitability of the approach for Ontario, any enhancements that may be required prior to its implementation, and potential advantages of the approach over others currently used in Ontario.

Due to the overlapping nature of several topics (e.g. water security and sustainability), minor adjustments were made in consultation with the MECP to the list of topics of study, such that one matrix was prepared for each of the following:

- Water quantity assessment
- Water security assessment and sustainability evaluation
- Cumulative effects on water resources and Environmental Flow Needs
- Water bottlers (approaches for assessing water quantity impacts of)
- Climate, population and land use change

Four to six approaches were analyzed and evaluated for each topic of study.

3. RESULTS OF THE ANALYSIS OF THE SCIENCE AND BEST SCIENTIFIC PRACTICES REVIEW

As described in Section 2.4, analysis and evaluation matrices were prepared for the following topics:

- Water quantity assessment
- Water security assessment and sustainability evaluation
- Cumulative effects on water resources and Environmental Flow Needs
- Water bottlers (approaches for assessing water quantity impacts of)
- Climate, population and land use change

The approaches and methodologies were selected from the literature review (described in Section 2.3) based on their potential relevance to Ontario, their successful implementation in other jurisdictions, and/or the novel concepts built into the approach. Where possible, a diversity of different types of approaches were presented, as Ontario itself has an extremely diverse range of environmental conditions, data availability, resources, etc., and a single approach will rarely be ideal for every individual situation.

It should be noted that approaches and methodologies were prioritized over specific tools (e.g. the 7Q20 would be considered a tool) since they would be more broadly applicable to the Ontario context and typically included a policy aspect in the discussion that often took socioeconomics into consideration. For these reasons, the selected approaches and methodologies are considered more broadly applicable to variable conditions and also applicable to surface water, groundwater and the interaction of the two. In addition, some of the approaches in the matrices were described as tools by their creators (e.g. the Michigan

Water Withdrawal Assessment Tool), but are included in the tables because they were deemed to be an approach. In such cases, the original names of the approaches were retained, so the "Michigan Water Withdrawal Assessment Tool" was *not* renamed to the "Michigan Water Withdrawal Assessment Approach". One exception to this, applies to the Water Bottling matrix which includes tools due to the limited availability of bottling-specific assessment approaches and methodologies.

Finally, the selection of approaches and methodologies avoided those that are already being used in Ontario or as noted above were deemed impractical or not applicable to Ontario.

The matrices are presented in Appendix B.

4. SUMMARY AND CONCLUSIONS

The present report and appendix provides an analysis and evaluation of the findings of the Science and Best Scientific Practices Review. The material has been presented in tabular format, in which it was evaluated against Ontario's physical context and policy framework.

An exhaustive literature search and review was conducted for the main topics of study, and a shortlist of approaches with potential relevance and applicability to Ontario is presented in a series of analysis and evaluation matrices for further consideration.

Respectfully submitted,
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5. REFERENCES

A list of the key references used in the analysis of each of the topics is included at the bottom of each table.

APPENDIX A

Glossary

Glossary of Terms and Definitions

(A living document for the duration of the project)

(Key References: MOECC RFB #6792, Information distributed to the Water Quantity Protection External Working Group, Regulations under the Ontario Water Resources Act, Oxford Dictionary of Earth Sciences, USGS Water Science Glossary)

Acre-foot (acre-ft) – a common measure in agricultural irrigation which represents the volume of water required to cover 1 acre of land (43,560 square feet) to a depth of 1 foot. Equal to 325,851 gallons or 1,233 cubic metres.

Adaptive Management - A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices. In active adaptive management, management is treated as a deliberate experiment for the purpose of learning. Management is flexible but within the context of a governance framework and vision within which it operates and to which decisions are cross-referenced. Management informs governance and vice versa over time.

Adjudication - conflict resolution via a litigation process drawing on the court system to provide a binding ruling based on the interpretation of law.

Alluvium - deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

Approach - a way of dealing with, for the purposes of this study, managing water resources management including policy, program and science aspects. For the purposes of a water quantity assessment, an approach means specifically a strategy or framework for the application of a water resources assessment that includes, but not limited to, defining objectives, data collection, analyses, tools and models, implementation, monitoring and adaptation.

Aquifer - A geological formation or structure that stores and/or transmits water, such as to wells and springs. Use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply for people's uses. Or in Ontario “Aquifer means a water-bearing formation that is capable of transmitting water in sufficient quantities to serve as a source of water supply" (R.R.O. 1990, Reg. 903: WELLS under Ontario Water Resources Act, R.S.O. 1990, c. O.40).

Aquifer (confined) - soil or rock below the land surface that is saturated with water. There are layers of impermeable material both above and below the aquifer. It is under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer.

Aquifer (unconfined) - an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall.

Arbitration - a form of conflict resolution where a neutral party or panel meeting with parties in a dispute to hear presentations and makes an award based on predefined rules and procedures

Artesian water - groundwater that is under pressure and is able to rise above the level at which it is first encountered when tapped by a well. It may or may not flow out at ground level. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is an artesian aquifer or confined aquifer. See *Flowing well*.

Artificial recharge - a process where water is put back into groundwater storage from surface-water supplies such as irrigation, or induced infiltration from streams or wells.

Average Annual Flow Map - the map entitled "Water Use — Average Annual Flow Conditions", dated November, 2004 and on file in the offices of the Ministry of the Environment and Climate Change at Toronto and available on the Government of Ontario website.

Base flow- sustained flow of a stream in the absence of direct runoff. It includes natural and human-induced stream flows. Natural base flow is sustained largely by groundwater discharge.

Bedrock - the solid rock beneath the soil and superficial rock. A general term for solid rock that lies beneath soil, loose sediments, or other unconsolidated material.

Best Available Science - information available on a topic that has been determined to be the best to be used to make informed science-based decisions or recommendations.

Best Science – for the purposes of this study, best available science includes the best approaches and tools available to do water quantity management science in the literature and Ontario / Jurisdictional practice under a variety of conditions.

Best Practices – are the practices and approaches being used for water management science in Ontario and other jurisdictions under a variety of conditions that are effective and efficient and produce reasonable results.

Bottled water - potable water that is intended for human consumption and that is packaged in bottles or other portable containers.

Capillary action - the means by which liquid moves through the porous spaces in a solid, such as soil, plant roots, and the capillary blood vessels in our bodies due to the forces of adhesion, cohesion, and surface tension. Capillary action is essential in carrying substances and nutrients from one place to another in plants and animals.

Co-management - a process of management in which government shares authority with resource users, with each given specific rights and responsibilities relating to information and decision-making.

Condensation - the process of water vapor in the air turning into liquid water. Water drops on the outside of a cold glass of water are condensed water. Condensation is the opposite process of evaporation.

Considerations / Conditions - for the purpose of this study means the range of Ontario conditions that need to be considered in reviewing and making recommendations on Ontario's water quantity management framework including policy, program and science.

Conflict Resolution - the management of disputes.

Consumptive use - that part of water withdrawn that is evaporated, transpired by plants, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumed.

Conveyance loss - water that is lost in transit from a pipe, canal, or ditch by leakage or evaporation. Generally, the water is not available for further use; however, leakage from an irrigation ditch, for example, may percolate to a groundwater source and be available for further use.

Cumulative Effects/Impacts - changes to surface water or groundwater resources that are caused or altered by an action in combination with other human or natural actions or conditions. In the context of the Assessment of Water Resources to Support a Review of Ontario's Water Quantity Management Framework (2018), Cumulative Effects include not only consideration of the changes to surface water and groundwater caused by multiple takings of surface or groundwater, but also considers the effects of climate change, population growth and related land use changes. In comparison, Cumulative Impacts only considers changes to surface water or groundwater resources that are caused or altered by multiple takings of surface or groundwater and their impact on other human or natural features.

Desalination - the removal of salts from saline water to provide freshwater. This method is becoming a more popular way of providing freshwater to populations.

Discharge - the volume of water that passes a given location within a given period of time. Usually expressed as volume over time (m^3/s).

Drainage basin - land area where precipitation runs off into streams, rivers, lakes, and reservoirs. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Large drainage basins, like the area that drains into the Grand River contain smaller drainage basins or sub-watersheds. See *Watershed*.

Drawdown - a lowering of the groundwater surface caused by pumping.

Drip irrigation - an irrigation method where pipes or tubes filled with water slowly drip onto crops. Drip irrigation is a low-pressure method of irrigation and less water is lost to evaporation than high-pressure spray irrigation.

Drought - a period of below-average precipitation in a given region, resulting in prolonged shortages in the water supply, whether atmospheric, surface water or ground water. What officially constitutes drought differs from jurisdiction to jurisdiction.

Ecosystem-based management - an integrated management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation.

Environmental Setting - the milieu or aggregate of the surroundings including climate, diversity, geographic variability, watershed characteristics, geological and hydrogeological variability and aquifer types.

Evaporation - the process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields, but not from leaf surfaces. See *Transpiration*.

Evapotranspiration - the sum of evaporation and transpiration.

Evidence-based decision making means - using the best available research, analytics, information and data supported by clear standards to guide decisions on policy and program development, delivery and evaluation process.

Environmental Flow Needs - the flows (quantity and timing) and water levels required in a water body to sustain freshwater ecosystems and the ecological function of the flora and fauna present within that water body and its margins.

Flood - an overflow of water onto lands that are used or usable by man and not normally covered by water. Floods have two essential characteristics: The inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream, lake, or ocean.

Flood, 100-year - a 100-year flood does not refer to a flood that occurs once every 100 years, but to a flood level with a 1 percent chance of being equaled or exceeded in any given year.

Flood plain - a strip of relatively flat and normally dry land alongside a stream, river, or lake that is covered by water during a flood. In Ontario, Under the Conservation Act, each Conservation Authority (CA) prescribes how it is determined. The Regulations for each CA use the Regulatory Flood Event Standard and the 100-year flood level plus wave uprush. The Regulatory Flood Event is a historic event of maximum flooding such as Hurricane Hazel for the Toronto area. Different CAs have different Regulatory Flood Events.

Flood stage - the elevation at which overflow of the natural banks of a stream or body of water begins in the reach or area in which the elevation is measured.

Floodway - the channel of a river or stream and the parts of the floodplain adjoining the channel that are reasonably required to efficiently carry and discharge the flood water or flood flow of a river or stream.

Flowing well/spring - a well or spring that taps groundwater under pressure so that water rises above ground surface without pumping. See *Artesian water.*

Freshwater - water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids; generally, more than 500 mg/L of dissolved solids is undesirable for drinking and many industrial uses.

Gauge height - the height of the water surface above the gage datum (zero point). Gage height is often used interchangeably with the more general term, stage, although gage height is more appropriate when used with a gage reading.

Gauging station - a site on a stream, lake, reservoir or other body of water where observations and hydrologic data are obtained.

Groundwater - (1) water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturated zone at atmospheric pressure is called the water table. (2) Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust.

Groundwater, confined - groundwater under pressure significantly greater than atmospheric, with its upper limit corresponding to the bottom of a bed with hydraulic conductivity distinctly lower than that of the material in which the confined water occurs.

Groundwater recharge - inflow of water to a groundwater reservoir from the surface. Infiltration of precipitation and its movement to the water table is one form of natural recharge. Also used to define the volume of water added by this process. Alternatively, "groundwater recharge" means the replenishment of subsurface water, (a) resulting from natural processes, such as the infiltration of rainfall and snowmelt and the seepage of surface water from lakes, streams and wetlands, and (b) resulting from human intervention, such as the use of stormwater management systems (O. Reg. 140/02: OAK RIDGES MORAINE CONSERVATION PLAN under Oak Ridges Moraine Conservation Act, 2001, S.O. 2001, c. 31)

Groundwater, unconfined - water in an aquifer that has a water table that is exposed to the atmosphere.

Headwater(s) - (1) the source and upper reaches of a stream; also the upper reaches of a reservoir. (2) the water upstream from a structure or point on a stream. (3) the small streams that come together to form a river. Also may be thought of as any and all parts of a river basin except the mainstream river and main tributaries.

High Use Watershed - the areas shown on the Average Annual Flow Map or the Summer Low Flow Map in Ontario Regulation 387/04 (Water Taking and Transfer).

Hydrologic cycle - the cyclic transfer of water vapor from the Earth's surface via evapotranspiration into the atmosphere, from the atmosphere via precipitation back to the Earth's surface where it either enters the subsurface through infiltration, evaporates into the atmosphere or becomes runoff that flows into streams, rivers, and lakes, and ultimately into the oceans. See *Water Cycle*.

Impermeable layer - a layer of solid material, such as rock or clay, which does not allow water to pass through.

Infiltration - flow of water from the land surface into the subsurface.

Injection well - refers to a well-constructed for the purpose of injecting treated water directly into the ground. Water is generally forced (pumped) into the well for dispersal or storage into a designated aquifer.

Instream flow - the amount of water needed in a stream to adequately provide for downstream uses occurring within the stream channel. Instream uses may include some or all of the following: aquatic habitat, recreation, wetlands maintenance, navigation, hydropower, riparian vegetation, and water quality.

Integrated water resources management (IWRM) - a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives. IWRM is based on the understanding that all the different uses of finite water resources are interdependent.

Irrigation - the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall.

Irrigation water use - water application on lands to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands, such as parks and golf courses.

Lotic waters - flowing waters, as in streams and rivers.

Mediation - a form of conflict resolution that uses a use of a neutral mediator who oversees negotiation between two parties.

Method(s) - a procedure, technique or routine.

Negotiation - a form of conflict resolution that involves the presentation of interests and working toward solutions within an acceptable settlement range among involved parties.

Ontario Water Managers or "Water Managers - any person responsible for the regulation, planning, development and distribution and use of water resources.

Peak flow - the maximum instantaneous discharge of a stream or river at a given location. It usually occurs at or near the time of maximum stage.

Percolation - (1) The movement of water through the openings in rock or soil. (2) the entrance of a portion of the streamflow into the channel materials to contribute to groundwater replenishment.

Permeability - the ability of a material to allow the passage of a liquid, such as water through rocks. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas impermeable materials, such as clay, do not allow water to flow freely.

Porosity - a measure of the water-bearing capacity of subsurface rock or unconsolidated overburden materials. With respect to water movement, it is not just the total magnitude of porosity that is important, but the size of the voids and the extent to which they are interconnected (effective porosity), as the pores in a formation may be open, or interconnected, or closed and isolated. For example, clay may have a very high porosity with respect to potential water content, but it constitutes a poor medium as an aquifer because the pores are usually so small.

Potable water - water of a quality suitable for drinking that at a minimum meets the requirements of the prescribed drinking water quality standards; or in Ontario, "Despite any other Act, a requirement that water be "potable" in any Act, regulation, order or other document issued under the authority of any Act or in a municipal by-law shall be deemed to be a requirement to meet, at a minimum, the requirements of the prescribed drinking water quality standards" (Safe Drinking Water Act, 2002, c. 32, s. 10."

Potentiometric surface/piezometric surface - the imaginary line where a given reservoir of fluid under pressure would rise if allowed to flow, for example if penetrated by wells; a potentiometric surface is based on hydraulic principles.

Precipitation - rain, snow, hail, sleet, dew, and frost.

Prior appropriation doctrine - the system for allocating water to private individuals used in most Western states. The prior appropriation system evolved in the western United States so that people could divert water for use on land that does not abut a water course. The doctrine was in common use throughout the arid west as early settlers and miners began to develop the land. The prior appropriation doctrine is based on the concept of "First in Time, First in Right." The first person to take a quantity of water and put it to Beneficial Use has a higher priority of right than a subsequent user. Under drought conditions, higher priority users are satisfied before junior users receive water. Appropriative rights can be lost through non-use; they can also be sold or transferred apart from the land. Appropriation rights are considered to be property rights and continue to exist as long as water continues to be used for beneficial purposes. Contrasts with *Riparian Water Rights*.

Prior Allocation - A prior allocation system is a government–controlled system where water rights are issued to individual users for specific volumes and purposes. Western Canadian provinces generally employ prior allocation systems where priority among users is also based on first in time, first in right, with seniority based on the date of application.

Priority of water use - a hierarchy of water users and the resulting prioritization of use.

PTTW - a permit-to-take-water under the *Ontario Water Resources Act*.

Rating curve - a drawn curve showing the relation between gauge height and discharge of a stream at a given gaging station.

Recharge - water added to an aquifer. For instance, rainfall that seeps into the ground.

Reclaimed wastewater - wastewater-treatment plant effluent that has been diverted for beneficial uses such as irrigation, industry, or thermoelectric cooling instead of being released to a natural waterway or aquifer.

Recycled water - water that is used more than one time before it passes back into the natural hydrologic system.

Reservoir - a pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

Return flow - (1) That part of a diverted flow that is not consumptively used and returned to its original source or another body of water. (2) (Irrigation) Drainage water from irrigated farmlands that re-enters the water system to be used further downstream.

Return flow (irrigation) - irrigation water that is applied to an area and which is not consumed in evaporation or transpiration and returns to a surface stream or aquifer.

Riparian water rights - the rights of an owner whose land abuts water. A riparian owner or occupier is a person whose land abuts the shore of a natural water course or water body and, under common law, they can take water for domestic and other purposes as long as their water use does not impair the rights of other riparian owners. Riparian rights differ between jurisdictions within Canada and in the United States from state to state and often depend on whether the water is a river, lake, or ocean. Riparian systems are typically employed in the eastern part of North America and are used in Ontario, Tennessee and North Carolina. Specifically, persons who own land adjacent to a stream have the right to make reasonable use of the stream. Shortages are expected to be shared among all users. Riparian users of a stream share the streamflow among themselves, and the concept of priority of use (Prior Appropriation Doctrine) is not applicable. Riparian rights cannot be sold or transferred for use on nonriparian land.

River - a natural stream of water of considerable volume, larger than a brook or creek.

Runoff - (1) That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers. Runoff may be classified according to speed of appearance after rainfall or melting snow as direct runoff or base runoff, and according to source as surface runoff, storm interflow, or groundwater runoff. (2) The total discharge described in (1), above, during a specified period of time. (3) Also defined as the depth to which a drainage area would be covered if all of the runoff for a given period of time were uniformly distributed over it.

Science - the body of knowledge, methodologies and tools used to understand, communicate, manage and support regulation of Water Resources, including work characterization, monitoring, data management, mapping, assessment and tools to manage these.

Setting - the physical, chemical and biological environment ((such as climate, geology, soil, and plants and animals living in or on the water) in which a resource is situated and which determine its characteristics and behaviour.

Source Water Protection Authority – A conservation authority or other person or body that is required to exercise and perform the powers and duties of a drinking water source protection authority under the Ontario Clean Water Act.

Spring - a water body formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of groundwater at or below the local water table, below which the subsurface material is saturated with water.

Stakeholders - people who have a share or an interest in water.

Stream - a general term for a body of flowing water; natural water course containing water at least part of the year. In hydrology, it is generally applied to the water flowing in a natural channel as distinct from a canal.

Streamflow - the water discharge that occurs in a natural channel. A more general term than runoff, streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Summer Low Flow Map - the map entitled "Water Use — Summer Low Flow Conditions", dated November, 2004 and on file in the offices of the Ministry of the Environment and Climate Change at Toronto and available on the Government of Ontario website;

Surface water - water that is on the Earth's surface, such as in a stream, river, lake, or reservoir.

Sustainability - development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. There are three spheres of sustainability: the economy, society and the environment. They have a dynamic relationship, which means that any change to one affects the others. It is the reason why we cannot consider our economy or quality of life separately from the well- being of our natural environment.

Tool – a process, method or computer program / routine used in the implementation of an "approach" as defined for the purposes of this project. For the purposes of this study a tool does not include a physical device or physical implement.

Transmissivity (T) – the rate at which groundwater is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is often expressed as the product of hydraulic conductivity and the full saturated thickness of the aquifer and has units of the form m^3/day/m.

Transpiration - process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores. See *Evapotranspiration*.

Tributary - a smaller river or stream that flows into a larger river or stream. Usually, a number of smaller tributaries merge to form a river.

Water bottling facility - any facility that requires a permit for taking ground water for the purpose of producing bottled water.

Water Bottling Study Area and **WBSA** - each of the 11 areas that are being assessed as part of the Assessment of Water Resources to Support a Review of Ontario's Water Quantity Management Framework (2018).

Water Cycle - the circuit of water movement from the oceans to the atmosphere and to the Earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transportation. See *Hydrologic Cycle*.

Water Quantity Assessment - the determination of the sources, extent, dependability and quality of water resources for their utilization and control. Water resources in turn can be defined as the water available, or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand.

Water Quantity Management Framework - policies, programs and science, information including data collection and assessment tools, used in the management of water use.

Water Quantity Protection External Working Group - an external working group established by the Ministry to provide an open and collaborative forum to share expertise and provide input to strengthen groundwater and surface water quantity protection as part of Ontario's strategy to better protect water in the province.

Water Quantity Study Area and **WQSA** - an area being assessed as part of the Assessment of Water Resources to Support a Review of Ontario's Water Quantity Management Framework (2018).

Water Resources - any groundwater and surface water source that supplies water to the natural environment and that are useful or potentially useful to study. In the context of the Assessment of Water Resources to Support a Review of Ontario's Water Quantity Management Framework (2018), the Great Lakes are not included in the Water Resources being addressed and the focus is on water resources quantity.

Water Security - the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water- borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. (UN-Water, 2013)

Water table - the top of the water surface in the saturated part of an aquifer that is at atmospheric pressure, also referenced as an unconfined aquifer.

Water year - continuous 12-month period selected to present data relative to hydrologic or meteorological phenomena during which a complete annual hydrologic cycle normally occurs. The water year used by the U.S. Geological Survey runs from October 1 through September 30, and is designated by the year in which it ends.

Watershed - land area where precipitation runs off into streams, rivers, lakes, and reservoirs. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Large drainage basins, like the area that drains into the Grand River, contain smaller drainage basins or sub-watersheds. See *Drainage basin*.

APPENDIX B

Task 1 Analysis Matrices

Table B-1
Water Quantity Assessment

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
Comprehensive Water Resource Assessment (WRA) (1) World Meteorological Organization, 2012 Meteorological readings allow for a traditional data assessment, analysis and conceptual model approach. The water quantity assessment is fundamentally a data/information collection exercise followed by the presentation of the data/information to provide value added products on the spatial and temporal characteristics of the available water supplies and their usage. Requires a large amount of data for more accurate representation.	It is a data assessment approach used for the determination of the sources, extent, dependability and quality of water resources for their utilization and control, and water resources. Are the water resources available, or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand. This is used to understand the key interactions in the catchment and confirm the key features of both short-term and long-term water balances.	Takes into account climate variability including different geographical regions and seasonal variability each year.	Aimed specifically at identifying environmental impact.	Spatial: Local to regional. Determination of hydrological boundaries across which both surface water and groundwater flows can either be measured with reasonable confidence or effectively assumed to be zero. Temporal: Large temperal scale is required for accurate assessment. Need to capture variation of water within all of its forms in the hydrological cycle, from season to season, from year to year and from decade to decade. Can identify trends in data that can be used to predict climate change to a certain degree.	Categories of data: hydro-meteorological, hydrogeological, biophysical, socio-economic, water-use. (a) Biophysical data – topography, soils, geology and vegetation – required for modelling and to set the environmental constraints; (b) Hydrometeorological data – characteristics of climate, surface water and groundwater – required to define the available resource characteristics; (c) Socio-economic data – land use and demography – required for understanding the water needs; and (d) Water-use data – required to complete the picture of supply–demand. Data is required for difference forms in the hydrological cycle, from season to season, from year to year and from decade to decade.	Analyses of time series and areal distribution of: • Precipitation • Evaporation Streamflow monitoring information, typically daily average data, and computational methods of base-flow separation are often used to estimate base flow. The monitoring information and related parameters, such as drainage area, are input into base-flow separation algorithms, which calculate an output time series of base-flow that can then be summarized on a monthly, seasonal, annual or length-of-record basis. Statistical analyses of stream flow records using United Kingdom base-flow index method and flow duration curves. Flow duration curves are often used to determine trigger points for limits on abstraction or introduction of water conservation measures. Hydrogeologic analyses for delineation of: aquifers; aquifer parameters; and recharge. Long term resource availability using conceptual and/or numerical models, water budgets etc.. Water footprint, which is the volume of water required throughout the production, processing and consumption per unit of output, is also considered in this approach. Water footprint is considered as an alternative of water demand in this approach.	Socio-economic factors are considered in this approach. Considers a range of future climate change scenarios from projections. It may also be useful to combine these with different scenarios of growth and societal development. The aim will be to check the robustness of future water resource plans against a plausible range of future circumstances so that major investments in water management, such as the construction of new reservoirs or major groundwater exploitation schemes, are soundly based. In the United Kingdom, the Environment Agency has produced a water strategy for England and Wales that considers four different climate and societal scenarios and their implications for water resources for the twenty-first century (Environment Agency, 2009). Water resources assessment should form a major part of any planning for sustainable development since, by definition, such development requires an assurance that primary resources, including water, will be available to support planned development in the long term.	When downloading digital topographic data, it is important to consider their scale/resolution, the geographical projection, and the techniques at hand to process and analyse the data (for example, GIS-based software). When working with digital topographic data, downloaded data with different projections can cause problems when superimposing and integrating different topographical maps. Does not consider cumulative impact of multiple takings, based on real time and can only forecast based on past trends.	Technical Material for Water Resources Assessment Sub-Saharan Africa Hydrological Assessment – West African Countries, Regional Report (World Bank and UNDP, 1992) Environment Agency (United Kingdom)24 (Environment Agency, 2009) Bureau of Meteorology (Australia)25 (Australian Bureau of Meteorology, 2011) Water Resources Assessment of Haiti26 (US Army Corps of Engineers,1999	Climate Change Sustainability CE & EFN	Ideal for areas with little to no field data, areas with streamflow data, and some meteorlogical data. Can be enhanced with more meteorological stations measuring precipitation and temperature.
Australian Water Resource Assessment (AWRA) modelling system (2)(3) The AWRA modelling system is an integrated continental hydrological simulation system designed and prototyped by CSIRO and the Bureau through the Water Information Research and Development Alliance initiative. The AWRA modelling system-(AWRAMS) is being developed and used in producing water balance fluxes for the National Water Account (NWA) and regular Water in Australia (WIA) since 2010. AWRAMS provides nationally consistent and robust water balance estimates at a national to regional and catchment scale for the past and present using observations where available, and modelling otherwise.	To produce water balance fluxes, robust water balance estimates, and model predictions of stream flows. The main objective is to find a single set of continentally applicable model parameters that best facilitates model predictions of streamflow, soil moisture and evapotranspiration in all catchments across Australia.	Produces results showing geographical variability, watershed characteristics and vegetation variability.	Specifically environmental impact, not at small scales. I.e. generalization of an area, but not site specific. Can be used for regional planning, but does not take water boundaries into account.	Spatial: National to regional and catchment scale. The water balance fluxes and stores are estimated with a ~5 km spatial resolution and daily time step. Temporal: Uses daily climate inputs, and uses a snap-shot in time modeling.	The AWRAMS uses on-ground observations and remotely sensed data sets, combined with hydrological science and computing technology to estimate water balance fluxes and storage. The model inputs can be divided into three types: 1) daily varying climate inputs, such as rain, temperature and solar radiation; 2) spatial grids such as static soil, vegetation and topography; 3) Streamflow data are required for calibration and validation processes. A maximum of 52 parameters need to be estimated in the calibration processes. Water data is collected by a range of organizations across Australia including climate, streamflow, surface storage levels and volumes, groundwater, agricultural water supply and use, water allocation and trade, urban water supply and use, urban water restrictions and water quality. Within each reporting region, various time-series analyses and reporting techniques are applied depending on the availability of data. Analysis and reporting units at the sub-regional level include hydrological units (surface catchments and groundwater aquifers), water management and planning areas, water supply systems and monitoring sites or clusters of sites (for example, stream gauges on tributaries flowing into a reservoir). Pumping data can also be included in the model.	The AWRAMS has two main modelling components: 1) A Landscape water balance component (AWRA-L) and 2) A River system component. AWRA-L is a one dimensional water balance model over the continent that has semi-distributed representation of the soil, groundwater and surface water storage. Outputs are spatio-temporally aggregated to provide daily, monthly and annual gridded estimates of landscape water yields, runoff, evapotranspiration, soil moisture, and groundwater recharge/storage/lateral flow at the regional and continental (national) scale seamlessly from the past to the present. AWRA-R is a conceptual river model that uses a node link flow network to accumulate catchment runoff (recorded at gauge or modelled by AWRA-L), route streamflow including river losses; incorporate reservoirs and model flooding and irrigation. It also includes pumping to and from the groundwater store where data is available and transfer of river/floodplain/irrigation losses from AWRA-R to be input into AWRA-L groundwater store.	It is flexible enough to use all available data sources, whether modelling data-rich or data-sparse regions, to provide nationally consistent and robust estimates of water balance terms. The assessment is a regularly updated AWRAMS online product; for example newest update uses the soil parameter for use as input to crop growth models and guidance for farmers. In the near future, the Bureau plans that regularly updated AWRAMS products such as river basin statistics, soil moisture (and/or evapotranspiration). AWRAMS provides a unique capability in terms of linking landscape, groundwater and river systems to better understand the national water situation in a consistent manner.	This approach does not adequately deal with the lateral transfer of water between grid cells and ignore some real world processes such as surface ponding. The input data for the models are also limited as climatic variables are not measured without error and are not measured everywhere. Therefore, the modelled results are best viewed in a relative sense as general patterns and changes of landscape water flows and storage over time and space. Groundwater representation in the model is very simplistic and may be a limiting factor at large scales. Other models use more groundwater data variables.	Australia uses this tool to produce water balance fluxes for the National Water Account (NWA).	Sustainability	Requires areas with heavy historical data and access to field parameters daily. Could be used in Ontario were a signifciant amount of temporal and spatial data exists, for example portions of the Grand River Watershed or the Oak Ridges Morain may have adequate data.
UNESCO **Guidelines for Conducting Water Resource Assessments (4)(5)** Traditional data assessment, analysis and conceptual model approach. This model assesses groundwater and surface water individually, and does not take into account interactions between each.	This method uses groundwater and surface water data to develop a conceptual model of water quantity in an area for planning and management. It uses a simplistic approach using groundwater flow models, meteorological data, and surface water data.	Produces results showing geographical variability, watershed characteristics and vegetation variability. Can take into account climate change in regional scales.	Used to determine environmental impacts, and can be used to plan for the future based on current trends. The basic model being used does not take into account climate change and its effect on water quantity.	Spatial: From local to regional scale. Temporal: Can be adopted to the temporal resolution of the collected meteorlogical or river basin data. Daily, monthly or annually.	Data used in the surface and groundwater balances can either be measured directly or estimated using standard methods. This is done through collection of field data, such as meteorlogical data, water table data, stream flow data, river run off observations, etc. Estimations are made when there is a lack of essential data, which allows certain conclusions to be drawn for different physiographic conditions. This includes precipitation data over a large area, since precipitation data is collected from points in an area and averaged. The data required for groundwater balance analyses can also be obtained from fieldworks including research drilling, exploitation wells, geophysical investigations and laboratory analyses. The typical required data are streamflow, stream and river levels, average daily discharges, precipitation, evaporation, evapotranspiration, runoff, spring yields, all kinds of water withdrawals and releases, temporal storage, elevation data for aquifer, surface elevation data for shallow aquifers, piezometric water levels, and filtration coefficient. Weekly or bi-weekly water table data is required depending on the aquifer/spring, flow rate and distance from surface water. More frequent data (weekly or biweekly) is required for higher yields (larger extractions of water).	To forecast changes in regional climate with global warming, atmospheric general circulation models (GSMs) are widely used, as are palaeoclimatic reconstructions of the climate of past warm epochs. Groundwater flow models are used to analyse/evaluate the groundwater regime and groundwater balance in order to assess the quanitity of groundwater in the system.	Using the daily values processed for a water management unit area and given the data provided by long-term analyses of water resource management balance parameters, it is possible to get good information about the present and future likelihood of meeting the demands put on water resources. Useful in areas with little to no data availability as estimations can be used in the approach; used in remote areas of Asia and Africa.	This approach divides the surface water and the groundwater in two separate categories and discusses them separately. The performance of the numerical model depends heavily on the quality of baseline and boundary conditions in order to produce an accurate prediction of future water quantity. In relatively small regions which do not represent watersheds from hydrological and hydrogeological points of view, the precision with which the water resources are evaluated is brought into question and thereby compromising the entire water resources assessment. Some errors in water availability estimates arise because estimates are derived from runoff data only.	Applied in south and west Asia, areas where water management has been minimal in the past and water planning is preformed on current information.	Climate Change	Can be implemented in areas where streamflow, surface water and some hydrogeological data is available. Would be ideal method in areas of high water taking, as water levels are measured weekly or biweekly and can notice changes in trends. Areas with an abundance of water table data include Guelph-Wellington Region.
Climate Change Impacts on Water Projections (6)(7) Updated projections for water availability for the UK 2015 There are four main steps in this approach: 1. Climate projections; 2. Hydrology and groundwater projections; 3. Water availability projections (including potential adaptation); 4. Assessment of changes in drought characteristics.	The approach to projecting climate has built on existing, freely available climate projections for the UK, including UKCP09 (UK Climate Projections 2009) and the Future Flows Climate projections (FFC).	Produces results showing geographically variability, climate variability, and soil characteristics (to determine evaporation (PE). Does not take into account climate change modelled data.	Used to determine water use for planning purposes based on effects of climate change on water quantity. The basic model used does not take into account specfic climate change information and its effect on water quantity. It is used at a larger regional scale, as it generalizes data for the area (not site specific analysis).	Spatial: National scale Temporal: models are based on daily temporal scale. All surface water and groundwater indicators are calculated as % change in 30-year future time periods compared with the average of 1961-90. Future time periods are 2030s, 2050 and 2080s.	Measured precipitation and evaporation are required for calibration of the climate models. The Probability Distributed Model (PDM) requires inputs of catchment-average rainfall and potential evaporation, with flow data for calibration. R-Groundwater (catchment groundwater model) requires inputs of groundwater level data for calibration. Data collection is required on a daily basis.	Catchment models (PDM, R-Groundwater) are used for hydrological and groundwater modelling. The PDM is a lumped rainfall–runoff model with three conceptual stores; a soil moisture store, and fast- and slow-flow stores. The model uses a probability distribution of soil moisture storage. This determines the time-varying proportion of the catchment that contributes to runoff, through either "fast" or "slow" pathways. R-Groundwater is a lumped catchment groundwater model written in the R programming language. It simulates a groundwater level time series at an observation borehole and generates time series of flow through aquifer outlets (discharge to a river, and groundwater flow out of the catchment). The model consists of three components: 1) a soil moisture balance model producing a time series of potential recharge; 2) a simple transfer function representing the delay in the time of the arrival of recharge from the base of the soil to the water table; and 3) a groundwater model based on a Darcian representation of flow. Hydrological and hydrogeological indicators produced by this approach are River Flow Quantiles, River Flow Means, River Flow Rolling Means and groundwater level.	Hydrology and groundwater projections produced a set of indicators that have the following characteristics: 1. Hydrological indicators that are at a spatial and temporal scale relevant to national water resource assessment; 2. Expression of relative changes in the hydrological indicators compared to the reference baseline 1961-1990 for the 2030s, 2050s and 2080s; uses past data for more accurate prediction of future; 3. Results can be used to create national strategy and water managment plans; 4. Presentation at a spatial scale appropriate for regional and national water resource assessment; 5. Provides both spatially coherent projections, based on FFC, and probabilistic projections, based on the UKCP09 climate projections, for Low, Medium and High emissions scenarios; and 6. Captures a plausible range of climate change uncertainty, including that from emissions scenarios, probability levels and climate models. This can create different scenarios to prepare for.	UKCP09 projections are not spatially coherent between different areas at any scale. This means that it is not possible to consider how the impacts of climate change at multiple locations coincide. UKCP09 projections are also not temporally coherent i.e. there is no consistency in the projections between the different time periods. Climate projections generated from global or Regional Climate Models (RCM) are not suitable for direct use in hydrological models because of differences in scale between modelled atmospheric processes and hydrological processes. Based on the latest scientific knowledge of how to exploit RCM outputs in hydrology, a bias correction and downscaling procedure was implemented over Britain to generate appropriate data. This can create inaccuracies in the data analysis and cause bias results. This approach divides the surface water and the groundwater in two separate categories and discusses them individually. When compared with observations over the pre-2000 reference period, the results typically showed the largest departures during dry conditions and in drier regions for surface flow, and an underestimation of groundwater levels.	United Kingdom	Climate Change	Could be used to create province wide water management strategy for Ontario.
Basin Wide Water Quantity Evaluation(8) The Delaware Estuary and River Basin calculates its water quantity through a base-flow recurrence analysis and statistical analysis. The method was used on a basin that spans four ecoregions, is home to about 9 million people, and supplies drinking water to another seven million in New York City and northern New Jersey living outside the basin.	Indicators of ground and surface water availability are used in this approach to assess the water quantity.	Produces results showing geographical variability, climate variability, ecology variation and soil characteristics. Does not take into account Climate Change.	Used to determine water takings based on trends of current data. Based on real time and can only predict future based on present trends and conditions.	Spatial scale: Watershed This approached used the 147 sub-basins delineated by the USGS to quantify groundwater availability for the entire Delaware River Basin. The area of 35,000 square kilometers was considered in order to define the alternative watershed scales and boundaries. Temporal scale: Daily	Streamflow data, surface water data, lithology, base flow index, land use information, geology, and surface water features are all data incorporated into the model used. Groundwater baseflows and aquifer storage and recovery are measured in the field, while consumptive uses and withdrawal quantities are monitored through water taking methods.	Different methods were used to estimate groundwater availability for the region underlain by fractured rock in the upper part of the basin and for surficial aquifers in the region underlain by unconsolidated sediments in the lower part of the basin. The tool used to estimate groundwater availability for the 109 sub-basin underlain by fractured rock were based on generalized lithology and physiographic province. A base-flow recurrence analysis was performed to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each index station to predict future base-flow. A GIS analysis then used lithology and base-flow data at the index stations to determine the average annual base flow for each watershed. Groundwater availability for watersheds that are underlain by unconsolidated surficial aquifers was based on predominant surficial geology and land use data. A base-flow recurrence analysis was also used to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each group of predominant surficial geology and land uses. The water demand projection tool developed for the purposes of this study has been designed to accommodate the modeling of alternative scenarios. Some examples of factors that can be adjusted in the projection model include water conservation assumptions, consumptive use estimates and average versus seasonal demands.	Only method identified that specifically includes bedrock water taking. Uses hydrological data from individual sub-basins to create estimate for larger basin areas; individual analysis then summarized as a whole.	Does not take into account climate variability within the region itself during analysis of the region as a whole. Does not plan for Climate Change.	Used for the Delaware Estuary and River Basin. No reference was made to other jurisdictions using this approach.	Sustainability, Security	Used in areas with fractured rock/bedrock, would be ideal for water taking in areas where water takings occur in fractured bedrock exclusively. This includes Northern Ontario and certain areas of Southern Ontario reliant on bedrock aquifers.

Table B-1
Water Quantity Assessment

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
The Soil and Water Assessment Tool (SWAT) (9)(10)(11)(12) The SWAT model was developed by the Agricultural Research Service of the United States Department of Agriculture and Texas A&M. The tool is a stochastic approach comparing Blue Water and Green Water Footprint components to probabilistic levels (50th and 30th percentile) of freshwater availability for human activities along with contrasting situations of BW provision, using different hydrological-based methodologies for specifying monthly Environmental Flow Requirements (EFRs), and the risk of natural EFR violation is evaluated by use of a freshwater provision index. The use of blue and green water flows/storage for human activities can be analyzed in the context of average hydroclimatic conditions and water scarcity and vulnerability indicators can then be computed and integrated into a water security analysis. NOTE: The information provided is not fully based on the theoretical concepts of the SWAT model, but rather based on the study methods of Rodrigues et al. (2014)	The main purpose of the model is to predict the impact of land management practices on water, sediment and agricultural chemical yields in large ungauged complex watersheds with varying soils, land use and management conditions over long period of time. It is a physically based model. The ''Blue water'' is represented by Water Yield which is the total amount of water leaving the basin/area and entering the main channel and by Groundwater Storage which is the difference between the total amount of water recharge to shallow and deep aquifers and the amount of shallow aquifer water that contributes to the main channel during the time step. It is the human water consumption from Blue water resources and it can be quantified based on the volume of surface and groundwater consumed as a result of the production of a good or service (e.g., domestic, industrial, power production, irrigation, etc.). ''Green Water'' is represented by the Actual Evapotranspiration and by the Soil Water Content. Water Footprint (WF) concept can establish the link between the depletion of water resources and increase in population.	This model could be used to show geographic variability, geological/hydrogeological variability (depending on available land use/soil type data). This model includes some climate variability, dependant on the precipitation and temperature information available. Does not do Climate Change.	This model can be used for planning as it provides a range in its water quantity estimates, showing impacts on surface water. Would not be ideal to use for water takings from groundwater as it does not use field data.	This model is ideally used at a regional or watershed scale. Would not be ideal at a site specific scale. Can be used to model future conditions based on historical trends, but does not account for Climate Change.	The data sets used in this study include a digital elevation model (DEM) to delineate the study area and to estimate the topographic features, land use and soil data are used for generating the HRUs (Hydrologic Response Units), meteorological (precipitation and temperature), stream flow data, and reservoir outflow data, and all data was incorporated in SWAT model development.	This model is calibrated and evaluated against the observed stream flow data, and the SUFI2 optimization algorithm was used for parameter estimation and sensitivity analysis. The Blue water is calculated by applying a modeling framework by combining both water yield and groundwater storage. Green water is estimated as the sum of evapotranspiration and soil water content. Sen's Slope method, which is the median of all pairwise slope in the data set, was used for estimating the annual trend of Blue and Green water. Scarcity, vulnerability, availability, and abstraction were calculated and analyzed.	Can be useful for areas with little to no GW field data. Still requires SW data. It was also anticipated that the water security assessment could provide useful information for understanding the emerging hot spots within a river basin/ watershed (ecosystem) due to the abstraction of water for human activities, such as irrigation, industrial use, energy production and domestic use. Integrated modeling is a useful tool to aid water managers in projecting the likely effects of management options when limited information is available.	Challenges with the SWAT tool include uncertainties associated with data and methods, the effects of Climate Change projections on Blue and Green freshwater provision, the expansion of the framework involving other sources of water (groundwater and reservoirs), the specific analysis of critical probabilistic water provision levels for vulnerability estimation and severity classification of both scarcity and vulnerability indicator values, and the estimates of non-consumptive water use provided by the Grey Water Footprint component (the water needed for the regulating ecosystem services). This tool incorporates both SW and GW, but not interactions between them.	Used in study in Brazil; Chifeng City, China and Savannah River Basin (SRB), USA	Sustainability, Security, Environmental Flow Needs	This tool would be ideal to determine the dependability of a water supply for the future in areas with less GW data and some SW data, as the results provide a range of values, not a specific estimate. Ontario currently uses a similar SWAT tool in certain areas.

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Table B-2
Water Security Assessment and Sustainability Evaluation

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
The Soil and Water Assessment Tool (SWAT) (9)(10)(11)(12) The SWAT model was developed by the Agricultural Research Service of the United States Department of Agriculture and Texas A&M. The tool is a stochastic approach comparing Blue Water and Green Water Footprint components to probabilistic levels (50th and 30th percentile) of freshwater availability for human activities along with contrasting situations of BW provision, using different hydrological-based methodologies for specifying monthly Environmental Flow Requirements (EFRs), and the risk of natural EFR violation is evaluated by use of a freshwater provision index. The use of blue and green water flows/storage for human activities can be analyzed in the context of average hydroclimatic conditions and water scarcity and vulnerability indicators can then be computed and integrated into a water security analysis. NOTE: The information provided is not fully based on the theoretical concepts of the SWAT model, but rather based on the study methods of Rodrigues et al. (2014)	The main purpose of the model is to predict the impact of land management practices on water, sediment and agricultural chemical yields in large ungauged complex watersheds with varying soils, land use and management conditions over long period of time. It is a physically based model. The ‘’Blue water’’ is represented by Water Yield which is the total amount of water leaving the basin/area and entering the main channel and by Groundwater Storage which is the difference between the total amount of water recharge to shallow and deep aquifers and the amount of shallow aquifer water that contributes to the main channel during the time step. It is the human water consumption from Blue water resources and it can be quantified based on the volume of surface and groundwater consumed as a result of the production of a good or service (e.g., domestic, industrial, power production, irrigation, etc.). ‘’Green Water’’ is represented by the Actual Evapotranspiration and by the Soil Water Content. Water Footprint (WF) concept can establish the link between the depletion of water resources and increase in population.	This model could be used to show geographic variability, geological/hydrogeological variability (depending on available land use/soil type data). This model includes some climate variability, dependant on the precipitation and temperature information available. Does not do Climate Change.	This model can be used for planning as it provides a range in its water quantity estimates, showing impacts on surface water. Would not be ideal to use for water takings from groundwater as it does not use field data.	This model is ideally used at a regional or watershed scale. Would not be ideal at a site specific scale. Can be used to model future conditions based on historical trends, but does not account for Climate Change.	The data sets used in this study include a digital elevation model (DEM) to delineate the study area and to estimate the topographic features, land use and soil data are used for generating the HRUs (Hydrologic Response Units), meteorological (precipitation and temperature), stream flow data, and reservoir outflow data, and all data was incorporated in SWAT model development.	This model is calibrated and evaluated against the observed stream flow data, and the SUFI2 optimization algorithm was used for parameter estimation and sensitivity analysis. The Blue water is calculated by applying a modeling framework by combining both water yield and groundwater storage. Green water is estimated as the sum of evapotranspiration and soil water content. Sen’s Slope method, which is the median of all pairwise slope in the data set, was used for estimating the annual trend of Blue and Green water. Scarcity, vulnerability, availability, and abstraction were calculated and analyzed.	Can be useful for areas with little to no GW field data. Still requires SW data. It was also anticipated that the water security assessment could provide useful information for understanding the emerging hot spots within a river basin/ watershed (ecosystem) due to the abstraction of water for human activities, such as irrigation, industrial use, energy production and domestic use. Integrated modeling is a useful tool to aid water managers in projecting the likely effects of management options when limited information is available.	Challenges with the SWAT tool include uncertainties associated with data and methods, the effects of Climate Change projections on Blue and Green freshwater provision, the expansion of the framework involving other sources of water (groundwater and reservoirs), the specific analysis of critical probabilistic water provision levels for vulnerability estimation and severity classification of both scarcity and vulnerability indicator values, and the estimates of non-consumptive water use provided by the Grey Water Footprint component (the water needed for the regulating ecosystem services). This tool incorporates both SW and GW, but not interactions between them.	Used in study in Brazil; Chifeng City, China and Savannah River Basin (SRB), USA	Water Quantity, Environmental Flow Needs	This tool would be ideal to determine the dependability of a water supply for the future in areas with less GW data and some SW data, as the results provide a range of values, not a specific estimate. Ontario currently uses a similar SWAT tool in certain areas.
A Continential Assessment (4) A simple and transparent conceptual framework has been developed to assess the European vulnerability to freshwater stress using runoff, in comparison to projections of future vulnerability for different degrees of global warming (1.5°C, 2°C and 4°C), under the high-rate warming scenario (RCP8.5).	It is a framework that has been developed to assess the vulnerability to freshwater stress under the present hydro-climatic and socioeconomic conditions, in comparison to projections of future vulnerability for different degrees of global warming. Different levels of adaptation to climate change are considered in the framework, by employing various relevant pathways of socioeconomic development.	Does geological variability, geographic variability, socioeconomic variability, and climate variability. Climate Change is also included.	This model can be used for planning to determine if the water supply is dependable into the future based on the hydrogeology, while also taking into consideration factors like socioeconomics.	Several studies have been performed addressing water vulnerability under Climate Change impacts at the European continental scale or regional level. The model must be run over several years to determine seasonal changes, trends in data, and different meteorological scenarios. The 6-months temporal scale was selected for the examination of short term meteorological drought associated with agricultural drought and changes to the seasonal variations. The 48-months temporal scale was employed for the description of long term droughts and effects on high capacity reservoirs related to drought indices at long time scales.	The datasets used for this study are an ensemble of global high resolution climate model simulations, generated with the use of the EC-Earth3-HRmodel in Atmospheric General Circulation Model (AGCM) mode. This model uses exposure indicators, sensitivity indicators, and indicators of adaptive capacity.	The relative exposure to freshwater availability was derived from the combined information of the mean and low annual runoff production, SPI and SRI indices, spatially aggregated at NUTS2 level over Europe, for the reference and the projected periods of the three SWLs.	This model uses water exploitation vulnerability for a set of socio-economic and climate scenarios. At the regional level several assessments use case specific scenarios of socioeconomic development that could be easily adjusted to the RCP/SSP framework. Other studies are focusing on the examination of drought assessment based on hydrological impacts not considering the future socioeconomic developments. Can provide results of higher end global warming.	Requires large amounts of data and historical records for better predictions. Not suitable for site specific analysis.	This model was applied to the European region.	Climate Change	This tool would be ideal to determine the dependability of a water supply for the future in areas with less GW data and some SW data, as the results provide a range of values, not a specific estimate. This approach would be useful for supporting regional level policymaking and implementation and strategic planning against future freshwater stress.
Regional Hydrogeological Water Managment Policy (5)(6) Water managers in the Regional Municipality of Waterloo have developed a science-based approach with certain principles of sustainable water governance. This approach demonstrates efforts to improve water use efficiency, the principles of sustainable water governance, and the current understanding of the water resource. The water management strategy meets the needs of the growing community, requires both the consideration of socio-political aspects of water governance and a sound science-based understanding of the resource itself. The management stategy incorporated requirements of the Source Water Protection Plan to protect surface and groundwater in the Region. For Waterloo Region, the basic principles of water governance are reflected in the societal components of the Region’s approach to water management. Scientific tools have evolved to provide a conceptual understanding of the complex Moraine water source and to translate this understanding into effective policy.	Waterloo Region uses a spatial geodatabase that links the conceptual hydrogeological framework with the numerical groundwater flow model. The model was based on a detailed characterization of the groundwater and surface water systems, and calibrated to available data under average (steady-state) and variable (transient) pumping and climate conditions. Following model development and calibration, the model was used to conduct a detailed water budget and risk assessment study that compared groundwater demands to available supplies.	The hydrogeological framework takes into account geographic variability, geological/hydrogeological variability data. This model includes some climate variability and socioeconomic variability. The models used does not include Climate Change, however the water managment plan incorporates it.	Several scenarios involving future municipal water demands and potential reductions in groundwater recharge due to planned land-use development were simulated{in the groundwater flow model, which is then used to predict municipal water demand in the future based on the existing system of wells without causing a significant reduction in groundwater discharge to ecologically sensitive streams and wetlands.	This approach has used data collected over the past 40 years, during all seasons, over parts of the watershed. Allows the user to consider the data at various time scales, from snapshots in time to inter-annual variability based on past historical data. Level of data required suggests a site specific to local scale would be the most ideal.	The groundwater flow model requires an understanding of the dynamics of the groundwater flow system (precipitation, recharge, storage and flow, discharge), the structure of the aquifers and aquitards that control the flow, the linkages to environmentally sensitive features and the potential impacts due to land-use changes. Environmental needs (sustained base-flow, wetland maintenance) can place a constraint on the groundwater volumes that are available for withdrawal. The quantity of water available for recharge can be potentially impacted as groundwater recharge areas are altered to accommodate development. Waterloo Region uses daily and weekly data collection to determine water taking impacts on water quantity.	The Tiered Water Budget Assessment Approach under Source Water Protection for the Region uses a mix of Climate Change modeling, population growth predictions, and environmental flow data to quantify and determine if water in their aquifers and surface water areas will be enough to sustain future development and growth in the Region. Flow data is processed through the Reservoir Yield Model. The water managment plan incorporates these values in determining water allocation. Geologic, geophysical, hydrogeologic, geochemical and modelling tools, all working together to create one conceptual model that can be used to give insight into the complexities needed for Source Water Protection within the Region.	The groundwater flow mode was also applied to delineate the capture zone for a well field in the Region under conditions of uncertainty, demonstrating a methodology that could be applied to other well fields.	Requires large amounts of data and historical records for better predictions.	Waterloo Region, Ontario , and other Ontario municipalities that include a Tiered Water Budget Assessment Approach under Source Water Protection	Climate Change, population growth, land use change, Environmental Flow Needs	The water management plan is suited for areas in Ontario where there is a significant amount of data on each of the elements in the hydrologic cycle. It would also be important that the local water managers have the capacity to use the tools to integrate various data sets into a comprehensive Conceptual Site Model of a physically complex system. The level of analysis is likely only warranted in areas with a high degree of dependence on groundwater.
Public Decision Making Water Plan (7) This plan uses input from public, tribal, and agency advisory committees and regional outreach processes as well as an optimization-modeling approach for groundwater use based on cost and water volume scales. By adding cost to waters volume, more constraints are placed on water allocation to ensure it goes to the greatest need. This social approach does not determine water quantity, but ensures sustainability by limiting water usage to certain sectors of water taking.	The online system is used to report conditions and support decisions at the state and region scales (http://indicators.ucdavis.edu), which was based on a data model containing the relationships among the main “entities” in the framework. Indicators are an abstract data type and sit at the heart of the model.	This model uses distributed rather than a lumped parameter model to account for climate variabilities within the state.	This model used to select water users can be used to determine water supply dependability and security into the future based on stakeholder needs, sustainability indicators, and hydrological factors.	Can be used at state and regional scale. The model uses counties and hydrologic regions as individual sub-domains, and can be assessed individually or as a collective. Allows the user to consider the data at various time scales, from snapshots in time to inter-annual variability based on historical data.	The corresponding metadata about the data sources, the geography, the decision to choose one indicator over another, and a myriad of other connecting details are also part of the online system. Required data include each indicators, their goals and objectives, the spatial extent (or regions) for which indicators are relevant, the analytical technique to generate indicator values (called a metric), the indicator report (reference) where indicators are described, and the data resources used to calculate their values.	Using contemporary web informatics tools to build understanding of environmental and social conditions supports good decisions by various stakeholders and decision makers. The online system has both relational and spatial database back ends (PostgreSQL and PostGIS) and was built using Drupal, a popular PHP-based web application framework. Web mapping, where the spatial extent of the indicator value is represented on to navigate the map interface to view and retrieve other indicator values across space.	Benefits of this framework are that it results in a fully documented, systematic analytical framework for sustainability indicator evaluation; the sustainability definition, sustainability goals, and corresponding indicators were developed with stakeholder input and feedback at the appropriate scale; conditions were assessed and corresponding indicator scores calculated according to transparently developed poor and good reference conditions; and indicator descriptions, findings, and data sources were provided through an online system.	Requires large amounts of data and historical records for better predictions. Requires public participation and contribution. Also shows transparency online, which may identify problem areas to public.	Has been implemented statewide in California and region wide in Santa Ana.	Climate Change	Could work at a regional scale to show transparency to public. Includes socioeconomic concerns and could work at watershed scales with lots of data.
Multicriteria Approach to Defining Success (8) An approach for defining and measuring the success of environmental water programs, using six criteria: Effectiveness, Efficiency, Legitimacy, Legal and administrative frameworks, Organizational capacity and Partnerships. These criteria emphasize the essential elements of the policy and governance indicators of success (effectiveness, efficiency, and legitimacy), as well as criteria that affect implementation capacity (legal frameworks, organizational capacity, and partnerships). By using these criteria sustainible managment practices can be implemented into laws and govermental policies.	Assist policy makers, water managers and practitioners in defining and recognizing success in environmental water programs, and maintaining successful programs over time. Can be applied to SW and/or GW management programs.	Can be applied to any geographic, climatic, economic setting.	Applicable to longer term programs with a targeted outcome (e.g. restoration programs, conservation programs).	Require implementation over decadal timescales and a wide range of spatial scales, from the very local through to multijurisdictional and multinational transboundary aquatic systems. Successful environmental water programs deliver not only improved environmental water regimes in the short term, but a sustained improvement in aquatic health over time with required long term observation.	Transparent reporting on allocation and reliability standards and requires data on water usage.	Software-driven decision support systems play an important role in allowing these complexities to be incorporated into decision making. One such tool is the seasonal environmental water decision support (SEWDS) tool (Horne et al., 2015), which aims to optimize environmental water, drawing on seasonal streamflow forecasts and ecological response predictions.	Represents an improvement over commonly used policies of evaluating success, whose focus was generally limited to easily measured outputs (efficiency and effectiveness). Input legitimacy: explicit consideration of access, equal representation, transparency, accountability, consultation and cooperation, independence and credibility. Output legitimacy: awareness, acceptance, mutual respect, active support, robustness, and common approaches to problem solving. Helps with development and maintenance of specific legal frameworks to support the monitoring of water use and enforcement of water rights. Promotes partnership between local, regional, national and/or multinational organizations. Has the capacity to enforce environmental water mechanisms.	Requires ongoing maintenance and investment to establish legitimacy.	Columbia Basin, United States. Murray-Darling Basin, Australia	Environmental Flow Needs, Water Quantity	Can be used to guide the development of watershed-scale and provincial water management programs. The approach's emphasis on legitimacy and partnerships will encourage public acceptance of a proposed program. Establishment of appropriate organizational capacity and legal and administrative frameworks will improve the resilience and longevity of positive results.

Table B-2
Water Security Assessment and Sustainability Evaluation

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
The Groundwater Sustainability Assessment Approach (13) It is an indicator based flexible sustainability assessment approach that identifies the key elements and approaches for assessing the sustainability of groundwater resources. The Driving-Force-Pressure-State-Impact-Response (DPSIR) framework is used in this approach. It is recommended to conceptualize the groundwater sustainability issues and ensure a link with policy and socioeconomic issues. This is done by a systems analysis approach to develop groundwater resources sustainability indicators.	This approach is used for 3 main purposes: a) informing senior water management officials and groundwater policy developers across Canada on data requirements, policy approaches and technical methods to support sustainable groundwater management; b) providing a standardized means by which jurisdictions can track the status of groundwater resources and the effectiveness of groundwater management strategies over time; and c) supporting communication by CCME member jurisdictions on the status of groundwater resources at a local, provincial/territorial or Canada-wide scale.	This approach could be used to show geographic variability, socioeconomic variability, and limited climate change variability. The DPSIR framework includes some climate variability and geological/hydrogeological variability. Does not do Climate Change.	This model can be used for planning to determine if the water supply is dependable into the future based on hydrogeology, socioeconomics and policymaking by completing a groundwater sustainability assessments.	This approach can be used for assessing the sustainability of groundwater resources at a local, provincial, territorial or Canada-wide scale. By their nature, indicators take a snapshot picture of a constantly changing groundwater system.	The DPSIR framwork requires a substantial amount of data: • Driving force indicators describe the social, demographic and economic developments in societies. eg: communicate factors related to an increased energy demand or increase in population or industrial development. • Pressure indicators describe the developments by human activities that use groundwater supplies and release contaminants into groundwater.eg. increase in the number of oil and gas wells being drilled in an area relative to groundwater use. • 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, groundwater flow systems including that being discharged (base flow) into surface water such as streams (as well as any specific chemicals of concern) over time and across the area of interest. • 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. eg. new techniques in drilling that use less potable groundwater or new policies to use of saline groundwater instead of potable groundwater.	The indicators may be used as evaluation tools by the jurisdictions as they consider how best to apply this preliminary assessment approach. The DPSIR framework is applied to the conceptual model.	The formal indicator selection process with pre-determined criteria that are rigorous and transparent will ensure the scientific credibility of the assessment approach and that adequate linkages exist between environmental, social and economic dimensions.	The indicator selection is based primarily on the consideration of what information is likely to be available, how readily criteria could be established, and what indicators are likely to be easily understood by policy developers and decision makers. These indicators are chosen by the approaches user, and may not take into account all indicators or the most suitable indicators may not be included.	Groundwater sustainability assessments, as defined in this approach, are not currently being undertaken by any jurisdiction in Canada. However, all jurisdictions have at least some of the critical elements (data, monitoring infrastructure, tools and resources), even if limited, to be able to participate in groundwater sustainability assessments	Sustainability, Security	All jurisdictions have at least some of the critical elements (data, monitoring infrastructure, tools and resources), even if limited, to be able to participate in groundwater sustainability assessments.

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Table B-3
Cumulative Effects & Environmental Flow Needs

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
Michigan Water Withdrawal Assessment Tool (1,2,3,4) The Michigan Water Withdrawal Assessment Tool (WWAT) is a screening tool as part of large water withdrawal assessment (>100,000gal/d). It determines the likelihood of a water withdrawal causing an adverse resource impact on nearby streams and rivers. First determines the level of flow necessary to protect stream and river ecosystems and the fish that inhabit them, then assesses the impact of proposed large quantity withdrawals. Uses a statistical model to estimate flow for ungauged stream and river segments.	Site specific Permitting – but uses area wide modeling to support decision Could be used to look at groups of takings (watershed scale)	Does geological variability, geographic variability, summer low flow, type and abundance of fish species Does not do climate change or non-summer seasons	Aimed specifically at identifying environmental impact; considers cumulative impact of multiple takings; models represent existing stress Could be used to assess interference with specific other takings, but Michigan doesn't use it this way.	Purpose of tool is site level, but considers watershed scale. Therefore could be used at local or watershed scale. Snapshot in time; considers summer low flow (but not other seasons). Doesn't forecast, doesn't do seasonal variation or climate variation.	Extremely data-heavy to set up, but simple to apply. Based on 3 models: 1) SW model uses soil, geology, land use and precipitation; 2) GW model uses geology (transmissivity, streambed conductance and storage coefficient), well depth, pumping rate, and distance from streams; 3) habitat suitability uses types and abundance of fish species. But other underlying datasets needed and used (climate data – precipitation, recharge).	3 interlinked models: 1) Withdrawal Model: determines amount of water in the aquifer, how much is being withdrawn, and from where and how it will affect streamflow; 2) Streamflow Model: determines how much water is flowing in the stream during summer low flow periods; 3) Fish Impact Model: determines what fish are in the stream, what is the likely effect of water withdrawal on the fish. Screening tool components: WMS Photos, ArcIMS, ArcView IMS, ASP Groundwater models, water accounting database	Demonstrates the value of having an integrated tool for screening purposes where there is a lot of data and a lot of competition for water. One of the few approaches that consider and protect fish on a regional basis. Easy to use (time savings), once set up. Could be used by proponents, the public (widely accepted by the public), to see whether water is available. Covers several scales; can do site, can do area up to watershed. Allows for the cumulative impact assessment of multiple smaller takings. Good for high-density, high-demand areas (e.g. Guelph, Norfolk)	Assumes 100% consumption on SW takings Data-heavy. Doesn't address smaller/local aquifer (e.g. perched aquifer). Screening-level tool only Not forward-looking, can't consider Climate Change, growth, land use change. Not suitable for low-density, low-use areas (e.g. Northern Ontario)	Michigan Only	Environmental Flow Needs	Improves on Ontario's screening approach in areas where GW takings have potential impact on an important SW feature in an area of high demand. Improves on Ontario's consideration of fish protection in screening level. Increases transparency for proposed takings, and understanding for the public.
Resource Assessment and Management (1,5) Resource Assessment and Management (RAM) is a spreadsheet tool used by regulators that incorporates actual reported SW withdrawal information to assess the cumulative impacts of SW taking. It is used to inform water licensing decisions using flow data, GW recharge, discharge, resource allocation for the environment and details of abstraction licenses (volumes and location).	Site specific Permitting – but uses area wide modeling to support decision. Retroactively assesses cumulative impacts to evaluate water bodies' progress towards meeting the EU's Water Framework Directive objectives. Applicable to SW assessments. Takes into account GW's influence of SW resources, but does not assess GW resources themselves.	Calculates current resource availability in a SW body at four flow percentiles: Q30, Q50, Q70 and Q95. Uses hydrological flow data (measured at gauges or calculated through a model), but does not account for variability in geological/ hydrogeological conditions, climate, watershed characteristics.	Aimed at measuring cumulative SW withdrawals in a water body; determines whether a new withdrawal will result in flows falling below a specified low flow target. Can be used to determine whether a new taking will result in interference with other uses.	• Considers average annual flows in SW bodies; does not capture seasonal variation. • Can provide a snapshot of current water withdrawals in a water body, and also provide insight into longer term trends. • Compiles site-specific data (licensed water withdrawals) to assess SW resources at the watershed scale.	• Requires actual water use data from licensed withdrawals • Requires continuous updates to account for new, revised and/or revoked licences • Requires a model or tool to estimate natural flows for the SW body being considered.	• RAM ledger: Excel spreadsheet compiling data on abstraction, discharge, natural flows for different water bodies • Water Resource GIS (WRGIS): information and data from the RAM ledgers are uploaded to the WRGIS • Low Flow Enterprise software tool: calculates flows for ungauged sites, and estimates variability and magnitude of flow regimes.	• Determines whether a water resource is over allocated compared to a specified low flow target • Output is a map illustrating resource availability by watershed/subwatershed. • Capable of accommodating large volumes of data: water withdrawal licensing threshold is 20 m3/day, so a large number of abstractions are captured. • All data consolidated into a central system (WRGIS)	• Will not capture the influence of reservoirs unless it is evident in the annual flow duration curves. • Approach requires that assumptions be made regarding consumptive use of different types of withdrawal licences. • Uses average annual flows when evaluating cumulative impacts; seasonal variability not considered.	England only	Environmental Flow Needs	• Centralized system like WRGIS and/or mapping of current water resource availability can be made publicly available and used as a screening tool for proponents. • Increases transparency for proposed takings and understanding for the public. • Potential to be used in Ontario as much of the data required by the RAM (actual water use data from licensed withdrawals) are currently collected through the Water Taking and Reporting System and the PTTW framework.
Healthy River Ecosystem Assessment System (THREATS) (6,7,8,12,13,14) THREATS was developed to address the lack of decision support software specific to cumulative effects assessment. Designed to be an internet open data and open source GIS platform. Uses existing monitoring data; can be used to look at effects and determine if there are perturbations outside of the normal range of variability, and to identify effects-based changes. Source code and development rights are currently owned by a private consulting firm, so publicly-available technical info about the platform is limited.	Provides support for watershed and land-use planning by consolidating data into a map-based platform. Aims to be a real-time assessment tool for watershed effects.	Accounts for geographic variability in geology, vegetation, land use. Can be used across time, environmental components and jurisdictions.	Identifies perturbations outside of the normal range of variability and effects-based changes. Onus is on the user to interpret what the perturbations and changes mean.	Incorporates site-specific and watershed-scale data. Allows the user to consider the data at various time scales, from snapshots in time to inter-annual variability.	Platform comes pre-loaded with data on landscape characteristics (e.g. geology, vegetation), known stressors (e.g. cities, roads, industrial activities, land use) and environmental indicators (e.g. water quantity, water quality, biological health (such as fish)).	Intended to be a user-friendly GIS platform, but appears to require the user to determine what data is/is not needed for their analysis, and to interpret the results; i.e. user needs to have sufficient knowledge and expertise in cumulative effects assessments.	User-friendly, comes pre-loaded with data sets obtained from federal/provincial regulators.	Appears to be more of a tool than an approach for conducting cumulative effects assessments; user needs to set up the analysis and interpret the results themselves.	Unknown if any specific jurisdiction is using THREATS. Platform is currently owned by a private consulting firm, who state in their promotional material that the platform is available for online use in Alberta and Ontario.	No explicit linkages, but potential to be used for assessments of climate change, land use change, drought susceptibility, etc.	Appears to bear many similarities to other online, GIS applications maintained by municipalities, Conservation Authorities, etc. Unclear what advantages THREATS has over them.
Colorado's Decision Support Systems (CDSS) (1,9,10,11) CDSS is a water management system involving an array of models and tools for predicting and managing cumulative impacts on environmental flow needs. CDSS was tailored to each of Colorado's major water basins.	Site-specific permitting. Assist in long-term planning by modelling future water demand and supply under different climate change scenarios. Can take into account GW use, but focus is on SW.	Accounts for geographical variability in climate, available water supplies, and crop lands	Aimed at identifying conditions that will impact on critical streams for endangered fish species, and helping in developing minimum instream flows.	Input data for the models are at the site level (e.g. specific flow gauge), and models are developed at the watershed scale. Simulations are in monthly or daily time steps. Small permitted abstractions (< 0.28 m3/s) are aggregated in a local area, while larger withdrawals (> 0.28 m3/s) are modeled at their specific locations. Involves real-time tracking of flows at specific SW bodies to maintain flow requirements agreed upon with downstream states. Incorporates historical and baseline flow data.	Extremely data-heavy to set up. Uses streamflow measurements, and meteorological data. Data from diversion gauges and well meters are also used in some instances. Ungauged stream flow is calculated using correlation to neighboring stream gauges or those in a similar watershed.	Models include: • StateCU (consumptive use model) • StateMod (water allocation model) • MODFLOW (GW models) Tools include: • TSTool (for creating model input files) • StateDGI (processes spatial data for use in the models) • StateView (data viewing tool) • StateWB (calculating water budgets for a watershed) • StateDMI (data management interface) • Lease Fallow Tool (evaluate potential lease fallow projects) • AUG 3 Denver Basin Model (Excel interface for facilitating the use of Denver Basin Models)	Works with real-time data. Reportedly capable of modelling 100% of the water use and consumptive use in a watershed. Models and datasets are available for download and can be used by the public.	Accurate estimates crop consumptive use are dependent on there being weather stations on the ground. Significant training likely required to understand and master the use of the many models and tools.	Colorado only	Environmental Flow Needs	Emphasis on public transparency: CDSS website includes free, web-based, interactive maps for viewing stream, structure, aquifer and well data. Website also includes a central database housing real-time, historic and geographic data (e.g. stream flow and diversion records, information on water rights, GW level information). As it is currently tailored to each of Colorado's major water basins, it has the potential to be used in Ontario at the scale of individual Conservation Authorities.

Table B-3
Cumulative Effects & Environmental Flow Needs

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
Range of Variability Approach (RVA) (15,16,17,18,19,20) An adaptive management approach for establishing flow management targets for a river, using Indicators of Hydrological Alteration (IHA). IHA represents a subset of 33 ecologically-important hydrological parameters, and RVA identifies a target range of flows for each. RVA recommends that flows be maintained within the flow management targets at the same frequency as what would occur naturally.	For determining ranges of flow values within which flows in a SW body should ideally be maintained. Can be used for defining EFNs for the purposes of permitting, watershed planning, etc. Developed to be a simple rule that can be used in the absence of strongly-defined empirical flow-ecology relationships.	Considers only flow statistics of a specific water body. Does not explain effect of climate, geographic variability, geological variability, etc. on flow statistics.	Aimed at maintaining the natural variability of flows in a water body (e.g. frequency and magnitude of low flow events and high flow events, the timing of extreme daily flows).	Site-specific. Quantifies long-term (inter-annual) and short-term (daily, monthly) variability in flows of a given water body.	Requires the availability of long-term historical streamflow data (ideally 20+ years) collected at daily time intervals.	Approach does not prescribe the use of specific tools, but the capability of calculating flow statistics (mean monthly flows, recurrence intervals, etc.) is required.	Flow targets are relatively simple to calculate (e.g. flows within one standard deviation of the mean monthly flow). Limited to desktop calculations.	Does not consider socio-economic interests when identifying target flow ranges. Requires a flow gauge to be present at the site of interest, and 20+ of daily flow data to have already been collected.	Has been used in river-specific assessments internationally, including (but not limited to): River Murray (Australia); Daipo Check Dam (Taiwan); Roanoke River (North Carolina)	None	Potentially suitable for scenarios that are not expected to generate significant socio-economic concerns. Proper use of RVA requires knowledge of and data about natural/pre-disturbance flow conditions. As there are relatively few streams in Ontario that are natural/undisturbed AND for which extensive hydrological data has been collected, many situations would require "natural" flows to be simulated.
Physical Habitat Simulation System (PHABSIM) (15,22) Habitat modeling software developed in the 1970s that predicts changes in available habitat with flow changes. Enables the quantitative prediction of suitable physical habitat in a river reach for chosen species and life stages under different river flow scenarios. Intended for use in situations where stream flow is a limiting factor controlling aquatic resources. End product is a habitat vs. discharge function for each target species and life stage.	Presents biological information in a format suitable for entry into the water resources planning process. Provides a variety of simulation tools characterizing the physical microhabitat structure of a stream. Describes flow-dependent characteristics of physical habitat. May be used for permitting purposes where the impacts to aquatic species in a specific river reach is of primary concern.	Accounts for biological responses of target aquatic species and life stages to changes in flow. For SW assessments only.	Though not specifically designed for that purpose, may be used to evaluate impacts of water takings on habitat suitability and availability.	Input data and habitat vs. discharge functions are specific to a river reach. Models snap shots in time - may indirectly reflect daily and seasonal variation in habitat availability and suitability by modelling many different flow conditions.	Requires field measurements, hydraulic calibration, and knowledge of species' physical habitat preferences (depth, velocity, substrate).	PHABSIM software	Relatively simple to implement. Precisely estimates the impacts of varying flows on the availability of suitable habitat.	Considers only aquatic species. Requires field measurements of the channel morphology. Described in the scientific literature as not using appropriate spatial scales, using outdated methods for modelling habitat preferences, no longer confirming to standard practices in ecological and wildlife modelling.	United States, United Kingdom	None	Could be used when there are concerns regarding an activity's potential impacts to a sensitive aquatic habitat feature located downstream. If additional interests (e.g. municipal water supply, agriculture) beyond aquatic species must be represented in the establishment of EFNs, PHABSIM would need to be used in conjunction with other applicable approaches.
Instream Flow Incremental Methodology (IFIM) (15,21,23,24) An approach in which quantitative methods are used to assess fish habitat trade-offs against other uses of water. Integrates concepts of water supply planning, analytical hydraulic engineering models and empirically-derived habitat vs. flow functions (derived using PHABSIM).	Designed to be a holistic decision-making tool that relates biotic values to stream discharge in equivalent terms to those used to estimate other anthropogenic beneficial uses (e.g. recreation, hydropower generation). Uses technical methods to provide specific recommendations for long-term planning (e.g. limitations on water use).	Considers variations in flows, habitat requirements of selected species, general well-being of aquatic biological populations. Different techniques (standard setting, midrange, and incremental) can be used based on the complexity of flow issues. For SW assessments only.	Used to help determine flow objectives, determine thresholds and design flow management strategies.	Input data and habitat/suitability vs. discharge functions are specific to a river reach. Models snap shots in time - may indirectly reflect daily and seasonal variation in habitat availability and suitability by modelling many different flow conditions.	Incorporates the use of PHABSIM, and therefore also requires field measurements, hydraulic calibration, and knowledge of species' physical habitat preferences (depth, velocity, substrate). Suitability of varying flow conditions for anthropogenic use must be quantified (e.g. suitability of increasing flow depths or flow velocities for paddling).	PHABSIM software. Key component is public consultation in order to determine suitability of varying flow conditions for anthropogenic use. Requires interaction and communication of all stakeholders or parties directly or indirectly affected by flow issues.	Accounts for human uses of, and value placed on, water. Precisely estimates the impacts of varying flows on the availability of suitable habitat.	Society value placed on different flow conditions may be difficult to quantify - requires consensus. IFIM studies are complex and require important subjective decisions.	Has historically been used in many EFN assessments, particularly in the United States.	None	Warrants consideration in situations with competing demands on water supply. Public consultation component will improve public acceptance of the approach.

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Table B4
Water Bottlers (approaches for assessing water quantity impacts of)
Note: no approaches for assessing water quantity impacts were identified that are exclusive to water bottling operations. The following table identifies approaches and tools that are more relevant to water bottling operations compared to most other large-scale water extractions.

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
Consumptive water use (1,4) Calculation of the quantity of water used in the bottling process, taking into account: water that is evaporated from the time it is extracted to the time it is bottled, water that is incorporated into the product, water that is not returned to the same basin where it was withdrawn, and water that is not returned during the same time period.	Provide a more holistic representation of water quantity impacts, taking into account the origin and destination of the extracted water, and the time that water is withheld from the hydrological cycle.	Applicable to any setting where water is being extracted, treated, packaged and brought to market.	Appears to only be done on a voluntary basis, but may be used to monitor the success of conservation measures, to inform decisions on water taking permit applications, and for long term planning.	• Calculated at the scale of the individual water bottling plant; can subsequently calculate an average for a specific company, the industry, etc. • Temporal scale: at least one production cycle (from time of extraction from source to shipment of final product).	• Volume extracted • Period of water extraction • Volume and destination of wastewater discharge • Volume of product packaged • Water losses (calculated based on the above)	• Tool for measuring water extraction (e.g. flow gauge on pump) • Tool for tracking final product numbers, volumes • Tool for measuring wastewater discharges • Database of water extractions, losses, production per unit of time	• Provides a better representation of how much water is "permanently" lost from a given source (i.e. aquifer, water body).	• Cumbersome to measure and track • Variability in water use is more pronounced for smaller producers (annual production > 200 million litres) • Higher water usage may be due to water treatment and/or sanitization requirements rather than inefficiencies in operation (e.g. reusable/refillable containers must be sanitized before being filled, while single-use bottles do not).	Unknown if used in any particular jurisdiction	Water Quantity, Water Sustainability	Could be used to inform decisions on water taking permit applications and assist with source protection planning.
Direct and indirect water use and consumption (1,4) Includes all water used and consumed in the supply chain, not just the water extracted and used by the water bottler. E.g., electricity generation for operating a beverage facility, production of primary and secondary packaging materials, disposal of waste materials.	Provide an estimate of the "water footprint", i.e. the amount of fresh water that is used directly or indirectly to produce a product, considering all steps in the production and distribution chain.	Applicable to any setting where water is being extracted, treated, packaged, brought to market, consumed and disposed.	Unknown if used outside of research/academic settings, but may be used for long term planning.	• Spatial scale may range from site-specific to global: must incorporate the locations of the water source, the bottling facility, the distributor, the consumer, and all ancillary services. • Temporal scale can be expected to span months or years in order to include all components of the production cycle.	• Volume extracted • Period of water extraction • Volume and destination of wastewater discharge • Volume of product packaged • Water losses (calculated based on the above) • Indirect water use and consumption	• Tool for measuring water extraction (e.g. flow gauge on pump) • Tool for tracking final product numbers, volumes • Tool for measuring wastewater discharges • Database of water extractions, losses, production per unit of time • Tools for measuring all of the above for all sources of indirect water use/consumption	• Provides a holistic assessment of the water quantity impacts, including water uses/consumption that are otherwise hidden/unknown to the layperson.	• Cumbersome to measure and track • Obtaining water usage and consumption data from suppliers may be difficult and time-consuming • May require many assumptions to address data gaps. • Outcome is dependent on the type(s) of calculations used.	Great Lakes Basin, Ontario Source Protection (however, different approaches are used to calculate consumptive use)	Water Quantity, Cumulative Effects, Water Sustainability	Could be used to inform the establishment of an industry-specific fee structure for PTTWs
Michigan Approach (5) Specific legislation for water bottlers is outlined under Section 325.1017 of the Safe Drinking Water Act	Applicable to SW and GW withdrawals for the production of bottled drinking water.	Applicable to any setting in Michigan where a proponent seeks to withdraw waters of the state for the purpose of producing bottled water.	Applicable to site-specific water takings	Licence issued for a site-specific withdrawal for a specified number of years. Spatial/temporal scales of studies accompanying a licence application are defined by the regulator.	• Specific data requirements are not specified. However, an application for a water bottling licence requires an evaluation of existing environmental, hydrological and hydrogeological conditions, and the anticipated effects of the withdrawal.	• Licence required if a proponent seeks to produce bottled drinking water from a new or increased large quantity withdrawal of more than 200,000 gallons (757,083 litres) of water per day from the waters of the state. • Licence also required if the water bottling operations will result in an intrabasin transfer of more than 100,000 gallons (378,541 litres) per day, averaged over any 90-day period.	• Allows the municipality in which the water extraction is taking place to charge a fee per volume of water extracted. • Before approval for withdrawal can be obtained, water bottlers are required to consult with local government officials and interested community members.	• Unclear if there are advantages to having regulation treating bottled water operations as distinct from other large scale water withdrawals.	Michigan	Environmental flow needs, cumulative impacts, water quantity, water sustainability	Michigan's approach for allowing municipalities to charge water withdrawal fees warrants further assessment. Implications of treating water bottling as distinct from other large scale withdrawals also warrants further assessment before adopting a similar approach in Ontario.
Water metering (1) A tool for recording volume of SW and/or GW withdrawn from a source	Quantification and documentation of the volume of water that is removed from a system (GW and/or SW).	Applicable to any setting where water is being extracted.	Applicable to permitting: permit conditions typically set thresholds on the volume of extractions.	• At the scale of individual pumps/extraction points • Temporal scale can range from instantaneous extraction rates (e.g. litres per second) to longer term (e.g. gallons per year).	• Volume extracted • Period of water extraction	• Tool for measuring water extraction (e.g. flow gauge on pump) • Database of water extractions per unit of time	• Straightforward to measure • More suitable for ensuring compliance during low flow periods (i.e. reduced/halted withdrawals during droughts)	Does not account for the actual consumption rate and whether water is returned to the watershed.	Globally	Water Quantity	Used in Ontario for water takers; daily extraction volumes are reported on an annual basis per the conditions of the Permit to Take Water.
Normalized volume (1,2,3) A tool for calculating the volume of water used per volume of product packaged	Provide a representation of the expenditures involved in creating a product.	Applicable to any setting where water is being extracted, treated, packaged and brought to market.	Appears to only be done on a voluntary basis, but may be used to monitor the success of conservation measures and to inform decisions on water taking permit applications.	• Calculated at the scale of the individual water bottling plant; can subsequently calculate an average for a specific company, the industry, etc. • Temporal scale: at least one production cycle (from time of extraction from source to shipment of final product).	• Volume extracted • Volume of product packaged	• Tool for measuring water extraction (e.g. flow gauge on pump) • Tool for tracking final product numbers, volumes • Database of water extractions, production per unit of time	• Concept is easily understood, interpreted and appreciated by the layperson. May influence consumer choices. • Allows for comparison across different food and beverage industries (e.g. water bottlers, distillers, wineries) • Can be used to monitor efficiencies in operation	• Variability in water use is more pronounced for smaller producers (annual production > 200 million litres) • Higher water usage may be due to water treatment and/or sanitization requirements rather than inefficiencies in operation (e.g. reusable/refillable containers must be sanitized before being filled, while single-use bottles do not).	Unknown if used in any particular jurisdiction	Water Quantity	Could be used to inform decisions on water taking permit applications.

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Table B-5
Climate, population and land use change

Approach	Purpose	Setting	Risks of Concern	Spatial and Temporal Scales	Data needs	Tools needs	Strengths / Benefits	Limitations / Challenges	Jurisdictions Using	Linkages	Considerations for use in Ontario
Water Demand Scenario Modelling Tool (1, 2) An approach developed by the Department of Water for the state of Western Australia. Forecast is based on a global model estimating future water demand for about 60 different economic sectors.	For forecasting future water demand. Considers both GW and SW.	Uses a multiple coefficient approach that accounts for potential population growth/decrease. Accounts for geographical variability by using different model parameters and predictions for the 19 different regions in the state. Accounts for climate change and the geographic variability of climate change's impacts.	Appears to have been developed primarily for research purposes, but can be used for long term planning. Unit water demand coefficients can be used for permitting purposes (e.g. setting thresholds for requiring a permit).	Forecasts developed for 19 regions in the state. Water demands forecast developed for the years 2020 and 2030, and compared to 2008 (baseline).	Requires: • Water consumption data by type of user. If unavailable, water consumption can be estimated. • Estimates of the future number of users for each type of user under consideration. • Region-specific climate change projections. • Estimates of the economic impacts of climate change.	• Forecasts are made by the Water Demand Scenario Modeling Tool • A separate economic model must be used to model growth rates for different industries	• Links future water demand to anticipated macro-economic trends. • Estimates of water use coefficients can be used for areas with sparse data. • Can inform water quantity and sustainability assessments by providing estimates of future water demand. • Could be used to identify thresholds for unit water demand coefficients that would help achieve long term water sustainability and security.	• Requires strong technical knowledge, expertise in order to: determine suitable unit water demand coefficients, whether to differentiate between water users (e.g. single detached dwellings vs. apartment dwellings), etc., and whether the unit water demand coefficients themselves are likely to change over time. • Does not account for evolving water tariffs, household incomes, etc. that may change unit water consumption, and may therefore represent an over-simplification of future water demand. • Assumes that the proportion of municipally-supplied water vs. self-extracted water will not change in the future.	Western Australia	Water security, Cumulative Effects	May be suitable for use in Ontario due to comparable geographical scale and model's ability to account for regional variability in water demand and climate change impacts.
Metropolitan Water District of Southern - Multivariate Statistical Model (1) Per the requirements of the Californian Urban Water Management Act, each drinking water service must prepare an urban water management plan (UWMP), covering a 30-year time period, and which must be updated every 5 years. UWMPs support the suppliers' long-term resource planning to ensure that adequate water supplies are available to meet existing and future water needs. To forecast future water demand, the Metropolitan Water District of Southern California uses a mutivariate statistical model to estimate the statistical relationship between per capita consumption and a set of explanatory variables (e.g. cost of water, household income, level of economic activity, etc.)	Ensure a long-term balance between water demand and resources available; provide for emergency management measures in the event of exceptional droughts. Approach may be used for GW and/or SW.	Accounts for types of water use (household, commercial, industrial, public), geographic variability and climatic (precipitation) variability.	Used for water management planning in urban environments. Could be used to assist decision-making on site-specific permits.	Applied at the regional scale and local scale. Projections of water demand are made at 5-year increments for 30 years into the future.	• Requires data on projected population and economic growth, water use by user type (single family dwellings, multi-family dwellings, industry, etc.), water service rates (price level and structure), etc. • Can input data on water conservation measures (if any) that are planned by the utility. • Model coefficients were determined by statistical processing of the results from 60 case studies in the U.S.	Requires the use of: • A forecasting model (e.g. IWR-MAIN program) that allows projected population and economic growth to be translated into drinking water demand; • An econometric (statistical) model to simulate the evolution of consumption ratios; and • A model of end uses to simulate the effect of conservation programs.	• Recognizes that changes in water demand are influenced by many factors, including water rates/tariffs, household income, climate, water conservation programs, etc. • Can be used to forecast the effect of water conservation measures on future water supplies.	• Weaker predictive capacity for long-range forecasting • Approach uses data on, but does not actually predict, population growth. The latter must be provided by other models/studies.	Southern California	Water security, Cumulative Effects	Approach potentially suitable for use by individual municipalities with centralized water distribution systems.
Thames Water (United Kingdom) Approach - Micro-component modeling of household demand (1,3,4) Involves the detailed simulation of the end-use of water by customers, in order to predict future water usage, taking into account projections in population growth and changes in land use. The approach estimates the volume of water associated with specific types of water use devices, primarily in domestic properties (showers, toilets, swimming pools, etc.).	Aims to identify future potential planning problems (e.g. demand exceeding supply) by assessing the micro-components of demand (e.g. frequency and volume of water use by household appliances). Accounts for SW and GW supplies.	Accounts for climate change, population growth, seasonal water usage, changes in technology and water usage of household devices (e.g. showers, toilets, dishwashers).	Water companies in the UK must develop a water resources management plan, including projections of household water demand. A micro-component modeling approach is used to estimate changes in water use over the coming 25 years, based on population and property projections.	Forecasts are performed at the "resource zone" level (there are 68 resource zones in England and Wales). Water demand is forecasted 25 years into the future; water resources management plans (and the forecasts contained therein) must be revised every 5 years.	Requires data on: • Current and projected populations • Property numbers and types • Estimates of leakage/loss	Specific tool requirements are not specified; however, the approach requires the use of calculations/tools that can produce the following (if such information does not already exist): • Annual water budgets based on usage data from the previous year; • Forecasts of water demand for different climate scenarios (dry years, wet years, etc.)	• More suitable than regional or national scale models for informing local planning. • Can be used to estimate the impacts of water conservation efforts and incentives. • Information is more relatable to the individual water user: provides insight into how their water usage and household devices collectively impact water quantity and sustainability.	• May represent an oversimplification of future water demand, as it does not account for changes in economic conditions (e.g. cost of water-efficient devices, household incomes) or for the evolution of technologies and plumbing code.	United Kingdom	Water security, Cumulative Effects	Can be used as a screening tool for proponents and regulators for water taking permit applications. More appropriate for use in urban settings with municipal water distribution systems, and where local-scale data is available on demographics and water usage.
Integrated Climate and Land Use Scenarios (ICLUS) Version 2 - U.S. EPA. (1,5,6,7) ICLUS (Version 1) is a land change modeling project that examines future changes in population, housing density and impervious surfaces in the U.S., and which developed nationwide housing development scenarios to 2100. Version 2 of the ICLUS project added dynamic climate variables and human migration to the demographic model.	The approach itself does not model effects to water resources, but it has been used in combination with watershed models to model climate change impacts on water quantity.	Accounts for climate change, growth in commercial and industrial land uses, urban growth, and land cover.	Developed for research purposes, but could potentially be used for urban planning.	• Provides spatially-continuous coverage of the conterminous U.S. • Projections are in 5-year time steps until 2100.	Requires • Census data • Climate data • Land cover/land use data	Requires the use of: • Climate models (First Institute of Oceanography-Earth System Model (FIO-ESM) and Hadley Global Environment Model 2 Atmosphere-Ocean (HadGEM2-AO)) • Spatial allocation model (land use, housing density) • Migration model	• Projections of population and land-use are based on the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios. • Output is a user-friendly interactive map available online to the public. • Provides spatially continuous output • Can be used in combination with watershed models to conduct water quantity assessments of different future climate, population growth and land use scenarios.	• Data-heavy • Not yet adapted to model GW supplies	United States	Cumulative Effects	Interactive and publicly-available mapping provides transparency and credibility to the public. Can provide projections for areas with limited data. May be used in Ontario to provide insight on future trends in land use, climate and population at the regional/provincial scale. May be less appropriate for site-specific water management decisions.

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