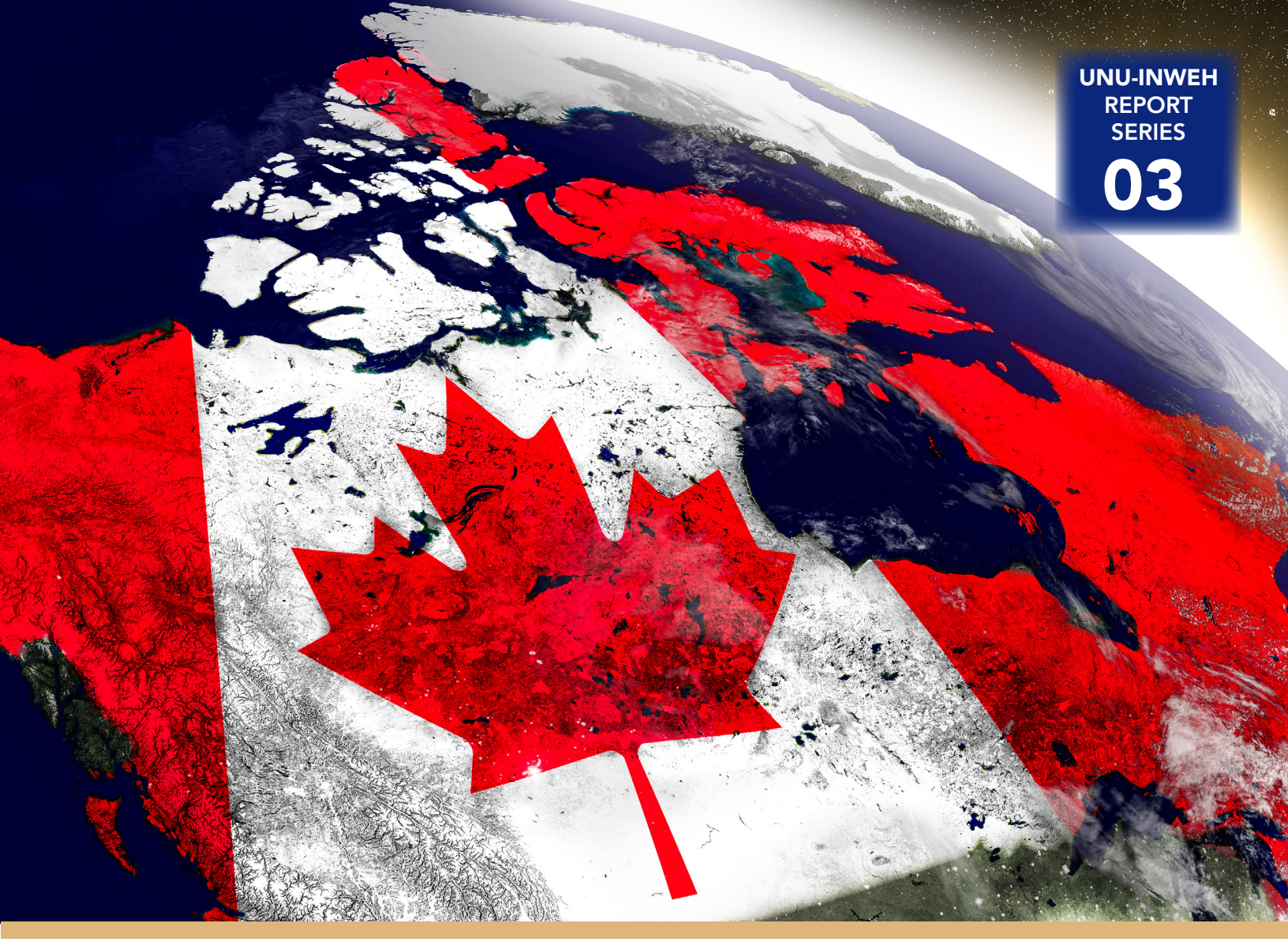

UNU-INWEH
REPORT
SERIES
03

Canada in the Global Water World: Analysis of Capabilities

Robert Sandford, Vladimir Smakhtin, Colin Mayfield, Hamid Mehmood, John Pomeroy, Chris DeBeer, Phani Adapa, Kerry Freek, Evan Pilkington, Raad Seraj, Russel Boals, Christine O'Grady, Charlotte MacAlister, Merrell-Ann Phare, Michael Miltenberger, Victoria Goodday, Anne Levesque, Allen Curry, Karen Kun, Matthew Gouett, Mark Fisher

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UNU-INWEH Report Series
Issue 03

Canada in the Global Water World: Analysis of Capabilities

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ACRONYMS

ARWU	Academic Ranking of World Universities
BOREAS	Boreal Ecosystem-Atmosphere Study
CCME	Canadian Council of Ministers of the Environment
CCRN	Changing Cold Regions Network
CEGEP	Collège d'enseignement général et professionnel in Quebec; (General and Vocational College)
CFCAS	Canadian Foundation for Climate and Atmospheric Sciences
CFI	Canada Foundation for Innovation
CIHR	Canadian Institutes of Health Research
CRC	Canada Research Chair program
CWRA	Canadian Water Resources Association
DRI	Drought Research Initiative
ECCC	Environment & Climate Change Canada
FCM	Federation of Canadian Municipalities
FSDS	Federal Sustainable Development Strategy for Canada
GAC	Global Affairs Canada
GEWEX	Global Energy and Water Exchanges Project
GLWQA	Great Lakes Water Quality Agreement)
GWF	Global Water Futures Program
HLPF	High-Level Political Forum
HLPW	High-Level Panel on Water
IP3	Improved Processes and Parameterization for Prediction in Cold Regions Hydrology Network
IPY	International Polar Year
IDRC	International Development Research Centre
IWRM	Integrated Water Resource Management
MAGS	Mackenzie Global Energy and Water and Exchanges Study
NSERC	Natural Sciences and Engineering Research Council of Canada
SDG	Sustainable Development Goal
SDG 6	Sustainable Development Goal 6, which pertains to water
SSHRC	Social Sciences and Humanities Research Council of Canada
WC^2N	Western Canadian Cryospheric Network
WCRP	World Climate Research Program
WSC	Water Survey of Canada

EXECUTIVE SUMMARY

This report critically examines, for the first time, the capacity of Canada's water sector with respect to meeting and helping other countries meet the water-related targets of the UN's global sustainable development agenda. Several components of this capacity are examined, including water education and research, investment in water projects that Canada makes internally and externally, and experiences in water technology and governance.

Analysis of the water education system suggests that there is a broad capability in institutions of higher learning in Canada to offer training in the diverse subject areas important in water. In most cases, however, this has not led to the establishment of specific water study programmes. Only a few universities provide integrated water education. There is a need for a comprehensive listing of water-related educational activities in universities and colleges — a useful resource for potential students and employers.

A review of recent Canadian water research directions and highlights reveals strong and diverse water research capacity and placed the country among global leaders in this field. Canada appears to be within the top 10 countries in terms of water research productivity (publications) and research impact (citations). Research capacity has been traditionally strong in the restoration and protection of the lakes, prediction of changes in climate, water and cryosphere (areas where water is in solid forms such as ice and snow), prediction and management of floods and droughts. There is also a range of other strong water research directions.

Canada is not among the top 10 global water aid donors in absolute dollar numbers; the forerunners are, as a rule, the countries with higher GDP per capita. Canadian investments in Africa water development were consistently higher over the years than investments in other regions of the global South. The contributions dropped significantly in recent years overall, also with a decline in aid flow to Africa. Given government support for the right business model and access to resources, there is significant capacity within the Canadian water sector to deliver water technology projects with effective sustainable outcomes for the developing world.

The report recommends several potential avenues to elevate Canada's role on the global water stage, i.e. innovative, diverse and specific approaches such as

- developing a national inventory of available water professional capacity, and ranking Universities on the strength of their water programmes
- coordinating national contributions to global sustainability processes around the largest ever university-led water research programme in the world – the 7-year Global Water Futures program
- targeting specific developmental or regional challenges through overseas development aid to achieve quick wins that may require only modest investments
- resolving such chronic internal water challenges as water supply and sanitation of First Nations, and illustrating how this can be achieved within a limited period with good will
- strengthening and expanding links with UN-Water and other UN organisations involved in global water policy work

To improve water management at home, and to promote water Canadian competence abroad, the diverse efforts of the country's water sector need better coordination. There is a significant role for government at all levels, but especially federally, in this process.

Keywords: *Sustainable Development Goals, water education, water research, water-related investments, water governance, water technologies, water security*

INTRODUCTION

The 2018 was a year of extraordinary global water events. The High-Level Panel on Water (HLPW)[1] convened by UN and the World Bank Group, and composed of 11 sitting Heads of State, released an open letter to fellow leaders, an outcome document, and short summaries of key initiatives. The HLPW outcome document (HLPW, 2018) presented key recommendations and a foundation for action, focusing on data, value, and water governance, setting up an integrated water action agenda at local, country and regional levels (encompassing water access, disaster risk reduction, water infrastructure, environment and human settlements), and catalysing partnerships and international cooperation to reduce the potential for water conflict.

Subsequently, the UN General Assembly launched the second UN Decade of Action (2018-2028) with the theme of "Water for Sustainable Development." This event followed the earlier adopted UN resolution on the Water Decade, supported by 177 UN Member States[2].

Both events occurred against the backdrop of on-going (in its third year) global sustainability effort – the implementation of the UN's 2030 Agenda - Sustainable Development Goals (SDGs)[3], which has a dedicated water goal — SDG6 — with many strong links to water contained in other SDGs (UN-Water, 2016). SDG6 itself is a revolutionary step forward in the global water development agenda. For the first time, it addresses not just the grand challenges of universal access to water and sanitation, but also the issues of resource management, efficiency and freshwater ecosystems. Other individual targets under SDG6 include expanding international cooperation and capacity and building support to developing nations in water and sanitation-related programmes.

The High-Level Political Forum (HLPF) held in July 2018, reviewed, amongst others, global progress towards SDG6, and expressed concern that this progress is slow and that the goal may not be met (UN-Water, 2018). These developments are a call for and an opportunity to individual UN Member States to take a pro-active position in resolving their own water challenges and helping others to resolve theirs, thus contributing to a more water-secure future.

Water is a defining characteristic of Canada. National statistics show mean annual water flow from 1971 to 2013 was 3,478 km³ (3rd in the world), while per capita availability is 104,000 m³ (2nd among developed countries).

On an average annual basis, Canadian rivers discharge an estimated 9% of the world's renewable water supply; and almost 9%, or 891,163 km², of Canada's total area is covered by fresh water. Canadians, meanwhile, represent under 1% of the world's population[4].

Canada's wetlands cover more than 1.2 million km²— about 14% of the country — and represent roughly 25% of the world's wetlands, making Canada the largest nation for wetlands (ECCC, 2013a).

Mean annual groundwater resources in Canada is estimated at 380 km³ (Geological Survey of Canada, 2014) and some 8.9 million Canadians, around 30% of the population, rely on groundwater for domestic use (ECCC, 2013b).

In 2013, water withdrawals for economic and household activities totaled 37.9 km³- i.e. around 1% of Canada's water resources[5]. This is one of the lowest levels in the world to date.

Canada's main water users in 2013 were electric power generation, transmission and distribution (68%), manufacturing (10%), households (9%), agriculture (5%) and mining and oil and gas extraction (3%). Total household water use was around 3.2 km³ in 2013, down 16% compared to 2005, while on a per capita basis water use has dropped from approximately 330 L/person/day to 250 L/person/day. However, pressures on water resources vary greatly across the country. Approximately 60% of Canada's fresh water drains north, i.e. away from the 85% of the population that lives within 300 km of the southern border.

Given the importance of water to the economy of Canada and to the identity of Canadians, it is only logical that Canada demonstrate leadership in the global water agenda. Canada has already committed to implementing the SDGs, including SDG6. The Federal Sustainable Development Strategy (FSDS; GoC, 2016) establishes goals and targets aimed at promoting clean growth, ensuring healthy ecosystems and building safe, secure communities. Of the 13 goals of FSDS, six relate directly and four relate indirectly to water. Implementing FSDS priorities as they relate to water, however, have yet to be embraced as standard practice.

[1] https://sustainabledevelopment.un.org/HLPWater
[2] http://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/71/222
[3] https://sustainabledevelopment.un.org/post2015/transformingourworld
[4] https://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/selected-thematic-maps/16888
[5] http://www.statcan.gc.ca/pub/16-201-x/16-201-x2017000-eng.htm

Other countries are attempting, in various ways, to position themselves more prominently on the global water stage. Tajikistan, for example, led the development of the UN Resolution for and subsequent launch of the Water Action Decade for Sustainable Development (2018-2028), and is hosting a regular high-level water conference (similarly to Hungary's regular Water Summit in Budapest). Japan and Germany are the top investors (in absolute terms) in water development aid.

A recently released US Global Water Strategy (US Government, 2017) explicitly recognises that a growing global water crisis may undermine economic growth, foster insecurity and state failure, and have adverse impact on US national interests. To address this global challenge, the US will aim to increase sustainable access to safe drinking water and sanitation services; encourage the sound management and protection of freshwater resources; promote cooperation on shared waters, and strengthen water-sector governance, financing, and institutions. The US will provide technical assistance; make targeted investments in sustainable infrastructure and services; promote science, technology and information; mobilise financial resources; engage diplomatically; and strengthen partnerships and intergovernmental organizations. Implementation of this Strategy will be coordinated through an Interagency Water Working Group comprised of representatives from 17 different US federal agencies.

While Canada does not need to follow the paths of other UN member states, it makes sense to define and coordinate the Country's own approach to achieve better visibility and impact in the global water domain.

The aim of this report is to examine, in factual and numerical terms, the capabilities of Canada's water sector and ways in which they can help Canada play a more prominent and unique global role. These capabilities have not previously been properly quantified and evaluated or widely profiled. This report examines several dimensions of Canada's contributions and capacities, including water education and research, internal and external water project investments, and water technology and governance experiences.

The report is targeted at

- water professionals in Canada looking for a synthesis of such information to better position their contribution to water-related SDGs in Canada and globally
- policy makers, including ministerial personnel tasked with implementation of the SDGs
- politicians, including Members of Parliament interested in promoting Canadian visibility on the global water stage
- educators in the water sector looking for better alignment of water programs with global sustainable development processes
- Canadian donors, development agencies and private foundations sponsoring water research and development projects outside of Canada
- environmental journalists concerned with trends in the global water sector, and
- citizens interested in Canadian and global water issues and challenges.

WATER EDUCATION

Education in Canada is a provincial responsibility and so varies between provinces.

This is most marked between Quebec and the other provinces since Quebec has the CEGEP (Collège d'enseignement général et professionnel) as a step between high school and university. The CEGEP is a post-secondary education collegiate; a CEGEP Diploma of College Studies is required for university admission (except for mature students). In most other respects there is a great deal of similarity between programs in all provinces. There were 1.7 million students (1,016,000 full-time and 290,000 part-time) in Canadian universities in 2016[6].

Three- or four-year university courses lead to baccalaureate degrees and can be followed by postgraduate degrees (e.g. M.A., M.Sc., M.Eng. and Ph.D.) with (typically) 2 years of study for a Master's qualification and a further 3 or 4 years for a Ph.D.

Unlike universities, colleges cannot usually grant degrees, although some may be enabled to do so by provincial legislation, by specific permission of the provincial Minister of Education, or by cooperation with universities. Their programs are often more technical in nature and provide specialied professional or vocational education in a wide range of employment fields.

Universities

Water education at universities is distributed over a wide range of departments, faculties, institutes and specialised units. The most direct involvement of universities in water issues is probably in Civil Engineering — most such departments have modules or sections of programmes on water and waste water treatment and often also deal with hydraulics, hydrogeology and hydrology. There are also geotechnical and biological specialities in some

[6]http://www.canadian-universities.net/Community-Colleges/index.html

universities in engineering or in science faculties that also encompass water issues.

A survey of Canadian universities shows that water-related programs are spread out between diverse departments and faculties. Table 1 lists identified baccalaureate degree programs with a strong water-related emphasis. While there are undoubtedly other programs that might claim a certain level of focus on water, Table 1 offers an idea of the range of water-related baccalaureate degrees throughout Canada. Similarly, at the postgraduate level, there is a number of water-focused Master's and Ph.D programmes (Tables 2 and 3).

Postgraduate degrees listed in Tables 2 and 3, both at the Master's and Ph.D. level, were those where a focus on water was claimed, as listed in the graduate documentation. There are many research projects on water issues by individual faculty members at most universities, but they would not be captured using this approach.

In addition to these postgraduate degrees, there are a few certificate and diploma programmes for postgraduate students. Examples include

- McMaster University (ON): Graduate Diploma - Water Without Borders programme
- University of Guelph (ON): i) Graduate Diploma in Engineering Design of Sustainable Water Resource Systems; ii) Graduate Diploma in Modeling Applications in Water Resources Engineering
- Université du Québec à Rimouski (Quebec): i) Diplôme d'études supérieures spécialisées (DESS) en gestion des ressources maritimes; ii) Diplôme d'études supérieures spécialisées en océanographie appliquée.

As a rule, these programs are very specialised and of shorter duration than a typical graduate degree.

The most common feature of water-related university programs, both undergraduate and postgraduate, is that they are given at the department level (biology, civil engineering, etc.) and retain many aspects of the traditional programs in those departments with the addition of water-related topics.

It is challenging to parse the multiple and complex skills requirements into a defined set of courses or programmes at universities or colleges, whether in Canada or in any other country. The range of expertise required to fully deal with the various water issues is very broad. It should include the management and operations of water supply, water quality, source water protection, water and wastewater treatment, integrated water resource management, public health, economic and legal issues, incorporation of indigenous knowledge and sociological and governance issues. Integrated Water Resources Management (IWRM) requires integration of these topics. One example of an integration attempt is the UN online Water Learning Centre[7]. It provides a "core curriculum" in the various aspects of IWRM through several regional centers throughout the world and is targeting practitioners (usually with a degree already) from diverse fields, so that they can interact and communicate based on that shared common knowledge.

Presence of a water-related research institute in a university is another proxy for a strong nucleus of water expertise. A research institute is defined as a separate or arms-length organizational body created around a certain purpose related to water science, management or policy. While the mandate of such institutes is primarily research, some of them also focus on education. Institutes can take a form of a group of departments or be an autonomous inter-disciplinary legal entity. Canada's major research institutes / centers are listed in Table 4.

There are other examples of group water research at universities. They often are very specialised or not organised into a centre or institute. A nation-wide Canadian Water Network[8] connects university researchers with similar interests throughout the country working on four focus topics: Blue Cities, Energy and Resources, Agriculture and Water, and Small and Indigenous Communities.

At the undergraduate level, every comprehensive, medical and primarily undergraduate university, as defined by Maclean's magazine, has some form of biology or biological sciences unit[9]. All 37 universities that have medical programs also have an engineering faculty. Because of the presence of these faculties in many universities there is a broad capability in institutions of higher learning in Canada to offer training in the diverse subject areas important to the water sector but in most cases, this has not led to the establishment of specific programs of study in water. Only a few universities are providing integrated water education at the undergraduate level (e.g. BSc in Freshwater Science at University of British Columbia, BA in Aquatic Resources at St. Francis Xavier University, Nova Scotia,

[7] http://wlc.unu.edu/
[8] http://www.cwn-rce.ca/
[9] https://www.macleans.ca/education/university-rankings/university-rankings-2018/

*Table 1: Water-related baccalaureate degree programmes in Canadian Universities**

Degree	University, Province
B.Sc. in Freshwater Science	University of British Columbia (Okanagan); BC
B.Sc. Honours in Environmental Science	Simon Fraser University, BC
B.Sc. in Geography (Land & Water Management)	Brandon University, Manitoba
B.Sc. in Environmental Science (Land & Water Stream)	Brandon University, Manitoba
B.Sc. in Environment and Natural Resources	University of New Brunswick, New Brunswick
B.A. in Aquatic Resources	St. Francis Xavier University, Nova Scotia
B.Sc. in Environmental Sciences	St. Francis Xavier University, Nova Scotia
Honours B.Sc. (Water Resource Science)	Lakehead University, ON
Honours B.Sc. (Water Resource Science) in Applied Environmental Water Management	Lakehead University, ON
B.Eng. in engineering and management in civil engineering	McMaster University, ON
B.Eng. in civil engineering	McMaster University, ON
Bachelor of Engineering and Society (in civil engineering)	McMaster University, ON
B.A. in Geography	Queen's University, ON
B.Sc. in Geography	Queen's University, ON
B.A. (Honours) in Geography	Queen's University, ON
B.Sc. (Honours) in Geography	Queen's University, ON
B.A. in Geography	Queen's University, ON
B.Sc. in Geography	Queen's University, ON
B.Sc. Honours in Water Sciences	Trent University, ON
B.Eng. in water resources engineering	University of Guelph, ON
B.A.Sc. in Civil Engineering	University of Ottawa, ON
B.Sc. in Environmental Science (Major, Minor)	University of Toronto, ON
B.A.Sc in Management Engineering or Civil Engineering or Chemical Engineering, or Electrical Engineering or Systems Design Engineering or Computer Engineering or Mechanical Engineering or Nanotechnology Engineering or Environmental Engineering or Biomedical Engineering or Mechanotronics Engineering. All labelled as "Water"	University of Waterloo, ON
Bachelor of Software Engineering (BSE) Labelled as "Water"	University of Waterloo, ON
B.Sc in Applied Water Science	Wilfrid Laurier University, ON
B.Sc. in Applied Water Science (Hons/4-year)	Wilfrid Laurier University, ON
Baccalauréat en génie des eaux (B. Ing.)	Université Laval, Quebec
B.Sc. in Environmental Earth Science (Water Science Minor)	University of Saskatchewan

**B.Sc.- Bachelor of Science; B.A.- Bachelor of Arts, B.Eng. –Bachelor of Engineering, B.A.Sc -Bachelor of Applied Sciences*

*Table 2: Water-related Masters' programs in Canadian Universities**

Degree	University, Province
M.Sc. - Civil and Environmental Engineering	University of Alberta, Alberta
M.Eng. - Civil and Environmental Engineering	University of Alberta, Alberta
M.Sc .- Civil Engineering	University of Calgary, Alberta
Master of Land and Water Systems (Vancouver)	University of British Columbia, BC
M.Eng. - Leadership in Integrated Water Management	University of British Columbia, BC
M.Sc. - Earth and Ocean Sciences	University of Victoria, BC
M.Sc. - Marine Biology and Environmental Biology	University of New Brunswick, New Brunswick
Master of Marine Studies (marine spatial planning & management)	Memorial University of Newfoundland; Newfoundland and Labrador
Master of Marine Management	Dalhousie University, Nova Scotia
M.Sc. Oceanography	Dalhousie University, Nova Scotia
M.A.Sc.and M.Eng. - Wastewater Treatment Engineering/Water Resources/ Environmental Information Systems	McMaster University, ON
M.Sc. - Hydrotechnical and Environmental Civil Engineering	Queen's University, ON
M.Sc. in Environmental and Life Sciences	Trent University, ON
M.A.Sc. and MEng in Engineering	University of Guelph, ON
M.A.Sc.- Water and Waste Processing	University of Ottawa, ON
M.Eng. - Water Resources Engineering	University of Ottawa, ON
M.A.- Geography or Economics	University of Waterloo, ON
M.Sc .-Geography, or Biology or Earth Sciences or Public Health and Water Systems	University of Waterloo, ON
M.A.Sc.- Civil Engineering or Chemical Engineering	University of Waterloo, ON
Master of Architecture (M. Arch.) - Water	University of Waterloo, ON
M.Math. -Applied Mathematics	University of Waterloo, ON
M.E.S - Social and Ecological Sustainability or Geography or Sustainability Management	University of Waterloo, ON
M.Eng.- Civil Engineering	University of Windsor, ON
M.E.Sc, M.Eng. - Civil and Environmental Engineering	Western University, ON
M.Eng. M.A.Sc. - Civil Engineering	Concordia University, Quebec
M.Eng. and M.Sc. - Hydraulic and Water Resources Engineering	McGill University, Quebec
M.Sc. en gestion des ressources maritimes	Université du Québec à Rimouski, Quebec
M.Sc. en sciences de l'eau	Université du Québec – INRS; Quebec
Maîtrise en génie des eaux - avec mémoire (M. Sc.)	Université Laval, Quebec
Maîtrise en génie civil: Systèmes hydrauliques et ressources hydriques	Universite de Sherbrooke; Quebec
Master's in Oceanography, Master's in Maritime Resource management	Université du Québec à Rimouski; Quebec
M.A.Sc, M.Eng - Environmental Systems Engineering -Water and Wastewater treatment, groundwater contamination and geotechnical engineering	University of Regina, Saskatchewan
M.E.S, M.Sc and Master of Water Security (MWS); M.Sc. in Geography	University of Saskatchewan; Saskatchewan

**Note: M.Sc.- Master of Science; M.A.- Master of Arts, M. Eng – Master of Engineering, M.A.Sc..-Master of Applied Sciences, M.E.S. - Master of Environmental Studies; M.E.Sc.- Master of Environmental Sciences; M.Arch. –Master of Architecture*

Table 3: Water-related Ph.D. programs in Canadian Universities

Degree	University, Province
Ph.D. - Civil and Environmental Engineering	University of Alberta, Alberta
Ph.D. –Water Resources Engineering	University of Calgary, Alberta
Ph.D. - Geological Engineering and Oceans and Fisheries	University of British Columbia, BC
Ph.D. – Earth and Ocean Sciences	University of Victoria, BC
Ph.D. - Marine Biology	University of New Brunswick, New Brunswick
Ph.D. - Civil Engineering - Environmental Engineering	Carleton University, ON
Ph.D. - Civil Engineering, Water Resources	Carleton University, ON
Ph.D. – Hydrotechnical and Environmental Civil Engineering	Queen's University, ON
Ph.D. - Environmental and Life Sciences	Trent University, ON
Ph.D. Engineering	University of Guelph, ON
Ph.D. in Biology, or Geography or Applied Economics or Applied Mathematics or Earth Sciences or Chemical Engineering or Civil Engineering or Social and Ecological Stability or Public Health and Health Systems	University of Waterloo, ON
Ph.D. – Environmental and Water Resources	Western University, ON
Ph.D. – Chemical and Biochemical Engineering – Water and Energy	Western University, ON
Ph.D. – Civil Engineering – Water Resource Engineering	Western University, ON
Ph.D. in Civil Engineering – Water Resources	Concordia University, Quebec
Ph.D. Civil Engineering – Hydraulics and Water Resources Engineering	McGill University; Quebec
Doctorat en génie civil: Systèmes hydrauliques et ressources hydriques	Université de Sherbrooke; Quebec
Doctorat en génie des eaux (Ph. D.)	Université Laval; Quebec
Ph.D. en sciences de l'eau	Université du Québec – INRS; Quebec
Ph.D. en gestion des ressources maritimes	Université du Québec à Rimouski; Quebec
Ph.D. Océanographie	Université du Québec à Rimouski; Quebec
Ph.D. in Environmental Systems Engineering (EVSE) in water and wastewater treatment, ground-water contamination or geotechnical engineering	University of Regina; Saskatchewan
Ph.D. in Environment and Sustainability; Ph.D. in Geography	University of Saskatchewan; Saskatchewan

Table 4: Water Research Institutes and Centres in Canadian Universities

Institute / Center	University, Province
Water Institute for Sustainable Environments	University of Lethbridge, Alberta
Centre for Coastal Science and Management - Pacific Water Research Centre	Simon Fraser University, British Columbia
Institute for the Oceans and Fisheries - Institute for Resources, Environment and Sustainability	University of British Columbia, British Columbia
Water & Climate Impacts Research Centre	University of Victoria, British Columbia
Marine Institute	Memorial University of Newfoundland, Newfoundland
Canadian Rivers Institute	University of New Brunswick, New Brunswick
Centre for Water Resources Studies	Dalhousie University, Nova Scotia
Global Water Institute	Carleton University, Ontario
Ryerson Urban Water	Ryerson University, Ontario
Institute for Watershed Science	Trent University, Ontario
Institute for Water Innovation	University of Toronto, Ontario
Water Institute	University of Waterloo, Ontario
Great Lakes Institute for Environmental Research	University of Windsor, Ontario
Laurier Institute for Water Science	Wilfrid Laurier University, Ontario
Concordia Institute for Water, Energy and Sustainable Systems	Concordia University, Quebec
Eau Terre Environnement	Institut national de la recherche scientifique (INRS) at l'Université Laval, Quebec
Centre for Hyrdology	University of Saskatchewan

*Table 5: Canadian and International rankings of the top Canadian Universities in 2018**

University	Shanghai Ranking		QS Ranking (International Only)	Maclean's Ranking** (Canadian only)
	Canadian	International		
University of Toronto	1	23	28	M2
University of British Columbia	2	43	47	M3
McGill University	3	70	33	M1
McMaster University	4	86	146	M6
University of Alberta	5-6	101-150	109	M5
University of Montreal	5-6	101-150	149	M11
The University of Calgary	7-9	151-200	239	M9
University of Ottawa	7-9	151-200	289	M9
University of Waterloo	7-9	151-200	163	C3
Laval University	10-12	201-300	402	M12
Queen's University	10-12	201-300	239	M4
Western University	10-12	201-300	214	M7
Dalhousie University	13-18	301-400	279	M8
Simon Fraser University	13-18	301-400	264	C1
University of Guelph	13-18	301-400	581-590	C4
University of Manitoba	13-18	301-400	601-650	M14
University of Saskatchewan	13-18	301-400	461	M15
University of Victoria	13-18	301-400	359	C2
York University	-	401-500 (2014)	481	C8
Université du Quebec à Montréal	-	301-400 (2016)	541-550	C12
Concordia University	-	401-500 (2017)	461	C10
Carleton University	-	401-500 (2015)	651-700	C5

**Note: Some Universities were last ranked in Shanghai system in a different year (given in parentheses). In such cases, the corresponding Canadian rank for 2018 was left blank;*

***Note: C=Comprehensive university; M= Medical university; Number = rank within category*

BSc in Applied Water Science at Wilfrid Laurier University, BSc in Water Science at Trent University, and Baccalauréat en génie des eaux (B. Ing.) at Université Laval, Quebec).

The international standing of Canadian universities is reasonable, considering the very large number of well-established universities around the world (Table 5). Nine out of 10 Canadian provinces have universities placed in international rankings, with Prince Edward Island being the only province with an unranked university. There are 19 Canadian universities in the top 500 in the world assembled by the Shanghai Academic Ranking of World Universities (ARWU)[10]. The ARWU uses six objective indicators to rank world universities, including the number of alumni and staff winning Nobel Prizes and Fields Medals, number of highly-cited researchers selected by Clarivate Analytics, number of articles published in journals of Nature and Science, number of articles indexed in Science Citation Index - Expanded and Social Sciences Citation Index, and per capita performance of a university. More than 1,200 universities are ranked by ARWU every year; the best 500 are published.

The Quacquarelli Symonds (QS) global ranking of Canadian universities is presented along with the ARWU rankings in Table 5[11]. The large differences in rankings by different sources reflect the different criteria used.

ARWU also ranks universities by subject area, using the similar criteria as above, but derived only from units involved in that subject. For "water studies," the University of Saskatchewan ranked 18th, the University of Waterloo 32nd, the University of British Columbia 49th and McGill University 51st to 75th, the University of Guelph 76th to 100th, and both Laval University and McMaster University ranked between 101st to 150th. Globally, the top three universities in water studies were the University of Arizona, the Swiss Federal Institute of Technology at Zurich, and the Delft University of Technology.

Although some agencies, such as ARWU, rank university water studies, they examine only the top universities in the world as determined by their criteria. It is probable that many universities with excellent water studies do not appear in the general listing and so are not eligible for ranking on their water studies programs. Also, the ranking system is typically based on an amalgam of numbers and quality assessments of papers, numbers of internationally recognised award winners, quality and impact of journals used, and similar measures. These may not be relevant or appropriate for the water sector. For these reasons it is important to develop specific and widely accepted measures of quality and impact of water researchers and educators. These assessments could be based on criteria such as the publication of material in the best water-related journals, awards and honours bestowed by organizations in the water sector, international and national impact of publications on the water sector, and others.

Colleges

Canada has 146 colleges and CEGEPs in 115 towns and cities covering 13 provinces and territories[12]. In colleges, water-related education is typically directed towards specific skills such as water supply management, waste treatment, distribution technologies, etc., usually involving training in the operational and management aspects of these areas. A random survey of 50 colleges from all provinces suggests that almost none has a speciality in water technology or similar training. Only a few have civil engineering diplomas or programs that include such topics. For example, Okanagan College in British Columbia offers a Water Engineering Technology Diploma.

General programmes in biology and environmental technologies are more common but almost none specify an emphasis on water. One reason for this dearth of specific programs may be a lack of demand from students, industry, or the largely municipally-governed water and wastewater treatment operations. Another reason may be that operators and practitioners in those operations may be trained by the operators themselves or by regional or provincial training systems. For example, the Walkerton Clean Water Centre in Ontario performs training for all aspects of drinking water plant operations and operators are required to have the certification and to pass mandatory renewal programmes[13]. An entry-level course for drinking water plant operators is available at several Ontario colleges. A similar process for wastewater treatment plant operators is managed by the Ontario Water Wastewater Certification Office (OWWCO). Operator certification in British Columbia is by the Environmental Operators Certificate Program. Similar programmes are offered at the Northern Alberta Institute of Technology (NAIT) in the form of specialization certificates in water treatment, wastewater treatment, and water distribution. Many other entities offer certificates in these areas.

[10] http://www.shanghairanking.com/aboutarwu.html
[11] The ranking cycle starts in June of a current year and ends at the end of May the following year: https://www.topuniversities.com/university-rankings/world-university-rankings/2019
[12] http://www.canadian-universities.net/Community-Colleges/index.html
[13] https://www.wcwc.ca/en/

Enhancing water education

In summary, the water education establishment in Canada is represented by two distinct groups:

- Larger universities with engineering and science faculties, with other departments and faculties contributing to water education at the undergraduate level. Very few universities have dedicated undergraduate programs in water. At the graduate level the same is true but a few universities (e.g. Waterloo) are trying to achieve greater integration between faculties and departments in graduate water education. A significant number of university research centres and institutes in the country also engage in graduate education at the Master's and Ph.D. levels.
- Colleges and other institutions that are primarily engaged in technical and operational training for water and wastewater treatment and distribution facilities. The private sector, together with government-led or publicly funded units also plays a significant role in this type of training.

In general, Canadian universities have not yet developed well-integrated programs that address the many water problems and processes. There are very often "islands" within universities that address water-specific areas. Recently, some universities have begun to establish postgraduate-level water management programs, e.g. the Master of Engineering Leadership in Integrated Water Management at the University of British Columbia.

One problem of water education is its interdisciplinary nature, which translates into the requirement for many different skill sets. The advent of IWRM as the "model of choice" for water management has only highlighted the problems. Models for education that take these difficulties into account are needed and early attempts have shown that they can be effective; the multi-faculty cooperation in the graduate-level water programs at the University of Waterloo is but one example.

Universities could enhance water education by developing more programs with an undergraduate specialization in water management, and by fostering more interdisciplinary and multidisciplinary graduate-level studies. Both have inherent problems: an undergraduate programme might have to be so generic in nature to cover all of the topics involved that it could become impractical or of insufficient rigour. Graduate programs rely on students having additional courses and experiences over and above their normal research activities and so might not be of sufficient depth or scope. A third option is to have a professional qualification (diploma, degree, certificate) in, for instance, the theory and practice of water management, to be completed after an undergraduate or graduate programme in a water-related topic. This could be made more generic by including essential information from many areas in the water sector so that the knowledge base and communication between water practitioners is improved.

There is a need for an organised and comprehensive listing of water-related educational activities in universities and colleges to identify, fully describe and collate these activities An available listing of the courses, programs, number of graduating students, postgraduate positions, specializations and collaborative activities in the education water sector would be useful for potential students navigating their way through the complex mix of water-related studies and for potential employers seeking qualified personnel.

WATER RESEARCH

Funding sources and programmes

The major federal funders of water research in Canada include the Canadian Institutes of Health Research (CIHR); the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Social Sciences and Humanities Research Council of Canada (SSHRC), collectively known as the Tri-Council. In addition, the Canada Foundation for Innovation (CFI) makes financial contributions to Canada's universities, colleges, research hospitals and non-profit research organizations to increase their capability to carry out high quality research.

The collective mission of CIHR, composed of 13 Institutes, is to create new scientific knowledge to enable its translation into improved health, more effective health services and products, and to strengthen Canada's health care system. CIHR's Institutes are not buildings or research centres, but networks of researchers brought together to focus on health problems. The two institutes whose research overlaps into water issues are the Institute for Indigenous Peoples' Health and the Institute for the study of Infection and Immunity[14]. Applicants for SSHRC funding may collaborate with researchers in fields other than the social sciences and humanities, which may include water[15]. NSERC is the national focal point for discovery and innovation in natural sciences and engineering and, naturally, supports a range of water-related research in these domains. The CIRH, NSERC, SSHRC and CFI coordinate their programs and activities to implement the federal government's science and

[14] http://www.cihr-irsc.gc.ca/e/193.html
[15] http://www.sshrc-crsh.gc.ca/home-accueil-eng.aspx

technology strategy[16]. Water research in Canada is also funded by provincial and territorial governments, private foundations, corporations and non-governmental organisations (Morris, 2014).

Special funding programmes are also created occasionally by the federal government. For example, the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)[17] was the main funding body for university-based research on climate, atmosphere, water and the oceans. It was established in 2000 as an autonomous Foundation, with original budget of CDN $60 million from the Federal government, boosted by another $50 million in 2003. CFCAS supported 24 collaborative networks, two major initiatives, and 158 projects. Three networks conducted research specifically on water. The Foundation received no federal funding after 2003. Its research support ceased in 2010.

Other examples include the Canada First Research Excellence Fund (CFREF), which to date has dispersed around $1 billion to 13 initiatives[18], including one on Global Water Futures (see further), and Networks of Centers of Excellence[19], whereby some 40 networks are supported (although none yet with explicit water dimension).

The Canada Research Chair (CRC) program was established in 2000 by the Federal government to boost research and development excellence in Canadian post-secondary educational institutions. Annually, $300 million is spent through CRC to attract and retain outstanding scholars and scientists. Of the 2000 CRCs, 1880 are regular allocations, distributed by area of research with 733 Chairs (39%) in natural sciences and engineering; 733 Chairs (39%) in health and, 414 Chairs (22%) in the social sciences and humanities[20]. As of October 2018, there were 39 Tier 1 (world leaders in their research field), and 50 Tier 2 (emerging world leaders in the field) CRCs whose research focused specifically on water resources management hydrology, aquatic ecosystem dynamics, improved technologies, water security and governance.

Research foci and example initiatives

While a broad thematic range of water-related research is conducted in Canada, certain topics traditionally attract more attention. In both the US and Canada, significant effort and investments over decades went into researching various aspects of the Great Lakes. In 2005, the US released a strategy, developed with the engagement of some 1,500 stakeholders, to address threats to Great Lakes water quality, with an estimated implementation cost of US $20 billion. This resulted in the subsequent creation of the US Great Lakes' Restoration Initiative, resourced at approximately US $300 million annually. This has enabled US progress on shared commitments under the Canada - USA Great Lakes Water Quality Agreement[21]. Since 2010, the initiative's funding has supported 2,900 protection and restoration projects by federal and non-federal partners. Now in its second phase (2014-2019), the initiative has four priority action areas:

- cleaning up Great Lakes Areas of Concern
- preventing and controlling invasive species
- reducing nutrient run-off, and
- restoring habitat to protect native species.

The US administration's 2019 budget blueprint proposes a 90% reduction in the initiative's funding, although Congress has and will likely continue to preserve it at historical levels.

The Government of Canada also invests tens of millions of dollars into various programs and initiatives that contribute to the restoration and protection of the Great Lakes. National programs include the Chemicals Management Plan (CDN $490 million over the period of 2015-2020) and the Canada Infrastructure Plan ($180 billion over 2016-202l, including $26.9 billion to green infrastructure). Examples of regional initiatives include the Clean-up and Safe Management of Radioactive Waste near Port Hope ($1.28 billion over 2012-2022) and the Ontario component of Growing Forward 2 ($54.8 million over 2013-2018). Through Budget 2017, some $44.8 million of new investment was allocated for the Great Lakes Protection Initiative, targeting the greatest threats to lake water quality and ecosystem health, including:

- preventing algae by reducing phosphorus loading
- enhancing the resilience of Lakes' coastal wetlands to future projected changes
- evaluating and identifying at-risk nearshore waters
- reducing releases of harmful substances
- engaging Indigenous Peoples in addressing Great Lakes issues; and
- increasing public engagement through citizen science.

Priorities of the Great Lakes Protection Initiative are supported through a combination of national

[16] http://www.ic.gc.ca/eic/site/113.nsf/eng/h_07655.html
[17] http://www.cfcas.org/about/
[18] https://www.canada.ca/en/innovation-science-economic-development/news/2016/09/canada-first-research-excellence-fund.html
[19] http://www.nce-rce.gc.ca/NetworksCentres-CentresReseaux/Index_eng.asp
[20] http://www.chairs-chaires.gc.ca/program-programme/allocation-attribution-eng.aspx
[21] https://www.epa.gov/glwqa

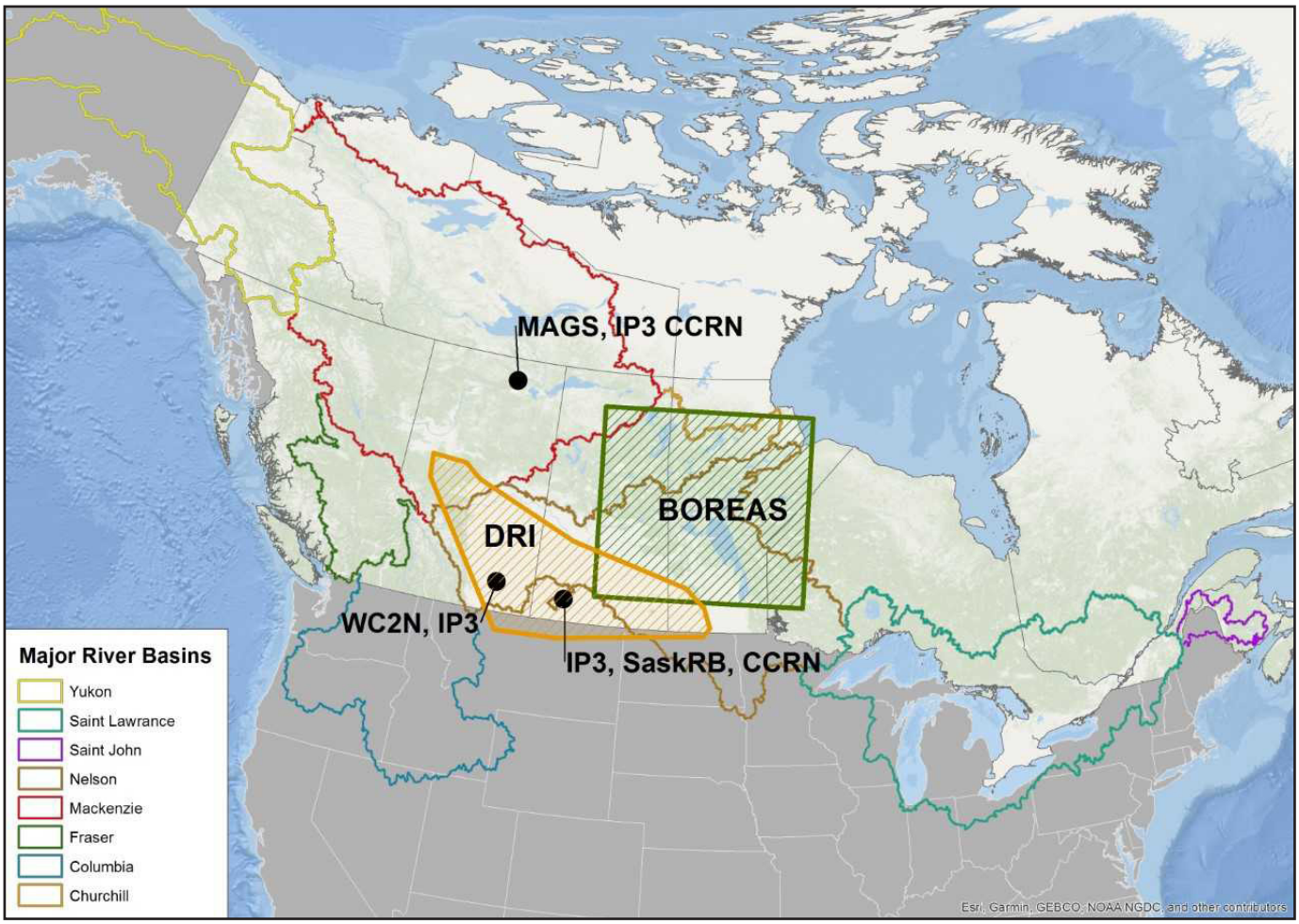


Figure 1: Locations and extent of various water and climate research initiatives of past decades. (Also shown: boundaries of the focal river basins of the Global Water Future Programme)

programmes outlined above. Budget 2017 also allocated new resources of $43.8 million over 5 years to Fisheries and Oceans Canada to address the threat of aquatic invasive species in the Great Lakes, the St. Lawrence River basin, and the Lake Winnipeg basin. In June 2017, through a joint investment of $57.5 million over the next five years, the federal government renewed its commitment to working collaboratively with Quebec to advance biodiversity conservation and sustainable use, and to improve water quality in the St. Lawrence River[22].

Northern and Western Canada have been the focus of numerous large-scale collaborative research initiatives aimed at improving the understanding and prediction of changes in climate, water and cryosphere (Figure 1). The first major effort focussed on the Mackenzie River Basin as a contribution to the Global Energy and Water cycle Exchanges (GEWEX)[23] project under the auspices of the World Climate Research Program (WCRP). The Mackenzie GEWEX Study (MAGS)[24] was a GEWEX regional project during 1994 - 2005 which produced the first comprehensive, large-scale assessment and synthesis of cold region atmospheric and hydrologic processes in northern Canada and contributed baseline data for parallel and subsequent research programs that continued to evolve, as described below, to this day (Stewart et al., 1998; Woo et al., 2008).

The Saskatchewan River Basin (SaskRB) project was a follow-up of MAGS aimed at creating modelling tools for basin-wide management under uncertain water futures. The project was subsequently expanded in 2013 to include the Mackenzie Basin. This fed into the Changing Cold Regions Network (CCRN, 2018) that was

[22] Most numbers quoted in this and preceding paragraphs are estimates of the Council of the Great Lakes Region or based on personal interviews with ECCC and US EPA. It is important to note, however, that these figures do not include investments by other federal departments in programmes that could directly or indirectly protect the quality of the Great Lakes
[23] https://www.gewex.org/about/
[24] www.usask.ca/geography/MAGS/

a five-year (2013–2018), $5 million Canadian research network aimed at integrating existing and new sources of data with improved predictive and observational tools to understand and predict interactions between the changing cryosphere, ecology, hydrology, and climate at multiple scales (DeBeer et al., 2015; 2016). The SaskRB and CCRN were led by the University of Saskatchewan's Global Institute for Water Security and Centre for Hydrology and involved over 45 scientists from eight Canadian universities and four Canadian federal government agencies. CCRN addressed issues of importance to Canada and the world, and has informed Canada's Federal, Provincial and Territorial governments, NASA and the Canadian Space Agency, the US National Center for Atmospheric Research, and the WCRP (CCRN, 2018).

The Boreal Ecosystem-Atmosphere Study[25] was a large-scale international initiative, funded by NASA, Environment Canada, and NSERC, focused on understanding exchanges of radiative energy, sensible heat, water, CO2, and other radiatively active trace gasses between the boreal forest and the lower atmosphere (Sellers et al., 1997; Hall, 1999). BOREAS was comprised of 85 science teams organised into six disciplinary groups, including one committed to hydrology. The study involved two intensive field campaigns in 1994 and 1996, with some infrastructure and reduced monitoring that continues today. BOREAS water-specific outcomes importantly demonstrated that resulting fluxes often lead to drier than expected atmospheric boundary layers, the hydrological implications of which were later seen in bigger, hotter, faster fires in the region. Understanding of the strong control of evapotranspiration in the biome led to better representation of this parameter in global climate models. BOREAS also generated new insights into the carbon cycle and its role in the global carbon budget and produced improved algorithms within climate and numerical weather prediction models.

The CFCAS-funded, Western Canadian Cryospheric Network[26] (WC²N - 2006-2011) focused on examining linkages between climatic change and Western Canada's glaciers. WC2N was a consortium of six Canadian and two American universities, as well as government and private scientists. Glaciers, well distributed in Western Canada, sensitive to changes in precipitation and temperature, and serve as frozen reservoirs of freshwater, and help understand past and present climate in the North Pacific region. This initiative provided important insights into the influence of the North Pacific climate system on glacier mass in the mountains of British Columbia (BC) and Alberta and led to the first complete glacier inventory and regional assessment of recent changes (Bolch et al., 2010). WC2N demonstrated that Canada may have lost some 300 glaciers in the mountain national parks region of the Rockies alone in the 85 years between 1920 and 2005. This loss is expected to continue with over 90% of the ice left in BC's interior ranges expected to disappear by the end of this century. The research conducted by WC2N continues to be used widely by BC Hydro and major water utilities and became the foundation for all subsequent glacial research conducted in Canada's western mountains.

The Improved Processes and Parameterization for Prediction in Cold Regions Hydrology Network (IP3) was another CFCAS-funded initiative in 2006-2010[27]. The prime objective of this network was to improve understanding of cold regions hydro-meteorology for prediction of ungauged basins, changes in snow and water supplies, and calculation of freshwater inputs to the Arctic Ocean. The IP3 network was composed of over 40 investigators and collaborators from Canada, the US, UK, and Germany. Improvement of the Cold Regions Hydrological Model (Pomeroy et al., 2007) was just one element of the research conducted by the IP3, that found many applications in Alberta, Saskatchewan, Manitoba, Yukon and Ontario for use in water resources assessments (Sandford, 2012).

Canada has been an active participant in major international water-related initiatives, including i) the International Polar Year (IPY) 2007-2008 – the largest-ever international research programme focusing on the Arctic and Antarctic regions, with thousands of scientists from more than 60 nations around the globe participating[28] and ii) the Prediction in Ungauged Basins (PUB) decade of the International Association of Hydrological Sciences (Pomeroy et al., 2013).

The Drought Research Initiative (DRI), a six-year (2005–2011) CFCAS-funded effort to better understand and predict Canadian Prairie droughts (Stewart et al., 2011; Hanesiak et al., 2011) was triggered by the 1999-2005 drought that affected agriculture, recreation, tourism, health, hydroelectricity and forestry. The drought contributed to negative or zero net farm income for several provinces for the first time in 25 years. Agricultural production across Canada fell an estimated $3.6 billion from peak years, Gross Domestic Product fell by approximately $5.8 billion, and more than 41,000 jobs were lost. Previously reliable water supplies such as

[25] http://daac.ornl.gov/BOREAS/bhs/BOREAS_Home.html
[26] http://wc2n.unbc.ca/
[27] http://www.usask.ca/ip3/
[28] http://www.api-ipy.gc.ca/pg_IPYAPI_016-eng.html

streams, wetlands, dugouts, reservoirs, and groundwater often failed. The DRI Network helped quantify the physical features of the recent drought; improved understanding of the processes and feedbacks governing the drought's formation, evolution, cessation, and structure, assessed and reduced uncertainties in drought prediction and its structure; compared similarities and differences of the recent drought to previous droughts of the region and others in the context of climate variability and change; and formulated lessons for mitigating future drought impacts.

An example of coordinated nation-wide research addressing another water extreme – floods – is the $5 million NSERC-funded FloodNet research Programme (2015-2019)[29]. FloodNet has the goals of radically advancing knowledge of flood regimes in the country, improving flood forecasting regionally and nationally. It is a multi-disciplinary research network, led by McMaster University. The collaboration between academic experts from 12 Canadian Universities, government scientists, and end-users (e.g., operational flood forecasters) is a key strength of FloodNet and will ensure that the new knowledge and technology developed will meet the user needs. Recommendations for enhancing flood forecasting and early warning systems (FFEWS) in Canada have been made before, but without concerted follow-up actions. The FloodNet program has already identified jurisdictional strengths and weaknesses and gaps in forecasting capacity across the country; important data needs, including more accurate precipitation, soil moisture and snow-water equivalent estimation; and appropriate automatic, integrated, real-time modelling tools and better communication between flood forecasting centres in provinces, with an ultimate goal of developing an integrated Canadian Adaptive Flood Forecasting and Early Warning System. In addition, students and post-doctoral fellows trained as part of the FloodNet research program will be uniquely and highly qualified to work in an area that is in high demand in the country. FloodNet is hence the response to the flood challenge in Canada.

A pioneering water research project was introduced by the Canadian Rivers Institute in 2018. New metrics are being developed and proposed that may help provide energy utilities around the world with the tools they need for making difficult decisions regarding dam renewals, i.e. should aging dams continue to operate or be decommissioned and removed? Helping governments and utilities make such decisions is a major and growing business worldwide. An estimated 80,000 large dams in the US alone are at or near the end of their design life. While Canada is not yet close to this point, breakthroughs in the science of dam renewal and removal could be of global relevance.

Global Water Futures

Global Water Futures (GWF)[30] is perhaps the most unique water-centric research initiative in Canada today and deserves a special word. The initial proposal for the program, led by the University of Saskatchewan in 2016 with key partners (University of Waterloo, Wilfrid Laurier University, and McMaster University), was approved by Canada First Research Excellence Fund for the seven-year period (2016-2023) to the level of $77.8 million. Together with contributions from the four partner institutions and other stakeholders, GWF is now a $290 million programme focused on water and climate challenges for Canada and for the cold regions of the world., which supply freshwater to over half of humanity. In total, GWF combines expertise from 18 Canadian universities and colleges, 39 federal and provincial government agencies, and 45 international institutions, is the largest university-led freshwater research project of its kind worldwide, and one of the largest water science collaborations in history.

GWF has three primary objectives:

- Deliver new capability for disaster warning to governments, communities and the public, including Canada's first national flood forecasting and seasonal flow forecasting systems, new drought warning capability, and water quality models and monitoring that warn of hazards to health and drinking water supply
- Diagnose and predict water and landscape futures in a changing climate, with information outputs tailored to user needs
- Develop new models, tools and approaches to manage water-related risks to multiple sectors, integrating natural sciences, engineering, and the social and health sciences, to deliver transformative decision-making tools for evidence-based responses to the world's changing cold regions.

To a large extent, the GWF defines Canada's current national water research agenda. GWF aims to provide global leadership in water science for cold regions and to address the strategic needs of the Canadian economy in adapting to change and managing the risks of uncertain water futures and extreme events. It builds on strengths in water security and cold-regions science, world-class research laboratories, and vast river basin observational sites in diverse ecosystems, with a community-centric scientific approach focused on those most affected, locally and downstream, by changes in cold regions.
The programme currently consists of 33 funded

[29] http://www.nsercfloodnet.ca/about
[30] http://www.nsercfloodnet.ca/about

pan-Canada projects and six core teams with over 850 participants, and it continues to build and expand nationally and internationally. In Canada, GWF focuses on major river basins and key ecological, climatological, and physiographic regions across the country (Figure 1), which are representative of the scientific and societal issues faced globally, and especially within "cold regions," where snow, ice, and frozen soils dominate water processes. Internationally, GWF is closely linked and contributes to many initiatives. Key partnerships include the Sustainable Water Futures Programme of Future Earth, UNESCO's International Hydrological Programme (IHP), the UN International Decade: Water for Sustainable Development, 2018–2028, and the WCRP and its GEWEX project. By 2023, GWF will deliver new scientific understanding, water data, monitoring technologies, and modelling tools to enable communities, industries and governments in Canada and the world to forecast, manage and make informed policy decisions in response to drought, flood, and water quality threats.

It is hoped that due to GWF, the integrated, high-resolution, pan-Canadian management of water will become possible within seven years. The GWF Program aims to position Canada as a global leader in water science for the world's cold regions, a global partner of choice for trans-disciplinary water research; and a provider for Canada and the world of strategic water management tools.

Research productivity and impact

The above review of recent Canadian water research directions, highlights and investments is hardly exhaustive. However, it reveals strong and diverse resident water research capacity that places the country among global leaders in this field.

Canada ranks high in water research productivity and impact. Figure 2 shows the top 10 countries by number of water-related publications in 2017; Figure 3 illustrates the same by the number of citations. This information was extracted, using over 1,000 water-related key words, from the Scopus database, which indexes the greatest number of water-related journals relative to other similar databases. While the numbers of publications and citations are not perfect performance statistics, they do point to Canada's high global visibility and impact in water research.

OVERSEAS DEVELOPMENT SUPPORT

Global security, and global water security, are in the interests of all nations. Preserving water security globally may be seen as a cornerstone of an equitable, prosperous future. Accordingly, Canada has been in the business of overseas development support for decades, providing direct aid, moderating conflicts, being an active member of UN and multilateral development banks, engaging Canadian consulting community in overseas projects, and by other means.

Winpenny et al. (2016) observed that official development finance to the water sector nearly tripled between 2003 and 2014, from an annual $6 billion to almost $18 billion. This increase coincided with implementation of the UN's Millennium Development Goals and the 2005-2015 International Decade of Action: "Water for Life." It was also noted that some 57% of all official water sector development financing was targeted to water supply and sanitation with the rest going to other subsectors, including IWRM, irrigation, hydroelectric power, and water resources policy and administrative management. The largest bilateral funders from 1995 to 2014 were Japan (averaging US $1.3 billion a year); Germany (averaging US $711 million a year); and the US (averaging US $494 million a year). Canada was not among the top 10 donors. The report further noted that even at its highest level of investments, in 2011, philanthropy contributed only about 2% of aid flows to the water sector, suggesting that much more can be done to direct private wealth toward achievement of SDG 6 and other related goals.

Some additional specific analysis of investments into overseas development aid has been done in the present report using the database of the Organisation for Economic Cooperation and Development Assistance Committee (OECD-DAC), the most comprehensive of the three databases also used by Winpenny et al. (2016). The OECD-DAC database is the source of information about Canadian investments overseas in various regions and countries over time. Figures 4 – 6 illustrate the structure and trends in Canadian contribution towards water-related development aid. Data for Canada include both International Development Research Centre (IDRC) and Global Affairs Canada (GAC) disbursements to developing countries, and cover the following categories:

- Water sector policy and administrative management
- Water resources conservation (including data collection)
- Water supply and sanitation - large systems
- Water supply - large systems
- Sanitation - large systems
- Basic drinking water supply and basic sanitation
- Basic drinking water supply
- Basic sanitation
- River basins' development
- Education and training in water supply and sanitation

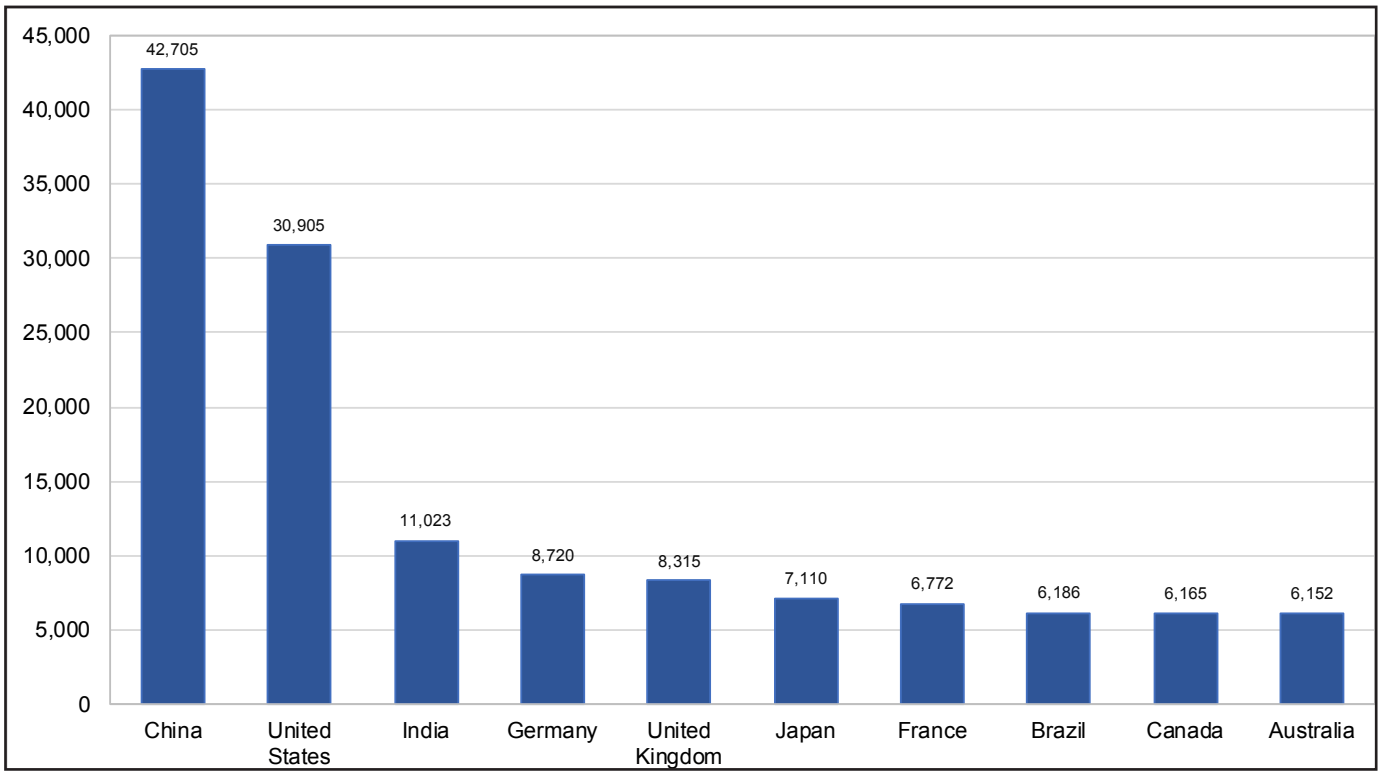


Figure 2: Top 10 countries by number of water-related publications; 2017. Data source: Scopus

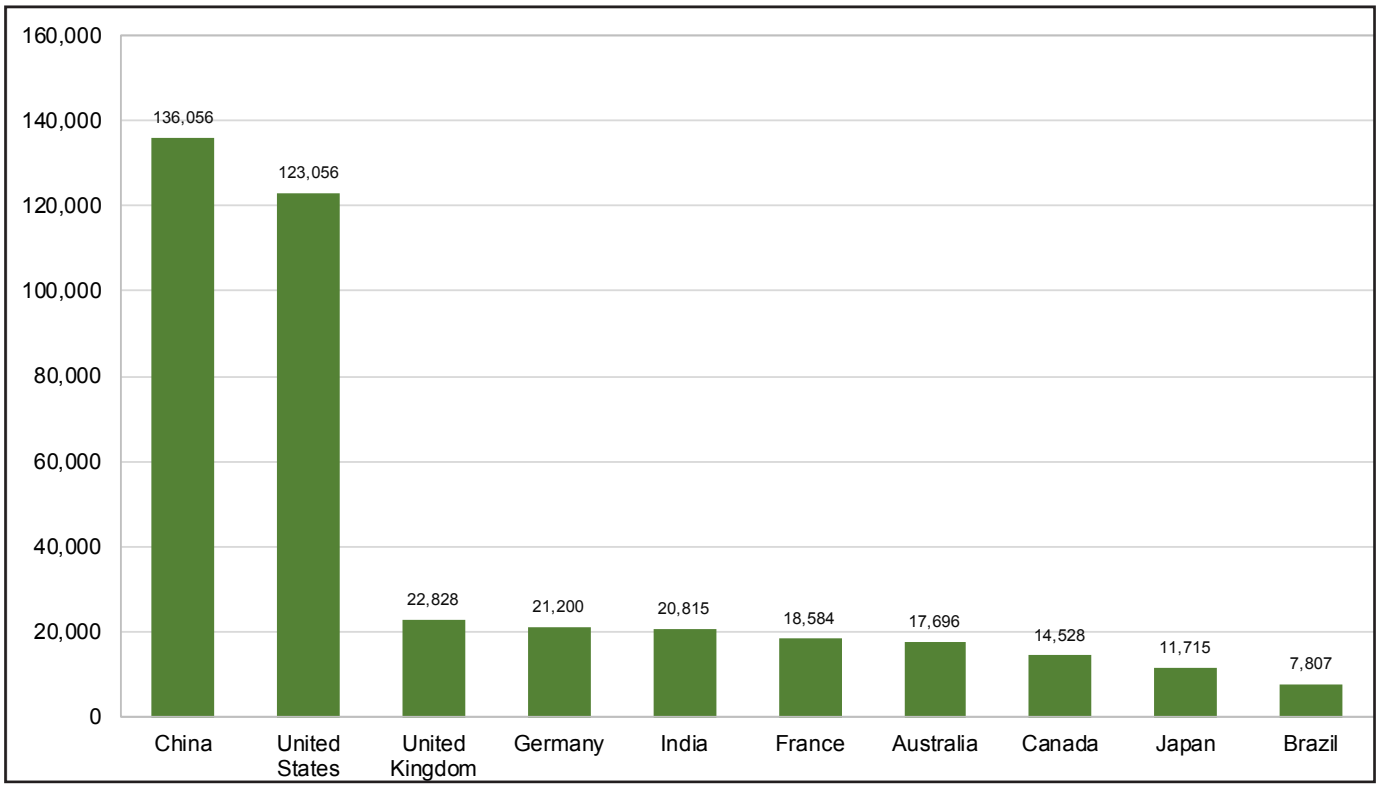


Figure 3: Top 10 countries by number of water-related citations; 2017. Data source: Scopus

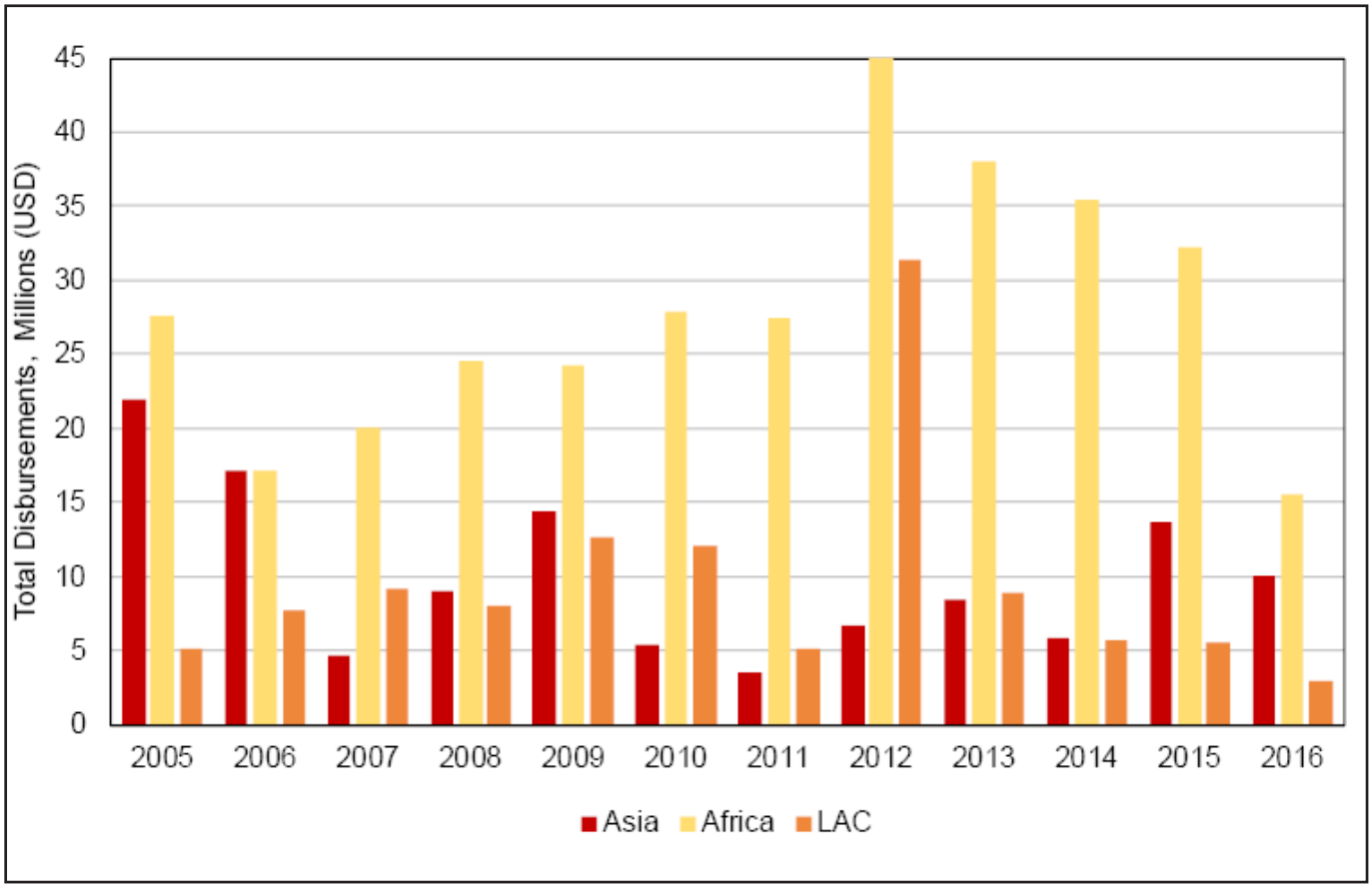
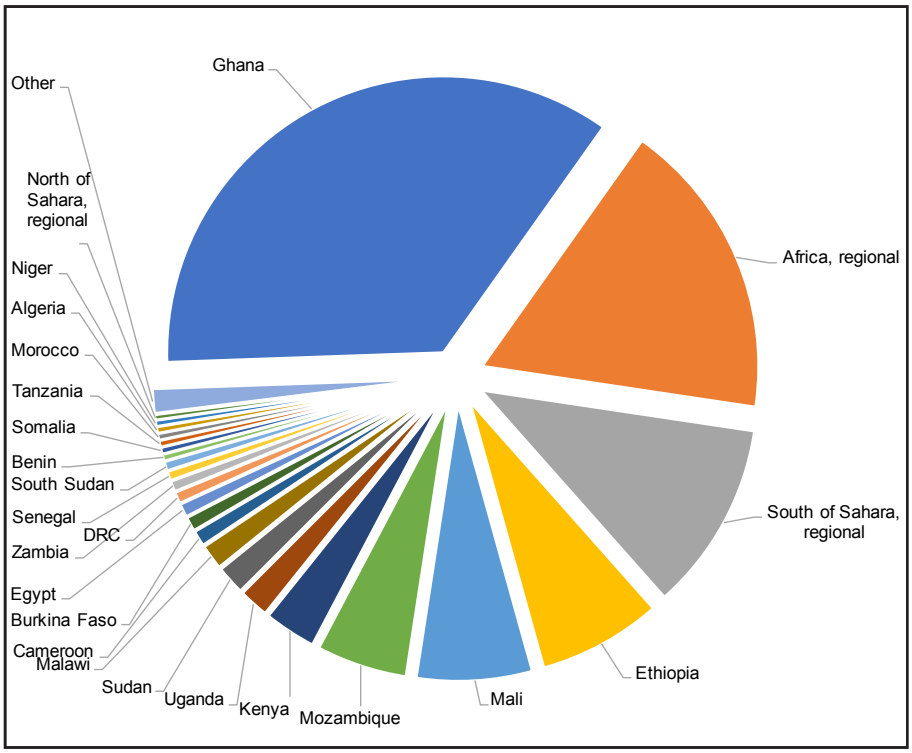
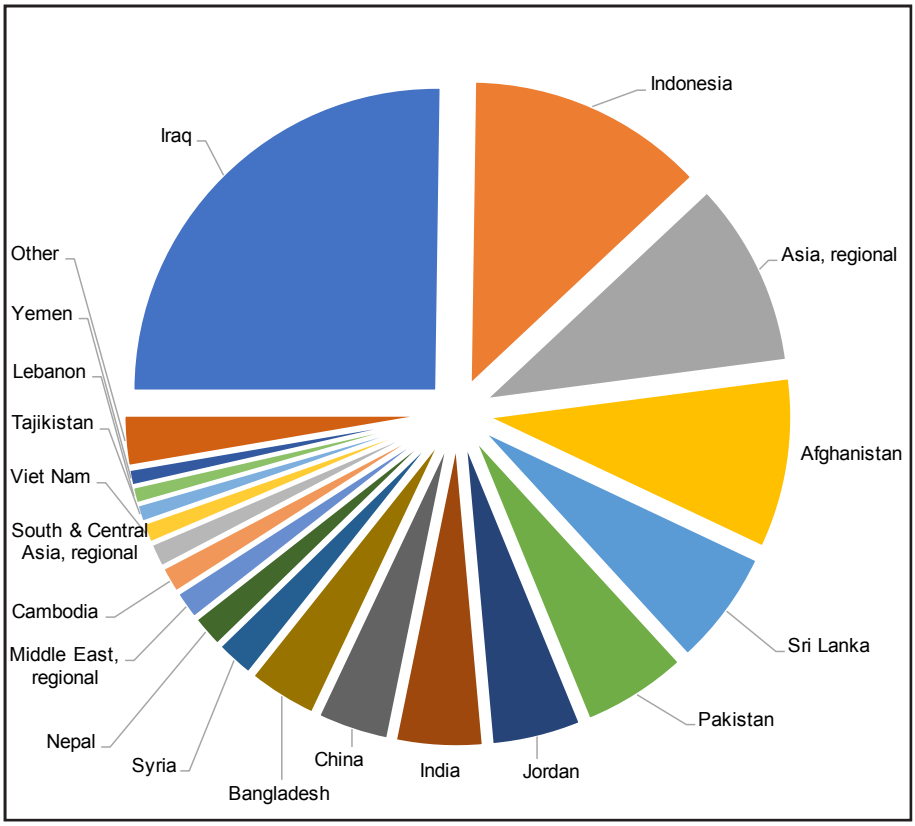


Figure 4: Annual total investments (USD) by Canada in the water sector of Africa, Asia, and Latin America and Caribbean (LAC), 2005-2016 synthesised from OECD-DAC data (https://stats.oecd.org/Index.aspx?DataSetCode=CRS1)

Figure 4 shows that Canadian investments in African water development were consistently higher over years than those in Asia or LAC, and in some years was more than double the total combined investment in the latter two regions. Contributions have dropped significantly in recent years, with the 2016 total roughly half that of 2013, and a particularly significant decline in Africa. Primary recipients of Canadian aid in the water sector over the most recent decade were Ghana and Ethiopia in Africa; Iraq and Indonesia in Asia; and Haiti, Honduras and Peru in LAC (Figure 5). Significant investment in each major region went into unspecified cross-country or sub-regional projects. While Canada remains outside of the top 10 global water aid donors in absolute dollar terms, the forerunners are, as a rule, countries with higher gross domestic product per capita (Figure 6). The proportion of water-related development aid in the total Canadian aid mix is currently around 1.5% - essentially the same as UK and USA (both just under 2%). The number for other countries ranges, as a rule, from 2% to 8%; Japan and Korea are the top investors at just over 8% and 7% respectively.

Despite relatively modest investments in the water sector in the developing world, Canadian assistance is highly visible. For example, IDRC has a long and respected history abroad. The IDRC is a Canadian Crown corporation established by Parliament in 1970 with a mandate "to initiate, encourage, support, and conduct research into the problems of the developing regions of the world…" (IDRC, 1970). IDRC's Urban Poverty and Environment Program sought to address the disproportionate suffering of urban poor as a result of 'environmental burdens including lack of basic environmental services, environmental degradation caused by pollution or over-pumping of water, and vulnerability to natural disasters. With a total budget of $18 million over six years (2006 – 2012) the Program provided funding to 60 projects focussing on urban agriculture, urban water and sanitation, waste management, vulnerability to natural disasters, with land tenure identified as a cross-cutting issue. Projects were funded in the LAC region, Sub-Saharan Africa, Asia, and the Middle East and North Africa. Fourteen projects addressed global issues (IDRC, 2005).


Ghana
Other
North of Sahara, regional
Niger
Algeria
Morocco
Tanzania
Somalia
Benin
South Sudan
Senegal
DRC
Zambia
Egypt
Burkina Faso
Cameroon
Malawi
Sudan
Uganda
Kenya
Mozambique
Mali
Ethiopia
South of Sahara, regional
Africa, regional


Iraq
Indonesia
Other
Asia, regional
Yemen
Lebanon
Tajikistan
Afghanistan
Viet Nam
South & Central Asia, regional
Cambodia
Sri Lanka
Middle East, regional
Pakistan
Nepal
Syria
Bangladesh
China
India
Jordan

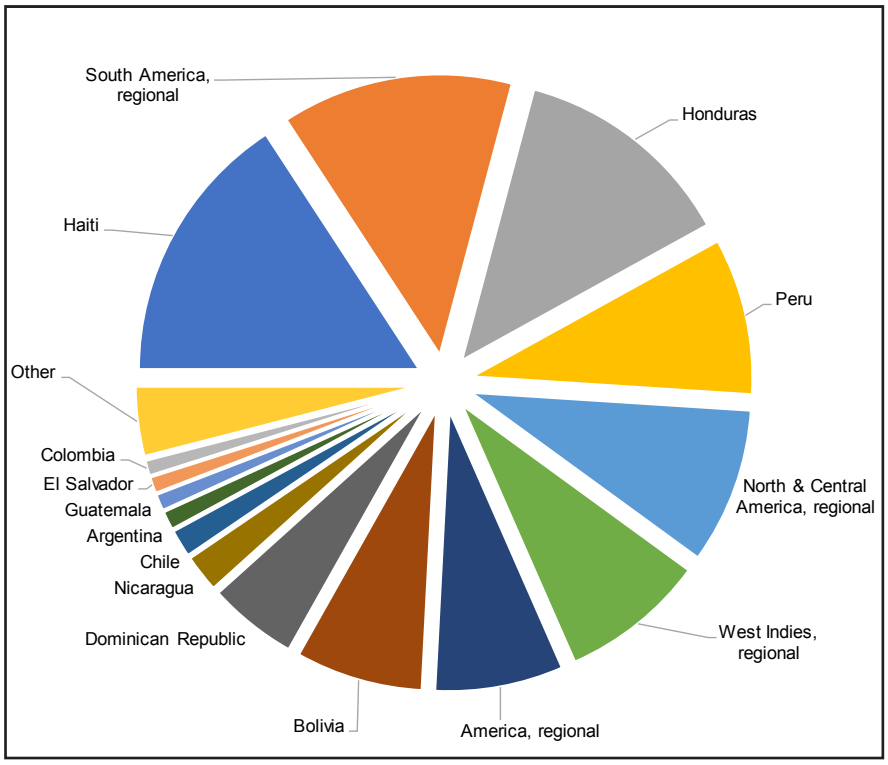


Figure 5: Proportionate structure of total investments in the water sector in 3 major regions of the global South (Africa (top), Asia (middle) and LAC (bottom)), 2005-2016 synthesised using OECD-DAC data (https://stats.oecd.org/Index.aspx?DataSetCode=CRS1)

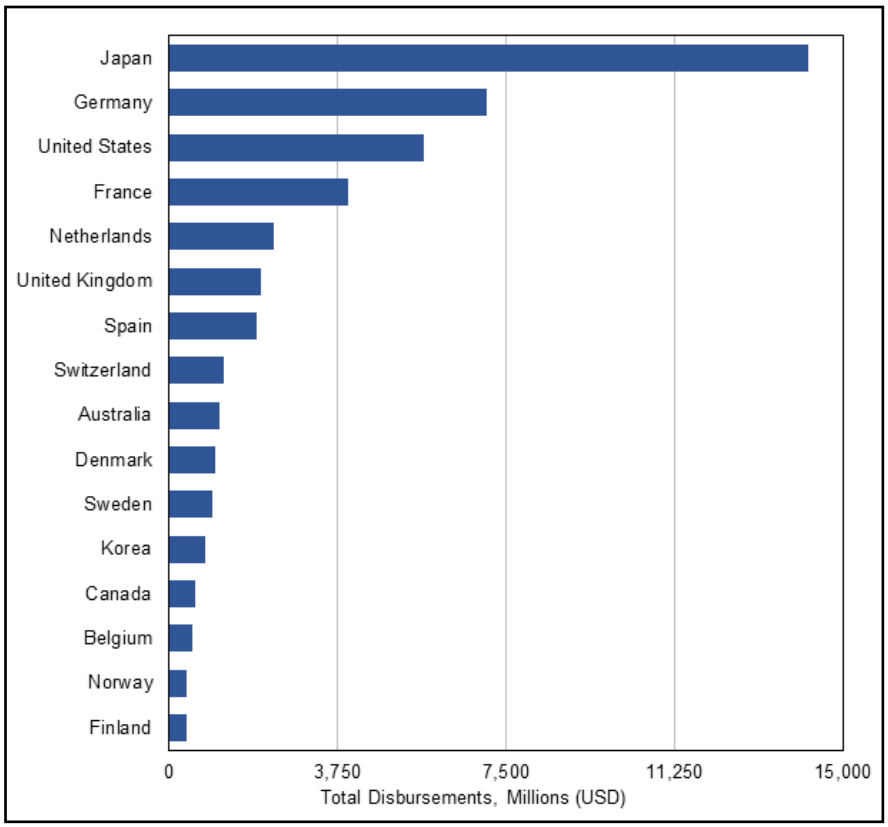


Figure 6: Comparison of total investments (USD) of selected developed countries in the water sector of developing nations over a period 2005-2016 synthesised from OECD-DAC data (https://stats.oecd.org/Index.aspx?DataSetCode=CRS1)

From 2006 to 2012 IDRC joined forces with the UK's Department for International Development (DFID) to jointly fund the Climate Change Adaptation in Africa Program. This programme supported 41 research projects in 33 African countries and made a lasting contribution to Africa's capacity to adapt to climate change by nurturing many researchers and institutions now active in improving understanding of the critical role water plays in defining climate (Lafontaine et al. 2012).

Expanding the geography of its support to research on adaptation to climate change in the water sector, IDRC initiated the Climate Change and Water program in 2010. Projects were launched in the most vulnerable countries on four continents. The programme engaged with sources of external finance, financial think tanks and the private sector (e.g. Environment and Climate Change Canada and Natural Resources Canada, the Development Bank of Southern Africa, the Private Finance Advisory Network, Frankfurt Business School, and Business for Social Responsibility). To now, over 270 water adaptation options for a changing climate have emerged from IDRC supported research[33]. In 2013 IDRC partnered again with the DFID to jointly provide $70 million of support over seven years to the Collaborative Adaptation Research Initiative in Africa and Asia. The 2018 compilation of policy-relevant water adaptation research supported by IDRC, provides a snapshot of Canadian contributions to adaptive capacity and innovation in the water sector overseas (MacAlister and Subramanyam, 2018).

IDRC's Strategic Plan aims to support at least 20 initiatives through 2020 that deliver solutions at scale, helping position Canada as a leader in innovative approaches to development (IDRC, 2015), including gender transformative water-research.

The characteristic and, to a large extent, unique feature of Canada's overseas development aid strategy has been and remains a strong gender focus that also influences water-related investments. Canada played a high-profile role at the 4th World Conference on Women in Beijing, in supporting adoption of the 1995 Declaration and Platform for Action[34]. Canada has become, for the 2017–2020 term, a member of the UN Commission on the Status of Women that evaluates progress on gender equality. In 2017, the Government of Canada launched the Plan for the Implementation of the UN Security Council Resolutions on Women, Peace and Security 2017-2022[35]. In many of the fragile and conflict-affected states that the Plan targets, women's role in water supply is a major issue.

Canada has recently introduced the new Feminist International Assistance Policy (GoC, 2018) under which it will invest CDN $150 million over five years (2017-2022)[35] to help local organizations in developing countries. The primary objective of this policy is to contribute to global efforts to eradicate poverty around the world through six key action areas: gender equality and the empowerment of women and girls; promotion of human dignity; growth that works for everyone; environment and climate action; inclusive governance; and peace and security. The "environment and climate" element of this policy, in particular, speaks directly to both SDG 6 (water) and SDG 13 (climate change). However, water issues, including sustainable access to clean water, adequate sanitation and proper hygiene, and integrated water resource management, affect every action area of the policy. The policy recognises that growing scarcity of resources under a changing climate — in particular, the lack of clean drinking water — coupled with a gender-based imbalance in household responsibilities, means a disproportionate impact on women and girls. The policy is a commitment to support women and girls to improve their access to water and other natural resources, as well as their participation in environmental decision-making.

Canada is also providing CDN $2.65 billion to help the most vulnerable countries adapt to and mitigate climate change by deploying clean energy technology and managing natural resources sustainably and transition to low-carbon, climate-resilient economies[36]. As water issues are inseparable from those of climate, this funding also supports SDG6 and the goal of water security globally.

There are, of course, reasons to think globally in Canada's own self-interest. For example, there is already a several trillion dollar per year global environmental services industry. Canadian industries capture considerably less than 1% of that lucrative market, compared with, e.g. Germany (25%)[37].

At the same time, Canadian water and wastewater firms have a global reputation for excellence. A report from the Blue Economy Initiative considered Canada's opportunity to be a "water solutions" country. Supported by a robust innovation ecosystem, the technologies and solutions

[33] www.adaptationoptions.ca
[34] http://www.un.org/esa/gopher-data/conf/fwcw/off/a--20.en
[35] http://international.gc.ca/world-monde/issues_development-enjeux_developpement/gender_equality-egalite_sexes/wps-fps-2011-2016.aspx?lang=eng
[36] https://climate-change.canada.ca/finance/
[37] https://www.flowcanada.org/

developed in Canada are addressing water challenges around the world. From conveyance and distribution to treatment and reuse, Canadian solutions are changing the way the world manages water. And Canada's specific expertise in developing and providing solutions that are scalable, modular, onsite, and easy to operate and maintain makes its companies ideal partners for regions in need of sustainable and affordable solutions (Gordon Foundation, 2013).

The Government of Canada's Trade Commissioner Service[38] estimated that in 2016 the sum of both operating and capital expenditures by utilities and industrial water users around the world was CDN $714 billion. Four companies — Real Tech Inc., MANTECH Inc., LuminUltra and TECTA-PDS — were specifically identified as leaders in water quality monitoring technologies. The Trade Commissioner Service also highlighted Ostara Nutrient Recovery Technologies ADI Systems, and Anaergia for advancements in wastewater treatment; and Greyter Water Systems, BQE Water, and Filterboxx for technological advancements in water reuse.

Canadian technologies offer a broad range of solutions, from cutting edge complex to the very simplest. An example of the latter is an inexpensive but highly effective bio-sand filter promoted by the Centre for Affordable Water and Sanitation Technology (CAWST)[39] and originally invented by CAWST co-founder Dr. David Manz in the early 1990s at the University of Calgary. This filter can remove, from contaminated water, >99% of worms and protozoa, up to 98% of bacteria, around 70 to 99% of viruses, up to 95% of dirt and cloudiness and up to 95% of iron. Unlike alternative technologies, the filter has no replacement parts or chemicals, thus requiring no long-term supply chain, and it can be constructed locally with local materials. As of 2013, well over 650,000 filters have been implemented in 55+ countries around the world, benefitting more than 4 million people.

There remains a significant unrealised opportunity for Canada to bring its water technology to emerging markets in developing countries. However, while more than 80% of Canada's water tech companies are exporting their products and services, very few have clear strategies for doing business successfully in these regions (WaterTAP, 2018). One of the main reasons that Canadian companies are not pursuing the opportunities is that they often do not know where to start. In order to increase their profile, they need to know more about emerging global challenges, innovations, and business and partnership opportunities in the international aid and development sectors. They need to learn about best practices on humanitarian logistics, supply chains, procurement, supplier management, and financing. They also need to know about new federal strategies and programs that support the growth of Canadian cleantech companies globally, and they need to be consulted on their unique requirements. Given the right business model and access to support and resources, Canada can deliver many more water technology projects with sustainable outcomes, which the world so greatly needs today[40].

There are, naturally, also opportunities to build stronger relationships with other countries in areas of water research and policy where Canada is traditionally strong – e.g. cold regions water management, or between the North American and the African Great Lakes –to transfer knowledge and build technical capacity in a number of areas, notably drinking water and wastewater infrastructure, farming and food production, hydro-power generation, education and skills training, border management, and water science and monitoring.

WATER GOVERNANCE AND INSTITUTIONS

The Canada Water Act (1986, and most recently revised in 2014) provides the framework for federal management of water resources in Canada, including research and the planning and implementation of programs relating to the conservation, development and utilization of water resources. The Canada Water Act calls for joint consultation between the federal and provincial governments in water resource matters. The federal government has jurisdiction in fisheries, navigation, federal lands (including First Nation reserve lands and waters, and First Nation drinking water), and international relations, including responsibilities to manage boundary waters shared with the US. It also has responsibilities for agriculture, health and the environment, and plays a significant role supporting aquatic research and technology, and ensuring national policies and standards are in place on environmental and health-related issues.

Within the federal government, over 20 departments and agencies have unique responsibilities for fresh water. As all levels of government hold key policy and regulatory levers which apply to water management, a central challenge is to ensure that these levers are developed and used collaboratively (ECCC, 2017b).

For the purpose of facilitating the formulation of policies and programmes with respect to the water resources

[38] http://www.tradecommissioner.gc.ca/trade_commissioners-delegues_commerciaux/index.aspx?lang=eng
[39] https://www.cawst.org/services/expertise/biosand-filter/more-information
[40] http://watertapontario.com/

of Canada and to ensure the optimum use of those resources for the benefit of all Canadians, Environment and Climate Change Canada (ECCC) can enter into joint water governance arrangements with one or more provincial or territorial governments where there is significant national interest (ECCC, 2017b).

ECCC also maintains an inventory of waters of significant national interest, consults on an on-going basis on water resource matters with the provinces and territories, and advises the government on priorities for research, planning, conservation and water policy. It also establishes or names joint commissions to take on projects associated with the coordinated management of waters of national interest (ECCC, 2017b).

The Canadian Council of Ministers of the Environment (CCME)[41], is a collaborative institution through which the provinces, territories, and federal government discuss and act on common approaches to many environmental priorities, including research, the development of science-policy linkages, acceleration of the development of water quality guidelines, and linking of networks that monitor and report on water quality across Canada. CCME is implementing a strategic vision for water endorsed by ministers in 2009. Current priorities are:

- improving jurisdictions' ability to evaluate cumulative impacts of allocation and withdrawals on surface water and groundwater.
- increasing jurisdictions' capacity to manage the impact of land use activities on surface water and groundwater quality, by continuing to develop technical tools such as Canadian Environmental Quality Guidelines
- developing tools to assist jurisdictions adapt to climate change impacts on the hydrologic cycle.

CCME is also monitoring implementation of the Canada-wide Strategy for the Management of Municipal Wastewater Effluent, endorsed by ministers in February 2009. The delivery of water activities is coordinated by CCME's Water Management Committee. The CCME also recognises climate change will eventually alter the availability of water, frequency of floods and droughts, permafrost, growable crops, the types of forest and wildlife that thrive, coastline erosion, and sea level height. CCME is assisting jurisdictions to adapt to climate change impacts by analysing Canadian and international approaches to water scarcity and flood management — a first step to considering additional CCME management approaches and tools on climate change water security.

Projects undertaken jointly by the federal and provincial governments involve the regulation, apportionment, monitoring or survey of water resources, and the pre-planning, planning or implementation of sustainable water resource programs. Federal and provincial governments have also jointly developed and implemented basin-wide action plans in collaboration with communities and other stakeholders. These action plans are designed to help resolve complex environmental issues, particularly deteriorating water quality that threatens human and ecosystem health. Provincial watershed alliances and groups assist in the protection of local watersheds. Examples include the Great Lakes Ecosystem Initiative, which coordinates actions to meet Canada's commitments under the 2012 Canada–US Great Lakes Water Quality Agreement (GLWQA), and the 2014 Canada–Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (COA). The GLWQA establishes broad, long-term objectives for Canada and the US for restoring and protecting the Great Lakes, while the COA provides a short-term (five-year) plan for achieving Canada's GLWQA commitments (ECCC, 2017a).

The Water Survey of Canada (WSC) is the national authority responsible for the collection, interpretation and dissemination of standardised water resource data and information nationally. In partnership with provinces, territories and other agencies, WSC operates over 2800 active hydrometric gauges across the country. The WSC has built its reputation through a cooperative approach with all levels of governments and business sectors. Earlier ad-hoc arrangements with the provinces were replaced in 1975 with comprehensive and national partnership agreements. The WSC plays a major role in the activities of numerous international and interprovincial boards and commissions involved in the management of Canada's water resources. It is the designated agency responsible for water resource monitoring in support of inter-jurisdictional agreements and treaties[42].

Governments at all levels do not normally have the resources to address all water data deficiencies. Citizen science and community-based water monitoring[43] has proven to provide cost effective, accurate scientific data to decision-makers. These approaches also have the added benefit of increasing the level of water literacy and empowering citizen engagement to help steward local watersheds. Community-based monitoring is gaining momentum across Canada and is a powerful means of achieving shared water management and sustainability objectives. A recent survey (Gordon

[41] https://www.ccme.ca/
[42] https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/monitoring/survey.html
[43] http://www.livinglakescanada.ca/news/projects/a-snapshot-of-community-based-monitoring-in-canada/

Foundation, 2018) suggests that community-based water monitoring has a unique role to play in supporting, amongst others, implementation of recommendations from the UN Declaration on the Rights of Indigenous Peoples in Canada, meeting the SDGs, monitoring the implementation of environmental legislation such as the Canadian Environmental Assessment Act (2012) and the Navigable Waters Act (2014), and implementing the terms of collaborative federal/provincial/territorial agreements on water quality monitoring . Living Lakes Canada in association with Living Lakes International maintains a roster of community-based monitoring training experts that can be assigned on short notice to help in developing countries.

Other federal-provincial-territorial ministerial councils play important roles in environmental protection with impacts on water part of their focus on sustainable development[44] . The Federation of Canadian Municipalities (FCM) works to identify water issues and best practices that municipalities are encouraged to take up in their policies, and practices. The Government of Canada and FCM recently announced the investment of $72 million for 48 community projects demonstrating strong actions on climate change. A specific focus of these projects is the reduction of vulnerability of many of the municipal services residents use every day — drinking water, sewage treatment, and roads — and on infrastructure that is near or past its intended lifecycle and was never designed to withstand rapid changes in climate patterns.

Health Canada, with its provincial and territorial counterparts and public health organizations, collect and synthesise data on waterborne diseases under the National Enteric Surveillance Program. These data are used in outbreak identification and response and are useful in identifying trends and communities or regions at risk[46].

All jurisdictions in Canada are actively addressing challenges related to aging or inadequate drinking water and wastewater treatment infrastructure. The federal, provincial, and territorial governments have established funding programs that support collaboration with municipalities in improving the quality of infrastructure, with funding for water and wastewater and water supply utilities a significant focus of these programs. The water infrastructure maintenance and replacement deficit in Canada is a significant challenge. In 2007, the FCM and McGill University released a wake-up call to policymakers, pointing to an infrastructure deficit in water supply and waste water and storm water systems – in the order of $31 billion. The FCM estimated another $56.6 billion was needed to build new infrastructure to meet the demands of a growing population and new provincial and federal regulatory requirements (Bitti, 2011). Later, FCM estimated that one third of Canada's municipal infrastructure is at risk of rapid deterioration.
Similar large-scale investments are addressing the need for improved water and wastewater treatment facilities to meet the health and environmental needs of Indigenous, First Nations, and Inuit communities. While not widely known, some jurisdictions within Canada are already engaged – very successfully – in consent-based governance tables with Indigenous Nations, the most exciting of which are in the area of legislative and policy development and agreement-making regarding water. This approach also supports implementation of Indigenous water jurisdictions (Phare et al. 2017). Through a "collaborative consent" process, participating governments, both Indigenous and non-Indigenous, can use agreement-making on water management as a foundation to meet not just the spirit and intent but the letter of UN Declaration on the Rights of Indigenous Peoples.

This collaborative governance process has recently been expanded beyond the Northwest Territories into initiatives that involve Indigenous Nations that were signatory to Treaty 1 and municipal government interests in Manitoba, where it holds promise for progress in relations over water. Participants in the process are hopeful that, 18 years into the 21st century, and soon after its 150th birthday, Canada is poised to finally step away from many of the negative aspects of its colonial past, especially as it relates to Indigenous peoples. This is certainly a past that Indigenous peoples throughout the world will recognise, many of them having experienced similar histories. The collaborative consent approach, which here forms the basis of respectful, nation-to-nation governance founded on common agreement on the importance of careful management of water, may well be something that Canada can share.

Another governance innovation is being provided by a Canadian-based organization called Water Innovation Lab Global[48], which has committed itself to equipping a new generation of water leaders around the world with an unparalleled skill- and mind-set to imagine, steer and create co-innovations that will tackle the world's most complex water governance challenges. What

[44] http://www.canadaspremiers.ca/wp-content/uploads/2017/09/water_charter_aug_4_2010.pdf
[45] https://fcm.ca/home/programs/municipalities-for-climate-innovation-program/municipalities-for-climate-innovation-program.htm
[46] https://www.nml-lnm.gc.ca/NESP-PNSME/index-eng.htm
[47] https://fcm.ca/home/programs/municipalities-for-climate-innovation-program/municipalities-for-climate-innovation-program.htm
[48] https://waterlution.org/water-innovation-labs/

distinguishes this initiative is its focus on developing a network across generations, disciplines and geographies. By engaging diverse stakeholders, the programme blends more formal governance engagement practices, like community consultation, with active problem solving and innovative solutions. Many projects have emerged around social mapping of human impacts on water systems, and on how important cultural elements are a driver to deeper and broader public engagement with water concerns. Since the program's inception it has incubated 40 projects, engaged 6,000 young water leaders, and created more than 500 uniquely trained new young water professionals in Canada, India, Brazil and four other countries.

Another example of SDG-related know-how of Canadian origin is the SDG6 Policy Support System (PSS)[49]. Almost three years after the launch of the SDGs most countries know what they must achieve. To meet water-related SDGs, they now need to better understand how they will achieve it. The PSS is a six-step process that draws from tools and mechanisms designed by international expert groups to support SDG6 action at the national level. It builds on lessons learned by countries actively strengthening their enabling environments. Built around six components (capacity, institutions, finance, gender, resilience and transparency), this open source system has been piloted in five countries — Korea, Tunisia, Ghana, Pakistan and Costa Rica — and is expandable to more countries and other SDGs.

The above review, although not comprehensive, suggests that Canada has diverse water governance experience and models that can be applied beneficially in other parts of the world. This experience and the state of the institutions that support water governance in Canada have not, however, evolved significantly over the past decades. While once a leading example in water management, it has been more than 30 years since the Canada Water Act was updated. During that time, the federal government has stepped back from its former high-profile presence, passing many of its water-related responsibilities to provinces and territories which, in turn, downloaded responsibilities to municipalities, often without adequate resources. Canada may need to revisit its water governance structure and strengthen it, particularly to address the evolving governance relationship with Indigenous Nations. It will benefit the country and create a better case for sharing Canada's experiences globally.

CONCLUSIONS AND RECOMMENDATIONS

Canada's water sector has significant potential to meet, and help others meet, the water-related SDGs. The **water education** establishment in Canada is represented by i) education at larger universities, where "water," with a few exceptions, is a cross-faculty topic, and ii) colleges, focusing primarily on operational water-utility training. Analysis suggests that to date few universities have specifically-labelled undergraduate or graduate programs in water education, and overall, they have yet to develop well-integrated programs that address the many interconnected water problems and processes. Specific postgraduate water management programs are emerging, and this process needs to accelerate. Part of the problem of water education is its interdisciplinary nature, which translates into the requirement for many different skill sets. Yet, to meet the needs of sustainable development, universities must find ways to enhance water education, including through development of programs with an undergraduate specialization in water management, and fostering more interdisciplinary and multidisciplinary studies at the graduate level.

Also needed is an organised and comprehensive listing of water-related educational activities in universities and colleges to identify, fully describe and collate these activities. This would be useful for potential students navigating their way through the complex mix of water-related studies, and for potential employers seeking qualified personnel. On larger note, very few countries know what water-related capacity they have and what capacity they need in the context of achieving national water-related targets. Canada could help develop such an inventory and share with the rest of the world the approach used to develop it, which may be very useful for many developing nations. Another pioneering move would be development of a proper ranking system of universities on the strength of their water programs.

The review of recent Canadian **water research**, although not exhaustive, reveals strong and diverse resident capacity that places the country among global leaders in this field. There is a range of university research centres, institutes and national research networks involved, supported by funding from three dedicated thematic research councils, and by provincial and territorial governments, private foundations, corporations and non-government organizations. Canada appears to be a top 10 country in terms of water research productivity (publications) and impact (citations).

Canadian water research has been very strong traditionally in restoration and protection of the Great Lakes, prediction of changes in climate, water and

[49] http://inweh.unu.edu/sdg-policy-support-system/

cryosphere, floods and droughts, to mention a few directions. A recently-started Global Water Futures Programme (GWF) – a seven-year (2016–2023) research initiative with a mission to improve disaster warning, predict water futures, and inform adaptation to change and risk management - covers much of Canada's national water resources research agenda. This is the largest university-led water research programme of its kind in the world, and one of the largest water science collaborations in history. GWF aims to provide global leadership in water science for cold regions and to address the strategic needs of the Canadian economy in the face of an uncertain water future. Being unique, due to its sheer size and range of partners, GWF has a chance for big development impact, and for illustrating how influential well-resourced, well-coordinated and targeted research can be. GWF can also be a natural nucleus around which Canadian-wide contribution to the UN Water Action Decade of 2018-2028, and to overall SDG6 process, can be built. GWP may consider making such an ambition known to Canada's federal government and reach out to all other relevant national players in the water sector to make this happen.

Although Canada remains outside of the top 10 global **water aid** donors in absolute dollar terms, the forerunners are, as a rule, the countries with higher GDP per capita. The proportion of water-related development aid in the total Canadian aid mix is currently under 2%, while for larger donors, this number varies, as rule, from 2% to 8%. Canadian investments in water development in Africa were consistently higher over many years relative to its investments in other regions of the global South. Those contributions dropped significantly in recent years overall, with significant decline in the African aid flow.

Canada has, however, been and remains quite visible in this domain with its IDRC- and GAC – branded support to a range of water-related projects. Also, the characteristic and charismatic feature of Canadian overseas development aid strategy has been and remains a strong gender focus that also influences water-related investments. Under new Feminist International Assistance Policy, Canada will invest $150 million over 5 years (2017-2022) to help local organizations in developing countries. The policy is a commitment to support women and girls to improve their access to natural resources, like water, as well as their participation in environmental decision-making. Therefore, even with comparatively smaller absolute investments, Canada has managed to position itself very well in this domain. This approach of targeting specific developmental or regional challenges, will likely continue, bringing Canada good international visibility and "quick wins" in development even with relatively small overseas investments.

There is also a significant potential for exported Canadian products and services. These can be enhanced with better information on emerging global challenges, business and partnership opportunities in the international aid and development sectors, as well as new federal strategies and programs that support the global growth of Canadian cleantech companies. Some Canadian organisations, or Canadian-based UN entities, can provide such advise and information services.

Canada should also consider strengthening and diversifying the existing UN links, including those with UN-Water. It can leverage on its past and present experiences and processes of moderating conflicts and consider spearheading one or two water-related UN Resolutions, as other UN member states have done. Possible foci for such resolutions, underpinning and reinforcing current water-related SDG processes, may include improved global groundwater governance and management, commitment to good environmental water management standards, and similar.

Canada has diverse **water governance** experience and models that have value to be shared with or applied in other parts of the world. The Canada Water Act calls for joint consultation between the federal and provincial governments in matters relating to water resources. And projects undertaken jointly by the federal and provincial governments involve the regulation, apportionment, monitoring, survey and planning of water resources. The critical importance of such cooperation must be recognised and continually strengthened. Health Canada, along with provincial and territorial health departments and public health organizations collect and synthesise data on waterborne diseases. All jurisdictions in Canada are actively addressing challenges related to aging or inadequate drinking water and wastewater treatment infrastructure. Federal-provincial-territorial ministerial councils play important roles in environmental protection with impacts on water as part of their focus on sustainable development.

Although the provision of appropriate water and sanitation facilities to Indigenous Nations remains a major problem in Canada, there are now investments in place aimed at addressing these water, health and environmental needs. Some jurisdictions in Canada are already engaged – very successfully – in consent-based governance tables with Indigenous Nations, the most exciting of which are in the area of legislative and policy development and agreement-making regarding water. This approach also supports the implementation of Indigenous water jurisdictions. The collaborative consent approach, which here forms the basis of respectful, nation-to-nation governance founded on common agreement on the importance of careful management

of water, may well be something that Canada can share. If the country, by 2030, resolves this internal challenge — as it should –- it will demonstrate leadership in this domain. This may then give an impetus to complete resolution of similar problems for Indigenous Nations worldwide.

Overall, the water sector in Canada continues to conduct itself in a compartmentalised manner, focusing primarily on processes rather than on achievements and results without a sense of urgency for change or coordination of existing capacity. Harnessing and fully realizing the Canadian water sector's substantial capacity will need government coordination and support. Canada should be innovative in selecting the means and avenues to significantly enhance its visibility and impact on the global water stage. Current geopolitical uncertainties; the urgency of responding to the climate change-induced acceleration of the global water cycle; Canada's commitment to its own Federal Sustainable Development Strategy, and Feminist Foreign Assistance Strategy, and a newly started Water Action Decade for Sustainable Development, provide impetus for government at all levels, but especially federally, to work harder to coordinate and orchestrate the significant capacity in Canada's water sector for the benefit of the country and the world. And if Canada is to develop a global water strategy similar to the US, even if for different reasons and ambition, the above suggestions will benefit the country.

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REFERENCES

Bitti, M.T. 2011 (Jan 5). Conversations for Change: Facing Canada's water woes. Financial Post. http://www.financialpost.com/executive/smart-shift/facing+canada+water+woes/2660041/story.html

Bolch, T., Menounos, B., and Wheater, R. 2010. Landsat-based inventory of glaciers in western Canada, 1985–2005, Remote Sensing of Environment, 114: 127–137.

Canadian Rivers Institute, 2018; Advancing the Science on Dam Renewal. http://canadianriversinstitute.com/media-room/they-be-dammed-advancing-the-science-on-dam-renewal

Changing Cold Regions Network (CCRN). 2018. Final Science Report. http://www.ccrnetwork.ca/documents/Reports/CCRN_Final_Progress_Report.pdf

DeBeer, C.M., Wheater, H.S., Quinton, W.L., Carey, S.K., Stewart, R.E., MacKay, M.D. and Marsh, P., 2015. The Changing Cold Regions Network: Observation, diagnosis and prediction of environmental change in the Saskatchewan and Mackenzie River Basins, Canada. Science China Earth Sciences, 58(1):46-60.

DeBeer, C.M., Wheater, H.S., Carey, S.K. and Chun, K.P., 2016. Recent climatic, cryospheric, and hydrological changes over the interior of western Canada: a review and synthesis. Hydrology and Earth System Sciences, 20(4):1573–1598.

ECCC- Environment and Climate Change Canada. 2013a. Water- In Canada. Government of Canada (GoC). https://www.ec.gc.ca/eau-water/default.asp?lang=en&n=5EA1D86E-1

ECCC- Environment and Climate Change Canada. 2013b. "How Much Groundwater Do We Have?" Canada's Groundwater Resources. Government of Canada (GoC). https://www.canada.ca/en/environment-climate-change/services/water-overview/sources/groundwater.html#howmuch

ECCC-Environment and Climate Change Canada. 2017a "5. Ecosystem initiatives and ecosystem-based approaches". Canada Water Act Annual Report for April 2015 to March 2016. Government of Canada (GoC). http://ec.gc.ca/eau-water/default.asp?lang=En&n=5790DB8F-1&offset=7

ECCC-Environment and Climate Change Canada. 2017b. Federal Policy and Legislation. Government of Canada (GoC). https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=E05A7F81-.

GEWEX- Global Energy and Water Exchanges. 2018. Changing Cold Regions Network (CCRN) Wraps Up at Final Meeting. http://ccrnetwork.ca/science/workshops/ccrn-5th-annual-meeting/docs/CCRN_GEWEX_News.pdf

Geological Survey of Canada. 2014. Canada's groundwater resources. Rivera, A. (Ed.) Fitzhenry and Whiteside, 824 pp. http://publications.gc.ca/collections/collection_2018/rncan-nrcan/M184-8-2014-eng.pdf

GoC - Government of Canada. 2016. Achieving a sustainable future – a Federal Sustainable Development Strategy for Canada. Environment and Climate Change Canada; Gatineau; 88 pp.: http://www.fsds-sfdd.ca/index.html#/en/goals/

GoC - Government of Canada. 2018. Canada's Feminist International Assistance Policy. http://international.gc.ca/world-monde/issues_development-enjeux_developpement/priorities-priorites/policy-politique.aspx?lang=eng

Gordon Foundation. 2013. Blue Economy Initiative Report. http://www.gordonfoundation.ca/blue-economy.ca/library

Gordon Foundation 2018. Community-based Monitoring: National Survey Results, February 2018. http://gordonfoundation.ca/app/uploads/2018/03/CBWM-Survey-Highlights.pdf

Hall, F.G., 1999. Introduction to special section: BOREAS in 1999: Experiment and science overview. Journal of Geophysical Research: Atmospheres, 104, 27,627–27,639.

Hanesiak, J. M., Stewart, R. E., Bonsal, B. R., Harder, P., Lawford, R., Aider, R., Amiro, B. D., Atallah, E., Barr, A. G., Black, T. A., Bullock, P., Brimelow, J. C., Brown, R., Carmichael, H., Derksen, C., Flanagan, L. B., Gachon, P., Greene, H., Gyakum, J., Henson, W., Hogg, E. H., Kochtubajda, B., Leighton, H., Lin, C., Luo, Y., Mccaughey, J. H., Meinert, A., Shabbar, A., Snelgrove, K., Szeto, K., Trishchenko, A., Van Der Kamp, G., Wang, S., Wen, L., Wheaton, E., Wielki, C., Yang, Y., Yirdaw, S. and Zha, T. 2011. Characterization and Summary of the 1999–2005 Canadian Prairie Drought. Atmosphere-Ocean, 49(4), 421-452.

HLPW -High-Level Panel on Water. (2018). Making Every Drop Count: An Agenda for Water Action. HLPW Outcome Document. https://sustainabledevelopment.un.org/content/documents/17825HLPW_Outcome.pdf

IDRC - International Development Research Centre. 1970. International Development Research Centre Act. P.C. 1971-11; SOR/71-25. https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/20071/IDL-20071.pdf?sequence=1&isAllowed=y

IDRC - International Development Research Centre. 2005 Urban poverty and environment Prospectus 2005-2010.

IDRC. https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/26334/121980.pdf?sequence=1&isAllowed=y

IDRC - International Development Research Centre. 2015. Investing in Solutions: Strategic Plan 2015-2020. https://www.idrc.ca/sites/default/files/idrc-strategic-plan-2015-2020.pdf.

Lafontaine, A., Oladipo, J., Dearden, P. N., and Quesne, G. 2012. Final evaluation of the IDRC/ DFID climate change adaptation in Africa programme. Climate Change Adaptation in Africa (CCAA). http://hdl.handle.net/10625/49107

MacAlister, C., and Subramanyam, N. 2018. Climate change and adaptive water management: Innovative solutions from the global South. Water International, 43(2), 133-144.

Morris, T. 2014 The Future of Freshwater Funding in Canada: Mobilizing Collective Resources for Healthy Watersheds. Canadian Environmental Grantmakers Network (CEGN) http://www.cegn.org/wp-content/uploads/2014/05/waterfunders-low.pdf

Phare, M-A., Simms, R., Brandes, O.M., Miltenberger, M. 2017. Collaborative Consent and Water in British Columbia: Towards Watershed Co-Governance. POLIS Project on Ecological Governance and Centre for Indigenous Environmental Resources. www.poliswaterproject.org/polis-research-publication/collaborative-consent-water-british-columbia-towards-watershed-co-governance/

Pomeroy, J., Gray, D., Brown, T., Hedstrom, N., Quinton, W., Granger, R., Carey, S. 2007. The cold regions hydrological model: A platform for basing process representation and model structure on physical evidence. Hydrological Processes, 21(19), 2650-2667.

Pomeroy, J.W., Whitfield, P.H., and Spence, C. (eds.), 2013. Putting prediction in ungauged basins into practice. Canadian Water Resources Association, ISBN 978-1-896513-38-6, 375 pp.

Sandford, R.W. 2012; Cold Matters: The State and Fate of Canada's Fresh Water, Rocky Mountain Books, 2012

Sellers, P., Hall, F., Kelly, R., Black, A., Baldocchi, D., Berry, J., Ryan, M., Ranson, K., Crill, P., Lettenmaier, D., Margolis, H., Cihlar, J., Newcomer, J., Fitzjarrald, D., Jarvis, P., Gower, S., Halliwell, D., Williams, D., Goodison, B., Wickland, D., Guertin, F. 1997. BOREAS in 1997: Experiment overview, scientific results, and future directions. Journal of Geophysical Research: Atmospheres, 102(D24), 28731-28769

Stewart, R.E., Leighton, H.G., Marsh, P., Moore, G.W.K., Ritchie, H., Rouse, W.R., Soulis, E.R., Strong, G.S., Crawford, R.W., and Kochtubajda, B., 1998. The Mackenzie GEWEX Study: The water and energy cycles of a major North American River Basin. Bulletin of the American Meteorological Society, 79, 2665–2683.

Stewart, R., Pomeroy, J., Lawford, R., 2011. The Drought Research Initiative: A comprehensive examination of drought over the Canadian prairies. Atmosphere–Ocean, 49, 298–302.

WaterTap. 2018. http://watertapontario.com/wp-content/uploads/2018/01/Canadas-Water-Industry-WEB.pdf

Winpenny, J., Trémolet, S, Cardone, R., Kolker, J., Kingdom, B., and Mountsford, L. 2016. Aid Flows to the Water Sector: Overview and Recommendations. World Bank, https://openknowledge.worldbank.org/handle/10986/25528

Woo, M.K., Rouse, W.R., Stewart, R.E., and Stone, J.M.R. 2008. The Mackenzie GEWEX Study: A contribution to cold region atmospheric and hydrologic sciences. In: Cold Region Atmospheric and Hydrologic Studies, the Mackenzie GEWEX Experience, Volume 1: Atmospheric Dynamics. Woo, M.K. (ed.), Springer, Berlin Heidelberg, 1 – 22

UN-Water 2016 Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development. http://www.unwater.org/publications/water-sanitation-interlinkages-across-2030-agenda-sustainable-development/

UN-Water 2018. SDG 6 Synthesis Report 2018 on Water and Sanitation. 195 pp. http://www.unwater.org/publication_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation/

US Government 2017 Global Water Strategy: https://www.usaid.gov/sites/default/files/documents/1865/Global_Water_Strategy_2017_final_508v2.pdf

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