Review of the State of Knowledge of Municipal Effluent Science and Research

Review of Effluent Substances

Executive Summary

Background

In November 2003, the Canadian Council of Ministers of the Environment (CCME) agreed to develop a Canada-wide strategy for municipal wastewater effluent (MWWE). The Strategy involves three principal tenets, including:

- Harmonizing the regulatory framework among the federal, provincial and territorial jurisdictions;
- Coordination of science and research activities; and
- Use of an environmental risk management model to guide decision making.

For the Strategy to be effective, the Development Committee (DC) must understand the current state of knowledge on MWWE; i.e., the science and research, evolving treatment technologies and best management practices. Consequently, the DC has commissioned this study to provide a comprehensive review of the current state of knowledge of MWWE science and technology respecting the treatment of conventional pollutants as well as emerging substances of concern.

The objectives of the entire study were to:

1. Prepare a comprehensive consolidated inventory of harmful substances and emerging problematic substances found or likely to be found in Canadian MWWE. Identify substance sources, typical effluent concentrations, and an annotated assessment of effects on the natural aquatic environment and on human health associated with the various substances or groups of substances.
2. Prepare an annotated summary of existing and emerging treatment technologies for treatment of conventional pollutants, harmful substances and emerging pollutants from objective 1. The technologies will be assessed for their applicability to variations in Canadian climates, environments, regions and receiving waters.
3. Provide a review of best management practices for specific issues related to municipal wastewater treatment, including but not limited to:
    - Infiltration and inflow to municipal sewer systems
    - Reduction and treatment of sanitary and combined sewer overflows (SSOs and CSOs)
    - Management of hauled wastes such as septage, landfill leachate or industrial/commercial wastewaters
    - Small or remote community wastewater issues, including treatment cost and pollutant management
    - Discharges of treated effluents to marine environments
    - Lagoon issues, including ice cover and ammonia removal in winter, and algae removal in summer
    - Flow reductions to wastewater treatment plants using alternative technologies and source control plans, including water reuse and reclamation technologies
    - Aging collection system needs and upgrading practices
    - Wastewater treatment facility performance monitoring and quality control practices.

This report addresses the first study objective and constitutes the deliverable for Task 1.

Methodology

Compilation of Substance Master List

The initial task involved the development of a list of wastewater substances for investigation and categorization. Many agencies or organizations, including a number to which Canada has been a collaborator, have established lists of substances of concern in the water environment as part of their agreement principles. The master list for this project was compiled from a number of environmentally significant lists, including the Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes with 25 priority toxics; the Canada-Ontario Agreement (COA) Respecting the Great Lakes Basin Ecosystem with 41 substances, and the European Union list of 33 priority substances in "Annex X" of the Water Framework Directive (2000/60/EC). The master list also included substances for which water quality guidelines have been developed by either Canadian (CCME) or U.S. (EPA) jurisdictions. A number of mostly non-specific substances that have often been monitored in MWWE (sometimes referred to as "conventional" parameters) were added to the Master List, including biochemical oxygen demand, colour, hardness, oil and grease, dissolved oxygen, pH, phosphorus, temperature, total dissolved solids, totals suspended solids, total organic carbon, total residual chlorine and turbidity.

Substances from two drinking water lists were included in the master list: Health Canada's Guidelines for Canadian Drinking Water Quality, and Health Canada's Drinking Water Substance Priority List. The drinking water substances were included in the municipal effluent substance list on the basis that data regarding human health effects of waterborne substances would be applicable to treated effluents as well, although drinking water guidelines *per se* would be applicable only to surface and groundwaters used as drinking water sources and not directly applicable to effluent.

Finally, the list was filtered to eliminate entries that were not applicable to an evaluation of municipal wastewater effluents, such as listings for taste, gasoline or other fuels, asbestos, sulphur and nitric oxides, and many of the chlorofluorocarbons or bromofluorocarbons that are of concern to air pollution. The compiled master list was comprised of a total of 242 substances.

Substance Categorization

From the Master list, the substances were categorized in three ways.

Method 1. Grouping by Chemical Class and Chemical Abstract Service (CAS) Number. This procedure recognizes that lists of substances are often organized according to the type of chemical and chemical structure and that users may seek information based on certain traditional groupings by chemical class.

Method 2. Grouping by Environmental Effects. Most substances on the Master List are there because of documented environmental and/or human health effects. Substances were sorted in terms of their environmental properties, such as whether they are persistent, bioaccumulative, and toxic or exhibit other important attributes.

Method 3. Grouping by Wastewater Process Treatability. Different levels of wastewater treatment will remove substances to different extents. Although there are many processes in use across Canada, the recommended classifications are: lagoon, primary, secondary, tertiary biological nutrient removal (BNR), tertiary filtration and several advanced processes (such as membranes) that are capable of additional reductions of the substances.

Sources of the wastewater substances were identified as either domestic, industrial/commercial or diffuse in nature, but the categories are not mutually exclusive. For example, some pesticides may enter wastewater treatment systems either from domestic use (insecticides for pets, washup of herbicide applicators) or from industrial manufacture or use. Substances from domestic sources include a variety of non-specific (conventional) pollutants, metals, organics, pharmaceuticals and personal care products. Substances from industrial or commercial sources are those that are manufactured, used or generated as by-products in processing. The industrial sources of substances in municipal wastewater were categorized by the 5-digit North American Industry Classification System. Substances from diffuse sources are those that enter the wastewater system from surface runoff or combined sewer systems, such as metals, oil and grease, pesticides and polycyclic aromatic hydrocarbons, PCBs, dioxins and furans, and pathogenic organisms.

Substance Assessment

Environmental benchmarking concentration guidelines, above which effects on aquatic biota, human health or human uses of water would result, were tabulated to identify those substances of greatest potential concern in municipal wastewater effluents. National guidelines developed by CCME or the U.S. EPA, established by rigorous technical review, were adopted for this purpose. CCME guidelines were preferentially selected and U.S. EPA guidelines were used in cases where a CCME guideline has not been developed for a given substance. In the absence of Canadian or U.S. national guidelines, provincial guidelines were selected to allow for a broader range of substances to be considered in the evaluation. Because the protocols for provincial guidelines development may not have been consistently subjected to the same rigorous protocols and level of scientific scrutiny, Substances that exceeded provincial water quality guidelines in MWWE have been recommended for further investigation of the basis for the guideline.

Concentrations of substances in municipal effluents were compiled from a number of sources, including a government reports, from municipalities in Western and Central Canada, and from the technical literature. The literature reviewed included in-house sources, published literature reviews and conference proceedings, and from internet searches. The effluent concentration data were entered into a spreadsheet containing the Master List of substances to allow comparison to benchmark concentrations. Data were also sought for representative concentrations of “emerging” substances of concern. Because these substances are in the emerging state of knowledge, there are few water quality guidelines available for use as benchmarks in comparisons. Because of the interest in effluent irrigation in Central and Western Canada, concentrations of emerging substances in groundwater or in soil aquifer treatment were reviewed.

Any substance that exceeded its respective CCME (or EPA) benchmark concentration for human or ecological protection was identified as a substance of potential concern for aquatic environments receiving MWWE. If a substance exceeded a provincial guideline, the substance was identified as of potential concern, but greater cautionary doubt as a potential substance of concern was attached to it than those flagged on the basis of exceeding a national guideline.

Three other groups of substances emerged as a result of the evaluation described above:

- Substances for which effluent data were found, but for which no national or provincial water quality guidelines exist for use as a benchmark. The environmental or human health implications of the effluent concentrations could not be evaluated;
- Substances for which water quality guidelines have been developed, but no information was found regarding MWWE concentrations or analytical method detection limits were not reported such that a comparison could be made to the applicable benchmark(s); and
- Substances lacking both water quality guidelines and effluent data.

All the substances on the Master List were grouped into one of the four applicable categories.

Results

Classifications

The first classifying procedure made use of the chemical nature of the substances by organizing all the chemicals on the Master List according to the general class and sub-class of chemical to which the substance belongs.

The vast majority of substances on the Master List produce some type of toxic effect among humans or aquatic biota if present at high enough concentrations. Toxic concentrations of all chemicals are specific to each exposed species and each substance; therefore, no attempt was made to rank all the substances in terms of relative toxicity. However, some substances exhibit additional characteristics that make them particularly problematic in the environment, such as persistence or the tendency to bioaccumulate, or to cause cancer (carcinogens). Other substances tend to be a problem from the standpoint of promoting eutrophication (nutrients), imparting objectionable taste or odour to water (undesirable aesthetic properties). Therefore, the Master List was also sorted according to this type of organization. Many of the substances in this table exhibit more than one of the aforementioned characteristics, and therefore the categories are not mutually exclusive. More than half the substances included in the Master List did not exhibit, or were not identified with, any of the environmental problems.

Potential Substances of Concern

Sixty-nine substances were identified as being of potential concern in MWWE because effluent concentrations were sometimes greater than benchmark concentrations for protection of human water uses or ecological health (Table ES.1). They included organic (priority pollutants and chemicals of emerging concern), inorganic and non-specific substances. Of the 69 substances identified as being of potential concern, 42 were flagged on the basis of a provincial water quality guideline, a limited number of studies (e.g., less than five studies), and/or the lowest benchmark was exceeded in only a small percentage of studies (<25). The evidence for these 42 substances is weaker than for the others. Judgment on application of provincial guidelines should be evaluated before a decision is made to include or exclude these substances from further consideration with respect to MWWE management. Judgment will also be required to determine whether substances for which only a small proportion of studies reported effluent concentrations greater than the benchmark are truly a concern in MWWE. Additional effluent data may be required for some substances, as well as rigorous environmental substance assessments, when adequate concentration data have been compiled.

Other uncertainties associated with the assessment are:

1. Many of the studies from which the data were taken were not from Canada, and thus may not be representative of the full range of treatment types, treatment performance, industrial versus domestic contributions, nor geographic locations in Canada;
2. Both effluent data and water quality guidelines were available for only some of all those included in the Master List, so many substances could not be evaluated with respect to potential risk to human health or aquatic environments. There are also limited substances for which guidelines exist for all possible water uses (e.g., for both marine and freshwater environments as well as for protection of human uses of water). Lack of guidelines may exist because there are inadequate data available in the literature to satisfy the protocols for guidelines development, rather than a lack of potential adverse effects; and
3. A substance may not pose a risk to human health or the environment even in cases where effluent concentrations exceed an identified benchmark, because a) there may be safety factor incorporated into the derivation of the benchmark (i.e., the lowest effect concentrations reported in the literature

may have occurred at levels that are higher than the benchmark by some factor), and/or b) the benchmark pertains to concentrations in receiving water, not effluent, and thus the assessment does not account for site-specific effluent mixing and dilution.

Substances Found but Lacking a Benchmark Guideline

A total of 26 substances were included in the Master List and found at quantifiable levels in MWWE, but currently lack a benchmark that could be used to evaluate the significance of the effluent data with respect to protection of human water uses or aquatic biota. Effluent data were also found for another 101 substances that were not included in the original Master List. Those ultimately identified as being prevalent in MWWE and posing risks to human health or the environment should be considered for environmental guidelines development.

Substances with a Benchmark Guideline but no MWWE Concentration Data

Many substances on the Master List (68 in total) have one or more water quality benchmarking guidelines, but either have no matching concentration data, or were reported as being less than an unspecified analytical method detection limit. Many of the substances in this grouping are more likely to be from diffuse sources, including pesticides, PCBs, PCDDs, and PCDFs, and are unlikely to be present in MWWE unless entering through inflow to sewers from surface runoff, or from combined sewers.

Substances with Neither Benchmarks nor MWWE Concentration Data

In this grouping of 34 substances are biological pathogens (viruses and protozoa such as *Giardia* sp.), chlorinated municipal effluents, and chlorinated disinfection by-products. The environmental significance of this group of substances is uncertain. There are also many industrial chemicals and pesticides in this class, which are likely to be of concern if discharged to the environment in sufficient quantities.

Substances with MWWE Concentration Data below Benchmark Guideline

Forty-four substances were found at concentrations below the most sensitive benchmark value used. Many of these substances are representative of the historical “priority pollutants” established by the U.S. EPA in the late 1970s. A substantial number of the substances appear in this list based on a limited number of studies (two or fewer), and so attempts should be made to validate their inclusion in this category

Effluent Irrigation

Besides direct discharge to surface waters, MWWE may be returned to the environment by application to land, either by irrigation, soil in filtration basins or by direct injection. European and American treatment facilities have decades of experience in some cases. Studies suggest that metals will bind fairly tightly to soils with little mobility in groundwater, even under conditions representative of acid rain. Some organic compounds may undergo sorption and/or biodegradation in the soil and in groundwater, while others, such as the antiepileptic drug carbamazepine are refractory and found in many groundwaters under the influence of infiltrated effluent. The more water-soluble and neutrally charged the organic substance is, the more likely it is to remain mobile and be transported with groundwater. When sorption is important to removal in the soil, factors such as organic matter content, pH and pore size are important. In other cases, bacteria may exist in almost all soils to biodegrade substances, as appears to be the case with the 4-nonylphenol, a metabolite of alkylphenol ethoxylate surfactants in wastewater treatment. Evidence suggests that in soil aquifer treatment, substance removal from effluent of secondary treatment quality is at least as good and possibly better than removal form an reverse osmosis permeate.

Key Information Gaps

Benchmarks

Many substances included in the Master List, and others identified as present in some MWWE based on review of the literature, do not have water quality guidelines. Without such guidelines, or a suitable alternative benchmark, it is impossible to judge whether substances identified in wastewater may impair receiving water uses. The list of substances should be reviewed in a systematic manner to identify those of greatest potential for adverse effects with a view to developing appropriate guidelines or alternative benchmarks.

MWWE Data

There is a lack of effluent concentration data for most of the substances on the project Master List. There are reasons for this paucity of data, including little or no regulatory pressure to monitor them, the cost of analyses, and the absence of commercially available capability to quantify some of the substances at low levels in complex wastewater. As a result of the paucity of concentration data, it is not possible to assess regional or other differences in substance concentrations within Canada. There is need for a comprehensive survey of the substances in MWWEs, but only after a review of the availability and adequacy of analytical methodologies.

Substance Treatability

Municipal treatment plants are designed to treat human waste and their ability to reduce effluent concentrations of industrial chemicals, pesticides, PPCPs and other substances is only partly understood. A compendium of treatability data, highlighting specific substance removal efficiencies by municipal wastewater treatment processes, including soil aquifer treatment, generated by many researchers in Canada (e.g., Environment Canada in Burlington and Ontario Region, Trent University, University of Guelph, Ryerson University) as well as internationally, would be very useful to environmental and health practitioners. Gathering of this information into a focused, yet comprehensive report would assist in filling gaps in substance treatability data.

Recommendations

Based on this assessment, it is recommended that:

- Substances identified as being of potential concern on the basis of applicable provincial water quality or drinking water guidelines should be evaluated to confirm or refute the suitability of such guidelines for use as benchmarks.
- Additional effluent data should be collected for substances that have water quality guidelines but have been rarely or never been measured in MWWE. For substances with neither concentration data nor benchmarking guidelines, if such substances are found to be prevalent in MWWE based on effluent monitoring surveys, such substances should be considered for potential water quality guidelines development. Effluent data could be collected by selecting facilities to represent a range of sizes, treatment type, industrial loadings, and geographic locations so as to represent a reasonable crosssection of Canadian facilities. Substances shown to be consistently below analytical detection limits could be eliminated from further consideration.
- Prior to any field survey of trace substances in MWWEs, a significant effort should be made to collect data from municipalities and other jurisdictions. If after this information collecting effort there are still missing data, the most significant potential substances of concern identified by this study should be compared to existing commercial analytical capabilities to determine if in fact the substances can be routinely measured at a useful level. The comparison of analytical protocols with the substances of potential concern should be completed by qualified laboratory personnel.

Substances identified by one of the above approaches as being present in MWWE, but for which no water quality guidelines exist, should be recommended to the CCME or to Environment Canada for potential development of water quality guidelines. In the meantime, it may be appropriate to consider the use/development of alternative, interim benchmarks to complete a preliminary screen of potential

substances of concern. For example, benchmarks published by Suter and Tsao (1996) have been routinely used in environmental risk assessments and may be adequate to ascertain whether MWWE concentrations of a given substance are typically well above or well below the benchmark concentration and thus should remain on, or could be eliminated from, the Master List.