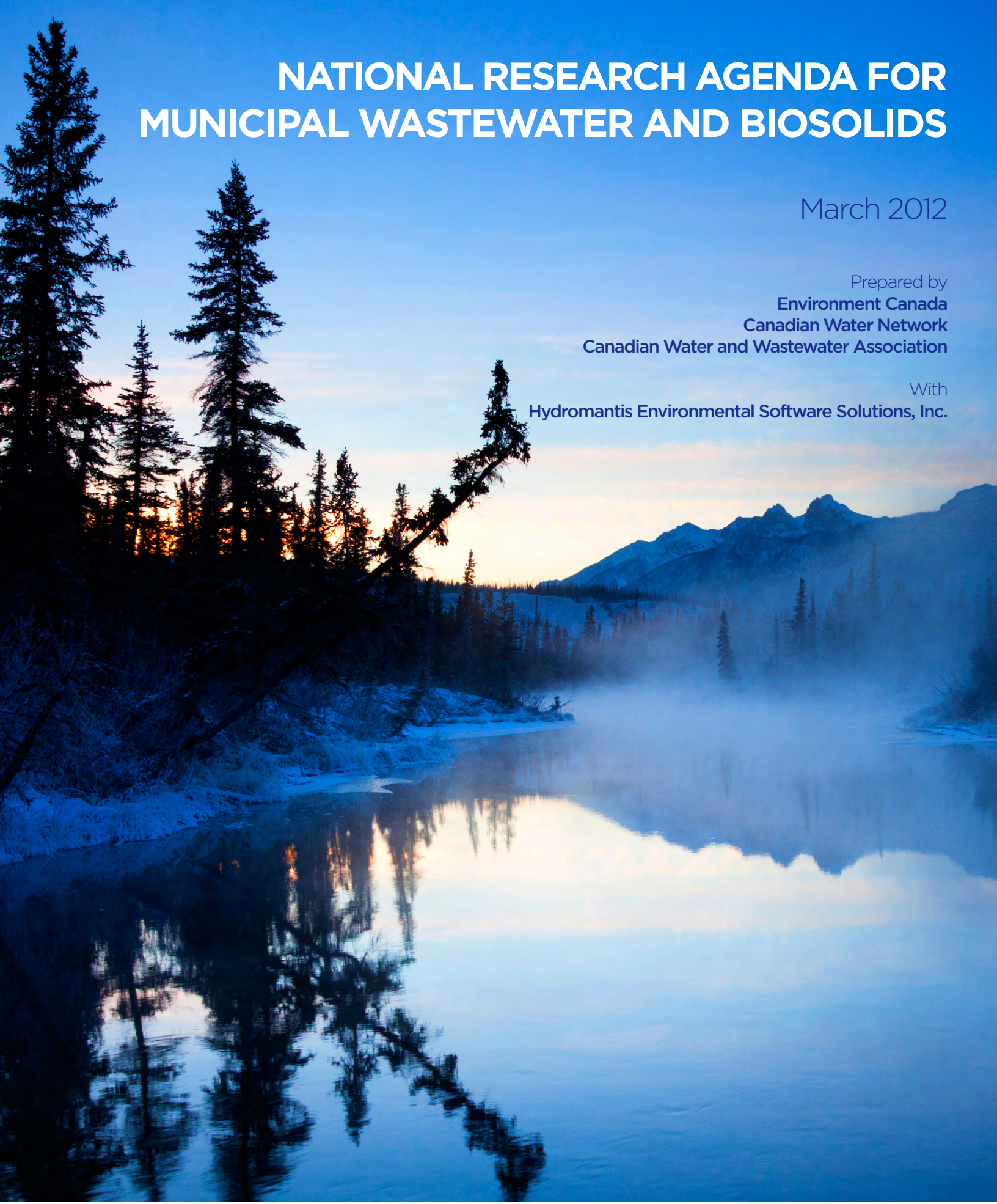
NATIONAL RESEARCH AGENDA FOR MUNICIPAL WASTEWATER AND BIOSOLIDS

March 2012

Prepared by
Environment Canada
Canadian Water Network
Canadian Water and Wastewater Association

With
Hydromantis Environmental Software Solutions, Inc.



Environment Canada Environnement Canada
CANADIAN WATER NETWORK RÉSEAU CANADIEN DE L'EAU
CWWA ACEPU
Hydromantis Environmental Software Solutions, Inc.

Acknowledgements

The Core Group of the Science and Research Coordinating Body responsible for the development of the National Research Agenda for Municipal Wastewater and Biosolids wishes to acknowledge the perseverance and exemplary efforts of Hugh Monteith of Hydromantis Environmental Software Solutions, Inc. of Hamilton, ON in the preparation of this Agenda.

Core Group:
John Lawrence, Environment Canada, Chair
Barbara Anderson, Ontario Ministry of the Environment*
Grahame Farquhar, Canadian Water Network
Jennifer Jackson, Canadian Water and Wastewater Association
Benoit Lebeau, Ontario Ministry of Agriculture, Food and Rural Affairs**
Peter Seto, Environment Canada

* representing the CCME Municipal Wastewater Coordinating Committee

** representing the CCME Biosolids Task Group

Foreword to the Research Agenda

The mandate for this project was to create a National Research Agenda; so a broad perspective was adopted in the delineation of possible research priority needs. Consequently, the needs of specific regions of the country may not appear to have been sufficiently emphasized in the ranking of possible research topics. In such cases, it should be borne in mind that the procedures used and the assumptions made in formulating the rankings can be subsequently adjusted by the reader if desired, to achieve closer alignment with specific regional needs. At the same time, an attempt was made to generate a large and comprehensive list of possible research topics and related example projects from which the reader can either select or insert those best suited to meet specific needs.

Many aspects of municipal wastewater and biosolids management are interrelated making it challenging to isolate specific research topics. For example, biosolids production and management can be studied in the context of: modifications to wastewater biotreatment processes; procedures for energy use and recovery; recovery of materials and products; impacts on receiving environments; or others. A research topic could focus on biosolids production, but could also investigate impacts due to modifications to wastewater biotreatment processes as a part of that work. Conversely, a research topic could focus on modifications to wastewater biotreatment processes with the investigation of impacts on biosolids production as a collateral investigation. In the development of this National Research Agenda, efforts were made to avoid double counting and/or redundancies by associating a research topic within only one Theme or Sub-theme. As a result, the reader may disagree with or choose to re-assign the location of a research topic in a particular Theme of Sub-theme. In many cases, it is simply a matter of interpretation.

The selection of criteria with which to prioritize possible research topics was an area of particular concern in developing the Agenda. Initially it was felt that the use of specific, granular criteria such as “Impact on receiving waters”, “Effects on nutrient removal” and “Impact on energy use” as examples was the correct approach. But it was ultimately decided that most of these aspects had already been addressed and accounted for in the formation of the Canadian Council of Ministers of the Environment (CCME) Municipal Wastewater Effluent (MWWE) Strategy and the draft Canada-wide Approach for the Management of Wastewater Biosolids. Thus, the extent to which a possible research topic supported either or both of these two initiatives formed the basis of the first two evaluation criteria. These reflect immediate needs of many municipalities and are considered to be in the short term.

It was also deemed important to look at needs that may exist in the longer term. Two additional, longer term criteria were therefore used to account for (a) contributions to sustainable wastewater and biosolids management through better energy management and materials recovery and reuse; and (b) support for national initiatives on climate change adaptation and mitigation including GHG reduction and wet weather flow implications.

An attempt was made to integrate into the ranking process, consideration for the three pillars of the Triple Bottom Line (TBL), Economic, Environmental and Social; this was done by weighing

the extent to which the four criteria supported each of the TBL pillars. Best judgment in the assignment of weightings is ultimately subjective, notwithstanding their impact on the resulting priority determined for specific research topics. As stated above, the reader should remember that the procedures used and the assumptions made in formulating the Agenda, including the choice of evaluation criteria and assignment of weightings, can be subsequently adjusted by the reader if desired, to achieve closer alignment with specific local needs.

The information and processes presented in this document are detailed and intricate. As a consequence, it is important for the reader to review the document in its entirety before conclusions are drawn about how well it covers the subject matter, and the value of its contents, including prioritization of research topics.

Table of Contents

List of Tables

Executive Summary

Introduction and Background

The Canadian Council of Ministers of the Environment (CCME) in its development of the "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" identified the need for coordinated scientific research as one of four components of the Strategy. It was recognized that, although significant research on municipal wastewater and biosolids was being undertaken in Canada, it lacked coordination in priority setting, execution and dissemination.

To address these issues, CCME proposed the formation of a Science and Research Coordination Body (S&RCB) to address research coordination and information dissemination on municipal wastewater and biosolids in Canada. The Canadian Water Network, Canadian Water and Wastewater Association, Environment Canada and Canadian Council of Ministers of the Environment, formed an initial S&RCB and developed a broad mandate with efforts to be focused in three strategic areas:

a) Formulation of a National Research Agenda for Wastewater and Biosolids (the Agenda) through a consultative process, the Agenda being a critical element of a prioritized, coordinated research program.
b) Agenda implementation through facilitation and management of partner-based research consortia.
c) Information dissemination through workshops, newsletters and a national website containing relevant municipal wastewater and biosolids research activities and results.

Delivery agencies for each of these three strategic areas included the Water Science and Technology Directorate of Environment Canada (EC) (lead in the development of the Agenda); the Canadian Water Network (CWN) (lead in the implementation of the second initiative); and the Canadian Water and Wastewater Association (CWWA) and its regional associations will manage information dissemination through their membership of practicing wastewater professionals. CCME, through the Municipal Wastewater Effluent Coordinating Committee and the Biosolids Task Group, acted as a catalyst for the formation of the S&RCB for Canada. These two groups hope that the S&RCB will be permanent and continue identifying research needs over the years, prioritizing and coordinating research projects and disseminating information for the industry and all stakeholders. The Biosolids Task Group and Municipal Wastewater Effluent Coordinating Committee can provide input and comments into the development of the research agenda to reflect individual jurisdictional research concerns.

As a preliminary step leading up to the formation of the S&RCB, a Core Group, consisting of delegates from CCME and representatives from the three delivery agencies, was formally struck in January 2011; it has focused its efforts on development of the Agenda with a view to both short and long term research priorities and relevance to Canadian needs.

The development of the Agenda has involved three main steps: identification of themes, subthemes and topics of research needs in Canada; priority ranking to formulate a preliminary list

of prospective topics; refinement of priority topics and identification of projects taking into account the most likely needs of Canadian communities in the relevant areas of wastewater and biosolids. Stakeholder input on the draft Agenda, research themes, evaluation criteria and priority topics was sought through a series of public outreach processes including: CWWA's Advanced Consultation Workshop at the 4th Wastewater Management Conference, and the 2011 Window on Ottawa Workshop. The draft document has been refined based on these comments.

It is intended that the Agenda should not just be restricted to serve as a reference for implementation of research projects by the CWN's Municipal Water Consortium, but also to serve as a reference for other pertinent funding agencies, research centres and academics alike to focus their efforts to address user needs on a national basis. In this respect, it is deemed essential to have wider input from potential end-users of the draft Agenda in the preparation of the final Agenda. In order to achieve this, the Draft Agenda has been posted for a 30-day Public Consultation in January 2012. Comments received have been incorporated into the Agenda revision. Following an Expert Panel workshop to review the consultation feedback and provide additional input, the final National Research Agenda has been completed in March, 2012.

Thereafter, the CWN will begin the setting up of end-user based Research Consortia to select research projects to be undertaken, to arrange suitable funding and to manage the progress of the research. The CWWA will subsequently undertake dissemination of information on research activities and outputs as they become available.

The Municipal Wastewater Effluent Coordinating Committee and Biosolids Task Group were involved in the process leading to the formation of the S&RCB for Canada. As of April 1, 2012, individual jurisdictions will be asked to participate in the S&RCB.

Establishing Research Themes, Subthemes and Topics

Prior to developing the Agenda, it was important to have some sense of current research directions and priorities both in Canada and internationally. The web-sites of several international agencies and organizations were consulted, and included those of:

- Canadian Water Network (Canada)
- International Joint Commission (Canada & United States)
- Japanese Institute of Wastewater Technology (Japan)
- Global Water Research Coalition
- PUB (Singapore)
- South African Water Research Commission (South Africa)
- Stowa Foundation for Applied Water Research (Netherlands)
- Suez Environmental – CIRSEE (France)
- Swiss Federal Institute for Aquatic Science and Technology - EAWAG (Switzerland)
- UK Water Research Industry (United Kingdom)
- US EPA Office of Research and Development (United States)
- Water Environment Research Foundation (United States)
- Water Quality Research (Australia)

- Water Research Foundation (formerly the American Waterworks Association (AWWA) Research Foundation) (United States)
- WateReuse Research Foundation (United States)
- Water Supply and Sanitation Technology Platform (WSWWTP) (European Union)

Information presented in published literature was also consulted to provide an indication of what subjects were being researched and presented in journal publications using a period from 2007 to 2010 to represent reasonably current work. The information gained from the data base search concerning research subjects was organized into themes, sub-themes and topics. Publications originating in Canada and sixteen other countries were identified and included in the search. This involved countries belonging to the Global Water Research Coalition (GWRC) plus China, Denmark, India, Japan, Korea and Sweden. Denmark and Sweden were included in the list because they have climates similar to Canada. China, India and Korea were included because of their substantial output of research publications. The exercise accessed the content of over 7,000 publications.

From this investigation and from a general consideration of Canadian needs, the research themes and sub-themes chosen for consideration in establishing a Canadian National Research Agenda for Wastewater and Biosolids are shown in **Table ES-1**. The sub-themes were further broken down into topics in order to classify the large number of diverse subjects under consideration. For clarity, the theme Decentralized Wastewater Systems in this report applies to such systems used in an urban setting; that is, the theme does not include systems that are commonly used in remote or more rural settings.

Although not a complete survey, the information in the literature search provided an indication of the level of research activity and possible research priorities existing during the period of examination up to 2010 over the range of countries considered. In the case of Canada, 70 publications dealing with biosolids research were accessed, along with 29 for WWTP processes and optimization, 17 for wet weather treatment, and 16 each for emerging substances of concern (including non-conventional contaminants from industrial sources discharging to municipal sewer systems) and nutrients. In the peer-reviewed technical literature on wastewater and biosolids research, publications identified as originating from Canada represented between 1% and 5% of all publications identified within each theme. The results of the search indicated that published Canadian research is spread somewhat thinly across many subject areas, with work on biosolids and WWTP processes and optimization being prominent. Biosolids subjects related to anaerobic digestion, emerging substances of concern (also referred to as emerging contaminants), heavy metals and nutrients were prominent. Other subjects with a relatively high number of publications included activated sludge (WWTP Processes and Optimization), pollutant loadings (Wet Weather Treatment) and receiving water effects (Emerging Substances of Concern).

Table ES-1. Themes and Sub-themes Selected for a National Research Agenda

	Theme	Sub-Themes
1	Municipal Wastewater Treatment	• WWTP Processes and Optimization • Nutrients • Emerging Substances of Concern (including Non-conventional Contaminants from Industrial Sources discharged to Municipal Sewer Systems) • Pathogens • Water Reuse
2	Biosolids	• Biosolids and Sludge Treatment and Management • Biosolids Application
3	Wet Weather Treatment	• Pollutant Loading • Hydraulic and Flow Prediction • Treatment and Retention • Conveyance Systems
4	Decentralized (Urban) Wastewater Systems	• Collection and Treatment Technologies • Social and Economic Issues
5	Climate Change and Sustainability	• Effects of Wastewater and Sludge Treatment on Climate Change • Climate Change Effects on Wastewater Collection • Climate Change Effects on Wastewater Treatment and Biosolids Management • Climate Change Effects on Receiving Waters • Sustainable Wastewater/Biosolids Management
6	Infrastructure	• Asset Management Tools • Asset Administration and Operation

Determining Research Priorities for a National Research Agenda

Establishing the Evaluation Matrix

The Agenda emphasizes targeted or applied research, as opposed to more basic, fundamental research.

A matrix approach that could evaluate topics for possible research projects against a set of criteria and weightings to determine areas of greatest need has been developed for the Agenda. The matrix analysis was conducted at the level of topics as opposed to the levels of theme or sub-theme.

The use of and need for more than one evaluation matrix has been considered at length, For example, separate matrices could be developed for wastewater and biosolids. Ultimately, one comprehensive evaluation matrix has been proposed due to the perceived difficulty in establishing a single set of priorities between two or more evaluation matrices.

A key element of the matrix process consists of establishing evaluation criteria, and weightings for those criteria, to identify research priorities. Evaluation criteria are intended to address both short and long term needs. The terms “short term” and “long term” are used to indicate approximate time frames of five years or less, and periods extending beyond five years into the future, respectively.

The following principles were used as the evaluation criteria:

- Support for the CCME Canada-wide Strategy for the Management of Municipal Wastewater Effluent (short term);
- Support for the draft Canada-wide Approach for the Management of Wastewater Biosolids (short term);
- Contribution to sustainable wastewater and biosolids management through better energy management and recovery, as well as materials recovery and reuse (long term);
- Addressing national initiatives on climate change adaptation and mitigation along with GHG reduction (long term).

Having established a set of evaluation criteria, the next step in the development of the ranking matrix is to develop a series of weighting factors, to assign greater or lesser importance to each of the criteria, based on judging them against environmental, social and economic values. Specifically, the weightings have been developed using the triple bottom line (TBL) concept of environment, social and economic considerations (Table 6 in body of report). Justifications used to assign weightings for the different criteria using the triple bottom line pillars are defined in Table 7 of the body of the report.

In classification of wastewater and biosolids research, there is frequently overlap between potential themes, subthemes and topics, particularly with respect to biosolids. As the criteria and weighting are being applied, it is important to minimize the overlap in justification of weightings for the different criteria. A result of ignoring the overlap, or so-called double-accounting, would be to award a higher importance to the topic than would be the case if the topic fell clearly within the bounds of only one criterion. Table 8 in the report explains how the potential overlap, or double-accounting has been minimized in the development of the Agenda.

Lastly, a value ranging from 0 to a maximum of 2 has been applied against each of the topics, depending on whether the listed projects or project clusters within the topic are deemed to be aligned with the evaluation criteria discussed above.

Results of the Matrix Evaluation

Based on the values assigned to topics and the criteria weightings, the highest possible point total for any topic would be 58. No one topic approaches this maximum, with 35.5 appearing as the highest point total. The reason for this apparent low point assessment is that no one topic fully addresses all of the four evaluation criteria. Topics either tended to address short term criteria, such as the Canada-wide Strategy for the Management of Municipal Wastewater Effluent (the Strategy) and the draft Canada-wide Approach for the Management of Wastewater Biosolids or the long term criteria, such as the sustainable wastewater/biosolids management, GHG reduction

or climate change adaptation/mitigation, but not both.

Two of the top five research topics identified are related to the theme of Municipal Wastewater Treatment, specifically with respect to optimization of processes and nutrient reduction or recovery. The other three topics in the top five include research into green infrastructure for treatment and retention in the Wet Weather Treatment theme, process research and optimization in the Biosolids theme, and research into energy reduction or recovery processes as part of sustainable wastewater/biosolids management in the Climate Change and Sustainability theme. These topics are then followed by several others falling within the Municipal Wastewater Treatment, Infrastructure and Climate Change and Sustainability themes.

At first observation, it may appear as though biosolids research is not well represented among the most highly ranked topics. The only topics appearing near the top of the priority rankings that are clearly identified in the Biosolids theme are Process Research and Optimization (32.5 points), and New Process Development, with a point value of 25.5. Upon closer inspection of the ranked priorities, however, biosolids-related research is well-represented in combination with wastewater research in the topics:

- Energy Reduction/Recovery Processes (Climate Change and Sustainability theme and Sustainable Wastewater/Biosolids Management subtheme) (31.5 points),
- Production of GHGs by Treatment Processes, (Climate Change and Sustainability theme and Effects of Wastewater and Sludge Treatment on Climate Change subtheme), (28.5 points), and
- In-plant conservation (Climate Change and Sustainability theme and Sustainable Wastewater/Biosolids Management subtheme) (28 points).

Conversely, topics related to decentralized treatment and water reuse, are found in the lower half of the 50th percentile rankings. Note that stormwater is urban runoff uncontaminated by municipal wastewater, and therefore considered separately from combined sewer overflow.

Within the research topics, a list of example research projects has been compiled that would typify the topics. The suggested research projects include a combination of those offered as representative of the research needs within the topic by this report's authors, and also those contributed by the Canadian Water and Wastewater Association's Committees on Biosolids and on Wastewater and Stormwater. Inclusion of these projects is not intended to imply they are the only research projects that should be considered; rather, they are offered as examples of the types of projects that might be funded. In a number of cases, the two sources of suggested research projects are almost identical, such as energy and nutrient extraction and carbon recovery/reuse, and potential use of ultrafiltration as a low energy alternative to disinfection.

While most of the example projects lie within the upper 50th percentile of the points assigned, projects lying in the lower 50th percentile are not to be neglected as unimportant. All the research needs are important, but just that some have a higher priority than others.

In this report, the rankings, criteria and weightings assigned are those dealing with research themes, sub-themes and topics on a national basis. Canada is a large country, however, both geographically and climatically diverse, with different demands, situations and priorities in different regions. As a result, top research priority topics and example projects identified at the

national level may not match well with those identified at regional or local levels, such as biosolids or wet weather issues, for example. Consequently, there is no "one-size-fits-all" Research Agenda to cover all specific regional and local needs throughout the country. Despite this drawback, the basic process as outlined herein, used for the development and application of the Matrix Evaluation framework to identify national research priorities is considered to be broadly applicable and useful at regional and local levels. Redefining the criteria and weighting factors to reflect the site-specific conditions is key to the successful use of the Matrix Evaluation framework at these regional or local levels.

Public Consultation

Public consultation has been carried out in the form of two workshops, namely CWWA's Advanced Consultation Workshop at the 4th Wastewater Management Conference, and the 2011 Window on Ottawa Workshop, as well as the 30-day full public review of the Draft Agenda document. While not every responding stakeholder agreed with every specific part of the matrix evaluation process, general support of the Draft Agenda document was evident, based on the consultation feedback. Consequently, the consultation did not result in substantial changes to the Consultation Draft in finalizing the Agenda.

Next Steps – A Canadian Consortium Approach

The original concept for the roll-out of the Agenda was to use a consortium-based approach, which has been used by the Canadian Water Network (CWN) to develop and facilitate research through the involvement of decision makers and end-users. It is anticipated that the CWN will be the delivery agency responsible for orchestrating the implementation of the Agenda leading to the development and management of research projects.

The Canadian Municipal Water Consortium (CMWC), which is one of the CWN's three active Consortia, is expected to be involved with the roll-out of the Agenda at least in the early stages. The CWN's Consortia are all based on the principal of relying on end-users for a) consultations to define areas of research need, b) manage calls for and review research proposals, c) assist with the management of research projects and d) implement the outcomes from the research. This approach is different from the more traditional investigator driven research in that end-users and their needs are prevalent in all phases of the work. Researchers and investigators play an essential role in the process, however, since it is they who respond to the calls and eventually conduct the research and participate in the dissemination of outcomes. The attempt with this approach is to create an end-user -researcher synergy. It is also designed to facilitate end-user support of research and ultimately uptake of its outcomes.

The goal of the consortium-based approach is to bring together potential stake-holders with interests in funding certain common research topics. Although it might be expected that topics ranked as high priority in the National Agenda would be of primary interest to potential funding stake-holders, the topics of common interest do not necessarily need to be those ranked among the Agenda's highest priorities. Rather, they can be topics of significant local or regional interest, or of mutual interest to a set of stakeholders based on geography or demographics (e.g. wet weather control, marine discharges, remote or rural treatment).

Canadian Capacity for Wastewater/Biosolids Research

A review of the current academic capacity (research centres, research chairs, university departments, etc.) indicates that the country has a diverse base of researchers who can address many of the needs of wastewater and biosolids research. However, this capacity often involves limited numbers of researchers in several of the subject areas. It is hoped that the roll-out of the Agenda will stimulate growth in Canadian research capacity in order to more adequately address end-user decision needs.

Canada's geography, demography and climate give rise to a set of special end-user wastewater- and biosolids-related needs that require attention. Capacity in Canada to conduct research addressing many of these needs exists but can and in many cases should be strengthened, so that end-user decision needs can be met. Several research areas to satisfy these needs include:

- cold temperature effects on wastewater processes;
- aquatic effects research;
- wastewater treatment using lagoons and wetlands;
- combined sewer overflows and stormwater management;
- infrastructure research;
- wastewater treatment plant optimization;
- emerging substances of concern (including non-conventional contaminants from industrial sources discharging to municipal sewer systems);
- sustainable wastewater/biosolids management; and
- greenhouse gas reduction and climate change adaptation/mitigation
- integration of research on social issues affecting wastewater and biosolids treatment/management with research derived from the engineering and natural sciences.

Prioritization of these needs may be accomplished using an evaluation approach such as demonstrated in this document.

Conclusions

1. In the peer-reviewed technical literature (2007-2010) on wastewater and biosolids research, publications identified as originating from Canada represent between 1% and 5% of all publications identified within each theme.
2. The majority of identified Canadian research publications focus on biosolids and municipal wastewater treatment processes, with little attention directed to water reuse, decentralized treatment or infrastructure.
3. Major themes identified for research needs include: municipal wastewater treatment; biosolids; wet weather treatment; decentralized (urban) wastewater treatment; climate change and sustainability; and infrastructure. Sub-themes and topics were identified within each major theme. Prioritization of these needs has been determined through the application of the Evaluation Matrix.
4. Principles for establishing the evaluation criteria for the Canadian Wastewater and Biosolids Research Agenda include supporting implementation of short term (the Strategy

and draft Canada-wide Approach for the Management of Wastewater Biosolids) and addressing long term (government initiatives on sustainability, and greenhouse gas reductions and climate change adaptation/mitigation) national commitments.

5. The triple bottom line (TBL) concept of environment, society and economy has been used to apply weightings for the four matrix evaluation criteria.
6. The top five topics as developed in this Research Agenda include two from the Municipal Wastewater Treatment theme, and one each from the Wet Weather Treatment, Biosolids, and Climate Change and Sustainability themes.
7. Although the Matrix Evaluation framework has been used here to identify national research priorities, it can be broadly applicable and useful at regional and local levels by redefining the criteria and weighting factors to reflect site-specific conditions.
8. Canada has historical research strengths in aquatic environmental effects, municipal wastewater treatment processes, and biosolids management and environmental effects.
9. Due to Canada's geography, demography and climate, several pertinent research areas have been identified for consideration, including: cold temperature effects on wastewater processes; aquatic effects research; wastewater treatment using lagoons and wetlands; combined sewer overflows and stormwater management; infrastructure research; wastewater treatment plant optimization; emerging substances of concern; sustainable wastewater/biosolids management; climate change adaptation/mitigation and greenhouse gas emission reductions; integration of research on social issues affecting wastewater and biosolids treatment/management with research derived from the engineering and natural sciences.

Recommendations

1. Following finalization of the Research Agenda, CWN should begin setting up end-user based Research Consortia to select research projects to be undertaken, to arrange suitable funding and to manage the progress of the research.
2. The CWWA should undertake dissemination of information on research activities and outputs as they become available from the Research Consortia.
3. The Research Agenda should be re-evaluated on a 5-year cycle by a wider group of stake-holders including wastewater professionals from academia, municipalities, senior levels of government, the private sector (consultants and equipment suppliers), other non-governmental organizations and funding agencies to update the process and results.
4. Stakeholders with interests in the management of municipal wastewater and biosolids should consider undertaking on-going support of a Canadian Science and Research Coordinating Body to maintain and perpetuate the Agenda Initiative into the future.

Introduction and Background

The Canadian Council of Ministers of the Environment (CCME) in its development of the "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (the Strategy), identified the need for coordinated scientific research as one of four components of the Strategy. It was recognized that, although significant research on municipal wastewater and biosolids was being undertaken in Canada, it lacked coordination in priority setting, execution and dissemination. Typically, research has been conducted by various stakeholders including academics, municipalities, and provincial/territorial and federal government agencies. Some of the research has been well documented in the public domain, while other research has not been communicated or available to other stakeholders who may have had similar interests and who would have benefited from the findings. Failure to disseminate research information results in some duplication of projects and spending of precious research dollars, reduced inter-agency collaboration, and the loss of opportunity to access such valuable information in support of decision-making. To maximize the utilization of available research budget and results, CCME considered that research in Canada could benefit from better coordination of priority settings, execution and dissemination.

To address these issues, CCME proposed the formation of a Science and Research Coordination Body (S&RCB) to coordinate and disseminate research on municipal wastewater and biosolids in Canada. The Canadian Water Network, Canadian Water and Wastewater Association, Environment Canada and Canadian Council of Ministers of the Environment, formed an initial S&RCB and developed a broad mandate with efforts to be focused in three strategic areas:

a) Formulation of a Canadian Research Agenda for Wastewater and Biosolids (the Agenda) through a consultative process, the Agenda being a critical element of a prioritized, coordinated research program.
b) Agenda implementation through facilitation and management of partner-based research consortia.
c) Information dissemination through workshops, newsletters and websites containing relevant municipal wastewater and biosolids research activities and results.

Delivery agencies have been named for each of these three strategic areas. Development of the Agenda has been led by the Water Science and Technology Directorate of Environment Canada (EC). The Canadian Water Network (CWN), having already formed consortia within its research mandate, will be the implementation agency for the second initiative. The Canadian Water and Wastewater Association (CWWA) and its regional associations will manage information dissemination. The Municipal Wastewater Effluent Coordinating Committee and Biosolids Task Group acted as a catalyst for the formation of the S&RCB for Canada. Many jurisdictions participating in these two groups hope that the S&RCB will be permanent and continue identifying research needs over the years, prioritizing and coordinating research projects and disseminating information for the industry and all stakeholders. The Biosolids Task Group and Municipal Wastewater Effluent Coordinating Committee can provide input and comments into the development of the research agenda to reflect individual jurisdictional research concerns.

As a preliminary step leading up to the formation of the S&RCB, a Core Group, consisting of delegates from the CCME and representatives from the three delivery agencies, was formally struck in January 2011; it has focused its efforts on development of an Agenda with a view to both short and long term research priorities and relevance to Canadian needs. Since a key part of the funding mechanism for conduct of the research is expected to involve partner-based research consortia, awareness of the needs of those willing to provide funding has been prominent.

The development of the Agenda has involved three main steps: identification of themes, subthemes and topics of research needs in Canada; priority ranking to formulate a preliminary list of prospective topics; refinement of priority topics and identification of projects taking into account the most likely needs of Canadian communities in the relevant areas of wastewater and biosolids. Stakeholder input on the draft Agenda, research themes, evaluation criteria and priority topics was sought through a series of public outreach processes including: CWWA's Advanced Consultation Workshop at the 4th Wastewater Management Conference, and the 2011 Window on Ottawa Workshop. The draft document has been refined based on these comments.

It is intended that the Agenda should not just be restricted to serve as a reference for implementation of research projects by the CWN's Municipal Water Consortium, but also to serve as a reference for other pertinent funding agencies, research centres and academics alike to focus their efforts to address user needs on a national basis. In this respect, it is deemed essential to have wider input from potential end-users of the Draft Agenda in the preparation of the final Agenda. In order to achieve this, the Draft Agenda has been posted for a 30-day Public Consultation in January 2012. Comments received have been incorporated into the Agenda revision. Following an Expert Panel workshop to review the consultation feedback and provide additional input, the final National Research Agenda has been completed in March, 2012.

Thereafter, the CWN will begin the setting up of end-user based Research Consortia to select research projects to be undertaken, to arrange suitable funding and to manage the progress of the research. The CWWA will subsequently undertake dissemination of information on research activities and outputs as they become available.

CCME's Municipal Wastewater Effluent Coordinating Committee and the Biosolids Task Group were involved in the process leading to the formation of the S&RCB for Canada. As of April 1, 2012, individual jurisdictions will be asked to participate in the S&RCB. Current S&RCB members hope that a diversified group of stakeholders that have interest in research relating to wastewater and biosolids management will maintain and perpetuate a Science and Research Coordinating Body to revise the Agenda from time to time, and to continue coordinating and disseminating research projects.

Recent events such as the announcement of funding to establish the GVRD Water Research Centre in Vancouver, and the establishment of the Pine Creek Water Research Centre in Calgary, the Southern Ontario Water Consortium in Waterloo and the CWN Municipal Water Consortium, coupled with the impending roll-out of the federal Wastewater Systems Effluent Regulation and the draft Canada-wide Approach for the Management of Wastewater Biosolids (the draft Approach) will raise the profile of wastewater and biosolids research and underscore the importance of a National Wastewater and Biosolids Research Agenda.

Establishing Wastewater/Biosolids Research Themes, Sub-Themes and Topics

Prior to developing the Agenda, it was important to have some sense of current research directions and priorities both in Canada and internationally. In order to provide this, a snapshot survey of research publications, documents, strategies, plans and agendas in the areas of municipal wastewater and biosolids prepared by major jurisdictions and organizations in Canada and around the world was carried out. The web-sites of several international agencies and organizations that were consulted included those of:

- Canadian Water Network (Canada)
- International Joint Commission (Canada & United States)
- Japanese Institute of Wastewater Technology (Japan)
- Global Water Research Coalition
- PUB (Singapore)
- South African Water Research Commission (South Africa)
- Stowa Foundation for Applied Water Research (Netherlands)
- Suez Environmental – CIRSEE (France)
- Swiss Federal Institute for Aquatic Science and Technology - EAWAG (Switzerland)
- UK Water Research Industry (United Kingdom)
- US EPA Office of Research and Development (United States)
- Water Environment Research Foundation (United States)
- Water Quality Research (Australia)
- Water Research Foundation (formerly the American Waterworks Association (AWWA) Research Foundation) (United States)
- WateReuse Research Foundation (United States)
- Water supply and Sanitation Technology Platform (WSSTP) (European Union)

Information presented in published literature was also consulted to provide an indication of what subjects were being researched and presented in journals publications. Because the scope of such an undertaking was daunting, the examination was limited to: a) searching by key-words, full documents were not reviewed; b) surveying refereed publications but not conference proceedings or technical reports; c) using a period from 2007 to 2010 to represent reasonably current work. Although several publication data bases are available, it was felt that “Environmental Science and Pollution Management (ESPM)” and “Scopus” provided adequate coverage and were thus used.

The information gained from the data base search concerning research subjects was organized into themes, sub-themes and topics. Publications originating in Canada and sixteen other countries were identified and included in the search. This involved countries belonging to the Global Water Research Coalition (GWRC) plus China, Denmark, India, Japan, Korea and Sweden. Denmark and Sweden were included in the list because they have climates similar to Canada. China, India and Korea were included because of their substantial output of research publications. The exercise accessed the content of over 7,000 publications.

From this investigation and from a general consideration of Canadian needs, the research themes and sub-themes chosen for consideration in establishing a Canadian National Research Agenda for Wastewater and Biosolids are shown in **Table 1**. For clarity, the theme Decentralized Wastewater Systems in this report applies to such systems used in an urban setting; that is, the theme does not include systems that are commonly used in remote or more rural settings.

Table 1. Themes and Sub-themes Selected for Establishing a National Research Agenda

	Theme	Sub-Themes
1	Municipal Wastewater Treatment	• WWTP Processes and Optimization • Nutrients • Emerging Substances of Concern (including Non-conventional Contaminants from Industrial Sources discharging to Municipal Sewer Systems) • Pathogens • Water Reuse
2	Biosolids	• Biosolids and Sludge Treatment and Management • Biosolids Application
3	Wet Weather Treatment	• Pollutant Loading • Hydraulic and Flow Prediction • Treatment and Retention • Conveyance Systems
4	Decentralized (Urban) Wastewater Systems	• Collection and Treatment Technologies • Social and Economic Issues
5	Climate Change and Sustainability	• Effects of Wastewater and Sludge Treatment on Climate Change • Climate Change Effects on Wastewater Collection • Climate Change Effects on Wastewater Treatment and Biosolids Management • Climate Change Effects on Receiving Waters • Sustainable Wastewater and Biosolids Management
6	Infrastructure	• Asset Management Tools • Asset Administration and Operation

The sub-themes were further broken down into topics in order to classify the large number of diverse subjects under consideration. A listing of these topics is presented in **Appendix A** organized under themes and sub-themes.

The survey of publications examined which of the research themes, sub-themes and/or topics were most prevalent. The top three of these were identified as shown in **Table 2** organized in descending order of the percentage of all publications accessed from a particular country.

Research on various aspects of biosolids, WWTP processes and optimization, nutrients, wet weather treatment and emerging substances of concern (also referred to as emerging contaminants) was prevalent in the publications accessed. Although not a complete survey,

Table 2. Distribution of Research Subjects in Publications on a per Country Basis

Country	Research Theme, Sub-theme or Topic	% of Total Reviewed	Research Theme, Sub-theme or Topic	% of Total Reviewed	Research Theme, Sub-theme or Topic	% of Total Reviewed
Australia	Water Reuse	32	Biosolids	18	WWTP processes & optimiz'n	17
Canada	Biosolids	41	WWTP processes & optimiz'n	18	Wet weather treatment	10
China	Biosolids	33	WWTP processes & optimiz'n	24	Nutrients	15
Denmark	Biosolids	34	Wet weather treatment	20	Nutrients	15
France	Biosolids	36	WWTP processes & optimiz'n	16	Wet weather treatment	14
Germany	Biosolids	25	WWTP processes & optimiz'n	14	Water reuse	14
India	Biosolids	37	WWTP processes & optimiz'n	22	Water reuse	21
Italy	WWTP processes & optimiz'n	26	Biosolids	19	Water reuse	17
Japan	Biosolids	35	WWTP processes & optimiz'n	16	Nutrients	16
Korea	Nutrients	26	Biosolids	25	Water reuse	12
Nether-lands	Decentralized WW Systems	20	Biosolids	16	WWTP processes & optimiz'n	15
Singapore	Nutrients	26	WWTP processes & optimiz'n	20	Emerging Substances of Concern	20
Spain	Biosolids	51	WWTP processes & optimiz'n	13	Water reuse	9
Sweden	Biosolids	44	WWTP processes & optimiz'n	19	Nutrients & Decentralized WW Systems	11
Switzer-land	Decentralized WW Systems	28	Emerging Substances of Concern	19	WWTP processes & optimiz'n	18
UK	Biosolids	32	WWTP processes & optimiz'n	14	Emerging Substances of Concern	12
USA	Biosolids	31	Wet weather treatment	20	Water reuse	12

the information provides an indication of the level of research activity and possible research priorities existing during the period of examination up to 2010 over the range of countries considered. In the case of Canada in descending order, 70 publications on biosolids research were accessed, with 29 for WWTP processes and optimization, 17 for wet weather treatment, and 16 each for emerging substances of concern and nutrients.

Table 3 presents a summary of the topics or subtopics addressed in the documents accessed in descending order of numbers of the publications found. The information is organized again by theme, sub-theme, topic and subtopic.

Table 3. Summary of Research Addressed in Publications Accessed

Theme or Sub-theme	Topic or Subtopic	#s of Papers Accessed
Nutrients	Biological nitrogen removal	591
Biosolids	Metals	417
Water Reuse	Irrigation	390
Water Reuse	Treatment	285
Biosolids	Compost	277
Biosolids	Emerging Substances of Concern	254
Decentralized WW systems	Treatment systems	250
Biosolids	Anaerobic digestion	227
WWTP processes and optimization	Activated sludge	165
Nutrients	Biological phosphorus removal	163
WWTP processes and optimization	Wetlands	155
Biosolids	Soil effects	148
Infrastructure	Pipes	141
WWTP processes and optimization	Granular sludge	132
Biosolids	Nutrients	122
Water Reuse	Sustainability	117
Wet Weather	Water pollution loadings	116
Emerging Substances of Concern	Receiving waters	110
Emerging Substances of Concern	Treatment	110
Nutrients	Modeling	100
Nutrients	Membranes	100
Climate Change and Sustainability	Newer energy recovery processes	85
WWTP processes and optimization	Disinfection/Oxidation	83
Decentralized WW systems	Grey water	81
Nutrients	Temperature effects	81
Nutrients	Chemical removal processes	79
Nutrients	Anammox	72

Continued

Table 3 (continued)

Theme or Sub-theme	Topic or Subtopic	#s of Papers Accessed
Biosolids	Pretreatment	69
WWTP processes and optimization	Modeling	66
Nutrients	Biofilms	65
Biosolids	Combustion	61
WWTP processes and optimization	Upflow anaerobic sludge blanket	60
Biosolids	Pathogens	55
Decentralized WW systems	Agriculture	55
WWTP processes and optimization	Odour	55
Wet weather treatment	Hydraulics and flow prediction	52
Climate Change and Sustainability	Sustainability	50
WWTP processes and optimization	Sequencing batch reactors	50
Wet weather treatment	Treatment and retention	50
Decentralized WW systems	Management	48
WWTP processes and optimization	Lagoons	48
Nutrients	Physical removal processes	46
Infrastructure	General	42
Nutrients	Biological aerated filters	41
Decentralized WW systems	Black water	40
Decentralized WW systems	Urine recovery	40
Emerging Substances of Concern	Analytical methods	40
WWTP processes and optimization	Automation	40
Emerging Substances of Concern	Water reuse	39
Emerging Substances of Concern	Ecotoxicity	38
Infrastructure	Maintenance	37
Biosolids	Odours	33
Climate Change and Sustainability	Value-added products	33
Climate Change and Sustainability	Climate change	32
Decentralized WW systems	Wetlands	30
Wet weather treatment	Green infrastructure	28
Emerging Substances of Concern	Hospitals	25
Water Reuse	Pathogens	23
Biosolids	Aerobic digestion	22
Infrastructure	Decision support	21
Nutrients	Environmental effects	19
Wet weather treatment	Construction and maintenance	18
Water Reuse	Social Issues	15

Continued

Table 3 (continued)

Theme or Sub-theme	Topic or Subtopic	#s of Papers Accessed
Biosolids	Management	14
Climate Change and Sustainability	Heat recovery	14
Nutrients	Modeling wetlands	14
Infrastructure	Pump stations	13
Nutrients	Receiving waters	13
Biosolids	Ecosystem effects	11
Emerging Substances of Concern	Lagoons	8
Emerging Substances of Concern	Wetlands	8
Biosolids	Thermal drying	7
Emerging Substances of Concern	Modeling	5

It is evident that the scope of international published research on wastewater and biosolids is broad as might be expected depending on needs, geographic and regional conditions and researcher/sponsor emphasis. Issues related to biosolids management, nutrients and water reuse appear to be particularly prevalent.

The involvement of Canadian researchers in the themes and sub-themes identified in **Table 1** is summarized in **Table 4**. The number of themes and sub-themes identified as including Canadian publications (at least one publication) is compared to the total number of publications in that theme or sub-theme from all countries considered. The information is presented in descending order of numbers of publications from all countries. From these data, the biosolids theme and the WWTP processes and optimization sub-theme are ranked 1 and 2 respectively for both Canada and the total of countries surveyed. Canada's percentages of the totals were 3.6% and 2.6% for these two subjects. In contrast the water reuse sub-theme and decentralized wastewater systems theme were found to be 1% and 0.7% respectively indicating that these two subjects may be considered less of a priority for Canada as compared to the aggregate of countries surveyed.

Table 4. Comparison of Global and Canadian Research Publications by Wastewater Theme or Sub-theme

Research Theme or Sub-Theme	Publications		
	Total: all Countries	Total: Canada	Canada: % of Total
Biosolids	1928	70	3.6%
WWTP Processes and Optimization	1099	29	2.6%
Nutrients	1021	16	1.6%
Water Reuse	913	9	1.0%
Decentralized Wastewater Systems	553	4	0.7%
Emerging Substances of Concern	383	16	4.2%
Wet Weather Treatment	322	17	5.3%
Infrastructure	254	6	2%
Climate Change and Sustainability	214	6	3%

Table 5 summarizes the focus of Canadian research publications on various subjects within the themes and sub-themes defined for this Agenda. The numbers of publications are presented as percentages of all Canadian publications in that theme or sub-theme. Only those research subjects in which publications represent greater than 10% are listed in the table.

Table 5. Canadian Publications by Wastewater Theme and Sub-theme

Theme or Sub-theme	Topic or Subtopic	No. of Publications	% of publications in Theme or Sub-theme
Biosolids	Anaerobic digestion	22	31%
Biosolids	Emerging Substances of Concern	11	16%
WWTP Processes and Optimization	Activated sludge treatment	10	34%
Biosolids	Heavy metals	9	13%
Wet Weather Treatment	Pollutant loadings	9	53%
Biosolids	Nutrients	7	10%
Emerging Substances of Concern	Receiving waters effects	7	44%
WWTP Processes and Optimization	Pathogens	5	17%
Nutrients	Bio-P processes	5	31%
WWTP Processes and Optimization	Disinfection/Oxidation	4	14%
WWTP Processes and Optimization	Lagoons	4	14%
Nutrients	Bio- N processes	4	25%
Emerging Substances of Concern	Ecotoxicity	4	25%
Wet Weather Treatment	Modeling & monitoring	3	18%
Nutrients	Modeling treatment	3	19%
Emerging Substances of Concern	Removal during treatment	3	19%
Climate Change and Sustainability	Value added product recovery	3	50%
Decentralized Wastewater Systems	Factors affecting treatment	3	75%
Infrastructure	Decision Support	2	33%
Infrastructure	Conveyances	2	33%
Climate Change and Sustainability	Innovative energy management	2	33%

The information in **Table 5** indicates that published Canadian research is spread somewhat thinly across many subject areas as might be expected with work on biosolids and WWTP processes and optimization being prominent. Biosolids subjects related to anaerobic digestion, emerging substances of concern, heavy metals and nutrients represent 4 of the top 7 in the list of all

research subjects. Research papers on anaerobic digestion led the overall list with 22 identified publications. Other subjects with a relatively high number of publications included activated sludge (WWTP Processes and Optimization), pollutant loadings (Wet Weather Treatment) and receiving waters effects (Emerging Substances of Concern).

The information gained from the snapshot survey has subsequently been used to make informed decisions on which research topics/subjects should be included in the evaluation matrix for establishment of the Research Agenda. It should be noted that additional topics identified through the consultation process have also been considered for inclusion in the final version of the Agenda.

Determining Research Priorities for a National Agenda

The development of the Agenda has involved five main steps: establishing a matrix of Research Themes, Sub-Themes and Topics that may be common to Canada; determining research priorities for the Agenda; refinement of priority topics and identification of examples of possible projects; identification of research strengths and the need to build capacity to address research topic needs in Canada; and public consultation to gather stakeholder input and feedback.

Establishing the Evaluation Matrix

The approach used for development of the Agenda emphasizes targeted or applied research as opposed to more basic, fundamental research. Basic research is primarily done to build capacity, and the research topics are usually aligned with the expertise and interests of individual principal investigators. This type of research is typically funded by special government funding agencies such as NSERC. In contrast, targeted research is mostly undertaken to address specific and often immediate end-user needs. This type of research is usually funded by end-users or by funding agencies and organizations established primarily to support end-user needs; the FCM Green Municipal Funds is an example of such an agency.

A matrix approach that could evaluate topics for possible research projects against a set of criteria and weightings to determine areas of greatest need has been developed for the Agenda. The matrix analysis is conducted at the level of topics (see **Appendix A**), as opposed to the levels of theme or sub-theme. Analysis at the topic level is considered necessary in order to address specific end-users needs and to lead to actual project "titles" selected to satisfy those needs. To illustrate this, consider in **Appendix A**, the theme "Municipal Wastewater Treatment" and the sub-theme "WWTP Processes and Optimization". Neither of these is sufficiently specific to lead directly to research project definition. Several topics are listed within this sub-theme including "Cold Temperature Processes" which can then be more easily analyzed for research needs relating, for example, to remote northern wastewater treatment lagoons and constructed wetlands performance as possible research projects.

The use of and need for more than one evaluation matrix has been considered at length, For example, separate matrices could be developed for wastewater and biosolids. Ultimately, one comprehensive evaluation matrix has been proposed due to the perceived difficulty in establishing a single set of priorities between two or more evaluation matrices.

A key element in developing the matrix process is the establishment of potential evaluation criteria and weightings for those criteria with which to identify research priorities. Initially, specific criteria such as human health risk, aesthetic impairment, and environmental risk (aquatic and terrestrial), were considered for evaluation of the themes, sub-themes and topics identified in the realm of wastewater and biosolids research. However, upon further analysis, it is realized that such specific criteria are already encapsulated in larger national initiatives in progress. Consequently, these specific criteria were re-formulated and integrated under four broader national initiatives.

In consideration of this thought process, the following four initiatives/principles have been used as the evaluation criteria:

- Support for CCME's Canada-wide Strategy for the Management of Municipal Wastewater Effluent (the Strategy) (short term);
- Support for the draft Canada-wide Approach for the Management of Wastewater Biosolids (short term);
- Contribution to sustainable wastewater and biosolids management through better energy management and materials recovery and reuse (long term);
- Addressing national initiatives on climate change adaptation and mitigation along with GHG reduction (long term).

The evaluation criteria above address both short and long term needs. The terms "short term" and "long tem" are used to indicate approximate time frames of five years or less and periods extending beyond five years into the future, respectively. Short term research priorities have been identified as those responding to CCME's Canada-wide Strategy for the Management of Municipal Wastewater Effluent (the Strategy), and the draft Canada-wide Approach for the Management of Wastewater Biosolids. The Strategy encompasses not only treated effluents discharged to surface waters, but combined and sanitary sewer overflows as well. The Strategy seeks to improve human health and environmental protection, and to improve clarity about the way in which MWWE is managed and regulated. The goals are to be accomplished by implementation of minimum National Performance Standards, and a process to conduct site-specific risk assessments and develop site-specific effluent discharge objectives (EDOs) and monitoring and reporting requirements. For sensitive receivers or areas with limited assimilative capacity, EDOs on nutrient loadings are more prevalent. As population growth and corresponding water stresses become more frequent, stringent control measures on nutrient discharges will be required. The Moving Forward Section of the Strategy document also notes the importance of research needed for wastewater treatment in Canada's Far North, and for emerging substances of concern such as pharmaceutical and personal care products, non-conventional contaminants from industrial sources, as well as the more generally acknowledged persistent organic pollutants and bioaccumulative substances.

The public consultation materials on the draft Canada-wide Approach for the Management of Wastewater Biosolids included a draft policy objective that focused on defining and promoting a Canada-wide approach to beneficial use and sound management of valuable resources (e.g., nutrients and organic matter) in municipal biosolids, municipal sludge and treated septage. The consultation materials also focused on the minimization of potential risks to the environment and human health, use of sludge incineration as a potential beneficial use if net energy is recovered and minimization of greenhouse gas emissions, for example by restricting sludge disposal in landfills.

Sustainability entered common speech following release in 1987of the Report from the World Commission on Environment and Development, more commonly called the Brundtland Commission, which was convened by the United Nations in 1983. In that report, the term sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

In adopting the theme of the Brundtland Commission report, in 2001 Environment Canada fostered the Corporate Environmental Innovation (CEI) initiative as one example of the Department's efforts to foster greater alignment of corporate activity with the goals of sustainable development. The CEI initiative is a partnership-based governmental initiative bringing together industry, the finance sector, academics, non-governmental organizations and other government departments with the objective of helping to accelerate innovation and to improve the environmental performance of companies (Moffatt and Auer, 2006).

As well, The Canadian federal government in 2008 passed the Federal Sustainable Development Act. An outcome of this Act was the Federal Sustainable Development Strategy, which uses four priority themes through which the goals, targets and implementation strategies of government decision-making are shaped. The four themes include:

1. Addressing climate change and clean air,
2. Maintaining water quality and availability,
3. Protecting nature, and
4. Shrinking the environmental footprint – beginning with government.

Given initiatives such as this, sustainable wastewater and biosolids treatment was considered one of the long term priorities for the Research Agenda. In this report, sustainable wastewater and biosolids treatment were considered to be those processes leading to neutral energy use, or even positive energy production, as well as the recovery of nutrients and other resources. Although the research needs of sustainable wastewater and biosolids treatment are clearly not as pressing as those ensuring compliance with CCME Strategies, never-the-less the benefits of developing research that leads to more sustainable treatment are considered great.

Canada ratified the Kyoto Protocol for reduction of greenhouse gas emissions (GHG) in 2002. Treatment of “waste”, including wastewater accounts for approximately 3 % of Canada’s total annual GHG emissions. While target reductions specified in the original protocol will not be achieved, the federal government through Environment Canada has great interest in reducing GHG emissions where possible. In that context, the research priority of reducing GHG emission and adopting mitigating strategies in the long term is high.

Climate change can cause extreme weather events, resulting in rainfall events of high intensity and duration. The extreme rainfall events contribute excessive loadings of water and pollutants to conveyance and treatment facilities and surface waters. The excessive flows often cannot be managed by existing infrastructure, and thus result in overflows and subsequent contamination of surface water.

Weighting Factors Applied to Matrix Evaluation Criteria

Having established a set of evaluation criteria, the next step in the development of the ranking matrix is to develop a series of weighting factors, to assign greater or lesser importance to each of the criteria, based on judging them against environmental, social and economic values. Specifically, the weightings have been developed using the triple bottom line (TBL) concept of environment, society and economy (**Table 6**).

Within each of the four criteria above, an arbitrary scale of 0 to 4 has been used to assign importance of these criteria's contribution to each of the three pillars of the TBL. A score of 4 in any TBL pillar indicates that the criterion is of the highest importance to that pillar. For example, sustainable wastewater treatment is very important to the economic pillar of the TBL, and therefore has a score of three or four. A score of 0 is indicative of no importance or negative impact of the criterion to that TBL pillar. An intermediate score of 2 was indicative of moderate importance of the criterion to that TBL pillar. **Table 6** provides the relative weightings developed using this procedure.

Table 6. Establishment of Weighting Factors for Evaluation Criteria

Criterion	Environmental Benefit		Social Benefit	Net Economic Benefit	Final Weight Assigned
	Water	Land, Air			
CCME Strategy	3	0	2	0	5
Draft Canada-wide Approach on Management of Biosolids	2	3	1	0	6
Sustainable WW/Biosolids Management (energy/resources)	1	2	3	3	9
GHG Mitigation & Climate Change	1	3	3	2	9

In the development of the weights assigned for the TBL pillars of environment, society and economy, the environmental benefit has been sub-divided into the water environment and the land/air environment. The environmental effects of treated wastewater relate first and foremost to the water environment, either directly, when effluent is discharged to surface water, or indirectly when treated effluent is applied to land. The Strategy specifically states that it does not address, among other discharges, air emissions or the management of biosolids. Conversely, the use of land application of biosolids as a beneficial use management option has the potential to impact the aquatic environment either as surface runoff or migration to groundwater, if the application process is improperly carried out.

Justification of the values of the weights used in **Table 6** are summarized below in **Table 7**.

Table 7. Justification of Weighting Factors for Criteria Assessment

Criteria	Triple Bottom Line Pillar	Weight Assigned (maximum of 4)	Justification
CCME MWWE Strategy	Environmental Benefit: Water	3	MMWE Strategy as adopted will result in improved effluent quality, thereby improving surface water quality and reducing risk to aquatic organisms
	Environmental Benefit: Air/Land	0	Air and land environments are excluded from CCME MWWE strategy
	Social Benefit	2	Improved effluent quality will result in reduction of nuisance and aesthetic complaints, thereby contributing to better quality of life. It may also result in improved long-term health benefits.
	Net Economic Benefit	0	The cost of the MWWE strategy is high at $10-13 billion, with no payback on capital expenditure.
Draft Canada-wide Approach for the Mgmt of WW Biosolids	Environmental Benefit: Water	2	Management of biosolids in accordance with provincial standards minimizes the risks of surface and groundwater contamination
	Environmental Benefit: Air/Land	3	Proper land application of biosolids results in return of nutrients and organic matter to the soil, better moisture content and tilth, and improves activity of soil microbes. Improved biosolids management strategies (e.g., elimination of sludge in landfills) will reduce emissions of GHGs.
	Social Benefit	1	Use of biosolids as a soil amendment reduces the need for chemical fertilizers, thus reducing life cycle costs for fertilizer production. This is balanced against the negative opinions of land application of biosolids held by a segment of the population.
	Net Economic Benefit	0	The costs for implementing the biosolids strategy are not expected to result in a net positive payback on capital invested.

Continued

Table 7 (continued)

Criteria	Triple Bottom Line Pillar	Weight Assigned (maximum of 4)	Basis for Weight Assigned
Sustainable WW/ Biosolids Mgmt (energy/ resources)	Environmental Benefit: Water	1	Recovery of nutrients from wastewater will improve surface water quality.
	Environmental Benefit: Air/Land	2	Adoption of sustainable WW/biosolids management practices will result in reduced need for purchased electricity to operate processes. On-site biogas use, or incineration, will reduce nitrous and sulphur oxide emissions from electricity generation, causing less damage to soils and crops.
	Social Benefit	3	Recovery of energy, nutrients and other resources from WW and biosolids treatment will result in reductions in use of virgin natural resources and will result in improved water and air quality.
	Net Economic Benefit	3	Recovery of energy (methane in biogas) and resources (e.g., phosphorus, ammonia) can have an acceptable payback of capital for municipalities.
GHG Mitigation & Climate Change	Environmental Benefit: Water	1	Extreme precipitation events from climate change will be lessened due to GHG reductions.
	Environmental Benefit: Air/Land	3	When treatment plants are optimized, both on-site (nitrous oxides and methane) and off-site GHG emissions (carbon dioxide) will be reduced. A reduced mass of solids for disposal will reduce emissions from vehicles hauling biosolids to the application sites. Surface runoff of soils and nutrients will be lessened because extreme precipitation events from climate change will be lessened.
	Social Benefit	3	Reduction in GHG emissions will improve quality of life, as more extreme weather conditions (flooding, drought, wind) will be lessened. Effects of climate change on society will be lessened.
	Net Economic Benefit	2	GHG emission reduction credits can be claimed when using biogas to offset purchased electricity.

In classification of wastewater and biosolids research, there is frequently overlap between potential themes, subthemes and topics, particularly with respect to biosolids. For example, energy reduction/recovery processes in sludge treatment might be judged as important in both the sustainability/energy reduction criterion (making plants more energy neutral), or in the GHG Reduction/Climate Change Adaptation and Mitigation criterion (reducing emissions of the GHG carbon dioxide from electricity generation), or in the Biosolids Approach criterion (energy recovery as beneficial use).

As the criteria and weighting are being applied, it is important to minimize the overlap in justification of weightings for the different criteria. A result of ignoring the overlap, or so-called double-accounting, would be to award a higher importance to the topic than would be the case if the topic fell clearly within the bounds of only one criterion.

In **Table 8**, the justifications used to assign weightings for the different criteria using the triple bottom line (TBL) pillars are defined to indicate how the potential overlap, or double-accounting has been minimized in the development of the Agenda. The first column denoted as "Assigned Evaluation Criterion" indicates that the weighting has been assigned to that criterion and TBL pillar based on the justification noted in Column 2. The "Potential Alternate Criterion not Applied" (Column 3) indicates that the weighting factor might also have been applied to that criterion, but was not so as to avoid the double-accounting

Table 8. Potential Overlap of Justifications for Assigning Weights to Criteria

Assigned Evaluation Criterion and TBL Pillar Addressed	Basis for Assigning to Evaluation Criterion	Potential Alternate Criterion not Applied
Draft Canada-wide Approach… Wastewater Biosolids (Land benefit)	Benefit of nutrients and trace elements, organic matter in biosolids to soil quality in land application	Sustainability/ Energy/Resource Recovery (Land benefit)
CCME MWWE Strategy	Reduced residual solids produced due to wastewater optimization or new process development	Draft Biosolids Approach (Land/air benefit); (also GHG Reduction/ Climate Change Adaptation/Mitigation) (Land/air benefit)
Sustainability/ Energy/Resource Recovery (Land/air benefit)	Reduced energy requirement for wastewater treatment due to optimization or new process development	CCME MWWE Strategy (Land/air benefit); (also GHG Reduction/ Climate Change Adaptation/Mitigation) (Land/air benefit)

Cont'd

Table 8 (cont'd)

Assigned Evaluation Criterion and TBL Pillar Addressed	Basis for Assigning to Evaluation Criterion	Potential Alternate Criterion not Applied
Sustainability/ Energy/Resource Recovery (Land/air benefit)	On-site biogas use, or sludge incineration, will reduce nitrous and sulphur oxide emissions from electricity generation, causing less damage to soils and crops	Draft Biosolids Approach (Land/air benefit); (also GHG Reduction/ Climate Change Adaptation/Mitigation) (Land/air benefit)
GHG Reduction/ Climate Change Adaptation/Mitigation (Land/air benefit)	Reduced surface runoff from biosolids-amended soils due to extreme precipitation events	Draft Biosolids Approach (Land/air benefit)
Draft Canada-wide Approach… Wastewater Biosolids (Land/air benefit)	Improved biosolids management strategies (e.g., elimination of sludge in landfills) will reduce emissions of GHGs.	GHG Reduction/ Climate Change Adaptation/Mitigation (Land/air benefit)
Sustainability/ Energy/Resource Recovery (Land/air benefit)	Recovery of nutrients from wastewater will improve surface water quality	CCME MWWE Strategy (Water benefit)
Sustainability/ Energy/Resource Recovery (Land/air benefit)	Adoption of sustainable WW/biosolids management practices will result in reduced need for purchased electricity to operate processes. On-site biogas use, or incineration, will reduce nitrous and sulphur oxide emissions from electricity generation, causing less damage to soils and crops.	Draft Biosolids Approach (Land/air benefit)
Sustainability/ Energy/Resource Recovery (Social benefit)	Recovery of energy, nutrients and other resources from WW and biosolids treatment will result in reductions in use of virgin natural resources and will result in improved water and air quality.	Draft Biosolids Approach (Social benefit)
Sustainability/ Energy/Resource Recovery (Economic benefit)	Recovery of energy (methane in biogas) and resources (e.g., phosphorus, ammonia) can have an acceptable payback of capital for municipalities.	Draft Biosolids Approach (Economic benefit)

Weighting Factors Applied to Each Research Topic

Lastly, a value ranging from 0 to a maximum of 2 has been applied against each of the topics listed in **Appendix A**, depending on whether the listed projects or project clusters within the topic were deemed to be aligned with the criteria discussed above. The results of this exercise are shown as raw points for each topic in **Appendix B**.

A step-by-step description and illustration of the process used in the Agenda to develop the evaluation matrix is provided in **Appendix C**.

Results of the Matrix Evaluation

Priority Ranking of Research Topics

Point values that have been applied to the Topics within the Themes and Subthemes are presented in **Appendix B**. The research matrix is a result of applying the weightings in **Table 6** to the point values assigned to each of the research topics in **Appendix B**. **Table 9** presents the resulting list of research topics in descending order of points assigned. Note that the ranking is based on evaluation criteria and weighting factors selected for a national perspective. Local or site-specific evaluation criteria and weightings would result in a different priority ranking.

Based on the point values assigned to topics and the criteria weightings, the highest possible point total for any topic was 58. As can be observed in **Table 9**, no one topic approaches this maximum, with 35.5 appearing as the highest point total. The reason for this apparent low point assessment is that no one topic fully addresses all of the four evaluation criteria. Topics either tend to address short term criteria, such as the Strategy and draft Canada-wide Approach for the Management of Wastewater Biosolids, or the long term criteria, such as the sustainable wastewater/biosolids management, GHG reduction or climate change adaptation/mitigation, but not both.

In **Table 9**, two of the top five research topics are related to the Municipal Wastewater Treatment Theme, namely, optimization of processes and nutrient reduction or recovery. The other three topics in the top five include research into green infrastructure for treatment and retention in the Wet Weather Treatment Theme, process research and optimization in the Biosolids Theme, and research into energy reduction or recovery processes as part of sustainable wastewater/biosolids management in the Climate Change and Sustainability Theme. These topics are followed by several falling within the Municipal Wastewater Treatment, Infrastructure and Climate Change and Sustainability Themes.

At first observation, it may appear as though biosolids research is not well represented among the most highly ranked topics. The only topics appearing near the top of the priority rankings that are clearly identified in the Biosolids Theme are Process Research & Optimization (32.5 points), and New Process Development, with a point value of 25.5. Upon closer inspection of the ranked priorities, however, biosolids-related research is well-represented in combination with wastewater research in the topics:

- Energy Reduction & Recovery Processes (Climate Change and Sustainability Theme/ Sustainable Wastewater/Biosolids Management Subtheme) (31.5 points),
- Production of GHGs by Treatment Processes (Climate Change and Sustainability Theme/ Effects of Wastewater & Sludge Treatment on Climate Change Subtheme), (28.5 points), and
- In-plant conservation (Climate Change and Sustainability Theme/Sustainable Wastewater/Biosolids Management Subtheme) (28 points).

Topics related to Decentralized Treatment theme and Water Reuse sub-theme, are found in the lower half of the 50th percentile rankings. Note that stormwater is urban runoff uncontaminated by municipal sewage, and therefore is considered separately from combined sewer overflow.

Table 9. Research Matrix Ranking of Themes, Subthemes and Topics by Point Total

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Municipal Wastewater Treatment	WWTP Processes & Optimization (incl. nutrients)	Optimization	10	3	9	13.5	35.5
Municipal Wastewater Treatment	Nutrients	Process Research	10	3	13.5	9	35.5
Wet Weather Treatment	Treatment & Retention	Green Infrastructure	7.5	0	13.5	13.5	34.5
Biosolids	Biosolids & Sludge Treatment & Management	Process Research & Optimization	2.5	12	13.5	4.5	32.5
Climate Change and Sustainability	Sustainable Wastewater/ Biosolids Management	Energy reduction/recovery processes	0	0	18	13.5	31.5
Municipal Wastewater Treatment	Emerging Substances of Concern	Source control (for both wastewater and biosolids)	10	12	9	0	31
Infrastructure	Asset Administration and Operation	Cost-effective Maintenance Schedule	7.5	9	13.5	0	30
Infrastructure	Asset Management Tools	Decision Support System Development/ Demonstration	5	6	18	0	29
Climate Change and Sustainability	Effects of Wastewater & Sludge Treatment on Climate Change	Production of GHGs by Treatment Processes	0	6	4.5	18	28.5
Climate Change and Sustainability	Sustainable Wastewater/ Biosolids Management	In-plant conservation	2.5	3	13.5	9	28

Continued

Table 9 (continued)

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Biosolids	Biosolids & Sludge Treatment & Management	New Process Development	0	12	9	4.5	25.5
Climate Change and Sustainability	Sustainable Wastewater/ Biosolids Management	Value-added products	0	3	18	4.5	25.5
Municipal Wastewater Treatment	WWTP Processes & Optimization	Cold Temperature Processes	10	6	0	9	25
Municipal Wastewater Treatment	WWTP Processes & Optimization	Small/Rural Treatment Systems	10	6	0	9	25
Wet Weather Treatment	Pollutant Loading	Combined sewer overflows	10	0	0	13.5	23.5
Wet Weather Treatment	Treatment & Retention	Combined sewer overflows	10	0	9	4.5	23.5
Municipal Wastewater Treatment	Water Reuse	Sustainability	0	0	18	4.5	22.5
Climate Change and Sustainability	Climate Change Effects on Wastewater Treatment & Biosolids Management	Land Application of Biosolids	0	9	0	13.5	22.5
Municipal Wastewater Treatment	WWTP Processes & Optimization (incl. nutrients)	Receiving Water Effects & Mitigation Strategies (incl. social issues)	10	12	0	0	22

Continued

Table 9 (continued)

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Municipal Wastewater Treatment	Emerging Substances of Concern	Receiving Water Effects & Mitigation Strategies (incl. social issues)	10	12	0	0	22
Municipal Wastewater Treatment	Emerging Substances of Concern	WWTP Influent & Discharge Loading Determination	10	12	0	0	22
Infrastructure	Asset Management Tools	Financial Support System Development/ Demonstration	5	3	13.5	0	21.5
Biosolids	Biosolids Application	Effects & Mitigation Strategies (including social issues	0	12	9	0	21
Biosolids	Biosolids & Sludge Treatment & Management	Contaminant identification, quantification and reduction	0	12	9	0	21
Wet Weather Treatment	Hydraulic & Flow Prediction	Lab-Scale Physical Modeling	7.5	0	0	13.5	21
Wet Weather Treatment	Hydraulic & Flow Prediction	Math modeling of sewer systems	7.5	0	0	13.5	21
Climate Change and Sustainability	Climate Change Effects on Wastewater Collection	Surcharging of sewer pipes and overflows and pump stations	7.5	0	0	13.5	21

Continued

Table 9 (continued)

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Climate Change and Sustainability	Climate Change Effects on Wastewater Treatment & Biosolids Management	WWTP Facilities	7.5	0	0	13.5	21
Climate Change and Sustainability	Climate Change Effects on Receiving Waters	Impact of Fluctuating Flows and Rising Temperature on Receivers	10	0	0	9	19
Municipal Wastewater Treatment	Emerging Substances of Concern	Water reuse	0	0	9	9	18
Wet Weather Treatment	Conveyance Systems	Sewer, tunnel and tank networks	7.5	0	4.5	4.5	16.5
Climate Change and Sustainability	Effects of Wastewater & Sludge Treatment on Climate Change	Energy consumption (C footprint) of different treatment processes	0	3	4.5	9	16.5
Decentralized Wastewater Systems	Collection & Treatment Technology	Source Separation & Treatment	0	0	9	7.2	16.2
Decentralized Wastewater Systems	Collection & Treatment Technology	Closed or Partially Closed Loop Recycling Reuse	0	0	9	7.2	16.2
Municipal Wastewater Treatment	Pathogens	Process Research	10	6	0	0	16.0

Continued

Table 9 (continued)

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Municipal Wastewater Treatment	Pathogens	Receiving Water Effects & Mitigation Strategies (including social issues)	10	6	0	0	16.0
Decentralized Wastewater Systems	Social & Economic Issues	LCA	0	0	10.8	4.5	15.3
Biosolids	Biosolids application	Best Management Practices	0	6	4.5	4.5	15
Municipal Wastewater Treatment	Water Reuse	Non-potable urban water reuse	0	0	9	4.5	13.5
Municipal Wastewater Treatment	Water Reuse	Treatment Technologies	0	0	9	4.5	13.5
Municipal Wastewater Treatment	Water Reuse	Pathogen disinfection	0	0	9	4.5	13.5
Decentralized Wastewater Systems	Social & Economic Issues	Health & environmental risk assessment	0	0	9	4.5	13.5
Decentralized Wastewater Systems	Social & Economic Issues	Public acceptance	0	0	9	4.5	13.5
Wet Weather Treatment	Treatment & Retention	Stormwater	0	0	9	4.5	13.5

Continued

Table 9 (continued)

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Infrastructure	Asset Administration & Operation	Innovative Design & Construction	0	0	13.5	0	13.5
Infrastructure	Asset Administration & Operation	New Rehabilitation Technologies	0	0	13.5	0	13.5
Municipal Wastewater Treatment	Water Reuse	Irrigation	0	0	9	2.7	11.7
Municipal Wastewater Treatment	Emerging Substances of Concern	Advanced Treatment Technologies	5	6	0	0	11
Municipal Wastewater Treatment	Emerging Substances of Concern	Optimization	5	6	0	0	11
Municipal Wastewater Treatment	WWTP Processes & Optimization	New Treatment Processes	5	3	0.9	0.9	9.8
Wet Weather Treatment	Pollutant Loading	Stormwater	0	0	0	9	9
Municipal Wastewater Treatment	Emerging Substances of Concern	Analytical Methods Development	2.5	3	0	0	5.5
Municipal Wastewater Treatment	Water Reuse	Social issues	0	0	4.5	0	4.5

Continued

Table 9 (continued)

Theme	Subtheme	Topic	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nat'l climate change adaptation & mitigation & GHG reduction	Points
Decentralized Wastewater Systems	Collection & Treatment Technology	Conventional Systems	2.5	1.8	0	0	4.3
Municipal Wastewater Treatment	WWTP Processes & Optimization	General Process Research	2.5	0	0	0	2.5

Examples of Possible Projects within Research Topics

Within the research topics, a list of example research projects has been compiled that would typify the topics. These are provided in **Table 10**. Example projects provided are those reflecting the sub-topics listed within each topic, as identified in **Appendix A**. The rationale used for development of the example projects within the research topics is presented in **Appendix D**. The example projects provided are intended to be illustrative of the research topics within the themes and sub-themes, but they should not be construed as the recommended projects coming out of the Agenda. The example projects are not listed in any particular order of importance or priority within each topic. The research projects listed in **Table 10** include a combination of those offered as representative of the research needs within the topic by this report's authors, and also those contributed by the Canadian Water and Wastewater Association's Committees on Biosolids and on Wastewater and Stormwater. In a number of cases the two sources of suggested research projects are almost identical, such as energy and nutrient extraction and carbon recovery/reuse, and potential use of ultrafiltration as a low energy alternative to disinfection.

While most of the example projects lie within the upper 50th percentile of the points assigned, projects lying in the lower 50th percentile are not to be neglected as unimportant. All the research needs are important, but just that some have a higher priority than others.

Public Consultation

Public consultation has been carried out in the form of two workshops, namely CWWA's Advanced Consultation Workshop at the 4th Wastewater Management Conference, and the 2011 Window on Ottawa Workshop, as well as the 30-day full public review of the Draft Agenda document. While not every responding stakeholder agreed with every specific part of the matrix evaluation process, general support of the Draft Agenda document was evident, based on the consultation feedback. Consequently, the consultation did not result in substantial changes to the Consultation Draft in finalizing the Agenda.

Table 10. Example Research Projects Illustrative of the National Research Agenda

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Municipal Wastewater Treatment	WWTP Processes & Optimization (including nutrients)	Optimization	35.5	Adaptation of sensors and automation for optimizing and controlling wastewater treatment processes
				Development and validation of improved models for facultative lagoons and wetlands used for process optimization
				Improvement of dynamic simulators for process operator training
				Development and demonstration of a low-cost reliable self-cleaning probe to continuously track DO levels in aeration basins
				Organizational and management issues
Municipal Wastewater Treatment	Nutrients	Process Research	35.5	Reduction of dissolved organic nitrogen
				Application of gas permeable membranes for efficient nitrification/denitrification
				Evaluation of Reactive Media Filtration process for P removal to achieve ultra low level in effluent
Wet Weather Treatment	Treatment & Retention	Green Infrastructure	34.5	Demonstration of on-site stormwater retention technologies, e.g. • Road-side bio-retention cells • Stormwater exfiltration/filtration systems
				Recovery, treatment and reuse of rainwater for irrigation or other benefits (roof-top cooling, golf course watering, park ponds, etc.)
Biosolids	Biosolids & Sludge Treatment & Management	Process Research & Optimization	32.5	Application of pre-treatment and membrane technologies to improve anaerobic digestion efficiency and biosolids quality
				**CWWA - improved dewatering with less polymer use*
				CWWA - Target "zero" sludge for ultimate disposal
				CWWA - better sludge buster

Continued

* CWWA denotes example projects suggested by the Canadian Water and Wastewater Association's Committees on Biosolids and on Wastewater and Stormwater

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Climate Change and Sustainability	Sustainable Wastewater/ Biosolids Management	Energy reduction/recovery processes	31.5	LCA comparison of energy recovery (incineration, gasification) of sludge in far north for communal heating relative to other sludge disposal methods
				Development of effective low-energy effluent disinfection technologies (exclusive of chemical disinfection by chlorination)
				Development of energy recovery devices from WW flowing in sewers or drop structures
				Development of technologies to recover energy from soluble organic substrates prior to aeration in secondary treatment (e.g. anaerobic treatment, microbial fuel cells, etc.)
				Production of biodiesel from algal biomass grown on nutrients in wastewater lagoons
				Recovery and use of latent heat value in wastewater, and recovery of energy from flowing wastewater (velocity and gravity) in collection system
				Investigation of the effects and benefits of co-digesting with some part of the organic fraction of MSW for energy recovery
				CWWA - is UF membrane treatment equivalent to disinfection: potential energy reduction
Municipal Wastewater Treatment	Emerging Substances of Concern	Source control (for both wastewater and biosolids)	31	Investigation of the effect of separate black and yellow water collection and treatment in hospitals on loadings of contaminants to municipal treatment systems (e.g. X-ray contrast media)
Infrastructure	Asset Administration and Operation	Cost-effective Maintenance Schedule	30	Use of sensors to predict rates of corrosion or pipe deflection in collection systems to monitor deterioration and plan for maintenance
				Use of sensors to predict and/or detect odour formation with automated corrective actions
				Models to predict failure or maintenance requirements

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Infrastructure	Asset Management Tools	Decision Support System Development/ Demonstration	29	Improved guidance manuals for cross-country Bench-marking, and for facilitation of setting up public-private partnership
				Guidance on full-cost accounting procedures and on life cycle assessments of assets
Climate Change and Sustainability	Effects of WW & Sludge Treatment on Climate Change	Production of GHGs by Treatment Processes	28.5	Quantification and mitigating procedures for minimizing N_2O emissions from municipal WWT
Climate Change and Sustainability	Sustainable Wastewater/ Biosolids Mgmt	In-plant conservation	28	Improved step-by-step guidance and benchmarking manuals for treatment plant operators
Biosolids	Biosolids & Sludge Treatment & Management	New Process Development	25.5	Investigation of geotextile bag filtration on reduction of pollutants (what are mechanisms, i.e. long retention time, freeze/thaw, aerobic/anaerobic conditions with depth from surface)
Climate Change and Sustainability	Sustainable Wastewater/ Biosolids Management	Value-added products	25.5	Recovery of commercially useful byproducts (e.g. construction aggregates from wastewater residual solids, or recovery of nutrients and biopolymers from de-watering supernatant liquor)
				Recovery of fertilizer-grade phosphorus from wastewater and sludge (separate from processes treating high strength sludge recycle streams e.g., OSTARA^{TM})
				CWWA - energy & nutrient extraction & carbon recovery/reuse
Municipal Wastewater Treatment	WWTP Processes & Optimization	Cold Temperature Processes	25	Effects and mitigation strategies for wastewater treatment impacts of MWWE effluents in cold, marine receiving waters and near shore embayment,
				Techniques for improvement of lagoon/wetlands system performance in Canada's Far North

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Municipal Wastewater Treatment	WWTP Processes & Optimization	Small/Rural Treatment Systems	25	Low-cost nitrification and algae control/removal in lagoon effluents prior to effluent discharge
Wet Weather Treatment	Pollutant Loading	Combined sewer overflows	23.5	Improved field monitoring techniques and modeling to quantify the frequency, flow and pollutant concentrations in storm/CSO events
Wet Weather Treatment	Treatment & Retention	Combined sewer overflows	23.5	Effectiveness of alternative disinfectants (e.g., chlorine dioxide, peracetic acid, ferrate) or improved UV/ozonation technologies for disinfection of CSOs (with attendant ESOC reduction)
				Development of innovative, low-cost strategies/processes to effectively reduce the discharge volume and/or pollutant loadings from CSOs, such as • Inflow reduction at source (e.g. foundation drains/down-spouts disconnection) • Chemically-enhanced RTBs or chemically-enhanced primary treatment of CSOs at the WWTPs
				Development of procedures, process or strategies to mitigate negative effects on WW and biosolids treatment due to influx of cold runoff and solids during rapid snowmelt events.
Municipal Wastewater Treatment	Water Reuse	Sustainability	22.5	Social-economic issues on the acceptability of water reuse
Climate Change and Sustainability	Climate Change Effects on Wastewater Treatment & Biosolids Management	Land Application of Biosolids	22.5	Improved modeling to estimate the effects of extensive runoff from biosolids-applied field during extreme wet-weather events

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Municipal Wastewater Treatment	WWTP Processes & Optimization (incl. nutrients)	Receiving Water Effects & Mitigation Strategies (including social issues)	22	Mitigation strategies for aquatic species impact in streams with seasonally high-proportion effluent contribution
				Decision assessment framework for socio-economic evaluation of impact of nutrient removal at WWTPs on receiving waters relative to control of non-point sources
				CWWA - chronic toxicity of WW effluents for Ceriodaphnia dubia (results biased with temperature?)
				CWWA - alternative methods for reducing Cu and Zn levels in sewage effluent
				Quantification of social benefits of improved effluent quality and integration of social benefits with economic benefits
Municipal Wastewater Treatment	Emerging Substances of Concern (ESOC)	Receiving Water Effects & Mitigation Strategies (including social issues)	22	Environmental fate (water column and sediments) and effects of ESOC in aquatic environment on aquatic and benthic organisms and potential bioaccumulation and effects
				CWWA - Surface Water Objectives for ESOC (analysis is required as part of CCME strategy - what are limits?)
Municipal Wastewater Treatment	Emerging Substances of Concern (ESOC)	WWTP Influent & Discharge Loading Determination	22	
Infrastructure	Asset Management Tools	Financial Support Systems	21	
Biosolids	Biosolids application	Effects & Mitigation Strategies (including social issues)	21	Development of whole biosolids-based bioassay protocols in soils using representative Canadian terrestrial organisms.
				Investigation of survival of norovirus, adenovirus and bacterial pathogens (*Clostridia* spp., campylobacter, *Listeria* spp, *S. Aureus*)

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Biosolids	Biosolids application (cont'd)	Effects & Mitigation Strategies (including social issues) (cont'd)	21	Environmental fate (soil and groundwater) and effects of ESOC (including nanomaterials) in terrestrial environment on soil organisms, predators and potential bioaccumulation and effects
				Investigation of which ESOC properties, if any, may lead to plant/crop uptake (roots/stems/leaves/fruit/grain) from biosolids-amended soils for locivores and human consumption
				Effects on health of humans near biosolids application sites
				Economic assessment of property values near biosolids application sites
				Socio-economic costs of crops grown with biosolids vs. crops grown with commercial fertilizers
Biosolids	Biosolids & Sludge Treatment & Management	Contaminant identification, quantification and reduction	21	Occurrence and reduction of nanomaterials through sludge and biosolids treatment processes
Wet Weather Treatment	Hydraulic & Flow Prediction	Lab-Scale Physical Modeling	21	
Wet Weather Treatment	Hydraulic & Flow Prediction	Math modeling of sewer systems	21	
Climate Change and Sustainability	Climate Change Effects on Wastewater Collection	Surcharging of sewer pipes and overflows and pump stations	21	Improved modeling to estimate at the municipal level the effects of extreme wet-weather events on the operation of the wastewater system, such as sewer pipes surcharge and overflows, increased peak flow at the WWTPs
Climate Change and Sustainability	Climate Change Effects on Wastewater Treatment & Biosolids Management	WWT Facilities	21	Effect of climate change on water demand and subsequent effect on wastewater collection and treatment infrastructure and operations.

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Climate Change and Sustainability	Climate Change Effects on Receiving Waters	Impact of Fluctuating Flows and Rising Temperature on Receivers	19	
Municipal Wastewater Treatment	Emerging Substances of Concern	Water reuse	18	
Wet Weather Treatment	Conveyance Systems	Sewer, tunnel and tank networks	16.5	
Wet Weather Treatment	Conveyance Systems	Sewer, tunnel and tank networks	16.5	
Climate Change and Sustainability	Effects of Wastewater & Sludge Treatment on Climate Change	Energy consumption (C footprint) of different treatment processes	16.5	
Decentralized Wastewater Systems	Collection & Treatment Technology	Source Separation & Treatment	16.2	Effect of grey water separation for recycle on on-site treatment systems (septic tanks)
Decentralized Wastewater Systems	Collection & Treatment Technology	Closed or Partially Closed Loop Recycling Reuse	16.2	
Municipal Wastewater Treatment	Pathogens	Process Research	16.0	Survival of viruses in UV light processes Removal of viruses in various types of treatment processes (e.g., lagoons vs. wetlands vs. activated sludge).

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Municipal Wastewater Treatment	Pathogens	Receiving Water Effects & Mitigation Strategies (including social issues)	16.0	Occurrence of antibiotic-resistant microbes downstream of municipal effluent discharges
Decentralized Wastewater Systems	Social & Economic Issues	LCA	15.3	
Biosolids	Biosolids application	Best Management Practices	15	Application of more stringent source control techniques to reduce harmful pollutant loadings from industrial and commercial discharges into sewer systems.
Municipal Wastewater Treatment	Water Reuse	Non-potable urban water reuse	13.5	Feasibility of grey water reuse in dry and remote/rural settings
Municipal Wastewater Treatment	Water Reuse	Treatment Technologies	13.5	
Municipal Wastewater Treatment	Water Reuse	Pathogen Disinfection	13.5	
Decentralized Wastewater Systems	Social & Economic Issues	Health & environmental risk assessment	13.5	
Decentralized Wastewater Systems	Social & Economic Issues	Public acceptance	13.5	

Continued

Table 10 (continued)

Theme	Subtheme	Topic	Points	Example Projects (in no particular priority order within Topics)
Wet Weather Treatment	Pollutant Loading	Stormwater	13.5	Impact of stormwater utility billing that encourages reduction of impermeable surfaces, and effect of the billing on enhancing stormwater treatment capacity, on receiving water quality
Infrastructure	Asset Administration & Operation	Innovative Design & Construction	13.5	Development of sewer appurtenances to reduce energy and turbulence in sewer drops and junctions to reduce odourous emissions
				Investigation of sewer conduit design for more efficient collection under low and normal flow
				Development of stronger pipe materials or coatings more resistant to H_2S corrosion
Infrastructure	Asset Administration & Operation	New Rehabilitation Technologies	13.5	
Municipal Wastewater Treatment	Water Reuse	Irrigation	11.7	
Municipal Wastewater Treatment	Emerging Substances of Concern	Advanced Treatment Technologies	11	Investigation of ESOC removal in waste stabilization ponds and wetlands: biodegradation, photolysis, settling as mechanisms
				Comparative evaluation of overall reduction of ESOC with and without primary clarification (non-removal of ESOC in primary sludge)
Municipal Wastewater Treatment	WWTP Processes & Optimization	New Treatment Processes	9.8	Evaluation of the sewer as a bioreactor; control of aerobic, anoxic and anaerobic environments to reduce loadings of organic carbon, nutrients, ESOC prior to arrival at treatment facility
				CWWA - reduced initial sludge production
Wet Weather Treatment	Treatment & Retention	Stormwater	9	
Decentralized Wastewater Systems	Collection & Treatment Technology	Conventional Systems	4.3	Nutrient reduction in septic tank leachates
Municipal Wastewater Treatment	WWTP Processes & Optimization	General Process Research	2.5	

Application of the Evaluation Matrix Framework for Regional Considerations

In this report, the criteria, weighting and rankings assigned are those dealing with research Themes, Subthemes and Topics on a national basis. Canada is a large country, however, both geographically and climatically diverse, with different demands, situations and priorities in different regions. As a result, top research priority topics and example projects identified at the national level may not match well with those identified at regional or local levels. Consequently, there is no "one-size-fits-all" Research Agenda to cover all specific regional and local needs throughout the country. Despite this drawback, the basic process used for the development and application of the Matrix Evaluation framework to identify national research priorities is considered to be broadly applicable and useful at regional and local levels. Redefining the criteria and weighting factors to reflect the site-specific conditions is key to the successful use of the Matrix Evaluation framework at these regional or local levels.

The list of Themes, Subthemes, Topics and example projects identified in a National Agenda should help in bringing together stakeholders that have similar interests in wastewater and biosolids research, and are willing to fund various projects whether they may rank high or low in the Agenda's prioritized list of topics.

Next Steps - A Consortium Concept for Canadian Wastewater Research

The original concept for the roll-out of the Agenda was to use a consortium-based approach. Reference was made to the value of such an approach in a report by MARBEK Resources Consultants (2008) for CCME. The report described the consortium approach used by the CWN to develop and facilitate research through the involvement of decision makers and end-users. As described in the Introduction and Background section of the Agenda, it is anticipated that the CWN will be the delivery agency responsible for orchestrating the implementation of the Agenda leading to the development and management of research projects.

The CWN currently has three consortia which are active, the Canadian Municipal Water Consortium (CMWC), the Canadian Watershed Research Consortium (CWRC) and the Secure Source Waters Consortium (SSWC). While the three consortia are managed somewhat differently, they are all based on the principal of relying on end-users for a) consultations to define areas of research need, b) manage calls for and review research proposals, c) assist with the management of research projects and d) implement the outcomes from the research. This approach is different from the more traditional investigator-driven research, in that end-users and their needs are prevalent in all phases of the work.

Both researchers and investigators play an essential role in the process since it is they who respond to the calls and eventually conduct the research and participate in the dissemination of outcomes. The attempt with this approach is to create an end-user -researcher synergy. It is also designed to facilitate end-user support of research and ultimately uptake of its outcomes.

The CWN's CMWC is expected to be involved with the roll-out of the Agenda at least in the early stages. It has been active since 2008 and has or is supporting research projects to investigate: a) removal and fate of emerging substances of concern in Canadian municipal wastewater treatment systems; b) the impact of emerging substances of concern in treated municipal effluents on receiving water ecology; c) the synthesis and performance of TiO_2 enhanced membranes for contaminant removal; d) improved disinfection using high shear stress environments; f) select contaminant removal using polymers in various forms; g) risk management in municipal drinking water.

The goal of the consortium-based approach is to bring together potential stake-holders with interests in funding certain common research topics. Although it might be expected that topics ranked as high priority in the National Agenda would be of primary interest to potential funding stake-holders, the topics of common interest do not necessarily need to be those ranked among the Agenda's highest priorities. Rather, they can be topics of significant local or regional interest, or of mutual interest to a set of stakeholders based on geography or demographics (e.g. wet weather control, marine discharges, remote or rural treatment).

Canadian Capacity in Wastewater/Biosolids Research

In order to properly address the research needs set out in the Research Agenda, it will be necessary to strengthen Canada's research capacity in some areas. The assessment of research capacity first examines historical strengths in wastewater and biosolids research, then assesses current research capacity, and ends with looking at potential research areas in which Canada might be a leading player on the global stage.

Historical Strengths

With respect to wastewater and biosolids research, Canada has had at least three historical strengths. The first relates to assessing the impact of pollutants on receiving water quality and biota. The work of David Schindler, Richard Vollenweider, Jack Vallentyne, Peter Dillon and Harold Harvey are examples of the exceptional Canadian research conducted through the late 1960s into the 1990s, looking at the aquatic effects of phosphorus and acid rain although the latter was not a wastewater contaminant. The establishment of Environment Canada's National Water Research Institute in Burlington, ON and the Freshwater Research Institute in Winnipeg, MB were key in developing this internationally recognized expertise. More recently, researchers like Mark Servos, Karen Kidd and Joanne Parrott have been assessing the effect of hormones and other endocrine disrupting compounds, contaminants found at very low concentrations in treated municipal effluents, on aquatic communities. Canada has a continuing body of research strength in this area.

A second strength was the in-depth knowledge of wastewater treatment processes and optimization techniques developed at Environment Canada's Wastewater Technology Centre (WTC), the National Research Council (NRC) and at several Canadian universities. Considering the WTC in particular, through the early 1970s to mid-1990s, the Centre and its staff achieved substantial international recognition. Exchanges between the Canadian wastewater engineers and other countries such as Sweden and Denmark were common. Through that time, much important research was being conducted on topics that are relevant today including to highlight a few:

- Biological nitrogen and chemical phosphorus removal (Paul Sutton, Earl Shannon, David Chapman)
- Computerized control of the dissolved oxygen process (Joe Stephenson, Gordon Speirs)
- Fate of trace contaminants in wastewater treatment processes (Henryk Melcer, John Bell, Hugh Monteith, Wayne Parker)
- Anaerobic treatment processes (Eric Hall)

Ontario Ministry of the Environment (OMOE) also played a key role in the research on control of phosphorus release into surface waters through the Canada-Ontario Agreement.

Additionally, Jiri Marsalek of the National Water Research Institute was instrumental in pioneering wet weather flow hydraulics and pollutant loading determinations, resulting in the establishment of an internationally recognized wet weather flow management research program.

With the change of focus of the WTC following privatization attempts, much of the collected expertise has been dispersed, primarily to the private sector. The WTC operates at a level significantly below its peak Moreover, many of the professionals that passed through the WTC during that period are near or now in retirement, leading to a substantial loss of institutional knowledge that can guide future efforts. There appears to be no such incubator of practicing wastewater treatment professionals in Canada at the present time. As noted in the section on Current Research Capacity below, however, there does appear to be a number of research centres or consortia that either are now or will be helping to fill this need for new practitioners.

The third strength is the continuing effort on biosolids research conducted by Agriculture and Agri-Food Canada led by Dr. Ed Topp, with collaboration from Environment Canada, the Ontario Ministry of the Environment (OMOE) and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). This research group examines many of the important issues of applying biosolids to land, such as the fate and mobility of pathogens and emerging substances of concern in soil and terrestrial organisms, transport of these pathogens and emerging substances of concern though soil into groundwater, and/or surface transport from soil in runoff to receiving waters.

Current Research Capacity

This section attempts to catalogue the capacity for wastewater and biosolids research currently available in Canada. It has been compiled principally though internet web-based searches. Although this report has attempted to be as complete as possible in the compilation of research capacity, there will undoubtedly be some omissions, and sincere apologies are offered here to those researchers or research centres/consortia inadvertently overlooked.

This report has compiled the Canadian research capacity according to several categories including:

- Wastewater Research Centres and Consortia;
- Canada Research Chairs;
- Natural Science and Engineering Research Council (NSERC) Industrial Research Chairs
- NSERC grants and scholarships to academic researchers in wastewater/biosolids treatment; and
- NSERC grants and scholarships to academic researchers with studies affiliated to wastewater treatment
- Other

Wastewater Research Centres and Consortia
Several research consortia involving universities, municipalities and various government ministries or agencies at the provincial and federal level were identified. Some of the research centres have adopted a broad range of wastewater/biosolids research programs, such as the Annacis Island Centre of Excellence, the Advancing Canadian Wastewater Assets Facility in Calgary, the Canadian Municipal Water Consortium, and the Southern Ontario Water Consortium.

The Centre for Water Resources Study at Dalhousie University is focused mostly on water and wastewater issues of Atlantic Canada, although two initiatives are of significant interest to the wastewater/biosolids research agenda, namely the Northern Municipal Wastewater Treatment Research Program in collaboration with Government of Nunavut, and the STEWARD program, a collaboration with Queen's University addressing buried infrastructure water technologies. The Centre for Control of Emerging Contaminants, centred at the University of Waterloo, has a more narrow focus addressing these contaminants through the water cycle, including municipal effluent discharge, receiving water effects and source water and drinking water treatment. The Centre of Alternative Wastewater Treatment centred at Fleming College in Lindsay, ON, focuses its research on constructed wetlands-based treatment. Within the Edmonton Waste Management Centre of Excellence, many aspects of biological nutrient removal are investigated. The Alberta Water Research Institute funds specific research initiatives in support of the Water for Life goals and objectives of safe, secure drinking water supply; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy.

Canada Research Chairs
The Canada Research Chairs is a permanent program established by the Government of Canada in the year 2000 to establish ultimately 2000 research professorships (to be known as Canada Research Chairs) in eligible degree-granting institutions across the country. The Canada Research Chairs program invests $300 million per year.

A search of the Canada Research Chairs website revealed that a substantial number of Canadian academic researchers hold Research Chairs in subjects that are pertinent to the Wastewater/Biosolids Research Agenda. Fourteen Chair-holders were identified as having research areas that were applicable to wastewater and biosolids research. A very wide range of subjects is addressed, ranging from material science to microbial processes, to nanomaterials to mathematics and modelling, and to receiving water effects. The diversity of expertise held within the Canada Research Chairs means that practically-oriented research can be brought to bear on the many aspects of Canadian wastewater and biosolids treatment issues.

Natural Science and Engineering Research Council (NSERC)
NSERC came into existence on May 1, 1978. University-based research had previously been supported through the Canada's National Research Council. In the 2011-2015 funding cycle, $29.6 million were earmarked for all Priority Area of Canada's Science and Technology Strategy. Of this total, 18% was allotted to Environmental Sciences and Technologies.

Research into wastewater and biosolids is addressed in two ways, including Industrial Research Chairs and NSERC Grants and Scholarships. With respect to wastewater and biosolids research, NSERC Industrial Research Chairs (IRCs) receive funding from their industrial partners (typically municipalities and private sector companies) and receive matching funding from NSERC. Nine IRCs have been established that relate to wastewater and water-based research.

NSERC Grants and Scholarships were awarded to a total of 56 researchers in wastewater and biosolids from across Canada between 2007 and 2011.Similarly, Additionally, NSERC Grants and Scholarships that were awarded to researchers affiliated with wastewater-related subjects

including water pollution (72 researchers); pollutants and toxic agents (36 researchers); and sanitary engineering (12 researchers).

Other

The Worsfold Water Quality Centre (WQC) of Trent University is dedicated to the development and application of innovative new techniques for the analysis of organic and inorganic materials. The focus of the Centre is the determination of trace quantities of inorganic and organic substances found in aquatic environments. The WQC includes chemists, environmental scientists, botanists, biologists, geologists and anthropologists. Research areas include cycling of trace metals in lakes and catchments, source partitioning of mercury input into lakes, innovative methods to measure radioactive elements at ambient levels, the release of pharmaceuticals from waste treatment facilities, analysis of proteomes, metal(oid) speciation analysis and isotope ratio determinations.

A detailed report on the status of wastewater and biosolids research in Canada and internationally has been prepared by Lishman and Monteith (2012). The report consists of examination of national wastewater/biosolids research priorities around the globe, and a extensive survey of technical publications on wastewater/biosolids research published in the technical literature between 2007 and 2010.

Water-related Research by University Discipline

A compilation of academics performing water-related research has been compiled by the Canadian Water Network. The disciplines involved in the water research are listed in **Table 11**. Disciplines specifically identified with the highest number of researchers include biology and geography, followed by Civil Engineering and Earth Sciences/Geology. Research on wastewater and biosolids falls within the Civil Engineering discipline.

Summary

This review of the current capacity in Canada for research of wastewater and biosolids treatment indicates that the country has a diverse base of researchers who can address many of the needs of wastewater and biosolids research. **Tables 2, 4 and 5,** presented earlier in this report, were developed from a snapshot of publications. The tables show that current Canadian researchers have been recently involved in a broad spectrum of research topics although some subjects addressing biosolids and WWTP processes and optimization appear to be more prominent than others such as subjects related to infrastructure management and renewal. While there appears to be a broad base of academic research capacity which can be brought to bear on wastewater and biosolids issues in Canada, this capacity often involves limited numbers of researchers in several of the subject areas. It is hoped that the roll-out of this Agenda will stimulate growth in Canadian research capacity in order to more adequately address end-user decision needs.

Table 11. Canadian Researchers in Water-Related Subjects by University Departmental Discipline

Departments	No. of Water Researchers
Biology	203
Chemistry	41
Civil Engineering	151
Earth Sciences/Geology	143
Economics	13
Geography	170
Other	354

Research Capacity that Canada Can Develop and Exploit

Canada's geography, demography and climate give rise to a set of special end-user wastewater and biosolids related needs that require attention. Capacity in Canada to conduct research addressing many of these needs exists, but can and in many cases should be strengthened, so that end-user decision needs can be met. Several research areas to satisfy these needs are described below together with specific topics to be addressed.

Cold Temperature Wastewater Research

Physical, chemical and biological wastewater treatment processes behave differently under cold and warm operating conditions. For example, biological treatment facilities that nitrify at warmer wastewater temperatures will slow or cease under winter conditions, causing effluent ammonia concentrations to rise. Suspended solids and particles have different settling properties in cold water than in warm water. Canada could become a leader in cold climate wastewater and biosolids treatment research through by either establishing a dedicated institution, or by creating a coordinated network of academics focusing on cold temperature treatment. Such research would be particularly valuable for small treatment systems being used in remote, northern communities.

Aquatic Effects Research

Many of the wastewater themes are associated with an element of receiving water impacts, such as nutrients, emerging substances, combined sewer overflows and runoff from biosolids-amended fields. Many Canadian universities have departments that are involved in these studies to some degree. A more structured, comprehensive assessment of current research and knowledge gaps in this expertise could enable Canada to address the knowledge gaps and play an even more significant role in global research on receiving water effects of municipal effluents.

Canada has among the largest freshwater reserves, and also one of the longest marine coastlines, in the world. Municipal effluents impact these receiving waters in both marine and freshwater environments. In particular, Canada's coastal cities are situated beside cold marine environments. While much of the world's research on municipal effluent effects on marine waters is done in warmer climates, Canada is well-positioned by its geography to better understand the effects of municipal effluent discharges into cold marine waters and the aquatic community therein.

Research on Treatment with Lagoons and Wetlands

Treatment of municipal wastewater in lagoons (facultative ponds; waste stabilization ponds) is a process commonly used in rural and small-town Canada. Many of these facilities may encounter problems of compliance with suspended solids or nutrient concentration limits due to algal growth or sub-optimal treatment. Research into optimizing procedures for lagoons, such as improved reduction of nutrients and improved efficiency of effluent suspended solids capture could result in improved compliance statistics. Development of improved models of lagoon treatment could help in this regard. Research suggests that lagoons can be at least as effective as secondary treatment facilities, but the reasons are not clear. Research into mechanisms and factors such as long retention times with natural biodegradation from biota; photolysis by sunlight; removal with settled solids, or other mechanisms could shed light on how to maximize removals of emerging substances of concern in lagoons. Some lagoons operate with an initial aerated cell, while others do not. Research could demonstrate whether there is a benefit from the additional energy needed for the mechanical aerators in terms of effluent quality or operational ease. Lagoons periodically need "de-sludging" to remove accumulated solids, which occupy volume and decrease the lagoon detention time and efficiency. Research may show there is a cost-effective method to reduce the rate of solids accumulation, thereby improving long-term performance and reducing the operational costs for de-sludging. Since many smaller Canadian municipalities depend on this treatment, there can be a clear benefit to Canada in general and other countries relying on lagoon technology from understanding the process and optimizing its performance.

Where facultative ponds are used (rural and smaller urban areas), research may turn them into producers of biodiesel from algae. Specifically, the lagoons could be engineered for maximizing algae production and recovery.

Wetlands can be natural or engineered, and they have been proven to be effective in polishing municipal effluents. The success of wetlands as the principal treatment technology is less certain and requires further investigation. In particular, they must be engineered to operate effectively in cold weather. Many of the systems in Canada's Arctic use a combination of lagoons and wetlands for treatment. Research is needed to evaluate the effectiveness of their operation and how to optimize their performance.

Aspects of wetland treatment of municipal wastewater that require further research include pretreatment requirements for removal of solids, optimization of removal of nutrients, pathogen

reduction, the reduction of emerging substances of concern, optimum vegetative development of a constructed wetland, biodiversity within the wetland, and the expected lifetime of operation.

Combined Sewer Overflows and Stormwater Management Research

Combined sewer overflows (CSOs) and stormwater can contain high concentrations of pathogens, as well as heavy metals, persistent, bioaccumulative and toxic (PBT) compounds such as polyaromatic hydrocarbons (PAHs), pesticides and other contaminants. When they are discharged to receiving waters during a storm, they become both an immediate and a long-term human health risk. In the U.S., billions of dollars are being invested in the control of CSOs and stormwater to achieve compliance with stringent regulations. Historically, Canada has lagged behind U.S. wastewater regulatory initiatives by 10 to 20 years. It is probable there will be Canadian stormwater regulations in the not-so-distant future.

Stormwater and CSOs result because our urban environment has created too much impervious surface. Urban designs need to incorporate the concept of retaining as much as possible of the run-off on-site before it reaches the collection system; that means application of green infrastructure such as porous pavements, infiltration systems, roadside bio-retention cells, and other decentralized stormwater treatment facilities (e.g, urban wetland parks). Consideration should be given to accelerating the development and use of rainwater harvesting, roof gardens and other "low-impact development" wet weather management technologies. Research efforts should also focus on minimizing the frequency and volumes of CSOs, and in developing efficient low-energy treatment for what CSO volume is produced.

Infrastructure Research

The Canadian infrastructure deficit is projected to run into the billions of dollars, but there is essentially no research being done in Canada (or elsewhere), as identified by this search, to address the existing deficit or to slow the failure rate of the wastewater collection and treatment infrastructure. Although the question "why is the no research?" is simple, the answer is not. It may be that the problem is being addressed by materials science research and was not captured in this search of wastewater research. It may be that the problem is so large that there is no vision as to how to attack it. It may be that the problem is not considered a topic attractive (in the vernacular a "sexy" topic) to researchers and funding bodies. Research that might address the infrastructure theme may include development of materials that are more resistant to hydrogen sulphide corrosion; improved sewer design to maintain wastewater velocity at both low and normal flows; designs to minimize turbulence and energy dissipation in sewers for odour reduction.

Research on Wastewater Treatment Plant Optimization

While there is a growing desire to operate WWTPs as energy efficiently as possible, there is also a growing trend to operate the facilities with reduced operator presence as part of municipal cost-savings efforts. To help a reduced operational staff workforce, the development of new sensors

that might help to indicate the onset of operational problems such as filamentous sludge bulking or foaming due to *Nocardia* would help operators to take corrective actions before the problem became severe. Other sensors might rapidly measure operational parameters such as biochemical oxygen demand (BOD) or indicator microbes as a measure of disinfection, to alert operators of impending problems with effluent quality. Improvements in existing technologies such as dissolved oxygen probes that do not become fouled with biomass in aeration tanks, are also needed. Studies to quantify the benefits of these improved techniques will help to convince plant staff to adopt their use.

Developments in applications of models and artificial intelligence at WWTPs might also remove some of the burden of reduced operational workforce by providing oversight of the operation, including potential forecasting based on historical data to warn of impending problems and suggesting potential solutions. Research that provides better mechanistic process models are needed to utilize the full value of modeling. Models that are operated off-line can be used to test a variety of scenarios to determine optimum operating strategies. Moreover, the simulation of wastewater treatment operations can be a very valuable training tool for operations staff to understand process unit functions and cause-and-effect of different operating procedures.

Research on Emerging Substances of Concern

The Canadian population in general appears to be concerned about pharmaceuticals, personal care products and other emerging substances of concern in treated municipal wastewater effluents, biosolids and ultimately in their drinking water. Issues that could be investigated include: better estimate of ESOC loadings discharged to the treatment plant and from the treatment plant to the environment; assessing removal efficiencies in municipal treatment facilities; and effects of the discharge of ESOC on organisms in receiving waters and in soils to which biosolids have been applied. Canada has expertise to address several of these issues; indeed, work on some of them is currently in progress.

Concern over pharmaceuticals could be mitigated by the development of technology for urine recovery. Such technology would recover nutrients and energy, and then treat the residual for removal of the pharmaceuticals. Development of this type of technology is highly sustainable and eco-friendly because of the removal of pharmaceuticals, and reduction of carbon and nutrient loadings to existing facilities which require energy there to treat. Countries like Switzerland and Germany are progressing on research of urine recovery, but it is still relatively early in the development stage.

Research on Sustainable Wastewater/Biosolids Management

Municipal wastewater officials are concerned with the costs of energy to treat wastewater. Research that can make wastewater treatment more sustainable, either through reduction of purchased energy (improved efficiency) or by onsite recovery of energy, will help to improve overall sustainability of the operations.

The activated sludge process is an early 20th century technology which requires large amounts of energy for carbon and nitrogen oxidation. The process results in voluminous quantities of microbial solids that require further treatment including thickening and dewatering to recover energy value from them by anaerobic digestion. It is time for a new paradigm of resource recovery from "used" water (energy from soluble organics, heat, gravity; nutrients, especially phosphorus).

Within the context of wastewater treatment processes, sustainability can be defined in a number of ways, including processes that have low energy requirements, have the ability to produce by-products of value, and that generate minimal quantities of residual streams. Hence such technologies would be considered preferable to existing treatment processes. Anaerobic bioprocesses are known to offer these benefits as the energy input associated with providing oxygen is not required, methane is generated as a process byproduct, and the growth of anaerobic biomass is less than that produced by aerobic processes. However, anaerobic processes have not typically been applied to municipal wastewater due to the slow growth of anaerobic microorganisms and hence their susceptibility to being washed out of the bioreactor.

Anaerobic treatment of wastewater rather than sludge for energy recovery has potential which researchers in the Netherlands appear to be investigating with up-flow anaerobic sludge blanket technology. Also, the introduction of membrane filtration into the anaerobic process could overcome this weakness that is associated with conventional configurations by maximizing biomass retention through effective solid liquid separation. While in theory there is considerable potential for the application of AnMBR technology to municipal wastewater, research into better process design and more efficient downstream nutrients and biogas recovery are needed into to make this technology viable.

Heavily urbanized areas in Canada are running out of land for biosolids application, but the alternatives to land application are uncertain. Research should focus on development of sustainable technologies (low carbon and land footprint) that allow for recovery of nutrients, energy and other materials (building aggregates, biobricks, slag, etc.) Although research into resource recovery from biosolids is underway, technologies often involve the use of harsh chemicals, high pressure, large reactors and a large spatial footprint.

A number of countries, especially in the European Union, have begun to voice concerns about the decline of existing stocks of phosphorus for use as fertilizers. Processes similar to the OSTARA™ struvite recovery system that recover the nutrient values from wastewater and/or biosolids will also be of significant value to address concerns of phosphorus fertilizer limitations.

Research on Climate Change Adaptation/Mitigation and GHG Emissions

Climate change also requires new research for improved wastewater and stormwater collection and treatment. The onset of more extreme precipitation events means that solutions must be found within existing or new infrastructure to manage the higher hydraulic and pollutant loadings associated with the storm events.

By signing on to the Kyoto Protocol, Canada has committed to reducing its national greenhouse gas (GHG) emissions. The energy required for waste treatment (including wastewater and biosolids) results in approximately 3% of Canada's total GHG emissions. There is clearly an opportunity to reduce the emissions from this sector, which are mostly attributable to the emissions from electricity generation used to power the prime movers (pumps, blowers, compressors, dewatering devices) used in wastewater collection and treatment.

Electricity purchased from utilities can be reduced not only by the development of more efficient equipment but also by development of new process technologies that minimize or even eliminate many of the energy intensive processes such as the use of nitritation (Anammox) process to bypass nitrification in biological nitrogen removal. Also, development of new treatment processes that convert chemical oxygen demand into recoverable methane (energy), thereby reducing the organic loading on downstream aeration processes, will result in significant reductions in purchased electricity and concomitant GHG emissions.

Nitrous oxide (N_2O) is one of the most powerful greenhouse gases, with a global warming potential approximately 310 time that of carbon dioxide. This powerful GHG can be emitted during the nitrification/denitrification process. With greater emphasis on biological nitrogen removal in many locations, the potential for emissions of N_2O also increases. There is a need to more fully understand the fundamental processes of N_2O during wastewater treatment, so that processes can either be optimized for minimization of emissions, or to develop alternative processes that avoid its formation altogether.

Additional Research Opportunities

Comments received during the public consultation period have highlighted the importance of social issues with respect to treatment and management of wastewater and biosolids. For example, Dr. Oberg (2012) of the University of British Columbia commented in her submission that "Management of municipal wastewater and biosolids has traditionally been seen as an engineering problem but it is becoming increasingly clear major challenges to sustainable management of wastewater and biosolids are tied to issues rooted in organizational, administrative, fiscal and legislative structures." This sentiment is representative of similar comments received from others in the public consultation. Consequently, integration of research on social issues affecting wastewater and biosolids treatment/management with research derived from the engineering and natural sciences presents a significant opportunity for Canada to contribute to the advancement of research in this field.

The septic tank is a 19th century technology. Research efforts may develop a better unit or treatment process for decentralized household treatment. In particular, the research may investigate how to turn the on-site treatment system into an on-site resource recovery unit. Benefits could include use of grey water for toilet flushing and irrigation, production of energy from digestion of black water; and recovery of nutrients for turf and gardens from yellow water and the final effluent.

Conclusions

1. In the peer-reviewed technical literature (2007-2010) on wastewater and biosolids research, publications identified as originating from Canada represented between 1% and 5% of all publications identified within each theme.
2. The majority of identified Canadian research publications focus on biosolids and municipal wastewater treatment processes, with little attention directed to water reuse, decentralized treatment or infrastructure.
3. Major themes identified for research needs include: municipal wastewater treatment; biosolids; wet weather treatment; decentralized (urban) wastewater treatment; climate change and sustainability; and infrastructure. Sub-themes and topics were identified within each major theme. Prioritization of these needs has been determined through the application of the Evaluation Matrix.
4. Principles for establishing the evaluation criteria for the Canadian Wastewater and Biosolids Research Agenda include supporting implementation of short term (the Strategy and the draft Canada-wide Approach for the Management of Wastewater Biosolids) and addressing long term (government initiatives on sustainability, and greenhouse gas reductions and climate change adaptation/mitigation) national commitments.
5. The triple bottom line (TBL) concept of environment, society and economy has been used to apply weightings for the four matrix evaluation criteria.
6. The top five topics in the Research Agenda include two from the Municipal Wastewater Treatment theme, and one each from the Wet Weather Treatment, Biosolids and Climate Change and Sustainability themes.
7. Although the Matrix Evaluation framework has been used here to identify national research priorities, it can be broadly applicable and useful at regional and local levels by redefining the criteria and weighting factors to reflect site-specific conditions.
8. Canada has historical research strengths in aquatic environmental effects, municipal wastewater treatment processes, and biosolids management and environmental effects.
9. Due to Canada's geography, demography and climate, several pertinent research areas have been identified for consideration, including: cold temperature effects on wastewater processes; aquatic effects research; wastewater treatment using lagoons and wetlands; combined sewer overflows and stormwater management; infrastructure research; wastewater treatment plant optimization; emerging substances of concern; sustainable wastewater/biosolids management; climate change adaptation/mitigation and greenhouse gas emission reductions; integration of research on social issues affecting wastewater and biosolids treatment/management with research derived from the engineering and natural sciences.

Recommendations

1. Following finalization of the Research Agenda, CWN should begin setting up end-user based Research Consortia to select research projects to be undertaken, to arrange suitable funding and to manage the progress of the research.
2. The CWWA should undertake dissemination of information on research activities and outputs as they become available from the Research Consortia.
3. The Research Agenda should be re-evaluated on a 5-year cycle by a wider group of stake-holders including wastewater professionals from academia, municipalities, senior levels of government, the private sector (consultants and equipment suppliers), other non-governmental organizations and funding agencies to update the process and results.
4. Stakeholders with interests in the management of municipal wastewater and biosolids should consider undertaking on-going support of a Canadian Science and Research Coordinating Body to maintain and perpetuate the Agenda Initiative into the future.

References

Lishman, L. and Monteith, H. 2012. Survey of Canadian and International Literature of Wastewater and Biosolids Research. In preparation. January.

MARBEK Resource Consultants Ltd. 2008. Towards the Establishment of a Canadian Municipal Wastewater Research Coordination Group. Final Report submitted to Canadian Council of Ministers of the Environment. March 31.

Moffatt, A. and Auer, A. 2006. Corporate Environmental Innovation (CEI): A government initiative to support corporate sustainability leadership. *Journal of Cleaner Production*, **14**, 589-600.

Oberg, G. 2012. Comment as received and recorded in the Comments Disposition Table from the Agenda Public Consultation in January and February, 2012.

Appendix A: List of Research Themes, Sub-Themes and Topics for Municipal Wastewater and Biosolids

THEME	SUBTHEME	TOPIC	SUB-TOPICS
MUNICIPAL WASTEWATER TREATMENT	WWTP Processes & Optimization	General Process Research	Biological Treatment
			Solids removal/settling
			Energy Management
			Disinfection
			Odour
			Lagoons
			Wetlands
		Cold Temperature Processes	Lagoons
			Wetlands
			Temperature effects on biological, physical and chemical treatment processes
		Small/Rural Treatment Systems	SBRs
			Lagoons
			Wetlands
			Package Plants
		New Treatment Processes	Granular sludge
			AUSB reactors
			Advanced oxidation
			In-sewer bioreactors
		Optimization	Automation
			Modeling
			Sensors
			Control
			System Integration
			Guidance Manuals
			Organizational/Management Issues
			Operator Training
		Receiving Water Effects & Mitigation Strategies (including social issues)	Cold temperature region
			Marine coastal region
			Estuary region
			Specific sensitive receiving waters
			Risk assessment and management
			Quantification of social benefits of improved effluent quality and integration of social benefits with economic benefits

Continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
MUNICIPAL WASTEWATER TREATMENT	Nutrients	Process Research	Nitritation
			Biofilms
			Biological aerated filters
			BNR
			BPR
			Media processes
			Chemical processes
			Membranes
			Gas permeable membranes
			Physical processes
		Optimization	Biological process modelling
			Wetlands modelling
			Temperature effects on processes
		Receiving Water Effects & Mitigation Strategies (including social issues) of N & P	Near-shore eutrophication
			Costal regions and estuaries
			Land-locked lakes
	Emerging Substances of Concern (including non-conventional contaminants from industrial sources discharging to municipal sewer systems)	Analytical Methods Development	ESOCs in water Matrix
			ESOCs in solids matrix
		WWTP Influent & Discharge Loading Determination	ESOC loadings to WWTP
			ESOC loadings to receiving waters from conventional processes (lagoons, wetlands, CAS, BNR, MBRs)
			ESOC loadings from land-applied biosolids
		Treatment Technologies	Staged, anaerobic, anoxic and aerobic environments
			Membrane processes
			Advanced oxidation
		Source control (for both wastewater and biosolids)	Manufacturing facilities
			Other Industry (secondary use)
			Household
			Commercial and institutional
			Hospital
			Long-term care centres
			Research facilities (academic, government, commercial)

Continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
MUNICIPAL WASTEWATER TREATMENT	Emerging Substances of Concern (including non-conventional contaminants from industrial sources discharging to municipal sewer systems) (cont'd)	Optimization	Modeling
			Biological, microbial and DNA-based sensors
		Receiving Water Effects & Mitigation Strategies (including social issues)	Chemical monitoring
			Biological response monitoring
			Ecotoxicity
			Relating chemical and biological response results
			Risk assessment and management
		Water reuse	Treatment technologies for direct reuse
			Treatment technologies for indirect reuse
	Pathogens	Process Research	Emerging pathogens of concern (including viruses, bacteria and parasites)
			Antibiotic resistant microbes
			Prions
			Physical processes (UV, gamma-rays, etc.)
			Chemical processes (incl. advanced oxidation)
		Receiving Water Effects & Mitigation Strategies (including social issues)	Impacts on health of humans downstream from effluent discharges
			Risk assessment and management
	Water Reuse	Irrigation	Golf courses and parks
			Agriculture
			Silviculture
			Greenhouses
		Non-potable urban water reuse	Street cleaning
			Toilet flushing
			Evaporative cooling
		Treatment Technologies	Disinfection
			Membranes
			Advanced oxidation
			Sand filters
		Pathogens	Advanced pathogen identification methods
			Sensors
			Representative pathogen indicators
		Sustainability	Watershed/water cycle

continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
MUNICIPAL WASTEWATER TREATMENT	Water Reuse (cont'd)	Sustainability (cont'd)	Water balance/ supply and demand
			Aquifer recharge for indirect potable reuse
			Aquifer recharge for saltwater intrusion barrier
		Social Issues	Public perception
			Risk assessment and management
			ESOC present in discharged treated effluents
			ESOC in replenished groundwater
BIOSOLIDS	Biosolids & Sludge Treatment & Management	Sludge Treatment Process Research & Optimization	Pretreatment technologies
			Dewatering technologies
			Anaerobic digestion
			Composting
			Aerobic digestion
			Combustion/Incineration
			Alkaline stabilization
			Thermal drying
			Gasification/ pyrolysis/plasma
			Stabilization processes for cold climates
			Production of manufactured soil
			Fate of nutrients in sequential biosolids treatment processes
			Social issues (e.g. odours)
		New Process Development	Geotextile bag
			AnMBR
		Contaminant identification, quantification and reduction	Emerging Substances of Concern
			Metals
			Nutrients
			Pathogens (including prions)
			Odourous compounds
	Biosolids application	Best Management Practices	Odour control
			Spreading guidelines
			Nutrient release
			Pathogen release
			Noise and dust control
			Vector control

continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
BIOSOLIDS	Biosolids application (cont'd)	Best Management Practices (cont'd)	GHG emissions, carbon sequestration and mineralization
			Use in land reclamation
		Effects & Mitigation Strategies (including social issues)	Runoff to receiving waters (nutrient, metals, ESOC, etc.)
			Subsurface migration to groundwater
			Aerosols
			Effects on health of humans near biosolids application sites
			Soil effects
			Crop uptake
			Animal uptake (worms, insects, voles, foxes, birds)
			Long-term monitoring of annually-applied biosolids sites for fate and accumulation of ESOCs
			Economic assessment of property values near biosolids application sites
			Socio-economic costs of crops grown with biosolids vs. crops grown with commercial fertilizers vs. organically grown crops
			TBL comparison of biosolids-to-ennergy vs. biosolids for soil amendment
			Public perception
			Risk assessment and management
			Odours
			bioaccumulation by grazing animals (e.g. milk from cows)
	Pollutant Loading	Combined sewer overflows	Field monitoring
			Modeling and estimation of overflow events
			Modeling and estimation of pollutant loads
			Receiving water impacts
			Effects of CSO and stormwater on recreational value of receiving waters and beaches
		Stormwater	Snow melt runoff
			Agricultural runoff from biosolids-amended fields

continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
WET WEATHER TREATMENT	Pollutant Loading (cont'd)	Stormwater (cont'd)	Climate change effects
			Stormwater quality assessment
			Receiving water impacts
	Hydraulic & Flow Prediction	Lab-Scale Physical Modeling	
		Math modeling of sewer systems	
	Treatment & Retention (cont'd)	Combined sewer overflows (cont'd)	Retention basins (conventional)
			Deep tunnel
			In-sewer storage & routing
			Chemically enhanced settling in retention basins
			Chemically enhanced primary treatment at WWTPs
			Effects on WW and biosolids treatment from influx of cold runoff and solids during rapid snowmelt events.
			Optimization of CSO treatment processes
		Stormwater (Conventional end-of-pipe treatment and retention)	Ponds
			Tanks
			Optimization of stormwater treatment processes
		Green Infrastructure	Low impact development (LID)
			Bio-retention cells
			Roof-top gardens
			Swales
			Porous pavement
			Foundation drain and downspout disconnection
			Rainwater collection and reuse
	Conveyance Systems	Sewer, tunnel and tank networks	Design & construction
			Maintenance
			I/I reduction
DE-CENTRALIZED WASTEWATER SYSTEMS (Urban)	Collection & Treatment Technology	Conventional Systems	Pressure and/or vacuum sewers
			Package plants/SBRs
		Source Separation & Treatment	Black water
			Grey water

continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
DE-CENTRALIZED WASTEWATER SYSTEMS (Urban)	Collection & Treatment Technology (cont'd)	Source Separation & Treatment (cont'd)	Urine separation
		Closed or Partially Closed Loop Recycling/Reuse	Toilet flushing, home utility water and garden/agriculture
			Energy (biogas) & material recovery
	Social & Economic Issues	LCA	
		Health & environmental risk assessment	
		Public acceptance	
CLIMATE CHANGE & SUSTAIN-ABILITY	Effects of Wastewater & Sludge Treatment on Climate Change	Energy consumption (C footprint) of different treatment processes	Primary treatment
			Secondary treatment
			Tertiary treatment including nutrient removal
			ESOC removal
			Advanced treatment for water reuse
			Disinfection
			Sludge dewatering processes
			Biosolids treatment processes
		Production of GHGs by Treatment Processes	Methane
			Nitrous oxides
	Climate Change Effects on Wastewater Collection	Surcharging of sewer pipes, pump stations and overflows	
	Climate Change Effects on Wastewater Treatment and Biosolids Management	WWT Facilities	Wet weather peak flow attenuation/control
			Property flooding
			Increased frequency/duration of CSOs
			Low flow in receiving streams due to extended drought
		Land Application of Biosolids	Extensive runoff from biosolids-applied fields
			Excessive migration of contaminants to groundwater/tile drainage
			Lack of oxygen in saturated solids for microbial biodegradation
			Effects of drought or excessive saturation of soil

continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
CLIMATE CHANGE & SUSTAIN-ABILITY	Climate Change Effects on Receiving Waters	Impact of Fluctuating Flows and Rising Temperature on Receivers	Impact of climate change on assimilative capacity
			Establishment of triggering points for revision of EDOs due to climate change
	Sustainable Wastewater/ Biosolids Management	In-plant conservation	Gas-permeable membrane for aeration
			energy efficient equipment (VFDs)
			solar drying of sludge
			on/off aeration
		Energy reduction/recovery processes	In-sewer heat recovery
			In-sewer hydraulic energy recovery
			Anaerobic co-digestion of organic wastes with sludge
			Anaerobic MBR for raw wastewater and/or sludge treatment
			Anaerobic fluidized bed or UASB reactors for raw wastewater and/or sludge treatment
			Improvements in WAS digestibility for enhanced biogas production
			Low energy disinfection
			Sludge pyrolysis and gasification
			Microbial fuel cells
			Digester gas fuel cells
			Algae growth for biodiesel production
			Effectiveness of biosolids for growing crops for energy
			Hydraulic turbines at discharge weirs or drops
			Socio-economic issues
			Life cycle assessment
		Value-added products	Phosphorus & nitrogen (ammonia) recovery
			Biodegradable biopolymer
			Volatile fatty acids
			Adsorbent chars and oil from sludge pyrolysis
			Ceramic materials from sludge ash

continued

Appendix A (continued)

THEME	SUBTHEME	TOPIC	SUB-TOPICS
CLIMATE CHANGE & SUSTAIN-ABILITY	Sustainable Wastewater/ Biosolids Management (cont'd)	Value-added products (cont'd)	Light weight aggregate materials
			Methanol from methane in digester gas (for denitrification)
INFRA-STRUCTURE	Asset Management Tools	Decision Support System Development/ Demonstration	Bench-marking guidance manual
			Public-private partnership
			LCA of sewer network & treatment facilities
			Modeling of sewer network
			Modeling to extend life of treatment process equipment
			Modeling to assess impact of climate change on life of assets
		Financial Support System Development/ Demonstration	Standardization of municipal financial accounting systems, such as revenues and expenditures
			How to manage financially the sewerage system (collection & treatment) cost
			Assessment of climate change on life cycle and replacement costs of assets
	Asset Administration & Operation	Innovative Design & Construction	Pipes (e.g., trenchless technologies)
			Pipe design (e.g. Oval) to accommodate variable flow
			Pipe materials of construction to fight corrosion and deflection
			Pump Stations
			Treatment facilities
		Cost-effective Maintenance Schedule	Preventative maintenance
			Routine maintenance
			Models to predict material/equipment deterioration
			Sensors to detect material/equipment deterioration
		New Rehabilitation Technologies	Pipes (e.g., no-dig)
			Pump Stations
			Treatment facilities
			I/I reduction

Appendix B: Raw Points Assigned to Research Topics by Criteria

THEME	SUBTHEME	TOPIC	CRITERIA			
			supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses national climate change adaptation & mitigation & GHG reduction
MUNICIPAL WASTEWATER TREATMENT	WWTP Processes & Optimization	General Process Research	0.5	0	0	0
		Cold Temperature Processes	2	1	0	1
		Small/Rural Treatment Systems	2	1	0	1
		New Treatment Processes	1	0.5	0.1	0.1
		Optimization	2	0.5	1	1.5
		Receiving Water Effects & Mitigation Strategies (including social issues)	2	2	0	0
	Nutrients	Process Research	2	0.5	1.5	1
		Optimization	2	0.5	1	1.5
		Receiving Water Effects & Mitigation Strategies (including social issues)	2	2	0	0
	Emerging Substances of Concern	Analytical Methods Development	0.5	0.5	0	0
		WWTP Influent & Discharge Loading Determination	2	2	0	0
		Treatment Technologies	1	1	0	0
		Source control (for both wastewater and biosolids)	2	2	1	0

continued

Appendix B (continued)

THEME	SUBTHEME	TOPIC	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses national climate change adaptation & mitigation & GHG reduction
MUNICIPAL WASTEWATER TREATMENT	Emerging Substances of Concern (cont'd)	Optimization	1	1	0	0
		Receiving Water Effects & Mitigation Strategies (including social issues)	2	2	0	0
		Water reuse	0	0	1	1
	Pathogens	Process Research	2	1	0	0
		Receiving Water Effects & Mitigation Strategies (including social issues)	2	1	0	0
	Water Reuse	Irrigation	0	0	1	0.3
		Non-potable urban water reuse	0	0	1	0.5
		Treatment Technologies	0	0	1	0.5
		Disinfection	0	0	1	0.5
		Sustainability	0	0	2	0.5
		Social issues	0	0	0.5	0
BIOSOLIDS	Biosolids & Sludge Treatment & Management	Sludge Treatment Process Research & Optimization	0.5	2	1.5	0.5
		New Process Development	0	2	1	0.5
		Contaminant identification, quantification and reduction	0	2	1	0
	Biosolids application	Best Management Practices	0	1	0.5	0.5

continued

Appendix B (continued)

THEME	SUBTHEME	TOPIC	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses national climate change adaptation & mitigation & GHG reduction
BIOSOLIDS	Biosolids application (cont'd)	Effects & Mitigation Strategies (including social issues)	0	2	1	0
WET WEATHER TREATMENT	Pollutant Loading	Combined sewer overflows	2	0	0	1.5
		Stormwater	0	0	0	1
	Hydraulic & Flow Prediction	Lab-Scale Physical Modeling	1.5	0	0	1.5
		Math modeling of sewer systems	1.5	0	0	1.5
	Treatment & Retention	Combined sewer overflows	2	0	1	0
		Stormwater	0	0	1	0.5
		Green Infrastructure	1.5	0	1.5	1.5
	Conveyance Systems	Sewer, tunnel and tank networks	1.5	0	0.5	0.5
DE-CENTRALIZED WASTEWATER SYSTEMS (URBAN)	Collection & Treatment Technology	Conventional Systems	0.5	0.3	0	0
		Source Separation & Treatment	0	0	1	0.8
		Closed or Partially Closed Loop Recycling Reuse	0	0	1	0.8
	Social & Economic Issues	LCA	0	0	1.2	0.5
		Health & environmental risk assessment	0	0	1	0.5
		Public acceptance	0	0	1	0.5

Continued

Appendix B (continued)

THEME	SUBTHEME	TOPIC	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses national climate change adaptation & mitigation & GHG reduction
CLIMATE CHANGE & SUSTAIN-ABILITY	Effects of Wastewater & Sludge Treatment on Climate Change	Energy consumption (C footprint) of different treatment processes	0	0.5	0.5	1
		Production of GHGs by Treatment Processes	0	1	0.5	2
	Climate Change Effects on Wastewater Collection	Surcharging of sewer pipes and overflows and pump stations	1.5	0	0	1.5
	Climate Change Effects on Wastewater Treatment & Biosolids Management	WWT Facilities	1.5	0	0	1.5
		Land application of biosolids	0	1.5	0	1.5
	Climate Change Effects on Receiving Waters	Impact of Fluctuating Flows and Rising Temperature on Receivers	2	0	0	1
	Sustainable Wastewater/ Biosolids Management	In-plant conservation	0.5	0.5	1.5	1
		Energy reduction/recovery processes	0	0	2	1.5
		Value-added products	0	0.5	2	0.5

Continued

Appendix B (continued)

THEME	SUBTHEME	TOPIC	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses national climate change adaptation & mitigation & GHG reduction
INFRA-STRUCTURE (cont'd)	Asset Management Tools	Decision Support System Development/ Demonstration	1	1	2	0
		Financial Support System Development/ Demonstration	1	0.5	1.5	0
	Asset Administration & Operation	Innovative Design & Construction	0	0	1.5	0
		Cost-effective Maintenance Schedule	1.5	1.5	1.5	0
		New Rehabilitation Technologies	0	0	1.5	0

Appendix C: Step-by-Step Development of Priority Ranking System for Wastewater/Biosolids Research Topics

This Appendix is intended to guide the reader through the steps taken in developing the prioritization system of research topics used in this report. It may also provide guidance for readers who choose to develop a different set of evaluation criteria and weighting factors for local considerations.

Step 1: Establish a set of evaluation criteria. One might consider, for example, criteria such as immediate and/or long-term chronic or sub-lethal threat to public health, immediate and/or long-term chronic threat to water quality, immediate and/or long-term chronic or sub-lethal threat to aquatic species/environment, immediate and/or long-term chronic or sub-lethal threat to biosphere. These are some examples of potential evaluation criteria, but one could also select as criteria support for municipality mission statement on sustainability, or other local/regional interests. In the Agenda report, the criteria used were:

- CCME MWWE Strategy (Short term)
- Draft Canada-wide Approach for the Management of Wastewater Biosolids (Short term)
- Energy and Resources Use/Recovery and Sustainability (Long term)
- GHG reduction and climate change adaptation and mitigation (Long term).

Step 2: Provide a weighting system for the criteria if they are not of equal importance in the prioritization process. It must be determined if and why one criterion should be more important than another. If more than one evaluation criteria are selected, the importance of each criterion relative to the others is defined by the weighting factors. The Research Agenda used support of the triple bottom line (TBL) to derive the weightings of the evaluation criteria. Specifically, each criterion was judged against importance to the TBL pillars of Environment, Society and Economy, as indicated in Table 6 (shown below) from the Agenda Report. Other users may define a different set of weighting factors. The span of the weighting factors must be determined. This report used a span of 0 to 4, with 0 indicating no importance whatsoever, and 4 indicating strong importance. The sum of the individual weighting factors for each criterion becomes the final weighting value assigned to that criterion.

In the Agenda report, the judgment used for the TBL weightings for the Strategy criterion is as follows:
Environmental benefit – Water: the Effluent Strategy will have a significant positive impact on receiving water quality due to reduction of biochemical oxygen demand (BOD), suspended solids and residual chlorine loadings, and will likely have a beneficial impact when effluent discharge objectives are implemented for nutrients. Score 3 of 4.
Environmental benefit – land/air: the Effluent Strategy as set out is deliberately focused on improvements to the water environment. The Strategy as proposed will have minimal, if any, impact on the land and air environments. Score 0 of 4.
Social benefit: the Effluent strategy, by reducing effluent discharges of BOD, suspended solids and residual chlorine will result in improvements to the water environment that will be reflected in improved aesthetics, recreational and sport-fishing. Score 2 of 4.

Economic benefit: the Effluent strategy, while considering the costs of implementation, is not focused on making implementation of financial benefit with a positive payback period. Score 0 of 4.

Total weighting for MWWE Strategy Criterion = 3 + 0 + 2 + 0 = 5.

Similar considerations were applied to the other criteria to arrive at the weightings shown in **Table C-1** (Report Table 6).

Table C-1. Establishment of Weighting Factors for Evaluation Criteria

Criterion	Environmental Benefit		Social Benefit	Net Economic Benefit	Final Weight Assigned
	Water	Land, Air			
CCME MWWE Strategy	3	0	2	0	5
Draft Canada-wide Approach for the Management of Wastewater Biosolids	2	3	1	0	6
Sustainable WW/Biosolids Management (energy/resources)	1	2	3	3	9
GHG Mitigation & Climate Change	1	3	3	2	9

Step 3. Consider the importance of the identified Research topics. The applicability to or support of the Research topics to the evaluation criteria selected must be considered. A second set of weighting factors is applied to reflect the topics' support or applicability. The Research Agenda used a span of 0 to 2 for the weighting of the research topics, with 0 implying no applicability whatsoever to the evaluation criterion, and 2 implying strong applicability. A user can supply other values for the span of weighting factors. **Table C-2**, representing part of **Appendix B** of the Agenda Report, illustrates how the factors were applied. Values assigned to each topic reflect the importance that the matrix user attaches to each topic in support of the adopted criteria.

The basis for assigning weights for the research theme of Municipal Wastewater Treatment, subtheme of Wastewater Treatment Processes and Optimization, and topic of Sensitive Receiving Environment Effects & Mitigation Strategies is described below and is illustrative of the process used for all topics.

Support CCME Strategy – municipal effluents discharged to the aquatic environment can have a broad array of impacts on water and sediment quality, and on the biota in the environment. Assessment of receiving water effects forms a foundation for establishing effluent discharge objectives (EDO), which is an important part of the Effluent Strategy Score 2 of 2.

Support Draft Canada-wide Approach for the Management of Wastewater Biosolids - transfer of pollutants in the biosolids applied to land can be washed into sensitive receiving waters as surface runoff, or migrate downward to groundwater, with subsurface flow and tile drainage impacting the sensitive receivers. Reduced pollutant concentrations in biosolids also result in lower potential risk to organisms in the soil, or minimize the contaminants uptake by crops and animals in the fields to which biosolids are applied. Assessment of receiving environment effects is an important part of the Draft Biosolids Approach to ensure safe application of biosolids. Score 2 of 2.

Contribute to Sustainable Wastewater/biosolids Management – There is little perceived contribution of research on sensitive receiving environment effects and mitigation strategies on implementation of sustainable wastewater and biosolids management. Score 0 of 2.

Address National Climate Change Adaptation and Mitigation, and Greenhouse Gas Reduction – There is little perceived contribution of research on sensitive receiving environment effects and mitigation strategies on adaptation and mitigation of climate change, and greenhouse gas emission reductions by wastewater treatment facilities. Score 0 of 2.

Step 4. Prioritize the Research Topics

The criteria weightings were multiplied by the topic weightings to arrive at the total point score used for prioritizing the topics. The result of this effort is shown in **Table C3.** The Report Table 9 is derived from the exercise, as described in Appendix C, with the research topics re-arranged and listed by decreasing priority ranking score.

Table C-2. Illustrative Example of Assignment of Research Topic Weightings to Evaluation Criteria

THEME	SUBTHEME	TOPIC	CRITERIA and WEIGHT			
			supports CCME MWWE strategy	**supports Draft Approach …WW Biosolids**	**contributes to sustainable WW/biosolids management**	**addresses national climate change adaptation & mitigation & GHG reduction**
			Weight: 5	*Weight:6*	*Weight:9*	*Weight:9*
Municipal Wastewater Treatment	WWTP Processes & Optimization	General Process Research	0.5	0	0	0
		Cold Temperature Processes	2	1	0	1
		Small/Rural Treatment Systems	2	1	0	1
		New Treatment Processes	1	0.5	0.1	0.1
		Optimization	2	0.5	1	1.5
		Sensitive Receiving Environment Effects & Mitigation Strategies (including social issues)*	2*	2*	0*	0*
	Nutrients	Process Research	2	0.5	1.5	1
		Optimization	2	0.5	1	1.5
		Sensitive Receiving Environment Effects & Mitigation Strategies (including social issues)	2	2	0	0

* topic weightings for the four evaluation criteria are explained in the text of Appendix C.

Table C3. Illustrative Example of Priority Ranking of Research Topics after Application of all Criteria Weighting Factors

THEME	SUBTHEME	TOPIC	supports CCME MWWE strategy	supports Draft Approach …WW Biosolids	contributes to sustainable WW/biosolids management	addresses nationall climate change adaptation & mitigation & GHG reduction	Total
Municipal Wastewater Treatment	WWTP Processes & Optimization	General Process Research	2.5	0	0	0	2.5
		Cold Temperature Processes	10	6	0	9	25
		Small/Rural Treatment Systems	10	6	0	9	25
		New Treatment Processes	5	3	0.9	0.9	9.8
		Optimization	10	3	9	13.5	35.5
		Receiving Water Effects & Mitigation Strategies (including social issues) & Mitigation Strategies	10	12	0	0	22
	Nutrients	Process Research	10	3	13.5	9	35.5
		Optimization	10	3	9	13.5	35.5
		Receiving Water Effects & Mitigation Strategies (including social issues) of N & P	10	12	0	0	22

Appendix D: Rationale for Development of Example Projects within Research Topics

Appendix A of the Agenda Report provides a listing of research topics and subtopics within the larger wastewater and biosolids themes and subthemes. The development of a list of projects that could be used as examples of research funded in the topics was largely dependent on the sub-topics identified within the topics. To illustrate the development of the example projects, the subtopics in the optimization topic of the theme and subtheme of Municipal Wastewater Treatment/Processes and Optimization are as follows (in no particular order):

- Automation
- Modelling
- Sensors
- Control
- System integration
- Guidance manuals
- Organizational/Management issues
- Operator training

Example projects suggested, therefore, need to reflect the list of sub-topics within each topic. **Table D1** provides a list of the example projects suggested for the optimization topic, with a rationale why the example projects would be supportive of and offer benefit to the research topic. A similar exercise was completed for each of the research themes and subthemes, but not necessarily for each topic.

Table D1. Illustrative Approach for Development of Example Research Projects in Municipal Wastewater Process Optimization Topic

Subtopic(s)	Example Project	Rationale for Consideration
Automation, Sensors, System integration	Adaptation of sensors and automation for optimizing and controlling wastewater treatment processes	Better control of effluent quality; reduced contaminant loadings; improved receiving water quality, resulting in long-term human health and environmental benefit
Modelling, Control	Development and validation of improved models for facultative lagoons and wetlands used for process optimization	Improved treatment efficiency of lagoons and wetlands; improved effluent quality from these processes; better ability to design and operated the processes

Continued

Table D1. (Cont'd)

Subtopic(s)	Example Project	Reasons for Consideration
Modelling, Operator Training	Improvement of dynamic simulators for process operator training	Better understanding of how the processes work; better ability to operate the processes under extreme fluctuations; better control of effluent quality; reduced contaminant loadings; improved receiving water quality, resulting in long-term human health and environmental benefit
Organizational/Management Issues	Identification of and strategies to overcome organizational barriers to optimal treatment plant performance	Improved morale of plant personnel; improved operation of treatment processes; improved effluent quality.
Sensors, Control	Development of a reliable self-cleaning probe to continuously track the DO levels in the aeration basin	Better control of dissolved oxygen in the aeration process; reduced need for operator attention and maintenance; improved energy efficiency of air blowers due to improved control, better control of nitrification and denitrification, thereby improving effluent quality and reducing receiving water impacts of ammonia