

# National Pollutant Release Inventory

## Guidance Manual for the Wastewater Sector

*Canadian Environmental Protection Act, 1999*

Canada



Environment  
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# National and Regional NPRI Offices

## Headquarters

National Pollutant Release Inventory  
Environment Canada  
9th Floor, Place Vincent Massey  
351 St. Joseph Blvd.  
Hull, QC  
K1A 0H3

Tel: (819) 953-1656  
Fax: (819) 994-3266  
E-mail: NPRI@ec.gc.ca

## Newfoundland and Labrador, Prince Edward Island, New Brunswick and Nova Scotia

National Pollutant Release Inventory  
Environment Canada  
16th Floor, Queen Square  
45 Alderney Drive  
Dartmouth, NS  
B2Y 2N6

Tel: (902) 426-4482 / 426-4805 / 426-5037  
Fax: (902) 490-0722  
E-mail: NPRI\_ATL@ec.gc.ca

## Quebec

National Pollutant Release Inventory  
Environment Canada  
105 McGill Street, 4th Floor  
Montreal, QC  
H2Y 2E7

Tel: (514) 283-1832 / 283-7303 / 283-0248  
Fax: (514) 496-6982  
E-mail: INRP\_QC@ec.gc.ca

## Ontario

National Pollutant Release Inventory  
Environment Canada  
4905 Dufferin Street, 2nd Floor  
Downsview, ON  
M3H 5T4

Tel: (416) 739-5994 / 739-4602 / 739-4608 / 739-5894  
Fax: (416) 739-4326 / 739-4762 / 739-4251  
E-mail: NPRI\_ONTARIO@ec.gc.ca

## Manitoba, Saskatchewan, Alberta, Northwest Territories and Nunavut

National Pollutant Release Inventory  
Environment Canada  
Twin Atria #2, Room 200  
4999-98 Avenue  
Edmonton, AB  
T6B 2X3

Tel: (780) 951-8989  
Fax: (780) 495-2615  
E-mail: NPRI\_PNR@ec.gc.ca

National Pollutant Release Inventory  
Environment Canada  
123 Main Street, Suite 150  
Winnipeg, MB  
R3C 4W2

Tel: (780) 951-8989  
Fax: (780) 495-2615

National Pollutant Release Inventory  
Environment Canada  
Room 300, Park Plaza  
2365 Albert Street  
Regina, SK  
S4P 4K1

Tel: (306) 780-6465  
Fax: (306) 780-6466

National Pollutant Release Inventory  
Environment Canada  
3rd Floor, Diamond Plaza  
5204 - 50th (Franklin) Avenue  
Yellowknife, NT  
X1A 2R2

Tel: (867) 669-4727  
Fax: (867) 873-8185

National Pollutant Release Inventory  
Environment Canada  
P.O. Box 607  
Iqaluit, NU  
X0A 0H0

Tel: (867) 975-4636  
Fax: (867) 975-4645

## British Columbia and Yukon

National Pollutant Release Inventory  
Environment Canada  
224 West Esplanade  
North Vancouver, BC  
V7M 3H7

*after April 21, 2003:*  
#201-401 Burrard Street  
Vancouver, BC  
V6C 3S5

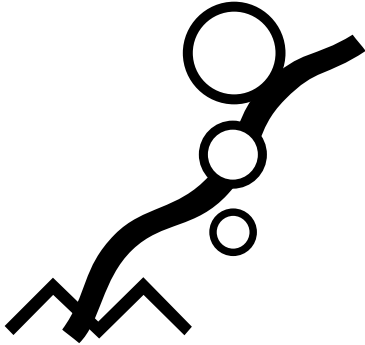
Tel: (604) 666-3221 / 666-3890 / 666-9864  
Fax: (604) 666-6800  
E-mail: NPRI\_PYR@ec.gc.ca

National Pollutant Release Inventory  
Environment Canada  
91782 Alaska Highway  
Whitehorse, YT  
Y1A 5B7

Tel: (867) 667-3402  
Fax: (867) 667-7962  
E-mail: NPRI\_YK@ec.gc.ca

## NPRI Help Desk

E-mail: nprihelpdesk@ec.gc.ca  
Tel: (819) 994-1672  
1-877-877-8375



# **National Pollutant Release Inventory**

## **Guidance Manual for the Wastewater Sector**

***Canadian Environmental Protection Act, 1999***

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This Manual has been reviewed by the following individuals at Environment Canada during its preparation:

Wilfrid Jan (Project Authority), NPRI, Headquarters

René Damecour, NPRI, Quebec Region

Henry Quon, NPRI, Pacific and Yukon Region

Chris Roberts, NPRI, Atlantic Region

Nick Zhao, NPRI, Ontario Region

James Arnott, MWWE, Headquarters

John Clarke, ETAD, Atlantic Region

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### Disclaimer

Should any inconsistencies be found between this Manual and the official *Canada Gazette* notice and its amendment, the notice published on December 29, 2001 and the amendment published on December 28, 2002, in the *Canada Gazette*, Part I, will prevail.



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# Preface

## Introduction

The National Pollutant Release Inventory (NPRI), a federal program created in 1992, is the only nation-wide, publicly-accessible inventory that provides information on pollutants released to the environment and transferred for disposal, treatment or recycling. For the 2002 reporting year, a total of 273 substances were in the NPRI. Some of these substances were manufactured, processed or used by municipal wastewater facilities (see the Terminology section of this Manual for the definition of municipal wastewater facility) and resulted in significant discharges to the environment. Under the authority of subsection 46(1) of the *Canadian Environmental Protection Act, 1999* (CEPA 1999), the discharges of NPRI substances from these wastewater facilities are required to be reported to Environment Canada.

Because the reporting requirements for wastewater facilities for the 2002 reporting year have significantly changed with the removal of employee thresholds and the use of an effluent-based trigger (10 000 cubic metres daily average discharge or greater), this Manual was developed to help wastewater facilities understand clearly whether and how they should report to the NPRI, and therefore also help improve the quality of reporting for the wastewater sector, in terms of both the number of reports submitted and the accuracy of information provided. The purpose of this Manual is to provide information on which wastewater facilities must report, and how they should calculate releases based on monitoring, mass balance, emission factor calculations or engineering estimates.

This Manual provides the information to supplement the *Guide for Reporting to the National Pollutant Release Inventory – 2002*. Information on the reporting requirements for Criteria Air Contaminants (CACs) may be found in the *Supplementary Guide for Reporting Criteria Air Contaminants to the National Pollutant Release Inventory* (hereafter referred to as the “CAC Supplementary Guide”). Reporters in the wastewater sector will require copies of these guidance documents, in addition to this Manual, to ensure proper reporting to the NPRI.

"Cette publication est aussi disponible en français sous le titre de « *Guide de l'INRP pour le secteur des eaux usées* »."

## Exclusions from this Manual

Some activities associated with wastewater sector services are not included in this Manual since they are covered in other guidance documents, i.e. the *Guide for Reporting to the National Pollutant Release Inventory – 2002*, and the *CAC Supplementary Guide*.

Such activities include:

- laboratory operations
- stationary combustion equipment operations
- sewage sludge incineration
- non-hazardous solid waste incineration, and
- hazardous waste incineration.

## Terminology

For terminology generic to the NPRI reporting requirements, refer to the *Guide for Reporting to the National Pollutant Release Inventory – 2002*.

Following are definitions of two basic terms used in this Manual:

*Municipal Wastewater Sector* - Refers to wastewater facilities serving communities, and includes, but is not limited to, wastewater facilities owned and/ or operated by municipalities; wastewater facilities on federal lands serving communities (such as military bases); and, wastewater facilities on aboriginal lands serving aboriginal communities. The wastewater facilities may also be owned and/or operated by private individuals or corporations in public-private partnership situations. The North American Industry Classification System (NAICS) code associated with this sector is 221320 (sewage treatment facilities).

*Wastewater Facility* - Refers to both the wastewater collection system and wastewater treatment system. It also

includes wastewater collection systems where wastewater is directly discharged to a water body without treatment. (See the “*Definition of Wastewater Facility*” section in Chapter One for more detail.)

## Step-by-Step Overview

This Manual provides information to complete Steps 1 and 2 as described in general terms in the *Guide for Reporting to the National Pollutant Release Inventory – 2002*.

In Step 1, reporters determine whether a report is required for their facility.

In Step 2, reporters estimate releases and transfers and collect the information required for the NPRI report.

In Steps 3 to 7, reporters install reporting software, enter facility information, enter NPRI substance data, check for errors and export data, and submit the report. These steps are not covered in this Manual, as they are generic for all reporters. Reporters can obtain information on these steps in the *Guide for Reporting to the National Pollutant Release Inventory – 2002*.

## Information Sources

To identify potential substances for reporting, reference should be made to various information sources, both general for the sector and specific to the facility.

The *Guide for Reporting to the National Pollutant Release Inventory – 2002*, identifies and describes four potential sources of information:

- Technical Guides
- Material Safety Data Sheets (MSDSs)
- Emission Factor Database of Selected NPRI Substances, and
- Permits and Certificates of Approval.

In addition, additional sources of information may be available to wastewater sector facilities in order to determine what NPRI substances may be present, released or transferred:

- monitoring data on influent, effluent and biosolids quality
- information from sewer use By-law monitoring or enforcement
- information from industrial sewer use compliance agreements or monitoring of industrial customer discharges
- information from the composition of the community industrial customer base
- NPRI reports submitted by industrial customers reporting releases to your municipal sewage treatment plant (the MSTPs transfer category reported)
- information on sewer system configuration (i.e., combined sewer system versus sanitary sewer system), and
- literature and technical information available on typical substances and their release concentrations to various media.

It should be noted that the NPRI does not require additional monitoring or measurement of the quantities or concentration of substances released to the environment, beyond those already required under the provisions of other laws or regulations. You are, however, required to show “due diligence” in obtaining the information required for reporting. Refer to the *Guide for Reporting to the National Pollutant Release Inventory – 2002* for more information.



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# 1. Chapter One

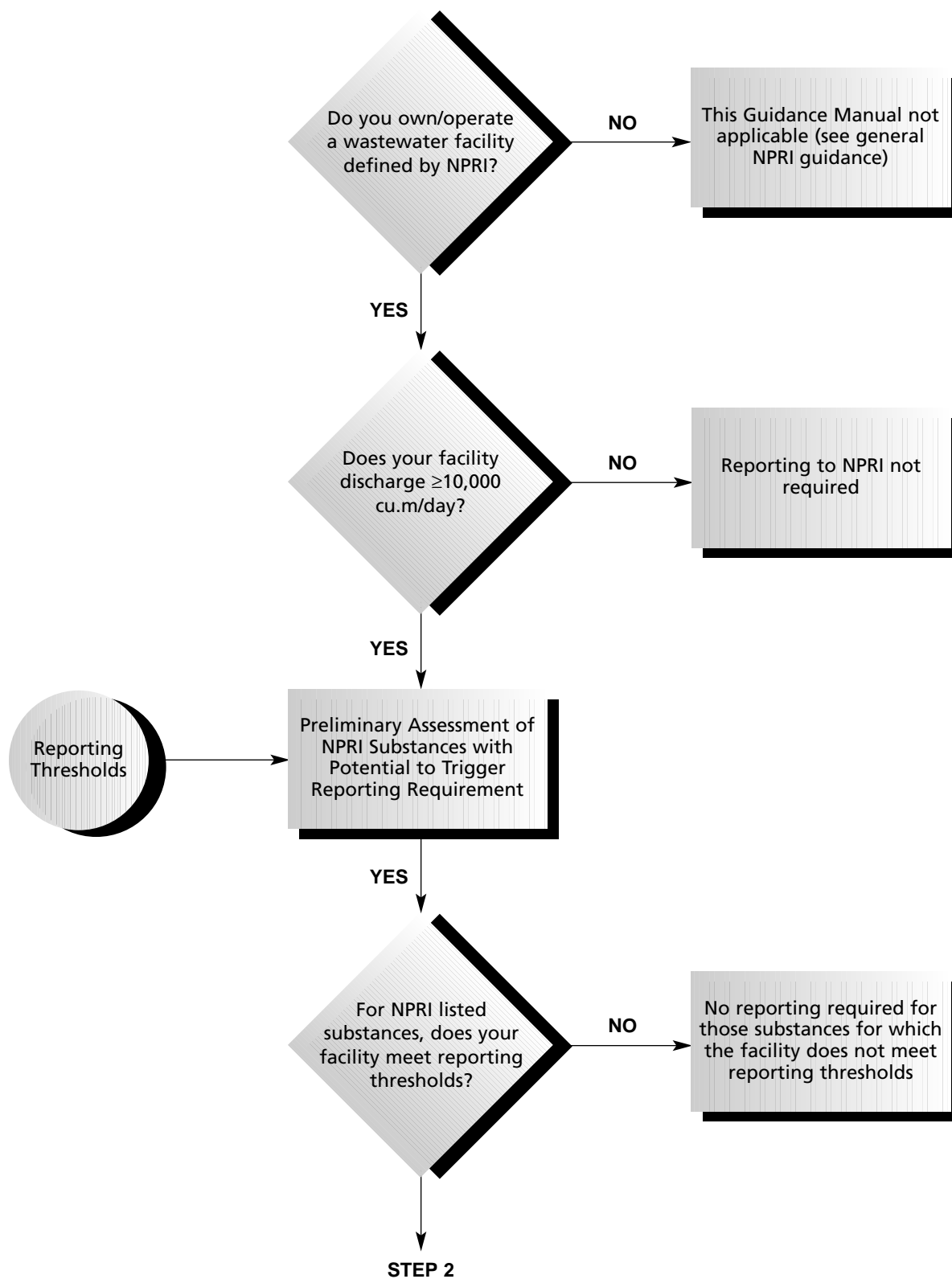
## Step 1: Determine Whether a Report is Required for Your Facility

### 1.1 Overview

Municipal wastewater facilities that met certain criteria must report releases of designated substances to the NPRI. This section identifies steps to determine whether your facility met the threshold requirements for reporting to the NPRI and, if so, whether any designated substances are of potential concern with respect to meeting the threshold for reporting on a substance-by-substance basis.

Figure 1 identifies the sequence of steps to determine whether a report is required. These steps are detailed further in this Chapter.

**FIGURE 1**  
**STEP 1: DETERMINE WHETHER A REPORT IS REQUIRED FOR YOUR FACILITY**



Do you own/operate  
a wastewater facility  
defined by NPRI?

## 1.2 Definition of Wastewater Facility for NPRI-Reporting Purposes

A wastewater facility is defined for NPRI purposes as wastewater collection systems that discharge treated or untreated wastewater into surface waters with an annual average flow rate of 10 000 cubic metres or more per day. Therefore, a wastewater facility for NPRI-reporting purposes includes both treatment and collection systems.

A *Wastewater Collection System* is the system of sewers and/or ditches that convey sanitary or combined sewage for a community. The volume of sewage released to surface waters from the collection system must be included in the calculation of annual average discharge per day from the wastewater facility. Potential effluent volumes of importance to include in the calculation of the annual average discharge per day from the collection system include:

- direct discharge of sewage from a main outfall where no treatment exists
- sanitary sewer system overflows
- combined sewer system overflows
- pumping station overflows, and
- bypass flows (for repair and maintenance activities or for emergency-response activities).

A collection system includes adjacent service areas or adjoining sewage sheds that function as a single integrated system for a community. Discharges to the environment from all components of the system must be considered when determining whether your facility met the flow threshold and substance reporting criteria for 2002. Where no treatment facilities exist, the wastewater facility consists of the entire collection system, and may require NPRI reporting if it met the basic reporting requirements.

Communities with collection systems discharging into another community's collection system do not have to report to the NPRI. Reporting may be required by the receiving community if it met the basic reporting requirements.

In addition to releases to water, releases of potential importance from the collection system for reporting purposes include releases to other media, including those to land from overflows or spills.

A *Wastewater Treatment System* means a plant or process location that accepts collection system flows of a community for the purposes of removing substances from the wastewater. The volume of both treated and untreated sewage released from the wastewater treatment system must be included in the calculation of annual average discharge per day from the wastewater facility. Potential effluent volumes of importance to include in the calculation of the annual average discharge per day from the wastewater treatment system include:

- process flow
- sludge treatment discharges (biosolids/ sludges)
- backwash and filter discharges released to surface waters (i.e., not including process waste recycled back into the wastewater treatment system)
- tank drainage released to surface waters (i.e. not including process waste recycled back into the wastewater treatment system), and
- bypass flows released to surface waters (untreated or partially treated) for repair and maintenance activities, or from hydraulic overloads.

In addition to releases to water, releases of potential importance from the treatment system for reporting purposes include those to air, to land on site, and transfers for disposal (including sludge and biosolids).

Does your facility discharge  $\geq 10,000$  cu.m/day?

### 1.3 Assessment of Whether a WASTEWATER Facility Met the Basic Reporting Criteria

The flow threshold that triggers NPRI reporting for a wastewater facility is an annual average discharge of 10 000 cubic metres or more per day into surface waters. Unlike many other sectors potentially required to report to the NPRI, there is no minimum threshold of employee hours<sup>1</sup>.

The daily average discharge is calculated based on the total flows in the reporting year. Total flows include effluent discharges, bypass event flows at the wastewater treatment plant and/or at pumping stations, combined sewer overflows and sanitary sewer system discharges to surface waters. The total of all these flows is divided by the number of days in a year (365 days or 366 days for leap years) to obtain the average daily discharge.

You must consider the total of discharges from all components that function as an integrated system for the community. The collection system may be comprised of several adjacent service areas, and there may be a number of treatment plants within the system. Collection systems that are not adjoining and serve distinct communities within a regional municipality may be considered separately.

Treatment plants must submit individual facility reports, including any overflows or other discharges from the collection system associated with the plant. Collection systems that discharge raw sewage may be reported as a single facility.

If your system did not meet the 10 000 cubic metres daily average discharge basic criterion, further action is not needed and no NPRI report is required. For Environment Canada's information and records, inform your regional NPRI office that you have completed the calculations and determined that no report is required. However, if it is determined that your facility did meet this basic reporting criterion, the next step is to determine whether any NPRI substances need to be reported.

Following are potential scenarios to describe wastewater systems:

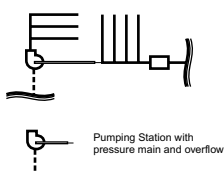
#### Scenario 1:

A community is served by a single gravity wastewater collection system with no overflows or pumping stations, and a treatment plant. The average daily flow threshold is applied to the release from the treatment plant, and a single facility report is submitted.



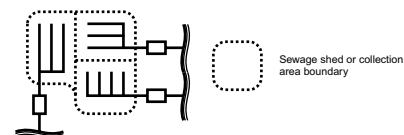
#### Scenario 2:

A community is served by a wastewater collection and treatment system that consists of two or more sewage sub-systems connected by pressure mains and a single treatment plant. The pumping stations have overflows that occasionally release to surface waters. The average daily flow threshold is applied to the release from the treatment plant, plus any overflows from the pumping stations. A single facility report is submitted for the system. Quantities of substances from overflow volumes from the pumping stations are reported as spills, and receiving waters are identified.



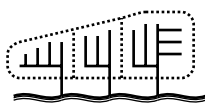
#### Scenario 3:

A community is served by a wastewater collection system that consists of two or more separate wastewater collection and treatment systems. The systems are not connected, but the separate systems serve adjacent service areas or sewage sheds and function as a single, integrated system for the community. The average daily flow threshold is applied to the total release from all treatment plants and overflows. Separate facility reports are submitted for each system.



#### Scenario 4:

A community is served by two or more collection sub-systems that release raw sewage to surface waters. The sub-systems serve adjacent (contiguous) sewage sheds and function as a single, integrated system for the community. The average daily flow threshold is applied to the total release from all sub-systems within the community. A single facility report is submitted for the system as a whole. Quantities of substances from the system are reported as direct releases, and receiving waters are identified.



<sup>1</sup> The Canada Gazette notice regarding this threshold level was published (December 29, 2001) as follows: "The following activities to which the 20 000-hour employee threshold does not apply, are identified for the purposes of Parts 1 to 4:(g) discharge of treated or untreated wastewater from a wastewater collection system with an annual average discharge of 10 000 cubic metres or more per day, into surface waters."



## 1.4 Reporting Thresholds

Facilities that met the basic reporting criteria must report releases of specified substances that met applicable threshold limits and threshold types. Table 1 is a summary of the reporting threshold characteristics for the substance groups, however it is important that reporters refer to the *Guide for Reporting to the National Pollutant Release Inventory – 2002* and the *CAC Supplementary Guide* for complete information and detail.

**TABLE 1**

GUIDANCE NOTATION	CANADA GAZETTE NPRI NOTICE REFERENCE	NUMBER OF SUBSTANCES/ GROUPS	TYPE OF THRESHOLD	THRESHOLD VALUE (PER YEAR)
Part 1A substances	Schedule 1, Part 1, Group 1 substances	241	Threshold is based on accumulated annual quantity of substance manufactured, processed or otherwise used (MPO).	10 tonnes
Part 1B substances	Schedule 1, Part 1, Groups 2, 3, 4 substances	6	Threshold is based on accumulated annual quantity of substance manufactured, processed or otherwise used (MPO).	Mercury and its compounds: 5 kg Cadmium and its compounds: 5 kg Arsenic, hexavalent chromium, lead, and their compounds, and tetraethyl lead: 50 kg.
Part 2 substances	Schedule 1, Part 2, substances	17 specific PAHs	Threshold is based on total releases and transfers as a result of incidental manufacture, or any quantity for wood preservation using creosote	50 kg for all 17 PAHs total (exception for wood preservation)
Part 3 substances	Schedule 1, Part 3, substances	2 (HCB, dioxins and furans)	Hexachlorobenzene (HCB) and polychlorinated dibenzo- <i>p</i> -dioxins and dibenzofurans (dioxins/furans) reportable releases are based on certain activities that do not include wastewater collection or treatment (but do include sewage sludge incineration <sup>2</sup> ). Part 3 substances are not addressed further in this Manual.	Not applicable to the Wastewater Sector
Part 4 substances	Schedule 1, Part 4, substances	7	Threshold is based on accumulated annual quantity of substance released to air <sup>3</sup> .	CO: 20 tonnes NO <sub>x</sub> : 20 tonnes <sup>4</sup> PM <sub>2.5</sub> : 0.3 tonnes PM <sub>10</sub> : 0.5 tonnes SO <sub>2</sub> : 20 tonnes TPM: 20 tonnes VOCs: 10 tonnes

<sup>2</sup> Covered in the Guide for Reporting to the National Pollution Release Inventory – 2002.

<sup>3</sup> Refer to the CAC Supplementary Guide if you operate stationary equipment or for more information on Part 4 reporting requirements.

<sup>4</sup> Nitrogen oxides are expressed as NO<sub>2</sub>.

For the wastewater sector, Environment Canada has determined that all substances in the influent, or produced during the process, at wastewater treatment facilities are incidentally processed or otherwise used in the process and are therefore to be considered “by-products” of the process<sup>5</sup>. Similarly, all substances in the collection system are considered “by-products” for purposes of reporting substances manufactured, processed or otherwise used.

As a result, no lower threshold of concentration by weight applies for substances in the influent, and wastewater treatment facilities are expected to report the releases of NPRI substances that exceeded the specific total annual accumulated mass reporting thresholds. However, for Part 1A and 1B substances found only in products used in the facility, reporting is not required if substance concentration in the product was below 1% by weight (e.g., fuels, solvents). Refer to the *Guide for Reporting to the National Pollutant Release Inventory – 2002*.

Preliminary Assessment of  
NPRI Substances with  
Potential to Trigger  
Reporting Requirement.

## 1.5 Information Sources and Factors to Consider for Preliminary Assessment of NPRI Substances

This section provides information sources and guidance for facilities on factors influencing the substances in wastewater.

### Information Sources

A review of all available information sources identified in the Preface should be conducted. NPRI reports by industries discharging to the sewer system and community Industrial Sewer Use monitoring and compliance information will be particularly relevant for wastewater facilities serving a mix of customers. Treatment plant operating permit compliance monitoring as well as other programs to monitor treatment system influent and effluent, or collection system wastewater quality will provide valuable information.

A literature review of reported concentrations of NPRI substances in wastewater was conducted. Tables 2a, b, and c, following, identify about 50 substances that are reported in literature for wastewater influent, effluent and biosolids, along with the range of concentrations of the substances and NPRI thresholds.

Appendix A-1 contains samples of information from the NPRI database of industrial customers reporting discharges of substances not identified in Table 2 to municipal sewage treatment facilities in 2000. Appendix A-2 identifies NPRI substances reported by industrial dischargers to municipal sewage treatment facilities, sorted by industry. (Appendix A-2 includes substances in Table 2 as well as others.) Appendix A can be used as reference to identify potential substances resulting from certain industrial customers, but should be used in combination with other information available for your community.

### Factors to Consider

Several factors will determine what NPRI substances of concern are released or transferred from wastewater facilities. In summary, these factors include:

- wastewater collection system customer base (e.g., the number and types of industrial dischargers to the system)
- wastewater collection system characteristics (i.e., combined system or sanitary system)
- wastewater treatment system configuration and process (i.e., passive versus active treatment systems, final destination of products from the process)
- substances used in, or produced by, the process (i.e., use of chemicals, transformation of substances in some treatment trains), and
- other emission considerations.

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<sup>5</sup> The definition of “by-products” as described in the NPRI notice, (published in the Canada Gazette on December 29, 2001) is as follows: “by-product” means a substance, listed in Schedule 1, which is incidentally manufactured, processed or otherwise used at the facility at any concentration, and released on site to the environment, released to surface water or transferred off-site for disposal.

### **Wastewater Collection System Customer Base**

The most important determinant of potential NPRI substances requiring reporting is the nature of the connected customer base.

In communities with predominantly residential customer sanitary sewage volumes, typical substances to assess for annual accumulation levels include ammonia and products of chlorination, such as chloroform (where chlorination is used for disinfection in the treatment process). Additional substances may include metals and other products from residential and commercial cleaning functions, including car washes.

In communities with a mix of residential and industrial and/or commercial customers, assessment of additional substances for potential reporting should be based on the nature of the discharges by non-residential customers. Metals such as copper, zinc and manganese are among the more common Part 1A substances in wastewater that may exceed the 10-tonne reporting threshold, depending on flow volumes and substance concentrations. The lower reporting thresholds for Part 1B substances, including mercury, cadmium, arsenic, lead and hexavalent chromium and their compounds, and Part 2 substances (PAHs) mean that these substances will be commonly reportable.

### **Wastewater Collection System Characteristics**

A second important determinant for NPRI substances that may be reportable is the type of sewer collection system. Combined sewer systems carry stormwater as well as sanitary sewage. Wastewater facilities treating combined sewage should consider the loadings of contaminants in the stormwater component of the flows when estimating levels of substances such as those commonly found in stormwater runoff. Such substances include, but are not limited to, arsenic, cadmium, chromium, cobalt, copper, mercury, nickel, lead, selenium, zinc and PAHs. For wastewater facilities serving a diverse industrial client base, substances present as a result of runoff will likely add to the total loadings already present in the wastewater stream. For wastewater facilities serving a primarily residential customer base with a combined sewer system, substances in the wastewater from runoff may not be present from sources other than the stormwater component of combined sewage.

### **Wastewater Treatment System Configuration and Process**

Wastewater treatment system configuration (or lack of a treatment system) will influence the quantities of substances released to various media, and can influence the transformation of some NPRI substances. For example, use of aeration during stages of the process will increase the quantity of volatile substances released to air. Wastewater treatment systems and potential substance release routes are discussed in detail in Chapter 2, *Identification of Wastewater Treatment System Configurations and Process Characteristics*.

### **Substances Used in, or Produced by, the Process**

In addition to substances in the influent, you must consider products used in the process and substances produced by the process. Compared to the list of potential substances in the influent, the list of potential NPRI substances used in or produced by the process is short. Some substances used or produced may also be present in the influent. The formation of substances identified will depend on the treatment process in place and substances used or present in the influent. Table 2a identifies uses or formation of NPRI substances in the process. Appendix B provides more information on substances used or produced in the process.

### **Other Emission Considerations**

Wastewater-treatment facilities may have other emission sources to consider when determining total NPRI substance amounts released or transferred. Emissions from the operation of stationary equipment, for example, may result in releases of particulate matter and nitrogen oxides. In addition, emissions or releases resulting from other on-site activities may need to be included in total releases or transfers of substances from the facility. For these types of emissions, which are not specifically related to wastewater stream releases and transfers, refer to the *Guide for Reporting to the National Pollutant Release Inventory – 2002* and the *CAC Supplementary Guide*. These releases or transfers need to be included in the estimates for total emissions of any NPRI substance.

**TABLE 2A – LITERATURE CONCENTRATION VALUES FOR NPRI SUBSTANCES REPORTED IN INFLUENT OR EFFLUENT AND SUBSTANCES USED OR PRODUCED BY THE WASTEWATER TREATMENT PROCESS**

NPRI SUBSTANCE	INFLUENT CONCENTRATION	EFFLUENT CONCENTRATION	USE IN PROCESS	FORMATION DURING PROCESS	CAS NUMBER	NPRI THRESHOLD (SEE TABLE 1 FOR TYPES)
Ammonia	14.8-44.1 ppm (CWWA, June 14, 2001) 26.1 ppm (Environment Australia, 1999)		NH <sub>4</sub> OH as caustic agent	Biological processes	*	10 t/yr (MPO)
Antimony	0-0.2 ppm (CWWA, June 14, 2001)				*	10 t/yr (MPO)
Benzene	1-2 ppb (Stubin et al., 1996)				71-43-2	10 t/yr (MPO)
Bis(2-ethylhexyl) phthalate	10-180 ppb (Stubin et al., 1996)				117-81-7	10 t/yr (MPO)
2-Butoxyethanol	33-80 ppb (Lepri et al., 1997) 2-44 ppb (Stubin et al., 1996)				111-76-2	10 t/yr (MPO)
Cadmium	0-0.1 ppm (CWWA, June 14, 2001)				*	0.005 t/yr (MPO)
Carbon disulphide	0.057ppm (Environment Australia, 1999)				75-15-0	10 t/yr (MPO)
Carbon tetrachloride	0 ppb (Stubin et al., 1996)	38 ppb (Stubin et al., 1996)			56-23-5	10 t/yr (MPO)
Chlorobenzene				Chlorine disinfection	108-90-7	10 t/yr (MPO)
Chloroform	6-17 ppb (Stubin et al., 1996)	3-45 ppb (Stubin et al., 1996)		Chlorine disinfection	67-66-3	10 t/yr (MPO)
Chromium (and its compounds except CrVI)	0-0.3 ppm (CWWA, June 14, 2001)	0-0.2 ppm (CWWA, June 14, 2001)			*	10 t/yr (MPO)
Chromium III	0.06 ppm (Environment Australia, 1999)				*	(See Chromium above)
Chromium VI (Hexavalent)	0.06 ppm (Environment Australia, 1999)				*	0.05 t/yr (MPO)
Cobalt (and its compounds)	0-0.1 ppm (CWWA, June 14, 2001)				*	10 t/yr (MPO)
Copper (and its compounds)	0-0.3 ppm (CWWA, June 14, 2001) 0.123 ppm (Environment Australia, 1999)	0.4 ppm (CWWA, June 14, 2001)	CuSO <sub>4</sub>		*	10 t/yr (MPO)



TABLE 2A – CONTINUED

NPRI SUBSTANCE	INFLUENT CONCENTRATION	EFFLUENT CONCENTRATION	USE IN PROCESS	FORMATION DURING PROCESS	CAS NUMBER	NPRI THRESHOLD (SEE TABLE 1 FOR TYPES)
Dibutyl phthalate	Di- <i>n</i> -butyl phthalate: 4-49 ppb (Stubin et al., 1996) Di- <i>n</i> -butyl phthalate: 14-68 ppb (Lepri et al., 1997) Di-iso-butyl phthalate: 32-114 ppb (Lepri et al., 1997) 0.044 ppm (Environment Australia, 1999)				84-74-2	10 t/yr (MPO)
<i>o</i> -Dichloro benzene (1,2-Dichloro benzene)	22 ppb (Stubin et al., 1996)				95-50-1	10 t/yr (MPO)
<i>p</i> -Dichloro benzene (1,4-Dichloro benzene)	4 ppb (Stubin et al., 1998)				106-46-7	10 t/yr (MPO)
1,2-Dichloro propane	1 ppb (Stubin et al., 1996)				78-87-5	10 t/yr (MPO)
Diethyl phthalate	3-250 ppb (Stubin et al., 1996)				84-66-2	10 t/yr (MPO)
N,N-Dimethyl-aniline		Dimethylaniline: 26-64 ppb (Clark et al., 1991)			121-69-7	10 t/yr (MPO)
N,N-Dimethyl-formamide		Dimethylformamide: 32 ppb (Clark et al., 1991)			68-12-2	10 t/yr (MPO)
Dimethyl phthalate		5-13 ppb (Lepri et al., 1997)			131-11-3	10 t/yr (MPO)
Ethylbenzene	0.4 ppm (CWWA, June 14, 2001) 1-11 ppb (Stubin et al., 1996)				100-41-4	10 t/yr (MPO)
Ethylene glycol	21-50 ppb (Lepri et al., 1997)				107-21-1	10 t/yr (MPO)
Hydrogen sulphide	Sulphide: 0-0.5 ppm (CWWA, June 14, 2001) 2.86 ppm (Environment Australia, 1999)			Anaerobic processes		10 t/yr (MPO)
Lead (and its compounds except tetraethyl lead)	0-0.1 ppm (CWWA, June 14, 2001) 0.06 ppm (Environment Australia, 1999)				*	0.05 t/yr (MPO)
Manganese	0-0.3 ppm (CWWA, June 14, 2001) 0.144 ppm (Environment Australia, 1999)				*	10 t/yr (MPO)

TABLE 2A – CONTINUED

NPRI SUBSTANCE	INFLUENT CONCENTRATION	EFFLUENT CONCENTRATION	USE IN PROCESS	FORMATION DURING PROCESS	CAS NUMBER	NPRI THRESHOLD (SEE TABLE 1 FOR TYPES)
Mercury (and its compounds)	0-3.1 ppm (CWWA, June 14, 2001)				*	0.005 t/yr (MPO)
Methanol			Carbon source for denitrification		67-56-1	10 t/yr (MPO)
Molybdenum trioxide	Molybdenum: 0-0.2 ppm (CWWA, June 14, 2001)				1313-27-5	10 t/yr (MPO)
Naphthalene	3-57 ppb (Stubin et al., 1996) 8-24 ppb (Lepri et al., 1997)				91-20-3	10 t/yr (MPO)
Nickel (and its compounds)	0-0.6 ppm (CWWA, June 14, 2001)				*	10 t/yr (MPO)
Nitrate ion	1.77 ppm (Bertrand-Krajewski et al., 1995)	24.8 ppm (Bertrand-Krajewski et al., 1995)		Formation in pre-treatment and secondary treatment	*	10 t/yr (MPO)
Nitrogen oxides (expressed as NO <sub>2</sub> )				Biological nitrogen removal processes	*	20 t/yr (releases to air)
Nitrioltriacetic acid (and its salts)			Chelating agent		139-13-9	10 t/yr (MPO)
N-Nitrosodiphenylamine	12-57 ppb (Lepri et al., 1997)				86-30-6	10 t/yr (MPO)
Nonylphenol	240-465 ppb (Lepri et al., 1997) 0.7-155 ppb (Bennie, 1999)			Biological processes	104-40-5	10 t/yr (MPO)
Phenol	8-490 ppb (Stubin et al., 1996)				108-95-2	10 t/yr (MPO)
Phenanthrene (a PAH)	8 ppb (Stubin et al., 1996)				*	0.05 t/yr released or transferred for 17 PAHs total
Phthalic anhydride (1,2-benzenedioic anhydride)	3-8 ppb (Lepri et al., 1997)				85-44-9	10 t/yr (MPO)

TABLE 2A – CONTINUED

NPRI SUBSTANCE	INFLUENT CONCENTRATION	EFFLUENT CONCENTRATION	USE IN PROCESS	FORMATION DURING PROCESS	CAS NUMBER	NPRI THRESHOLD (SEE TABLE 1 FOR TYPES)
Selenium (and its compounds)	0-0.1 ppm (CWWA, June 14, 2001)				*	10 t/yr (MPO)
Silver (and its compounds)	0-0.1 ppm (CWWA, June 14, 2001)				*	10 t/yr (MPO)
Tetrachloroethylene	5-78 ppb (Stubin et al., 1996)	100-420 ppb (Supply & Service Canada, 1993)		Chlorine disinfection	127-18-4	10 t/yr (MPO)
Toluene	0.4-2.3 ppm (CWWA, June 14, 2001) 2-47 ppb (Stubin et al., 1996)	2-110 ppb (Stubin et al., 1996)			108-88-3	10 t/yr (MPO)
1,2,4-Trichlorobenzene	2-44 ppb (Stubin et al., 1996)				120-82-1	10 t/yr (MPO)
Trichloroethylene	1-46 ppb (Stubin et al., 1996)	100-420 ppb (Supply & Service Canada, 1993)		Chlorine disinfection	79-01-6	10 t/yr (MPO)
Vanadium (and its compounds)	0-0.1 ppm (CWWA, June 14, 2001)				7440-62-2	10 t/yr (MPO)
Xylene		1-79 ppb (Clark et al., 1991)			1330-20-7	10 t/yr (MPO)
Zinc (and its compounds)	0-0.4 ppm (CWWA, June 14, 2001) 0.213 ppm (Environment Australia, 1999)	2.0 ppm (CWWA, June 14, 2001)	Possible sources		*	10 t/yr (MPO)

\* No single CAS number applies to this NPRI listing

**TABLE 2B – LITERATURE CONCENTRATION VALUES FOR NPRI SUBSTANCES REPORTED IN SLUDGE**

NPRI SUBSTANCE	CONCENTRATION IN SLUDGE	DRY SLUDGE PRODUCTION RATE	CAS NUMBER	NPRI THRESHOLD (SEE TABLE 1 FOR TYPES)
Arsenic	4 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	0.05 t/yr (MPO)
Cadmium	2-4 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-21, 24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	0.005 t/yr (MPO)
Copper	330-550 mg/kg dry weight (Guo and Bassner, 1996) 275-775 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-21, 24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	10 t/yr (MPO)
Lead	72-150 mg/kg dry weight (Guo and Bassner, 1996) 45-190 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-21, 24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	0.05 t/yr (MPO)
Mercury	1.2-3.3 mg/kg dry weight (Guo and Bassner, 1996) 3 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-21, 24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	0.005 t/yr (MPO)
Nickel	35-120 mg/kg dry weight (Guo and Bassner, 1996) 20-28 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-21, 24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	10 t/yr (MPO)
Selenium	5 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	10 t/yr (MPO)
Zinc	1100-2800 mg/kg dry weight (Guo and Bassner, 1996) 335-935 mg/kg dry weight (Water Environment Federation, vol.3, 1998, p.24-21, 24-26)	0.23 kg/m <sup>3</sup> (Grites and Tchobanoglous, 1998, p.945)	*	10 t/yr (MPO)

\* No single CAS number applies to this NPRI listing

TABLE 2C – LITERATURE CONCENTRATION VALUES FOR NPRI SUBSTANCES REPORTED IN AIR

NPRI SUBSTANCE	AIR EMISSION FACTOR	OTHER RELATED DATA	CAS NUMBER	NPRI THRESHOLD (SEE TABLE 1 FOR TYPES)
Ammonia	2.2 g/m <sup>3</sup> (Battye et al., 1994)		*	10 t/yr (MPO)
Chloroform	0.014 g/m <sup>3</sup> (USEPA, Apr. 1987)		67-66-3	10 t/yr (MPO)
Nitrogen oxides (expressed as NO <sub>2</sub> )	0.00025-32.9 g/m <sup>3</sup> (estimate)	N <sub>2</sub> O: 0.002-0.02 g N <sub>2</sub> O-N/g sewage-N (Barton and Atwater, 2002); 0.04-524 g N/m <sup>3</sup> sewage (CWQA, June 14, 2001)	*	20 t/yr (releases to air)
Total volatile organic compounds	1.07 g/m <sup>3</sup> (USEPA FIRE, FIRE6.23)		*	10 t/yr (releases to air)

\* No single CAS number applies to this NPRI listing



## 1.6 Identification of a Short-List of NPRI Substances for Emission Estimation in Step 2

### Introduction

If your facility met the basic reporting criterion for daily average discharge volume and you expect that some NPRI substances were present or released in excess of the mass reporting thresholds, you next must identify specific substances of potential concern. The technique recommended in this section is designed to develop a list of potential substances for your particular facility that will require further calculations for reporting purposes (i.e., substances that will be carried forward to Chapter 2, *Estimating Releases and Transfers*).

Literature reports of substances in wastewater influent, effluent and biosolids reveal about 50 NPRI substances with measurable concentrations. (These are identified in Tables 2a, b and c, above.) These results are provided for reference purposes as part of the initial screening assessment. Substances of concern for individual facilities will vary based on a number of factors, as identified in the sub-section above.) Using monitoring data, literature values, and an assessment of non-residential discharges to the sewer system, it is possible to assess what NPRI substances may be of potential concern.

### Selecting Substances of Potential Concern

Whether or not a substance has the potential to reach the reporting threshold levels in a year will depend on the concentration of the substance in the raw wastewater and the annual average daily flow rate of the facility. You should review information available to you to identify NPRI substances present at concentrations sufficient to trigger a reporting requirement. Based on your average flow rate, the following formula can be used to ascertain the concentrations of substances required to exceed the reporting thresholds for your particular facility:

$$C_{\text{substance}} = (T \times 10^{-6} \text{ tonne/g}) / (Q_{\text{facility}} \times 365 \text{ d/yr}) \quad \text{EQ - 1}$$

where:

$$\begin{aligned} C_{\text{substance}} &= \text{concentration of a substance in the influent that will trigger a reporting requirement, mg/L, or g/m}^3, \text{ or ppm} \\ T &= \text{NPRI threshold}^6, \text{ tonne/yr} \\ Q_{\text{facility}} &= \text{average daily flow rate of discharges from your collection/ treatment system, m}^3/\text{d} \end{aligned}$$

<sup>6</sup> For substances with lower thresholds, it may be more convenient to use kilograms rather than tones, inserting the appropriate conversion factor.

The results of these calculations can be compared to concentrations from monitoring data, literature values and other information sources (such as an Industrial Waste Program) to determine which substances may be of concern.

For facilities with high daily average flow rates, some NPRI substances may be reportable at threshold concentrations less than the method detection limits. In such cases, information from biosolids concentrations or from the reported information in the NPRI database will be needed to estimate releases or transfers, as discussed in Chapter 2.

For the purposes of initial assessment of threshold amounts, it is assumed that substances present in parts per million (ppm) are measurable in terms of milligrams per litre (or grams per cubic metre).

#### **Triggering Reporting for Part 1 Substances**

Part 1 (both 1A and 1B) substances are assessed on the basis of whether they were manufactured, processed or otherwise used (MPO). As a general rule, reporting for Part 1 substances is triggered by the amount of substance initially present in the raw wastewater (collection system and treatment plant). Part 1 substances reduced in volume by the treatment process must be assessed on the basis of raw wastewater concentrations, even if the amount of substance released or transferred, subsequent to treatment, was less than the trigger reporting threshold. For example, the concentration by weight of many organic substances on the Part 1 substance list is greater in raw wastewater than the total weight released or transferred because the substances were transformed by biological wastewater treatment. (Release and transfer calculations are described in Chapter 2.)

Exceptions to the general rule for triggering Part 1 substances on the basis of raw wastewater concentrations include:

- Part 1 substances produced as a result of the process (e.g. chlorine disinfection by-products); in this case, the quantity of substance produced should be used to determine whether the threshold was exceeded
- Part 1 substances present in the raw wastewater *and* produced by the process (e.g., nonylphenols); in this case, the quantity of substance in the raw wastewater plus that produced should be used to determine whether the threshold was exceeded
- Part 1 substances used in the process; in this case, the total amount of substance used, plus any present in the raw wastewater, should be used to determine whether the threshold is exceeded.

On an annual basis, a substance present at:

- 1 ppm will accumulate to 10 tonnes with a daily flow rate of just over 27 300 m<sup>3</sup>/d
- 2.7 ppm will accumulate to 10 tonnes with a daily flow rate of just over 10 000 m<sup>3</sup>/d
- 10 ppm will accumulate to 10 tonnes with a daily flow rate of just over 2 700 m<sup>3</sup>/d
- 25 ppm will accumulate to 10 tonnes with a daily flow rate of about 1 100 m<sup>3</sup>/d.

Note that Part 1A NPRI substances present in the raw wastewater at concentrations of 2.7 ppm (2.7 mg/l) or higher will trigger a reporting requirement at the minimum flow criterion of 10 000 m<sup>3</sup>/d.

The substances with lower thresholds (i.e., Part 1B substances) will accumulate to their threshold levels with concentrations in parts per billion (ppb) for many facilities. For example, the reporting threshold for mercury is 5 kilograms. At a concentration of 1 ppb (1 mg/l) in the raw wastewater, mercury will accumulate annually to 5 kilograms with a daily flow of 13 700 m<sup>3</sup>/d.

Refer to the literature values provided in Tables 2a and b for indications of which substances may be of typical concern for your flow rate. When reviewing figures in Table 2b, remember that biosolids data is only useful to estimate raw wastewater concentrations for Part 1 substances. As a result, calculations must take into account removal efficiencies in the process and releases to other media, as described in Chapter 2 of this Manual.

### **Triggering Reporting for Part 2 and Part 4 Substances**

Part 2 substances are assessed on the basis of quantities released. The quantities of Part 2 substances in biosolids, effluent, overflows (or other untreated discharges), and released to air are used to determine whether the reporting trigger was met. For a conservative assessment, Part 2 substance concentrations in raw wastewater could be used to assess trigger thresholds.

Part 4 substances are assessed on the basis of quantities released to air. Part 4 substances may be released throughout the collection system, the treatment process or through operation of stationary equipment on site. (On-site stationary equipment is not addressed in this Manual; it is covered in other NPRI guides.)

Emission factors, where available, could be used to assess what Part 4 substances exceeded the release threshold. Emission factors are discussed in Chapter 2 and Appendix D. The reporting requirements and instructions on calculating emissions for Criteria Air Contaminants (CACs) are detailed in the *CAC Supplementary Guide*.

### **Preliminary List**

Based on the calculations of your facility flows with reporting threshold limits, along with additional community-specific sources of information and literature values, you will be able to develop a list of potential substances of concern. This list of substances forms the basis for calculations of releases and transfers in the next step, described in Chapter 2.





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## 2. Chapter Two

### Step 2: Estimate Releases and Transfers and Collect the Information Required for the NPRI Report

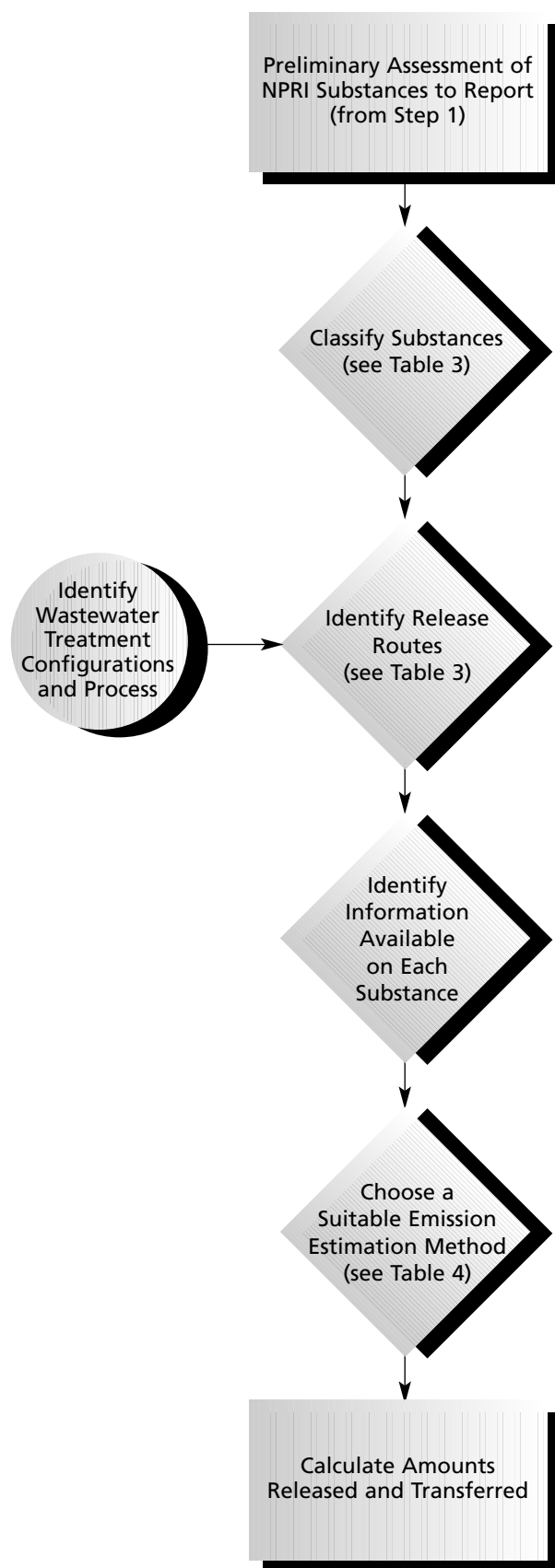
#### 2.1 Overview

From Step 1, reporters will have a list of substances that potentially exceeded their respective threshold reporting limits. The next step is to estimate quantities of these substances released to each media (air, water or land) or, alternatively, the quantities of substances transferred.

Step 2 is comprised of several steps, as identified in Figure 2.

As a result of the more detailed calculations and information review of wastewater information in Step 2, reporters may discover that some substances did not exceed threshold limits to trigger reporting. In addition, reporters may find that they have insufficient information to assess the presence of certain substances. For this reason, the final number of substances reported might be less than that initially developed in Step 1.

**FIGURE 2**  
**STEP 2: ESTIMATE RELEASES AND TRANSFERS**



Classify Substances  
(see Table 3)

## 2.2 Classify Substances

Various substances respond differently to the treatment process, and this response will affect the calculations of volumes released to air, water, sludge or biosolids (treated sludge).

NPRI substances of potential concern for municipal wastewater treatment facilities can be classified into five groups according to their physical properties and behaviours during treatment:

- metals
- volatile organic compounds
- volatile inorganic compounds
- non-volatile compounds, and
- special substances.

### Metals

Metals do not change throughout such treatment processes, although they can occur in different forms. As a result, the total released and/or transferred is equal to the total in raw wastewater. Metals are released primarily to sludge and biosolids. There are insufficient data to assess what portion of metals is captured in raw solids (screenings, grit and scum). Effluent can also contain trace amounts of metals, depending upon the type of treatment employed. Metals are not normally released to air. (See mercury under *Special Substances*, following.)

Typical reporters will likely base metal release and transfer estimates on biosolids monitoring results. As indicated in the section, *Release and Transfer Calculations*, this estimation method must take into account removal efficiencies of the process to calculate releases to water on the basis of known solids' concentrations.

### Volatile Organic Compounds

Volatile organic compounds (VOCs) can be degraded to simple compounds, depending on the type of biological treatment used. As a result, the total released and/or transferred is less than the total in influent when biological treatment is involved. It is important to note that substances listed in Parts 1A and 2 in this category must be considered individually with respect to the 10-tonne reporting threshold. In addition, if the aggregated air releases of all VOCs is 10 tonnes or more, the total amount must be reported collectively as "VOCs". (Total VOCs is reportable as a Part 4 substance.)

Nonylphenol is an exception found at wastewater treatment facilities of a VOC that increases in concentration as a result of biological treatment. Nonylphenol is formed as a result of biodegradation of nonylphenol ethoxylates.

VOCs are released to air, effluent, sludge and biosolids, but available data to assess partitioning between effluent and sludge or biosolids are limited. There are also insufficient data to assess whether VOCs are typically present in raw solids.

### Volatile Inorganic Compounds

Volatile inorganic compounds behave in a similar way to VOCs. They are released to air, effluent and sludge. Their possible presence in biosolids and raw solids must be determined for each individual compound. Unlike VOCs, volatile inorganic compounds can be either decomposed or formed, depending on the type of treatment used. Partition data between effluent, sludge and biosolids are generally lacking.

### Non-volatile Compounds

Non-volatile compounds are released to effluent, sludge and biosolids, and can be altered during the treatment processes. Air emissions are not likely. There are insufficient data to assess if non-volatile compounds are present in raw solids.

**Special Substances**

Special substances are those compounds which cannot be generalized by each of the above four groups. For the wastewater sector, the only special substance of concern is mercury. Mercury is released to all media (air, water and land), but data to assess partitioning between these media are lacking.

**Substance Summary**

Substances identified in Tables 2 a, b and c (Chapter 1), are categorized in Table 3 into the five substance groups. In some cases, substances are known to be present for various release routes, but there is no reliable information available to estimate release proportions; in such cases, question marks (?) are shown in Table 3. (For example, nonylphenols are known to be present in biosolids, but their typical concentration relative to influent concentrations is not known.)

**TABLE 3 – NPRI SUBSTANCE CLASSES PROCESSED, USED AND MANUFACTURED AT MUNICIPAL WASTEWATER TREATMENT FACILITIES AND THEIR RELEASE ROUTES**

CLASS	SUBSTANCE	RELEASE ROUTE				
		AIR	EFFLUENT	SLUDGE	RAW SOLIDS	BIO-SOLIDS
Metals	Antimony	X	✓	✓	?	✓
	Arsenic	X	✓	✓	?	✓
	Cadmium	X	✓	✓	?	✓
	Chromium (III)	X	✓	✓	?	✓
	Chromium (VI)	X	✓	✓	?	✓
	Cobalt	X	✓	✓	?	✓
	Copper	X	✓	✓	?	✓
	Lead	X	✓	✓	?	✓
	Manganese	X	✓	✓	?	✓
	Nickel	X	✓	✓	?	✓
	Selenium	X	✓	✓	?	✓
	Silver	X	✓	✓	?	✓
	Vanadium	X	✓	✓	?	✓
	Zinc	X	✓	✓	?	✓
Volatile Organic Compounds	Benzene	✓	✓	✓	?	?
	<i>Bis</i> (2-ethylhexyl) phthalate	✓	✓	✓	?	?
	2-Butoxyethanol	✓	✓	✓	?	?
	Carbon tetrachloride	✓	✓	✓	?	?
	Chlorobenzene	✓	✓	✓	?	?
	Chloroform	✓	✓	✓	?	?
	Dibutyl phthalate	✓	✓	✓	?	?
	<i>o</i> -Dichlorobenzene (1,2-Dichlorobenzene)	✓	✓	✓	?	?
	<i>p</i> -Dichlorobenzene (1,4-Dichlorobenzene)	✓	✓	✓	?	?
	1,2-Dichloropropane	✓	✓	✓	?	?
	Diethyl phthalate	✓	✓	✓	?	?
	N,N-Dimethylaniline	✓	✓	✓	?	?
	N,N-Dimethylformamide	✓	✓	✓	?	?
	Dimethylphthalate	✓	✓	✓	?	?
	Ethylbenzene	✓	✓	✓	?	?
	Ethylene glycol	✓	✓	✓	?	?
	Methanol	✓	✓	✓	?	?
	Naphthalene	✓	✓	✓	?	?
	N-Nitrosodiphenylamine	✓	✓	✓	?	?
	Nitrilotriacetic acid	✓	✓	✓	?	?
	Nonylphenol	✓	✓	✓	?	?
	Phenol	✓	✓	✓	?	?
	Phenanthrene (a PAH)	✓	✓	✓	?	?
	Phthalic anhydride	✓	✓	✓	?	?
	Tetrachloroethylene (behaves as a VOC, though technically not a VOC)	✓	✓	✓	?	?
	Toluene	✓	✓	✓	?	?
	Total volatile organic compounds	✓	✓	✓	?	?
1,2,4-Trichlorobenzene	✓	✓	✓	?	?	
Trichloroethylene	✓	✓	✓	?	?	
Xylene	✓	✓	✓	?	?	
Volatile Inorganic Compounds	Ammonia	✓	✓	✓	?	✓
	Carbon disulphide	✓	✓	✓	?	?
	Chlorine (total residual) or chloramines	✓	✓	✓	?	?
	Hydrogen sulphide	✓	✓	✓	?	?
	Nitrogen oxides	✓	✓	✓	?	?
Non-volatile Compounds	Molybdenum trioxide	X	✓	✓	?	?
	Nitrate ion	X	✓	✓	?	?
Special Substances	Mercury	✓	✓	✓	?	✓



## 2.3 Identify Release Routes

The release routes for various substances depend on their classification (i.e., their physical properties). Release routes for which literature information exists are identified in Table 3. Which of these release routes are available for substance release or transfer will depend, in part, on the wastewater system configuration and process characteristics as identified in the next Section.

In addition to releases of substances from the wastewater treatment system, reporters must consider release routes available via the collection system. For example, release of Part 4 substances to air can occur in the collection system as well as at treatment facilities.



## 2.4 Identification of Wastewater Treatment System Configuration and Process Characteristics

### Introduction

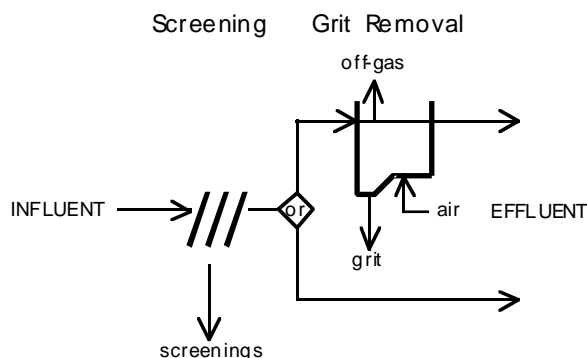
Following are schematics of typical wastewater treatment facility configurations in Canada. Some general items to note with respect to the configurations are:

- Arrows into the schematic indicate inputs, such as coagulants. These inputs may be zero at your facility. Therefore, if there is an arrow into the schematic at a point where you do not add materials or energy, the schematic may still apply to your plant.
- Arrows out of the schematic indicate outputs from the process, such as screening materials, biosolids or effluent. These are the points in the process that may result in reportable substances being released or transferred.
- To keep schematics generic, some have options (shown with a diamond “or”) indicated. For example, disinfection is an option at the end of many plant configurations.
- At the end of each configuration, a summary of emission points from that process is listed. All emission points in the facility and in the collection system must be considered when estimating release amounts.

Identify the configuration that most closely matches the plant on which you are reporting. Once your facility is identified, identify emission points that apply to your facility to continue.

### 1. Direct Discharge or Preliminary Mechanical Plant

FIGURE 3



### Summary

This configuration includes no treatment, or simple preliminary treatment. The system entails:

- screening and release of effluent to a water body (screening may be as simple as the grates on the main outfall), or
- screening followed by grit removal and release of effluent to a water body.

### Features

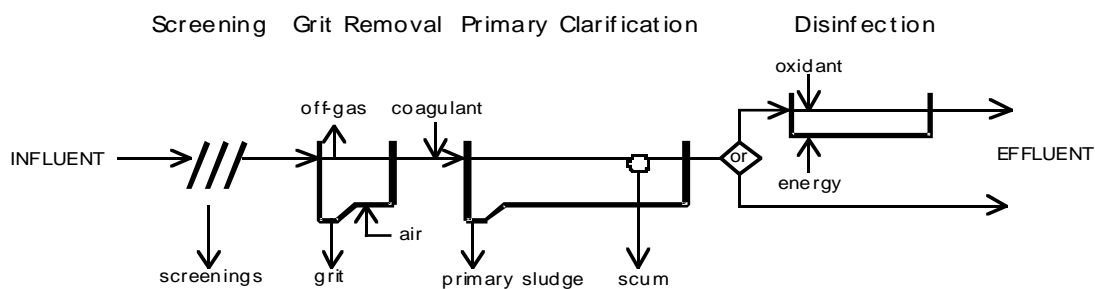
- Direct discharge is the release, without treatment, of wastewater to a surface water body.
- Preliminary treatment is the most basic level of treatment.
- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- With the addition of grit removal, preliminary treatment also removes heavier, settleable particles.
- Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids, and
- effluent.

## 2. Primary – Mechanical Plant

FIGURE 4



### Summary

Primary treatment uses a series of separators to remove solids from the water stream. No controlled biological treatment takes place.

### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier, settleable particles
- Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.

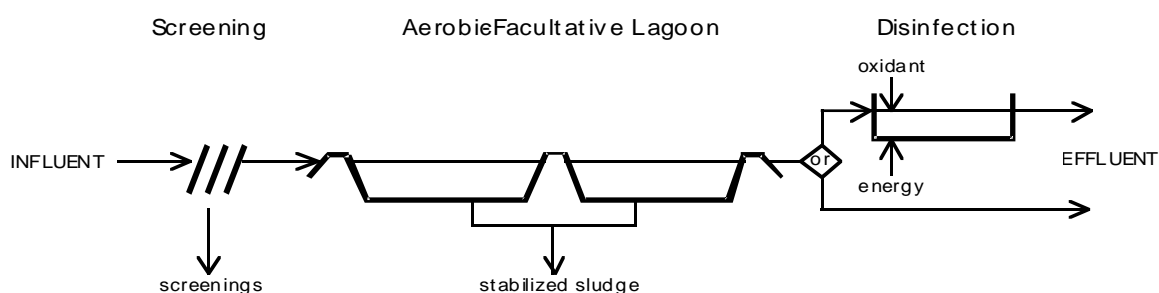
- Primary clarification removes a fraction of the solids and organics from the water stream, producing primary sludge and scum outputs. The sludge may be further treated [note: could include digestion] prior to disposal.
- Coagulant may or may not be used to increase solids' removal in the primary clarification stage. Typical coagulants used are metal salts — aluminum sulphate or ferric chloride. If not used, this arrow input on the diagram is zero. Primary treatment facilities using coagulants are sometimes referred to as *Enhanced Primary Plants*.
- Primary plants may or may not include disinfection. If there is no disinfection, the effluent from the primary clarifiers is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or an energy input, such as UV radiation. Dechlorination using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- primary sludge
- scum, and
- effluent.

### 3a. Secondary Lagoon – Aerobic-facultative (also known as Facultative)

FIGURE 5



#### Summary

Aerobic-facultative lagoons (or facultative lagoons) are configured as single or multiple-cell facilities. Treatment occurs through passive air-water interface transfers and photosynthetic reactions. The lower anaerobic zone of an aerobic-facultative lagoon provides sludge stabilization, volume reduction and storage. Lagoons are classified as secondary treatment facilities, although their performance in terms of contaminant removal efficiency is often well below that of other secondary plants.

#### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Aerobic-facultative lagoons comprise an upper aerobic zone and a lower anaerobic zone. Settleable solids are stored in the lower zone where they are anaerobically reduced to inert solids. Aerobic treatment occurs in the upper zone by means of passive air-water interface transfers and photosynthesis. Mechanical systems to increase oxygen transfer rates are not used in this configuration.



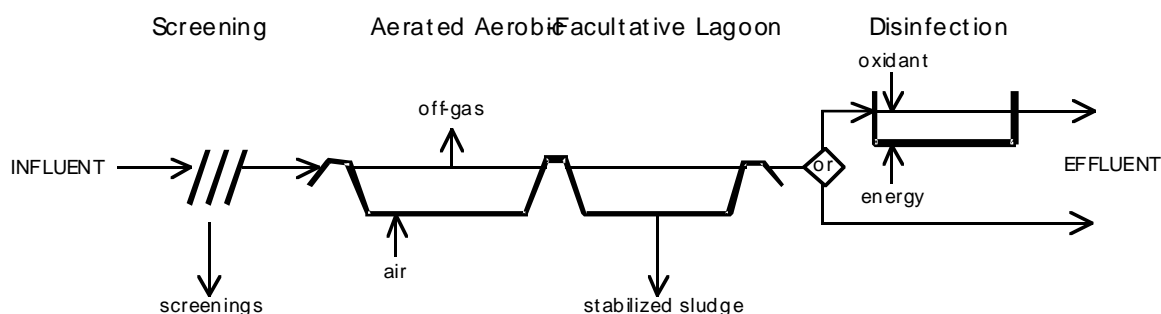
- Figure 5 depicts a two-cell facility for illustrative purposes. However, this configuration applies for any number of lagoon cells.
- Lagoons may or may not include disinfection. If there is no disinfection, lagoon effluent is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or an energy input, such as UV radiation. Dechlorination using a reducing agent, such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- lagoon biosolids (when removed periodically), and
- effluent.

### 3b. Secondary Lagoon – Aerated

FIGURE 6



#### Summary

Aerated lagoons are configured as single- or multiple-cell facilities. The aerated cell is equipped with mechanical systems to actively supply oxygen. The lower anaerobic zone of an aerated aerobic-facultative lagoon provides sludge stabilization, volume reduction and storage. Aerated lagoons are classified as secondary treatment facilities, although their performance in terms of contaminant removal efficiency is often well below that of other secondary plants.

#### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Mechanical aeration systems are typically surface mechanical or diffused air (depicted as the air input arrow in Figure 6.) Off-gassing from mechanically-aerated lagoons is at higher levels than from the passive system (Figure 5).
- Aerated lagoons can be configured as either a complete-mix cell, followed by an aerobic-facultative lagoon for solids separation, or by a partially-mixed aerated lagoon which allows solids' separation and anaerobic stabilization in the lower, unmixed zone.
- Figure 6 depicts a complete-mix first stage and aerobic-facultative second stage lagoon for illustrative purposes. However, this configuration applies to any lagoon system equipped with a mechanical aeration system.

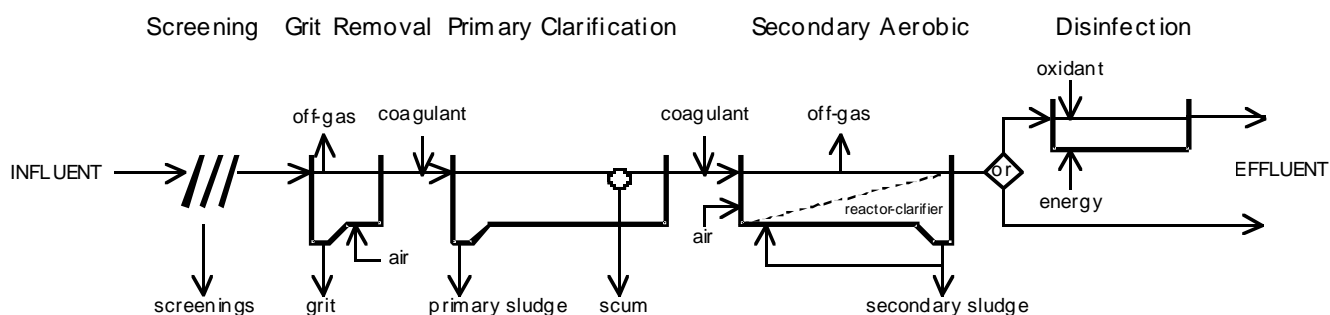
- Lagoons may or may not include disinfection. If there is no disinfection, the lagoon effluent is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- lagoon biosolids (when removed periodically), and
- effluent.

## 4. Secondary Treatment – Activated Sludge (Suspended Growth)

FIGURE 7



### Summary

Conventional activated sludge plants include biological treatment and primary clarification (for solids' separation). The activated sludge process comprises an aerated biological reactor and a secondary clarifier for solids' separation. Some sludge is returned to the reactor to maintain the aerobic biomass at an optimal concentration for high-treatment efficiency through the metabolic synthesis of organic and inorganic compounds. This configuration also includes activated sludge facilities practising *Enhanced Secondary Treatment* — coagulant addition for phosphorus removal and aeration capacity for nitrification demands.

### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier, settleable particles. Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.
- Primary clarification removes a fraction of the solids and organics from the water stream, producing primary sludge and scum outputs.
- Coagulant may or may not be used to increase solids' removal in the primary clarifier. Typical coagulants used are metal salts — aluminum sulphate or ferric chloride. If not used, this arrow input on the diagram is zero.
- The secondary aerobic stage comprises a complete-mix reactor with either mechanical or diffused-air aeration systems followed by a secondary clarifier. A portion of the sludge from the clarifier is recycled to maintain an optimal mixed-liquor concentration in the reactor. The reactor and separator phases of an activated sludge plant configured as a sequencing batch reactor, are combined in a single tank.

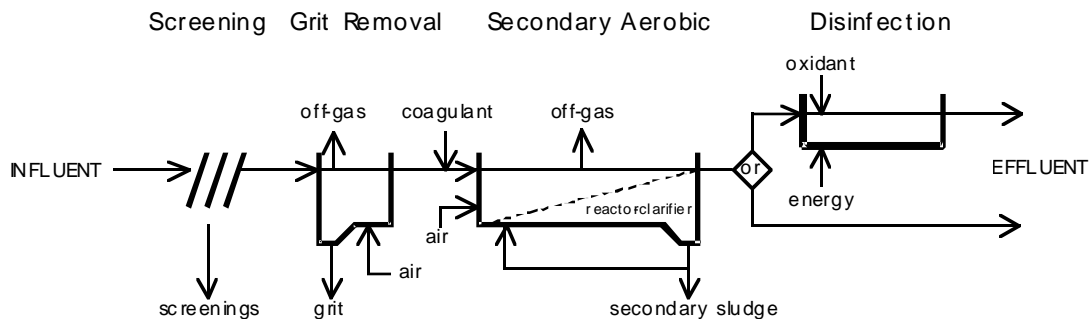
- Coagulant for phosphorus removal may or may not be added prior to the secondary aerobic stage. If not, the input arrow in the diagram would be zero.
- Primary and waste-activated sludge is usually stabilized on site through anaerobic or aerobic digestion and further thickened or dewatered prior to ultimate disposal. (See *Biosolids Processing* at the end of this section.)
- Activated Sludge plants may or may not include disinfection. If there is no disinfection, the effluent from the secondary clarifier is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or as an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- primary sludge
- scum
- waste-activated sludge, and
- effluent.

## 5. Secondary Treatment – Extended Aeration (Suspended Growth)

FIGURE 8



### Summary

Typically, extended aeration plants are of smaller capacity than conventional activated sludge plants and do not include primary sedimentation. They are characterized by long hydraulic-retention times, higher mixed-liquor concentration and long sludge ages.

### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier, settleable particles. Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.
- The secondary aerobic stage comprises a complete-mix reactor with either mechanical or diffused-air aeration systems followed by a secondary clarifier. A portion of the sludge from the clarifier is recycled to maintain an optimal mixed-liquor concentration in the reactor. The reactor and separator phases of an extended aeration plant configured as a sequencing batch reactor, are combined in a single tank.

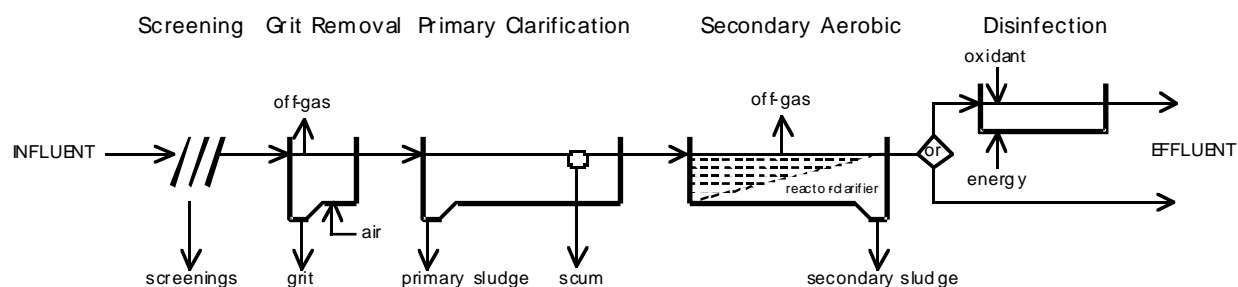
- Coagulant for phosphorus removal may or may not be added prior to the secondary aerobic stage. If not, the input arrow in the diagram would be zero.
- Waste-activated sludge is usually stabilized on site through aerobic digestion and may be further thickened or dewatered prior to ultimate disposal. (See *Biosolids Processing* at the end of this section.)
- Extended aeration plants may or may not include disinfection. If there is no disinfection, the effluent from the secondary clarifier is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or as an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- waste-activated sludge, and
- effluent.

## 6. Secondary Treatment – Fixed Film (Trickling Filter, Rotating Biological Contactor)

FIGURE 9



### Summary

Fixed film plants rely on the development of biological growth through direct contact with air. They are also referred to as “attached growth” or “supported growth” plants. The most common fixed film configurations are Trickling Filters (TFs) and Rotating Biological Contactors (RBCs). TFs may be configured as a packed tower with forced air or a shallow, naturally-ventilated circular filter bed. RBCs comprise a series of circular, closely-spaced, partially-submerged, parallel plastic plates rotating on a horizontal shaft. With each revolution of the shaft, the biomass is progressively exposed to air and then submerged in the flow. Coagulants for phosphorus removal may be used.

### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier settleable particles. Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.
- Primary clarification removes a fraction of the solids and organics from the water stream, producing primary sludge and scum outputs.
- For TFs, the secondary aerobic stage comprises a system of fixed nozzles or rotating distribution arms to evenly distribute the raw influent over a tower or filter bed of artificial or natural biomass support media (e.g. plastic or stone). TFs often incorporate pumped effluent recycle to keep the biomass wet.

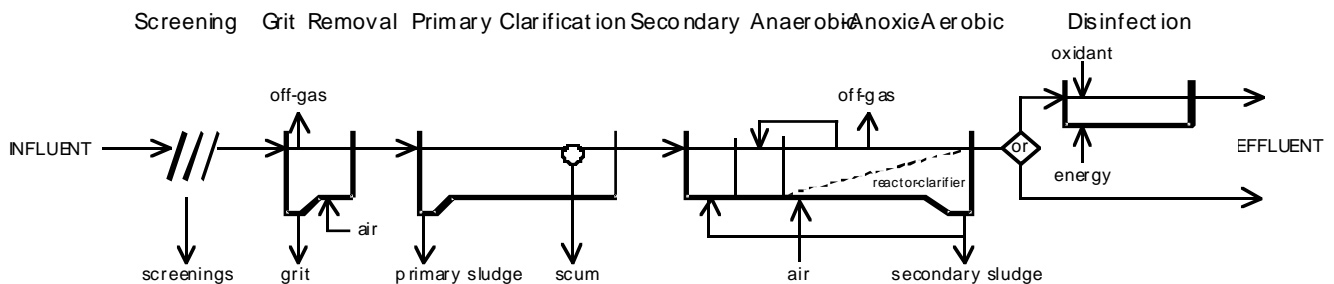
- An RBC aerobic zone comprises a semi-circular baffled trough in which the plates rotate, bringing the biomass into contact with the raw influent.
- Biomass continually sloughs off the support media and is separated in the final clarifier.
- Fixed film processes may be configured for nitrification, requiring the addition of sequential aerobic zones.
- Fixed film plants typically use less energy than suspended growth plants.
- Sludge may be stabilized on-site through anaerobic or aerobic digestion and further thickened or dewatered prior to ultimate disposal. (See *Biosolids Processing* at the end of this section.)
- Fixed film plants may or may not include disinfection. If there is no disinfection, the effluent from the secondary clarifier is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or as an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- primary sludge
- scum
- secondary sludge, and
- effluent.

## 7. Secondary Treatment – Biological Nutrient Removal (Suspended Growth)

FIGURE 10



### Summary

Biological Nutrient Removal (BNR) implies nitrification, de-nitrification and biological phosphorus removal. BNR plants are essentially activated sludge plants with anaerobic and anoxic zones ahead of the aerobic reactor and an aerated mixed liquor return to the anoxic zone. BNR plants can include any number of sequential anaerobic, anoxic and aerobic zones and the difference in configuration between them and a conventional plant is usually clear. Oxidation ditches can be converted to BNR by careful selection of the pumping rate and positioning of the raw influent feed.

Biological Phosphorus Removal (BPR) plants eliminate the secondary anoxic de-nitrification zone and aerated recycle but maintain the front-end anaerobic zone to promote the growth of a biomass containing a higher proportion of cellular phosphorus. Coagulants are not necessarily used in BPR plants, although coagulants may be used to achieve higher phosphorus removal efficiency.

## Features

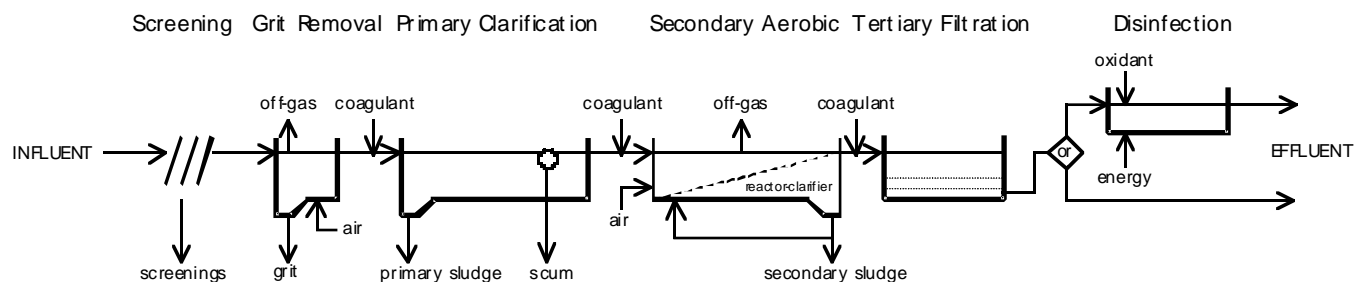
- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier settleable particles. Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.
- Primary clarification removes a fraction of the solids and organics from the water stream, producing primary sludge and scum outputs.
- The anaerobic and anoxic reactors ahead of aeration are usually mixed. The aerobic stage comprises a complete-mix reactor with either mechanical or diffused air aeration systems followed by a secondary clarifier. Return-activated sludge from the clarifier is combined with the incoming raw feed in the anaerobic reactor. The recycle flow rate to the anoxic zone is typically several times greater than the raw influent flow.
- BNR facilities produce less sludge than plants using coagulants.
- Primary and waste activated-sludge is usually stabilized on site through anaerobic or aerobic digestion and further thickened or dewatered prior to ultimate disposal. (See *Biosolids Processing* at the end of this section.)
- BNR and BPR plants may or may not include disinfection. If there is no disinfection, the effluent from the secondary clarifier is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or as an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

## Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- primary sludge
- scum
- waste-activated sludge, and
- effluent.

## 8. Tertiary Treatment – Activated Sludge (Suspended Growth) with Filtration

FIGURE 11



## Summary

Tertiary plants typically involve the addition of filtration to a conventional activated sludge process for high solids' removal.

## Features

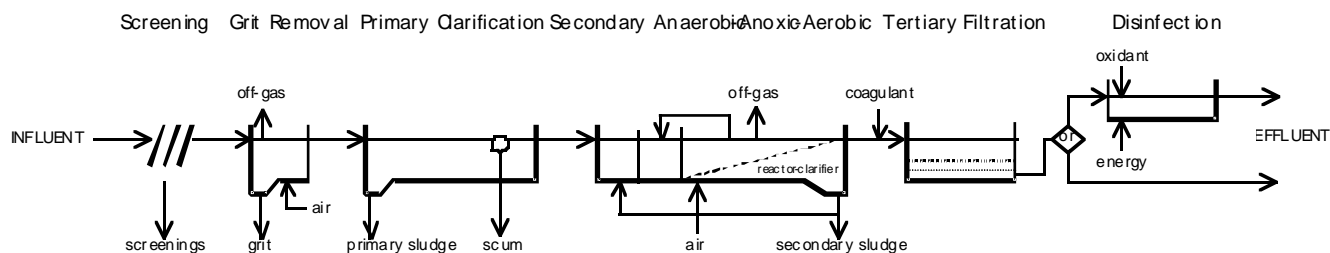
- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier settleable particles. Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.
- Primary clarification removes a fraction of the solids and organics from the water stream, producing primary sludge and scum outputs.
- Coagulant may or may not be used to increase solids' removal in the primary clarifier. Typical coagulants used are metal salts — aluminum sulphate or ferric chloride. If not used, this arrow input on the diagram is zero.
- The secondary aerobic stage comprises a complete-mix reactor with either mechanical or diffused air aeration systems followed by a secondary clarifier. A portion of the sludge from the clarifier is recycled to maintain an optimal mixed-liquor concentration in the reactor. The reactor and separator phases of an activated sludge plant configured as a sequencing batch reactor, are combined in a single tank.
- Coagulant for phosphorus removal may or may not be added prior to the secondary aerobic stage. If not, the input arrow in the diagram would be zero.
- Typically, filters are a granular media that provide higher solids' removal through particle straining and physical-chemical reactions if coagulants are used.
- Primary and waste-activated sludge is usually stabilized on site through anaerobic or aerobic digestion and further thickened or dewatered prior to ultimate disposal. (See *Biosolids Processing* at the end of this section.)
- Tertiary-activated sludge plants may or may not include disinfection, although they are more likely to do so. If there is no disinfection, the effluent from the secondary clarifier is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or as an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

## Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- primary sludge
- scum
- waste-activated sludge, and
- effluent.

## 9. Tertiary Treatment – Biological Nutrient Removal (Suspended Growth) with Filtration

FIGURE 12



### Summary

Tertiary Biological Nutrient Removal (BNR) plants typically involve the addition of filtration to a conventional BNR process for high solids' removal.

### Features

- Screening removes larger solids and objects from the water stream. The size of material removed depends on the spacing of the bars.
- Grit removal removes heavier settleable particles. Air may or may not be used for grit removal. If not, this arrow input on the diagram is zero and the rate of off-gassing will be lower.
- Primary clarification removes a fraction of the solids and organics from the water stream, producing primary sludge and scum outputs.
- The anaerobic and anoxic reactors ahead of aeration are usually mixed. The aerobic stage comprises a complete-mix reactor with either mechanical or diffused air aeration systems followed by a secondary clarifier. Return-activated sludge from the clarifier is combined with the incoming raw feed in the anaerobic reactor. The recycle flow rate to the anoxic zone is typically several times greater than the raw influent flow.
- BNR facilities produce less sludge than plants using coagulants.
- Typically, the filters are a granular media that provide higher solids' removal through particle straining and physical-chemical reactions if coagulants are used. Primary and waste-activated sludge is usually stabilized on site through anaerobic or aerobic digestion and further thickened or dewatered prior to ultimate disposal. (See *Biosolids Processing* at the end of this section.)
- Tertiary BNR plants may or may not include disinfection, although they are more likely to do so. If there is no disinfection, the effluent from the secondary clarifier is released directly. If disinfection is provided, it could be through the input of an oxidant, such as chlorine, or as an energy input, such as UV radiation. Dechlorination, using a reducing agent such as sulphur dioxide, may or may not be practised prior to discharge.

### Potential Sources of Reportable NPRI Substance Releases

- air releases
- screening solids
- grit solids
- primary sludge
- scum
- waste-activated sludge, and
- effluent.

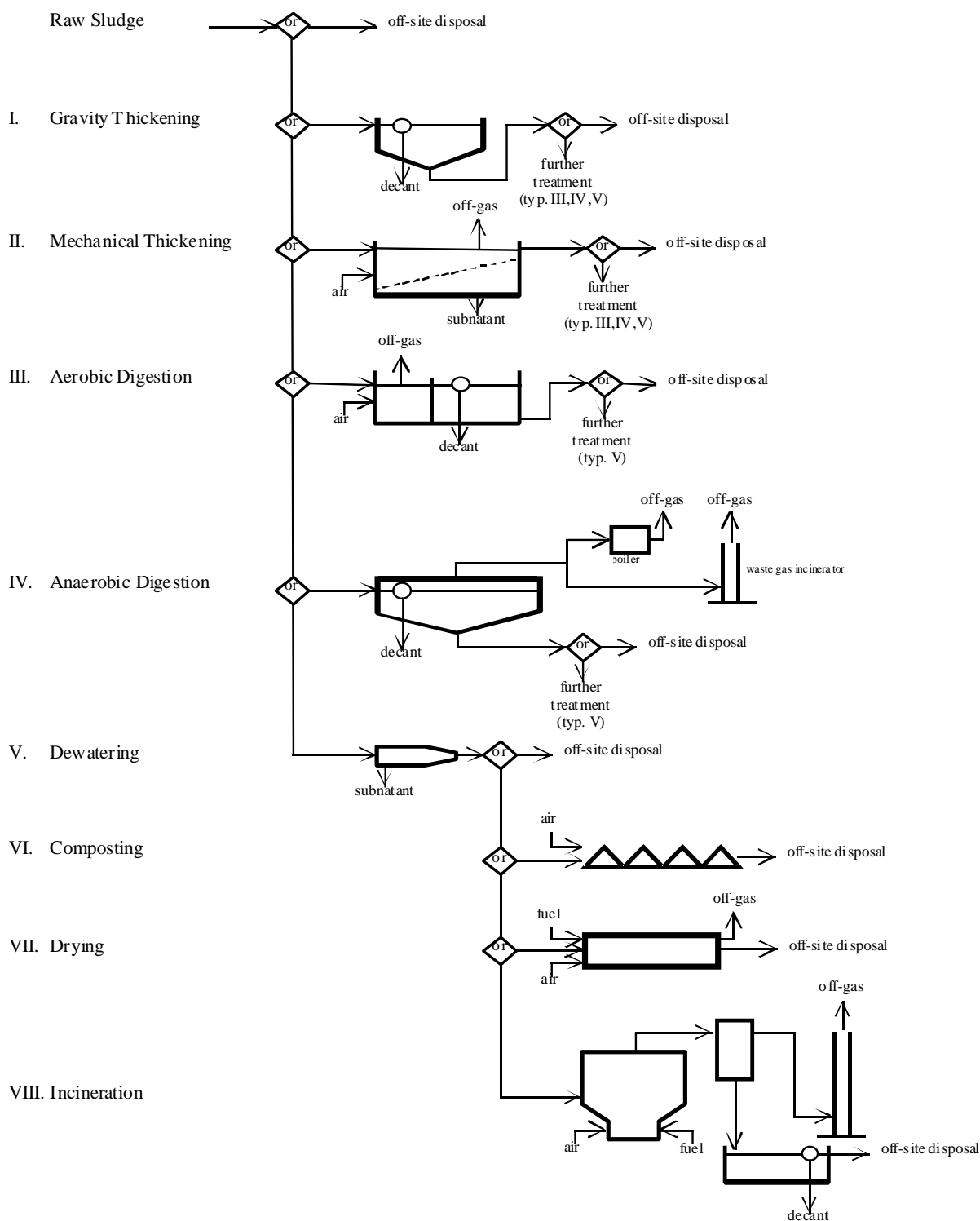


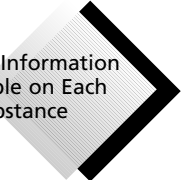
### 10. Biosolids Processing

Biosolids treatment is the stabilization of solids removed from primary and/or secondary sedimentation units. Treatment for biosolids can involve a series of processes. Figure 13 identifies typical biosolids processes, various combinations of which are in use for biosolids treatment at wastewater facilities. Each of these processes may result in air or on-site releases, or may result in transfers off site when biosolids are transported for disposal or land application.

Identify the biosolids treatment components applicable to your facility. These will assist you in identifying releases or transfer routes for your facility.

FIGURE 13





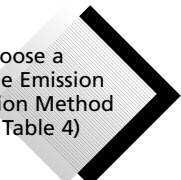
Identify Information Available on Each Substance

## 2.5 Identify Information Available on Each Substance

In the preceding steps, a list of potential substances that trigger reporting requirements has been developed based on flows and literature or facility data. In addition, the most common substances will have been classified, and generic release routes identified. Also, from the process diagrams, you should have a list of potential release routes for the substances. The final information required is substance-specific information to enable the estimation of releases and transfers. There are several potential sources of information, including:

- measured data on effluent, biosolids, air emissions and raw wastewater
- measured data on industrial customer discharges
- reported information in the NPRI database
- a database of your connected industrial or commercial customers
- compliance agreements for sewer use
- emission factors for air releases for specific substances or processes (further information in next section and Appendix D).

Based on a Canadian Water and Wastewater Association (CWWA) survey of Canadian municipalities, the most common source of information on NPRI substances for the sector is from biosolids' test results. At the time of the survey, it did not appear to be common practice for municipalities to rely on Industrial Sectors' NPRI reports to retrieve information on discharges to municipal sewer systems. Similarly, data from Industrial Sewer Use Programs was not used or accessed for NPRI substance information. These sources of information are recommended for use when gathering data on discharge quantities to the sewer system.



Choose a Suitable Emission Estimation Method (see Table 4)

## 2.6 Choose a Suitable Emission Estimation Method

### Estimation Methods

There are four methods of estimating quantities of substances released or transferred, as identified in the *Guide for Reporting to the National Pollutant Release Inventory – 2002*, and the *CAC Supplementary Guide*. In declining order of expected accuracy, the four methods are:

- monitoring or direct measurement
- mass balance calculations
- emission factors, or
- engineering estimates.

Appendices C, D, E and F provide information on monitoring, emission factors, mass balance, and engineering estimation, respectively. Appendix G provides information on the behaviour of some NPRI substances in specific wastewater processes and may be useful for reporters who are calculating emissions on a process-by-process basis.

### Suitability of Methods for the Various Substance Classifications

The applicability of the four methods to each substance class is summarized in Table 4. In general:

- The monitoring or direct measurement method can be applied (indicated by a check mark) to all release routes except for many air releases.
- The mass balance method can be used for releases of all substance classes to each media.
- The emission factor method is applicable to air emissions of both volatile organic and inorganic compounds. In theory, this method can be applied to releases to all media, but the available data for the wastewater sector is limited to air emissions of volatile organic and inorganic compounds.

- The engineering estimation method can be based on either removal efficiency or mass transfer principles:
- The removal efficiency-based engineering estimation method is applicable to releases other than air of all substance classes. Data available to the wastewater sector are, however, limited to metals and volatile organic compounds. There are insufficient removal-efficiency data for the other three classes of substances.
- The mass transfer-based engineering estimation method is only applicable to air emissions of volatile organic and inorganic compounds.

**TABLE 4 – APPLICABILITY OF EMISSION ESTIMATING METHODS TO SUBSTANCE CLASSES**

SUBSTANCE CLASS	RELEASE ROUTE	EMISSION ESTIMATING METHOD				
		MONITORING OR MEASUREMENT	MASS BALANCE	EMISSION FACTOR	ENGINEERING ESTIMATION	
					REMOVAL EFFICIENCY	MASS TRANSFER
Metals	Air	N/A	✓	N/A	N/A	N/A
	Effluent	✓	✓	no data	✓	N/A
	Sludge	✓	✓	no data	✓	N/A
	Raw Solids	✓	✓	no data	✓	N/A
	Biosolids	✓	✓	no data	✓	N/A
Volatile Organic Compounds	Air	✓	✓	✓	N/A	✓
	Effluent	✓	✓	no data	✓	N/A
	Sludge	✓	✓	no data	✓	N/A
	Raw Solids	✓	✓	no data	✓	N/A
	Biosolids	✓	✓	no data	✓	N/A
Volatile Inorganic Compounds	Air	✓	✓	✓	N/A	✓
	Effluent	✓	✓	no data	no data	N/A
	Sludge	✓	✓	no data	no data	N/A
	Raw Solids	✓	✓	no data	no data	N/A
	Biosolids	✓	✓	no data	no data	N/A
Non-volatile Compounds	Air	N/A	✓	N/A	N/A	N/A
	Effluent	✓	✓	no data	no data	N/A
	Sludge	✓	✓	no data	no data	N/A
	Raw Solids	✓	✓	no data	no data	N/A
	Biosolids	✓	✓	no data	no data	N/A
Special Substances (Mercury)	Air	✓	✓	no data	N/A	N/A
	Effluent	✓	✓	no data	no data	N/A
	Sludge	✓	✓	no data	no data	N/A
	Raw Solids	✓	✓	no data	no data	N/A
	Biosolids	✓	✓	no data	no data	N/A

✓ – applicable and data potentially-available or attainable  
 N/A – not applicable

### Practical Application of Methods for Calculations

In most cases, a combination of methods will be used to estimate releases and transfers. For example, with monitoring information on biosolids' concentrations of substances, estimation of releases to water can also be made. This estimation requires knowledge of your facility's removal efficiencies or, alternatively, you may rely on literature values for removal efficiencies. (Available literature values are provided in Appendix F, Table F-1). Extrapolation from monitoring data, with assistance of engineering estimation, is expected to be the most common method used by the wastewater sector to estimate releases to water and transfers off site in biosolids.

As indicated in Appendix D, emission factors for the wastewater sector are limited essentially to air releases. However, emission factors are expected to be the most common method used for estimating releases to air for the sector. Emission factors for plant-wide secondary, process-specific functions, or substance-specific emission factors (in a limited number of cases) may be used.

Given limited information on partitioning of substances between air/water/solids in the wastewater treatment process, the use of emission factors for substances released to water or solids will be limited. Particular chemistry and/or engineering expertise may be required to undertake engineering estimation methods using mass-balance principles, although in the absence of alternative-estimation methods, this should be done where information indicates the presence of an NPRI substance in excess of reportable trigger levels.

Calculate Amounts  
Released and Transferred

## 2.7 Calculate Amounts Released and Transferred

### Introduction to Estimating Releases and Transfers

For the wastewater sector, releases of NPRI substances to air, water and land must be estimated. In addition, the fate of NPRI substances in sludge and biosolids must be reported in terms of on-site releases (i.e., storage on site, spills or leaks) or transfers off site (for land application or disposal in landfill, incineration, or other).

Based on the most common information and reportable substances, two scenarios are provided for calculating amounts released and transferred — releases to air using emission factors, and releases to water and transfers off site using monitored biosolids data and engineering estimation.

### Releases to Air Using Emission Factors

For this scenario, it is assumed that the facility has no monitored data for air releases, although some information on volatile substances may be available from raw wastewater, effluent or biosolids' monitoring. With the list of substances from Step 1 that indicate the reporting trigger was exceeded:

- Identify all substances that were released to air, using Table 3.
- From the Process Diagrams, identify processes where releases to air occurred, and also identify points in the collection system where releases to air were likely to occur.
- From Appendix D, choose emission factors for the processes and collection system points identified. If applicable, you may choose to use the plant-wide emission factors for substances on your list. Otherwise, choose emission factors for specific components of your treatment and collection system.
- Using the emission factors, and flows in your facility, calculate the releases to air from each release source, and total the releases to air for each applicable substance.

In cases where there is no emission factor for the substance on the initial list, but monitoring data or NPRI release data indicates it is likely present in your system at quantities sufficient to trigger reporting, then you should research the volatility of the substance and other physical properties and use the engineering estimation method to estimate releases and transfers. Appendix F provides information on this estimation method, and Appendix H provides sample calculations for each of the four estimation methods. For volatile substances that are not very volatile and for which there are no emission factors, you can assume releases to water and sludge/biosolids only, in the absence of emission factors. Nonylphenols are an example of such substances.

### Releases to Water and Transfers Off Site Using Monitored Biosolids Data and Engineering Estimation

For this scenario, it is assumed that the facility has data for NPRI substances as a result of biosolids' monitoring and that the biosolids are transferred off site for disposal. With the list of substances from Step 1 that indicate the reporting trigger was exceeded:

- Identify all substances that were released to sludge, using Table 3.
- From the Process Diagrams, identify processes where sludge and biosolids were produced.

- For your facility, estimate the total volume of biosolids (or, if appropriate, sludge) produced annually. Be sure the final volume estimate is developed for the same sludge condition as the monitored data available (e.g. dry weight). Also ensure units of measure are compatible with the monitored data (e.g., kg per tonne).
- Using the concentration of specific NPRI substances in the biosolids, estimate transfers of these substances that resulted when biosolids were transferred off site. Report this amount for each substance in the “off-site transfers for disposal” category.
- Identify removal efficiencies from wastewater to biosolids for the substances of interest. These may be developed based on data for your facility using the facility’s sludge production rate, moisture condition and volume changes, and raw wastewater concentrations. Alternatively, you can use literature values as indicated in Table D-1 in Appendix D.
- Working from the removal efficiency of the substance to solids in the process, calculate the portion of substance remaining in effluent.
- Based on effluent flows and the portion of substance partitioned to water, calculate the amount of substance released to water annually.

### **Calculation Examples**

Appendix H contains examples of emission-estimating calculations using various estimation methods.

### **Estimation Software**

Appendix I contains an overview of available emission-estimation software. This information is provided for reference purposes only; the software is neither recommended nor endorsed by Environment Canada for use by reporters.



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## 3. Chapter Three

### Additional Guidance

#### 3.1 Smaller Wastewater Collection and treatment Facilities

Reporting to the NPRI is easier for facilities with lower average daily flows because, for the majority of substances (i.e., Part 1A substances), the concentration of substances in the influent will be at readily detectable limits to be reportable. As indicated in Chapter 1 (section 1.6), a concentration of 2.7 ppm will accumulate to 10 tonnes with an average flow rate of about 10 000 cubic metres per day. If your average flow is 20 000 m<sup>3</sup>/day, Part 1A substances must be present in the raw wastewater at concentrations of 1 ppm to be reportable.

In summary, assuming you met the minimum daily flow requirement, the steps to follow to determine what substances to report are:

- For your average daily flow rate, calculate what concentration you need in the influent to accumulate to the mass threshold for the various substance groups. (See Equation (EQ-1), section 1.6, to calculate concentrations required to trigger reporting for your flows.)
- Review your monitoring data to determine which substances may meet these concentrations.
- Review information on non-residential dischargers to your system (i.e., Industrial Waste Program information or sewer-use compliance agreements) to determine what non-residential types of substances may be present in sufficient quantities. Appendix A may also be of assistance in this assessment.
- Look up your system on the NPRI database via the Internet at [www.ec.gc.ca/pdb/npri](http://www.ec.gc.ca/pdb/npri) to see who reported transfers of substances, and the quantities transferred, to your system in previous years. (Discharges to sewerage systems are reported as “transfers to MSTP (municipal sewage treatment plant).”)
- Review the literature data in Tables 2a, b and c to identify substances that are reported in wastewater to identify additional substances that would typically be present in sufficient concentrations to accumulate to reportable quantities for your flow rate.
- Using this information, choose an appropriate emission estimate method, as described in this Manual, and estimate releases from your facility.

Total ammonia (i.e., NH<sub>3</sub> + NH<sub>4</sub><sup>+</sup>) is the most likely substance you will have to report. Other substances depend on the specific characteristics of your facility and community. Metals with low reporting thresholds (such as mercury, cadmium, lead, arsenic and hexavalent chromium) can often be present at reportable levels, especially in communities with combined sewer systems.

#### 3.2 Questions and Answers

##### ***What substances do I have to report?***

Based on typical ammonia concentrations, all facilities meeting the minimum average daily flow threshold will be required to report ammonia releases. A rule of thumb for smaller facilities at the lower threshold flow (i.e. 10 000 cubic metres per day) is that they will also have to report Part 1A substances present in the influent at concentrations of about 2.7 mg/l. Part 1B substances should be assessed individually for likelihood of their presence in sufficient quantities. Larger facilities must determine substances to report through calculations on the basis of information available to them, as described in more detail in this Manual.

##### ***How do I use monitoring data that show some readings below the detection limit and others above the detection limit?***

Guidance on this question is provided in the *Guide for Reporting to the National Pollutant Release Inventory – 2002*, under the heading Method Detection Limit.

##### ***Can I get information from the NPRI database on discharges to my sewer system?***

Dischargers transferring reportable substances to the municipal sewage treatment plant (MSTP) are required to report quantities to the NPRI. These transfers can be found in the NPRI database for your community. Check each discharger connected to your system to determine if they reported substance transfers in the MSTP category.

***Last year, I reported dioxins and furans, but there is no information in this Manual on these substances. Why not?***

Dioxins and furans, along with HCB, are Part 3 Substances that are not required to be reported for wastewater treatment or collection systems. Although some wastewater facilities reported on these substances in the past, it is not a requirement of the NPRI to do so. These substances *are reportable* for sewage-sludge incineration.

***Why is phosphorus listed as an NPRI substance, but there is no information in this Manual on phosphorus?***

For the 2002 reporting year, only elemental yellow or white allotropes of phosphorus are reportable to the NPRI. Changes to the reporting requirements for phosphorus may be made for the 2003 reporting year, or in future years. Phosphorus discharges from wastewater facilities may then become reportable.

***I run a small, mostly residential, wastewater facility. What is the simple way to report?***

Refer to Section 3.1 for specific guidance for smaller facilities.

***Our community is served by two separate collection and treatment systems on each side of a river. Do we consider the flows from each system separately?***

Systems divided by a river or harbour are considered to be adjacent if they function as a single, integrated system for the community. The flow threshold would be applied to the two systems in total, but separate facility reports would be submitted (excludes systems with no treatment plant, in which case a single report would be submitted).

***We have several collection and treatment systems serving communities within our amalgamated regional municipality. Do we consider the total flow from all systems within the regional municipality?***

Combine the flows from only the systems or groups of sub-systems that are contiguous or adjacent. If the systems serve distinct and separate communities within your regional municipality, you may consider them separately.

***Sewage sludge from one of our treatment plants is pumped through a force main to another treatment plant. How do we report the quantity of substances in that sludge?***

Unless the receiving plant was built solely for the purpose of treating sludge from the originating system, report the quantity as an off-site transfer to an MSTP.

***We have three collection and treatment systems that service our city. The systems have flows of 7 500, 8 200 and 9 000 m<sup>3</sup>/day. Individually, the systems do not meet the flow threshold. Do we have to report?***

If the service areas are adjacent, including being separated by a river or other body of water, and they function as a single, integrated system for your city, you must apply the total flow of 24 700 m<sup>3</sup>/day to the 10 000 m<sup>3</sup>/day threshold. Separate reports would be submitted for each facility.

***Do I have to monitor more substances now to report to the NPRI?***

No, the NPRI does not require additional monitoring, but reporters are expected to demonstrate due diligence in using information reasonably available to them to report.

***We contract out the operation of our city's municipal treatment system to a private company. Who is required to submit the NPRI report for our system?***

The NPRI notice requires the owner or operator of a facility to provide information to Environment Canada. The operator is expected to compile the information because they are most familiar with day-to-day operations. However, in the event of failure to comply with the notice, both parties would be subject to enforcement action.



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## Bibliography

- Araujo, K.; M. Colina; R. Mazurek; J. Delgado; H. Ledo; E. Gutierrez; and L. Herrera, "Mercury determination by CV-AAS in wastewater and sewage sludge from a stabilization pond system", *Presenius Journal of Analytical Chemistry* 355, 1996, 319-320.
- Ahel, M.; W. Giger; and M. Koch, "Behaviour of alkylphenol polyethoxylate surfactants in the aquatic environment – I. occurrence and transformation in sewage treatment", *Water Research* 28, 1994, 1131-1142.
- Banister, F.; W. P. Moeller, Jr.; E. M. Natarius; and K. M. Sampson, "Spin away odor and decay in sewage drop structures", *Water Engineering and Management* 146 (2), 1999, 13-18.
- Barton, P.; and J. W. Atwater, "Nitrous oxide emissions and the anthropogenic nitrogen in wastewater and solid waste", *Journal of Environmental Engineering* 128 (2), 2002, 137-150.
- Basu, S.; Z. C. Gu; and K. A. Shilinsky, "Application of packed scrubbers for air emissions control in municipal wastewater treatment plants", *Environmental Progress* 17 (1), 1998, 9-18.
- Battye, R.; W. Battye; C. Overcash; and S. Fudge (EC/R Inc., Durham, North Carolina, USA), "Development and selection of ammonia emission factors", prepared for U.S. Environmental Protection Agency, Office of Research and Development, Washing, D.C., August 1994.
- Beck, W. B.; M. K. Henry; and V. H. Edwards, "Controlling VOC emissions during wastewater treatment", *Chemical Engineering* 107 (8), August 2000, 113-116.
- Bennie, D. T., "Review of the environmental occurrence of alkylphenols and alkylphenol ethoxylates", *Water Quality Research Journal of Canada* 34, 1999, 79-122.
- Bennie, D. T.; C. A. Sullivan; H.-B. Lee; and r. J. Maguire, "Alkylphenol polyethoxylate metabolites in Canadian sewage treatment plant waste streams", *Water Quality Research Journal of Canada* 33, 1998, 231-252.
- Bertrand-Krajewski, J.-L.; M. Lefebvre; B. Lefai; and J.-M. Audic, "Flow and pollutant measurements in a combined sewer system to operate a wastewater treatment plant and its storage tank during storm events", *Water Science and Technology* 31 (7), 1-12.
- Canadian Water and Wastewater Association (CWWA), "National survey of wastewater treatment plants", Ottawa, Ontario, June 14, 2001.
- Chapman, D. T.; and W. G. Randle, "Evaluation of estimates of phosphorus concentrations and loadings from Ontario municipal wastewater treatment plants", prepared by Wastewater Technology Centre for Ontario Ministry of Environment, February 1990.
- Clark, L. B.; R. T. Rosen; T. G. Hartman; L. H. Alaimo; J. B. Louis; C. Hertz; C.-T. Ho; and J. D. Rosen, "Determination of nonregulated pollutants in three New Jersey publicly owned treatment works (POTWs)", *Research Journal of the Water Pollution Control Federation* 63 (2), 1991a, 104-113.
- Crites, R.; and G. Tchobanoglous, "Small and Decentralized Wastewater Management Systems", WCB/McGraw-Hill, New York, 1998.
- Czepiel, P. M.; P. M. Crill; and R. C. Harriss, "Methane emissions from municipal wastewater treatment processes", *Environmental Science and Technology* 27 (12), 1993, 2472-2477.
- D'Amato, R. M, II; and G. R. DeHollander, "Gaseous emissions from wastewater facilities", *Water Environment Research* 71 (5), 1999, 715-720.
- Dawson, D. S.; and W. L. Beyerlein, "Gaseous emissions from wastewater facilities", *Water Environment Research* 69 (4), 1997, 550-554.

- Dawson, D. S.; and W. L. Beyerlein, "Gaseous emissions from wastewater facilities", *Water Environment Research* 68 (4), 1996, 510-516.
- Dawson, D. S.; and M. A. Gokare, "Gaseous emissions from wastewater facilities", *Water Environment Research* 66 (4), 1994, 375-378.
- DeHollander, G. R., "Gaseous emissions from wastewater facilities", *Water Environment Research* 70 (4), 1998, 580-585.
- Devai, I.; and R. D. Delaune, "Emissions of reduced gaseous sulfur compounds from wastewater sludge: redox effects", *Environmental Engineering Science* 17 (1), 2000, 1-8.
- Droste, R. L., "Theory and Practice of Water and Wastewater Treatment", John Wiley & Sons, New York, 1997.
- Dyke, P. H.; C. Foan; M. Wenborn; P. J. Coleman, "A review of dioxin releases to land and water in the UK", *The Science of the Total Environment* 207, 1997, 119-131.
- Edmonton, 2000 NPRI report by Gold Bar Wastewater Treatment Plant, obtained from <http://www.gov.edmonton.ab.ca>.
- Eilbeck, W. J.; and G. Mattock, *Chemical Processes in Waste Water Treatment*, John Wiley & Sons, New York, 1987.
- Ejlertsson, J.; M.-L.; Nilsson; H. Kylin; A. Bergman; L. Karlson; M. Oquist; and B. H. Svensson, "Anaerobic degradation of nonylphenol mono- and diethoxylates in digester sludge, land filled municipal solid waste, and land filled sludge", *Environmental Science and Technology* 33, 1999, 301-306.
- Elliott, J.; and S. Watkins, "Controlling Volatile Organic Compound Emissions from Industrial Wastewater", *Pollution Technology Review No.197*, Noyes Data Corporation, New Jersey, 1990.
- Environment Australia, "Emission estimation technique manual for sewage and wastewater treatment", March 1999.
- Environment Canada, "Guide for Reporting to the National Pollutant Release Inventory – 2001", 2002.
- Environment Canada and Health Canada, "Priority substances list assessment report – nonylphenol and its ethoxylates", April 2001, available from Environment Canada's Web site at <http://www.ec.gc.ca/substances/ese/eng/psap/final/reports/NPEs.pdf>.
- Environmental Expert, information obtained from <http://www.environmental-expert.com>, 2002.
- Frechen, F.-B.; and W. Koster, "Odour emission capacity of wastewaters – standardization of measurement method and application", *Water Science and Technology* 38 (3), 1998, 61-69.
- Fresenius, W; W. Schneider; B. Bohnke; and K. Poppinghaus (eds.), "Waste Water Technology – Origin, Collection, Treatment and Analysis of Waste Water", Springer-Verlag, Berlin, 1989.
- Guo, T.; and J. Baasner, "Technical note: using FIMS to determine mercury content in sewage sludge, sediment and soil samples", *Journal of Automatic Chemistry* 18 (6), 1996, 221-223.
- Hayes, L., "Control of hydrogen sulfide emissions associated with wastewater treatment plants", *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management* 3 (1), 1999, 35-38.
- Jones, K. C.; and A. P. Sewart, "Dioxins and furans in sewage sludges: a review of their occurrence and sources in sludge and of their environmental fate, behaviour, and significance in sludge-amended agricultural systems", *Critical Reviews in Environmental Science and Technology* 27 (1), 1997, 1-86.

- Kimochi, Y.; Y. Inamori; M. Mizuochi; K.-Q. Xu; and M. Matsumura, "Nitrogen removal and N<sub>2</sub>O emission in a full-scale domestic wastewater treatment plant with intermittent aeration", *Journal of Fermentation and Bioengineering* 86 (2), 1998, 202-206.
- Kirk-Othmer, *Encyclopedia of Chemical Technology*, 3<sup>rd</sup> ed., vol.11, John Wiley & Sons, New York, 1980.
- Kirk-Othmer, *Encyclopedia of Chemical Technology*, 3<sup>rd</sup> ed., vol.17, John Wiley & Sons, New York, 1982.
- Lee, H.-B.; and T. E. Peart, "Occurrence and elimination of nonylphenol ethoxylates and metabolites in municipal wastewater and effluents", *Water Quality Research Journal of Canada* 33, 1998, 389-402.
- Lepri, L; P. Desideri; and M. Del Bubba, "Analysis of organic pollutants in a wastewater treatment plant", *Annali di Chimica* 87 (5), 1997, 317-335.
- Maguire, R. J., "Review of the persistence of nonylphenol and nonylphenol ethoxylates in aquatic environments", *Water Quality Research Journal of Canada* 34, 1999, 37-78.
- Marsalek, J.; B. Brownlee; T. Mayer; S. Lawal; and G.A. Larkin, "Heavy Metals and PAHs in Stormwater Runoff from the Skyway Bridge, Burlington, Ontario", *Water Quality Research Journal of Canada*, 32(4): 815-827.
- Mayer, G. J.; I. S. Cheng; P. Pau; and F. Mohamed, "Emissions of air toxics from wastewater treatment plants", *Water Environment Research* 66 (2), 1994, 140-144.
- Ministry of Health and Environmental Protection of the Netherlands, "Handbook of Emission Factors: Part 1 – Non-industrial Sources", 1980.
- Montreal, 2000 NPRI report by Station d'epuration des eau, obtained from <http://www.cum.qc.ca>.
- Mulloy Do, K. B., "Sewage workers: toxic hazards and health effects", *Occupational Medicine: State of the Art Reviews* 16 (1), 2001, 23-38.
- Naylor, C. G., "Environmental fate and safety of nonylphenol ethoxylates", *Textile Chemist and Colorist* 27, 1995, 29-33.
- NRC, "User's guide for the urban airshed model", Institute for Chemical Process and Environmental Technology, National Research Council of Canada, Ottawa, 1992.
- Ontario Ministry of the Environment, "Step by step guideline for emission calculation, record keeping and reporting for airborne contaminant discharge", April 2001.
- Ortuno, J. F.; J. Saez; M. Llorens; and A. Soler, "Phosphorus release from sediments of a deep wastewater stabilization pond", *Water Science and Technology* 42 (10-11), 2000, 265-272.
- Ottawa (City of), 2000 NPRI report by Robert O. Pickard Environmental Centre, obtained from <http://www.city.ottawa.on.ca>.
- Park, K. Y.; J. W. Lee; Y. Inamor; M. Mizuochi; and K. H. Ahn, "Effects of fill modes on N<sub>2</sub>O emission from the SBR treating domestic wastewater", *Water Science and Technology* 43 (3), 2001, 147-150.
- Patterson, J. W., "Wastewater Treatment Technology", Ann Arbor Science Publishers, Michigan, 1995.
- Paxeus, N., "Organic pollutants in the effluents of large wastewater treatment plants in Sweden", *Water Research* 30 (5), 1996a, 1115-1122.
- Paxeus, N., "Vehicle washing as a source of organic pollutants in municipal wastewater", *Water Science and Technology* 33 (6), 1996b, 1-8.

- Schmid, H.; H. Bauer; R. Ellinger; M. Fuerhacker; J. Sree; and H. Puxbaum, "Emissions of NO, TVOC, CO<sup>2</sup>, and aerosols from a pilot-scale wastewater treatment plant with intermittent aeration", *Atmospheric Environment* 35, 2001, 1697-1702.
- Schroeter, H.O., "Toxic Contaminant Loadings from Municipal Sources in Ontario Areas of Concern", *Water Quality Research Journal of Canada*, 32(1): 7-22 (1997)
- Shine, B., "Methods for estimating volatile organic compounds emissions from batch processing facilities", *Journal of Cleaner Production* 4 (1), 1996, 1-7.
- Sommar, J.; X. Feng; and O. Lindqvist, "Speciation of volatile mercury species present in digester and deposit gases", *Applied Organometallic Chemistry* 13, 1999, 441-445.
- Stephenson, R. L.; and J. B. Blackburn, Jr., "The Industrial Wastewater Systems Handbook", Lewis Publishers, New York, 1998.
- Stubin, A.; T. M. Brosnan; K. D. Porter; L. Jimenez; and H. Lochan, "Organic priority pollutants in New York City municipal wastewaters: 1989-1993", *Water Environment Research* 68 (6), 1996, 1037-1044.
- Supply and Services Canada, "Priority substances list assessment report – chlorinated wastewater effluents", Government of Canada, Environment Canada and Health Canada, 1993.
- Toronto, 2000 NPRI report by Works and Emergency Services, obtained from <http://www.city.toronto.on.ca>.
- U.K. Environment Agency, "Endocrine-disrupting substances in the environment: what should be done?", Consultative Report, Rio House, Waterside Drive, Azter West, Almondsbury, Bristol BS32 4UD, U.K., January 1998 ([www.environment-agency.gov.uk](http://www.environment-agency.gov.uk)).
- U.S. EPA, "Preferred and alternative methods for estimating air emissions from wastewater collection and treatment", prepared for Emission Inventory Improvement Program of the U.S. Environmental Protection Agency (U.S. EPA), by Eastern Research Group, North Carolina, March 1997, obtained from the U.S. EPA Web site at <http://www.epa.gov/ttn/chief/eiip/techreport/volume02/ii05.pdf>
- U.S. EPA, "Hazardous air pollutant emissions from process units in the synthetic organic chemical manufacturing industry - background information for proposed standards. Volume 1C: Model Emission Sources", EPA-453/D-92-016c, U.S. EPA, Research Triangle Park, NC, November 1992.
- U.S. EPA, "Toxic air pollutant emission factors – a compilation for selected air toxic compounds and sources", EPA-450/2-88-006a, U.S. EPA, Research Triangle Park, North Carolina, October 1988.
- U.S. EPA, "Preliminary compilation of air pollutant emission factors for selected air toxic compounds", EPA-450/4-86-010a, U.S. EPA, Research Triangle Park, North Carolina, April 1987.
- Wade, L. G., Jr., "Organic Chemistry", Prentice-Hall, New Jersey, 1987.
- Water Environment Federation, "Design of Municipal Wastewater Treatment Plants, Volume I – Planning and Configuration of Wastewater Treatment Plants", Water Environment Federation and American Society of Civil Engineering, Virginia, U.S.A., 1998a.
- Water Environment Federation, "Design of Municipal Wastewater Treatment Plants, Volume II – Liquid Treatment Processes", Water Environment Federation and American Society of Civil Engineering, Virginia, U.S.A., 1998b.
- Water Environment Federation, "Design of Municipal Wastewater Treatment Plants, Volume III – Solids Processing and Disposal", Water Environment Federation and American Society of Civil Engineering, Virginia, U.S.A., 1998c.

## Appendix A-1 NPRI Substances Not Identified in Tables 2 a, b, c

### Reported Transferred to Municipal Sewage Treatment Plants (MSTPs) in 2000 by Various Industries

SUBSTANCE	INDUSTRIAL SECTOR SIC 2-DIGIT
2-Ethoxyethanol	Leather and Allied Products Industries
Acetophenone	Electrical and Electronic Products Ind.
Acrolein	Chemical and Chemical Products Ind.
Acrylic acid (and its salts)	
Aluminum (fume or dust)	Fabricated Metal Products Ind. (Except Machinery and Trans. Equipment Ind.)
Antimony (and its compounds)	Electrical and Electronic Products Ind.
Arsenic (and its compounds)	Primary Metal Industries
Benzo(a)anthracene	
Benzo(a)pyrene	
Benzo(b)fluoranthene	
Benzo(g,h,i)perylene	
Benzo(k)fluoranthene	
Bis(2-ethylhexyl) adipate	Chemical and Chemical Products Ind.
Butyl acrylate	
Cyclohexanol	
Dibenzo(a,h)anthracene	Primary Metal Industries
Dichloromethane	Chemical and Chemical Products Ind.
Diphenylamine	Refined Petroleum and Coal Products Ind.
Ethyl acrylate	Chemical and Chemical Products Ind.
Fluoranthene	Primary Metal Industries
Formaldehyde	Chemical and Chemical Products Ind.
Formic acid	Chemical and Chemical Products Ind.
Hydrochloric acid	Beverage Industries
Hydrogen sulphide	Chemical and Chemical Products Ind.
<i>i</i> -Butyl alcohol	Chemical and Chemical Products Ind.
Indeno(1,2,3-CD)pyrene	Primary Metal Industries
Isopropyl alcohol	Chemical and Chemical Products Ind.
Methyl acrylate	
Methyl ethyl ketone	
Methyl methacrylate	
Molybdenum trioxide	Primary Metal Industries
<i>n</i> -Butyl alcohol	Chemical and Chemical Products Ind.
<i>n</i> -Hexane	Food Industries
Nitric acid	
Nitrotriacetic acid (and its salts)	Chemical and Chemical Products Ind.
N-Methyl-2-pyrrolidone	Leather and Allied Products Industries
Perylene	Primary Metal Industries
Phosphoric acid	Food Industries
Phosphorus (yellow or white)	Fabricated Metal Products Ind. (Except Machinery and Trans. Equipment Ind.)
<i>p</i> -Phenylenediamine (and its salts)	Chemical and Chemical Products Ind.
Pyrene	Primary Metal Industries
Sodium fluoride	Transportation Equipment Industries
Sodium nitrite	Fabricated Metal Products Ind. (Except Machinery and Trans. Equipment Ind.)
Styrene	Chemical and Chemical Products Ind.
Sulphuric acid	Food Industries
<i>tert</i> -Butyl alcohol	Chemical and Chemical Products Ind.
Thiourea	Motor Vehicle, Parts and Accessories Industries, Wholesale
Vinyl acetate	Chemical and Chemical Products Ind.



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## Appendix A-2

# NPRI Substances Reported Transferred To Municipal Sewage Treatment Plants (MSTPs) in 2000 by Various Industries

(Sorted by Industrial Discharger, Includes Tables 2a, b, c Substances)

SUBSTANCE	INDUSTRIAL SECTOR SIC 2-DIGIT
Sulphuric acid	Beverage Industries
Phosphoric acid	
Hydrochloric acid	
Zinc (and its compounds)	Chemical and Chemical Products Ind.
Xylene (mixed isomers)	
Vinyl acetate	
Toluene	
<i>tert</i> -Butyl alcohol	
Styrene	
Sodium nitrite	
Sodium fluoride	
<i>p</i> -Phenylenediamine (and its salts)	
Phosphorus (yellow or white)	
Phosphoric acid	
Phenol (and its salts)	
Nonylphenol polyethylene glycol ether	
Nitrilotriacetic acid (and its salts)	
Nitric acid	
Nitrate ion in solution at pH $\geq$ 6.0	
Nickel (and its compounds)	
<i>n</i> -Butyl alcohol	
Molybdenum trioxide	
Methyl methacrylate	
Methyl ethyl ketone	
Methyl acrylate	
Methanol	
Lead (and its compounds)	
Isopropyl alcohol	
<i>i</i> -Butyl alcohol	
Hydrogen sulphide	
Formic acid	
Formaldehyde	
Ethylene glycol	
Ethylbenzene	
Ethyl acrylate	
Dichloromethane	
Dibutyl phthalate	
Cyclohexanol	
Copper (and its compounds)	
Chromium (and its compounds)	
Butyl acrylate	
<i>Bis</i> (2-ethylhexyl) adipate	
Benzene	
Antimony (and its compounds)	
Ammonia (Total)	
Aluminum (fume or dust)	
Acrylic acid (and its salts)	
Acrolein	
2-Butoxyethanol	
Zinc (and its compounds)	Electrical and Electronic Products Ind.
Nitrate ion in solution at pH $\geq$ 6.0	

SUBSTANCE	INDUSTRIAL SECTOR SIC 2-DIGIT
Mercury (and its compounds)	
Lead (and its compounds)	
Formaldehyde	
Copper (and its compounds)	
Ammonia (Total)	
Acetophenone	
Zinc (and its compounds)	Fabricated Metal Products Ind. (Except Machinery and Trans. Equipment Ind.)
Sulphuric acid	
Sodium nitrite	
Phosphorus (yellow or white)	
Nitrate ion in solution at pH $\geq$ 6.0	
Nickel (and its compounds)	
Manganese (and its compounds)	
Lead (and its compounds)	
Hydrochloric acid	
Copper (and its compounds)	
Chromium (and its compounds)	
Cadmium (and its compounds)	
Ammonia (Total)	
Aluminum (fume or dust)	
2-Butoxyethanol	
Sulphuric acid	Food Industries
Phosphoric acid	
Nitric acid	
Nitrate ion in solution at pH $\geq$ 6.0	
<i>n</i> -Hexane	
Hydrochloric acid	
Ammonia (Total)	
Isopropyl alcohol	Food, Beverage, Drug and Tobacco Industries, Wholesale
Xylene (mixed isomers)	Leather and Allied Products Industries
Nonylphenol polyethylene glycol ether	
N-Methyl-2-pyrrolidone	
N-Methyl-2-pyrrolidone	
Isopropyl alcohol	
Formaldehyde	
Ethylene glycol	
Dibutyl phthalate	
Chromium (and its compounds)	
Chromium (and its compounds)	
<i>Bis</i> (2-ethylhexyl) phthalate	
2-Ethoxyethanol	
2-Butoxyethanol	
Zinc (and its compounds)	Local Government Service Industries
Mercury (and its compounds)	
Copper (and its compounds)	
Ammonia (Total)	
Thiourea	Motor Vehicle, Parts and Accessories Industries, Wholesale
Copper (and its compounds)	
Chromium (and its compounds)	
Aluminum (fume or dust)	
Silver (and its compounds)	Other Manufacturing Industries
Phenol (and its salts)	
Nitrate ion in solution at pH $\geq$ 6.0	
Methyl ethyl ketone	
Chromium (and its compounds)	
Zinc (and its compounds)	Other Service Industries
Nickel (and its compounds)	
Cyanides (ionic)	
Copper (and its compounds)	



SUBSTANCE	INDUSTRIAL SECTOR SIC 2-DIGIT
Chromium (and its compounds)	
Cadmium (and its compounds)	
Lead (and its compounds)	Other Utility Industries
Ammonia (Total)	
Isopropyl alcohol	Paper and Allied Products Industries
Ethylene glycol	
Lead (and its compounds)	Plastic Products Industries
Chromium (and its compounds)	
Zinc (and its compounds)	Primary Metal Industries
Sulphuric acid	
Sodium nitrite	
Silver (and its compounds)	
Selenium (and its compounds)	
Pyrene	
Phenol (and its salts)	
Phenanthrene	
Perylene	
Nonylphenol polyethylene glycol ether	
Nickel (and its compounds)	
Naphthalene	
Molybdenum trioxide	
Mercury (and its compounds)	
Manganese (and its compounds)	
Lead (and its compounds)	
Indeno(1,2,3-CD)pyrene	
Hydrochloric acid	
Fluoranthene	
Ethylene glycol	
Dibenzo(a,h)anthracene	
Copper (and its compounds)	
Chromium (and its compounds)	
Cadmium (and its compounds)	
Benzo(k)fluoranthene	
Benzo(g,h,i)perylene	
Benzo(b)fluoranthene	
Benzo(a)pyrene	
Benzo(a)anthracene	
Arsenic (and its compounds)	
Antimony (and its compounds)	
Ammonia (Total)	Primary Textile Industries
Phenol (and its salts)	Refined Petroleum and Coal Products Ind.
Methanol	
Isopropyl alcohol	
Antimony (and its compounds)	
Ammonia (Total)	
Zinc (and its compounds)	Rubber Products Industries
<i>p</i> -Phenylenediamine (and its salts)	
Vinyl acetate	Storage and Warehousing Industries
Methanol	Storage and Warehousing Industries
Zinc (and its compounds)	Transportation Equipment Industries
Sodium nitrite	
Sodium fluoride	
Nitrate ion in solution at pH $\geq$ 6.0	
Nickel (and its compounds)	
Methanol	
Manganese (and its compounds)	
Lead (and its compounds)	
Ethylene glycol	
Copper (and its compounds)	

<b>SUBSTANCE</b>	<b>INDUSTRIAL SECTOR SIC 2-DIGIT</b>
Chromium (and its compounds)	
2-Butoxyethanol	
Ethylene glycol	Transportation Industries
Phenol (and its salts)	Wood Industries
Nitrate ion in solution at pH $\geq$ 6.0	
Formaldehyde	
Copper (and its compounds)	
Chromium (and its compounds)	
Arsenic (and its compounds)	

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## Appendix B

# Substances Used or Formed During the Wastewater Treatment Process

### Ammonia

Ammonia is an NPRI substance present in wastewater influent, formed during treatment processes and used at treatment plants. The influent ammonia concentration was reported to be in the 15-44 ppm range (Canadian Water and Wastewater Association (CWWA), June 14, 2001; Environment Australia, 1999). Additional ammonium ion can be introduced to municipal wastewater treatment plants if ammonium hydroxide is used as a caustic agent (Droste, 1997, p.777).

### Chloroform, Chlorobenzene, Trichloroethylene and Tetrachloroethylene

Chloroform, chlorobenzene, trichloroethylene and tetrachloroethylene are four NPRI substances present in wastewater influent and formed during chlorination disinfection. A study of 37 municipal wastewater treatment plants in Ontario showed that the maximum concentration of trichloroethylene and tetrachloroethylene in chlorinated effluent was in the range of 100-420 mg/L (Supply and Services Canada, 1993, p.14). Another study of municipal wastewater treatment plants in Galt, Welland and Waterloo, Ontario, observed effluent levels in the range of 0.5 to 2.64 mg/L for chloroform, trichloroethylene and tetrachloroethylene (Supply and Services Canada, 1993, p.14). The influent concentration was reported to be 6-17 ppb for chloroform, 5-78 ppb for tetrachloroethylene, and 1-46 ppb trichloroethylene (Stubin et al., 1996). Since they have been detected in wastewater influent, the presence of these four chlorinated substances in effluent may not be solely the result of chlorination (Glaze and Henderson, 1975; Grove et al., 1985; Supply and Services Canada, 1993, p.11).

The formation of chloroform has been confirmed by plant data. Analysis of wastewater samples collected from 14 municipal wastewater treatment plants in New York City indicated that the chloroform concentration was increased from the 6-17mg/L range in influent to the 3-45 mg/L range in effluent (Stubin et al., 1996). Chlorine disinfection was performed at all 14 plants. A survey conducted by the CWWA of 738 municipal wastewater treatment plants across Canada revealed a much higher chloroform concentration in effluent, in the neighbourhood of 0.6 ppm (CWWA, June 14, 2001).

### Copper

Copper is an NPRI substance present in wastewater influent and used at treatment plants. Copper sulphate ( $\text{CuSO}_4$ ) may be used at municipal wastewater treatment plants (Droste, 1997, p.777). A survey conducted by the CWWA of 738 municipal wastewater treatment plants across Canada indicated that the maximum copper concentration could increase from 0.3 ppm in influent to 0.4 ppm in effluent (CWWA, June 14, 2001). This may be the result of the use of copper compounds, such as copper sulphate, at some plants.

### Hydrogen Sulphide

Hydrogen sulphide ( $\text{H}_2\text{S}$ ) is an NPRI substance present in wastewater influent and formed during treatment processes. The influent hydrogen sulphide concentration was reported to be 2.86 ppm for large, industry-intensive municipalities (Environment Australia, 1999).

Hydrogen sulphide can be generated during the course of wastewater collection and treatment. It is formed under anaerobic conditions, i.e., in absence of oxygen, from microbial decomposition of sulphur-containing organic matter or from reduction of mineral sulphites and sulphates (Hayes, 1999). Sulphate ions are usually present in domestic wastewater at concentrations of 30-60 mg/L (Cheremisinoff, 1995, in Hayes, 1999). The Deer Island wastewater treatment plant in Massachusetts, was reported to handle influent sulphate concentrations in the 80-100 mg/L range and hydrogen sulphide was the most common of the sulphur-containing gases generated from sulphate reduction in a wastewater collection and treatment system (Basu et al., 1998). Oxidized food waste was considered to be the major source of sulphates contained in domestic wastewater.

### Methanol

Methanol is an NPRI substance used at wastewater treatment plants. It is a carbon source for denitrification (Stephenson and Blackburn, Jr., 1998, p.291). The stoichiometric methanol requirement is 2.5 mg/L of methanol per mg/L of nitrate nitrogen removed. An actual methanol dose can be as high as 3 mg/L per mg/L of nitrate nitrogen removed. If residual methanol is present in wastewater, environmental releases would be expected.

### Nitrate Ion

Nitrate ion ( $\text{NO}_3^-$ ) is an NPRI substance present in wastewater influent and formed during treatment processes. The influent nitrate ion concentration was reported to be 1.77 ppm (Bertrand-Krajewski et al., 1995). The formation of nitrate ion has been observed at municipal wastewater treatment plants. Many plants are designed to include nitrification as part of their secondary treatment process, converting ammonia to nitrate.

**Nitrogen Oxides**

Nitrous oxides are gaseous NPRI substances formed during wastewater treatment processes. Nitrous oxide ( $N_2O$ ) is the principal nitrogen oxide compound generated during wastewater treatment. It has been reported to result from biological nitrogen removal processes (Park et al., 2001). It is formed during nitrification or denitrification in an activated sludge process (Kimochi et al., 1998) as well as during the aerobic phase of a sequencing batch reactor (Park et al., 2001). The formation of nitric oxide (NO) was also reported in an activated sludge process and its air emission rate was determined to be 0.58 g NO/person-yr (Schmid et al., 2001).

Many studies observed air emissions of nitrous oxide through aeration from a biological nitrogen removal process and provided estimates on its air emission factors based on laboratory results. Kimochi et al., 1998, reported an emission rate in the range of 0.43-1.89 g  $N_2O$ /person-yr based on measurements of an activated sludge process which contained dissolved  $N_2O$  in liquid in the 0.5-4 mg/L range. Peter et al., 1995, (in Kimochi et al., 1998) reported a higher rate at 3.2 g  $N_2O$ /person-yr for a treatment plant consisting of both primary and secondary processes.

Nitrogen-containing ions were reported to be precursors of nitrous oxide ( $N_2O$ ) and conversion rates were obtained by several researchers from laboratory experiments. Zheng et al., 1994, (in Barton and Atwater, 2002) demonstrated the conversion of ammonium ion ( $NH_4^+$ ) to  $N_2O$  during nitrification and reported the conversion rate in the range of 2.3-7.0% when dissolved oxygen concentration varied between 0.1 and 6.8 mg/L. They also reported  $N_2O$  conversion as high as 16% and as low as 2.3% at solids retention times of three days and 10 days, respectively. Hanaki et al., 1992, (in Barton and Atwater, 2002) observed that as much as 8% of influent nitrate ion, ( $NO_3^-$ ) was transformed to  $N_2O$  during denitrification. In experiments conducted in a sequencing-batch reactor (SBR), Oakyasu et al., 1997, (in Barton and Atwater, 2002) found that  $N_2O$  emitted represented 40% of nitrogen removal.

Upon reviewing literature data, Barton and Atwater, 2002, found that conversion to  $N_2O$  at treatment plants was much lower than reported by the above laboratory studies. Kimochi et al., 1998, (in Barton and Atwater, 2002) reported conversion to  $N_2O$  between 0.01 and 0.08% of influent nitrogen at a plant with both primary and secondary processes. A low nitrous oxide emission rate at less than 0.1% of influent nitrogen was also reported for a Swiss wastewater treatment plant with a predenitrification anoxic tank followed by three aerobic tanks (Schulthese and Gujer, 1996, in Barton and Atwater, 2002). Sumer et al., 1995, (in Barton and Atwater, 2002) reported even lower conversion to  $N_2O$  at 0.001% of influent nitrogen at an activated sludge plant in Germany.

**Nitrotriactic Acid**

Nitrotriactic acid is an NPRI substance which may be used as a chelating agent at municipal wastewater treatment plants (Droste, 1997, p.777).

**Nonylphenol**

Nonylphenol (NP) has been reported to exist in raw sewage wastewater as well as forming as a final degradation product of nonylphenol ethoxylates (NPEs) during biological treatment processes. Analysis of raw sewage samples, collected from nine municipal sewage treatment plants in Ontario, Quebec, New Brunswick and Nova Scotia in 1995 and 1996, indicated that the NP level ranged from 0.7 to 155 ppb and the NPEs level from 3 to 67 ppb (Bennie, 1999; Maguire, 1999; Bennie et al., 1998; Lee & Peart, 1998 & 1995). Under both anaerobic and aerobic conditions, NPEs have been found to degrade to NP (Ejlertsson, 1999; Lee & Peart, 1998). Other degradation products include mono and diethoxylates under anaerobic conditions and nonylphenoxyacetic acid and nonylphenoxyethoxyacetic acid under aerobic conditions (Ahel et al., 1994). The conversion of NPEs to NP by more than 90% has been reported (Naylor, 1995). Most literature data suggests that NP is the ultimate degradation product and cannot further degrade (U.K. Environment Agency, 1998).

The formation of nonylphenol during biological treatment has been confirmed by plant data. Lepri et al., 1997, observed that the nonylphenol concentration was increased from 240-465 mg/L in influent to 1000 mg/L in effluent from a biological treatment process following primary treatment.

**Zinc**

Zinc is an NPRI substance present in wastewater influent. A survey conducted by the CWWA of 738 municipal wastewater treatment plants across Canada indicated that the maximum zinc concentration increased from 0.4 ppm in influent to 2.0 ppm in effluent (CWWA, June 14, 2001). Sources of zinc in the process, however, are not clear.

## Appendix C

### Monitoring or Direct Measurement Method of Estimation

The monitoring or direct measurement method should be used whenever data are available.

The principle of the monitoring or direct measurement method is to use measured release or transfer data to calculate the annual release or transfer of a substance from a wastewater process. The calculation equation is:

$$E = R \times t_{op} \times 10^{-3} \text{ tonne/kg} \quad \text{EQ C-1}$$

where:

$$\begin{aligned} E &= \text{annual release or transfer, tonne/yr} \\ R &= \text{average release or transfer rate, kg/d} \\ t_{op} &= \text{operation days during a reporting year, d/yr} \end{aligned}$$

The average release or transfer rate (R) is determined as an arithmetic mean value of release or transfer rates obtained during all monitoring or measurement events over a reporting year. A release or transfer rate by air, effluent or sludge is determined by multiplying measured substance concentration by measured flow rate as follows.

For air emission:

$$R_{air} = C_{air} \times V_{air} \times A \times 10^{-3} \text{ kg/g} \quad \text{EQ C-2}$$

where:

$$\begin{aligned} R_{air} &= \text{air release rate, kg/d} \\ A &= \text{wastewater surface area, m}^2 \\ C_{air} &= \text{substance concentration in gas, g/m}^3 \text{ (monitoring or measurement data)} \\ V_{air} &= \text{gas flux, i.e., volume flow per unit wastewater surface area, m}^3/\text{d-m}^2 \text{ (monitoring or measurement data)} \end{aligned}$$

For aqueous release or transfer:

$$R_{liq} = C_{eff} \times Q_{eff} \times 10^{-3} \text{ kg/g} \quad \text{EQ C-3}$$

where:

$$\begin{aligned} R_{liq} &= \text{aqueous release or transfer rate, kg/d} \\ C_{eff} &= \text{substance concentration in effluent, g/m}^3 \text{ (monitoring or measurement data)} \\ Q_{eff} &= \text{daily volume of effluent discharged, m}^3/\text{d} \text{ (monitoring or measurement data)} \end{aligned}$$

For release or transfer by sludge:

$$R_{sol} = C_{sludge} \times Q_{sludge} \times 10^{-6} \text{ kg/mg} \quad \text{EQ C-4}$$

where:

$$\begin{aligned} R_{sol} &= \text{release or transfer rate by sludge, kg/d} \\ C_{sludge} &= \text{substance concentration in sludge, mg/kg of dry sludge (monitoring or measurement data)} \\ Q_{sludge} &= \text{daily sludge production, kg/d (dry weight) (monitoring or measurement data)} \end{aligned}$$

For release or transfer by water in sludge (where the substance is not adsorbed in solids, but is present in the water fraction of the sludge):

$$R_{sludge(water)} = C_{eff} \times Q_{sludge} \times S_{water} / \rho_{water} \times 10^{-3} \quad \text{EQ C-5}$$

where:

$$\begin{aligned} R_{sludge(water)} &= \text{release or transfer rate by water fraction of sludge, kg/d} \\ C_{eff} &= \text{substance concentration in effluent, g/m}^3 \text{ (monitoring or measurement data)} \\ Q_{sludge} &= \text{daily sludge production, kg/d (dry weight) (monitoring or measurement data)} \\ S_{water} &= \text{water content of sludge (\%)} \\ \rho_{water} &= \text{density of water kg/m}^3 \end{aligned}$$



## Appendix D

### Emission Factor Method of Estimation

Emission factors are used for emission estimation when monitoring or measurement data are not available and data required by the mass balance method are lacking. Emission factors are generally derived from results of source tests or sampling conducted at one or more sewage treatment facilities. Although in theory they can be applied to all media (air, water and sludge), available emission factors for the wastewater sector are currently limited to air releases for process-specific elements and facility-wide secondary facility air emissions. Emission factors for wastewater are provided in three sections following — Plant-Wide Emission Factors, Process-Specific Emission Factors and Substance-Specific Emission Factors.

The basic equation used for air emission estimation based on emission factors is:

$$E = F_{\text{uncontrol}} \times Q \times (1 - f) \quad \text{EQ D-1}$$

where:

E	=	air emission quantity of a substance per time
$F_{\text{uncontrol}}$	=	uncontrolled emission factor
f	=	emission control equipment efficiency
Q	=	activity level (i.e. volume of wastewater treated per time)

The equation for the emission factor method can have different forms, depending upon the units of emission factors. Emission factors for wastewater treatment facilities are commonly given either as “quantity emitted per quantity present in wastewater” or “quantity emitted per volume of wastewater treated”. Accordingly, the emission estimating equation takes the following two common forms:

$$E = F_{\text{uncontrol}} \times C \times Q \times t_{\text{op}} \times (1 - f) \times 10^{-6} \text{ tonne/g} \quad \text{EQ D-2}$$

$$E = F'_{\text{uncontrol}} \times Q \times t_{\text{op}} \times (1 - f) \times 10^{-6} \text{ tonne/g} \quad \text{EQ D-3}$$

where:

E	=	annual air emission of a substance from a wastewater process, tonne/yr
$F_{\text{uncontrol}}$	=	uncontrolled air emission factor, g emitted per g in wastewater influent
$F'_{\text{uncontrol}}$	=	uncontrolled air emission factor, g emitted per m <sup>3</sup> of wastewater treated
C	=	substance concentration in wastewater influent, g/m <sup>3</sup>
Q	=	daily volume of wastewater treated, m <sup>3</sup> /d
$t_{\text{op}}$	=	operation days during a reporting year, d/yr
f	=	emission control equipment efficiency, %

An emission factor is defined as the emission rate of a substance to air, water or land relative to a level of source activity (Environment Canada, Guide for Reporting to the NPRI – 2001, p.120; Environment Australia, 1999, wastewater manual, p.15; Ontario Ministry of the Environment, April 2001, p.11). It is generally derived from results of source tests or sampling conducted at one or more sewage treatment facilities. An emission factor is usually expressed as a ratio of quantity released to process or equipment throughput.

Emission-control equipment is used to reduce air pollutants generated from wastewater processes. It includes caustic scrubbers, biofilters, thermal oxidizers, catalytic oxidizers, absorbers, condensers, etc. (Dawson and Gokare, 1994). As a conservative approach, the emission control efficiency is assumed to be zero if it is unknown.

Compiled in this Appendix are emission factors for air releases found in the literature. Most of these factors refer to uncontrolled rates. Some emission factors were, however, measured at point sources equipped with emission-control devices (e.g., wet scrubber). These are commonly referred to as controlled emission factors. Little information has been found in the literature for emission factors to estimate releases to water and land from wastewater collection or treatment.

The emission factor method is applicable to all processes and configurations which generate air releases. A facility may develop its own emission factors based on monitoring and/or measurement data. Such site-specific emission

factors are applicable to processes which have been monitored and/or measured as well as to similar processes of other facilities, if they are operated under comparable conditions.

#### **U.S. Environmental Protection Agency (EPA) Source Classification Code**

Emission factors reported by the EPA are often associated with sources of emissions identified by source classification code (SCC). This code is used in many EPA data systems, such as its AIRS Facility Subsystem (AFS), National Emission Trends (NET) database, and Factor Information and REtrieval database (FIRE), and many state agency emissions data systems.

Each SCC for a point source consists of eight digits and represents four levels of source description. The first level uses only the first digit and provides the most general information on a category of emissions. The second level of description is associated with the first three digits and subdivides each first-level category into major industry groups. For example, 1-01 indicates External Combustion in Utility Boilers, and 1-02 indicates External Combustion in Industrial Boilers. The third level of description requires the first six digits to be specified and identifies a specific industry or emission source, e.g., Cotton Ginning (3-02-004), or Primary Copper Smelting (3-03-005). The fourth level of description is associated with the full eight-digit code. It specifies the particular emitting process within the third-level source category. For example, SCC 3-03-005-06 specifies the Ore Concentrate Dryer emission source at a Primary Copper Smelting facility (3-03-005). Further details on SCC may be obtained from the Web site of the EPA's Technology Transfer Network at <http://www.epa.gov/ttn>.

The SCC associated with air emissions from sewage treatment is 5-01-007-xx. The first level of description by digit 5 represents the category of Waste Disposal. The second level is specified by the first 3 digits (5-01) which indicates the group of Solid Waste Disposal (government). The third level is described by the first six digits (5-01-007) and identifies Sewage Treatment as a specific type of facility. The last two digits (xx) describe various individual emission sources within a sewage treatment facility (Table D-1).

**TABLE D-1 – EPA SOURCE CLASSIFICATION CODE FOR SEWAGE TREATMENT** (EPA Web site: <http://www.epa.gov/ttn>)

SOURCE CLASSIFICATION CODE	SOURCE
5-01-007-01	Entire plant
5-01-007-02	Primary settling tank
5-01-007-03	Secondary settling tank
5-01-007-04	Aeration tank
5-01-007-07	POTW*: headworks screening
5-01-007-08	Communitor
5-01-007-10	Collector sewers
5-01-007-15	POTW: aerated grit chamber
5-01-007-19	Lift station
5-01-007-20	POTW: primary settling tank
5-01-007-31	POTW: diffused air activated sludge
5-01-007-32	POTW: mechanical mix air activated sludge
5-01-007-33	POTW: pure oxygen activated sludge
5-01-007-34	POTW: trickling filter
5-01-007-40	POTW: secondary clarifier
5-01-007-50	POTW: tertiary filters
5-01-007-60	POTW: chlorine contact tank
5-01-007-61	POTW: dechlorination
5-01-007-65	Weir
5-01-007-69	Storage basin or open tank
5-01-007-71	POTW: gravity sludge thickener
5-01-007-72	POTW: DAF sludge thickener
5-01-007-81	POTW: anaerobic digester
5-01-007-89	Sludge digester gas flare
5-01-007-91	POTW: belt filter press
5-01-007-92	POTW: sludge centrifuge
5-01-007-93	POTW: sludge drying bed
5-01-007-95	Sludge storage lagoons/drying beds
5-01-007-99	Other not classified

\*POTW: publicly-owned treatment works



**Group 1: Plant-Wide, Air-Emission Factors**

Compiled in Table D-2 are uncontrolled air-emission factors for entire secondary municipal wastewater treatment plants with aerobic digestion. The source classification code for entire secondary plants is 5-01-007-01. These emission factors are obtained primarily from two EPA sources:

- EPA's Factor Information REtrieval (FIRE) Data System (FIRE 6.23)
- EPA document: EPA-450/2-88-006a, October 1988

These emission factors are based on emission models for hypothetical, publicly-owned treatment works (POTWs) and represent an average POTW that also treats industrial wastewater (EPA-450/2-88-006a, October 1988). The FIRE data system appears to have intentionally doubled the emission factors reported (except styrene and there may be an error for aniline), suggesting a more conservative approach in estimating air emissions using emission factors. This has, however, caused many emission factors to exceed one, implying the quantity emitted to air is greater than the quantity present in influent. From a mass balance point of view, an emission factor should be less than one unless the substance in question is formed during the process. This is normally not the case for volatile organic compounds. Consequently, emission factors should be used with caution.

**TABLE D-2 – PLANT-WIDE, AIR-EMISSION FACTORS FOR MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-01)**

NPRI SUBSTANCE	AIR-EMISSION FACTOR	REFERENCE
Acrolein	0.18 kg/kg in influent	EPA FIRE (FIRE 6.23)
Acrylonitrile	0.24 kg/kg in influent	EPA FIRE (FIRE 6.23)
Ammonia	2.28 kg/1000 m3 influent	EPA FIRE (FIRE 6.23)
Aniline	1.2 kg/kg in influent	EPA FIRE (FIRE 6.23)
Benzene	1.14 kg/kg in influent	EPA FIRE (FIRE 6.23)
1,3-Butadiene	1.7 kg/kg in influent	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	1.42 kg/kg in influent	EPA FIRE (FIRE 6.23)
Chlorobenzene	1.04 kg/kg in influent	EPA FIRE (FIRE 6.23)
Choroform	1.04 kg/kg in influent	EPA FIRE (FIRE 6.23)
2-Chlorophenol	0.03 kg/kg in influent	EPA, Oct.1988
Cresol	o-Cresol (2-Cresol)	0.012 kg/kg in influent EPA FIRE (FIRE 6.23)
	p-Cresol (4-Cresol)	0.0018 kg/kg in influent EPA FIRE (FIRE 6.23)
Dibenzofuran	0.97 kg/kg in influent	EPA, Oct.1988
o-Dichlorobenzene		
(1,2-Dichlorobenzene)	0.41 kg/kg in influent	EPA, Oct.1988
p-Dichlorobenzene		
(1,4-Dichlorobenzene)	0.78 kg/kg in influent	EPA FIRE (FIRE 6.23)
Dichloromethane	1.04 kg/kg in influent	EPA FIRE (FIRE 6.23)
2,4-Dichlorophenol	0.009 kg/kg in influent	EPA, Oct.1988
N,N-Dimethylformamide	0.08 kg/kg in influent	EPA FIRE (FIRE 6.23)
Ethylbenzene	1.12 kg/kg in influent	EPA FIRE (FIRE 6.23)
Hexachlorobenzene	0.52 kg/kg in influent	EPA FIRE (FIRE 6.23)
Naphthalene	0.32 kg/kg in influent	EPA FIRE (FIRE 6.23)
Nitrobenzene	0.04 kg/kg in influent	EPA FIRE (FIRE 6.23)
Phenol	0.0018 kg/kg in influent	EPA FIRE (FIRE 6.23)
Styrene	0.5 kg/kg in influent	EPA FIRE (FIRE 6.23)
Toluene	1.16 kg/kg in influent	EPA FIRE (FIRE 6.23)
1,2,4-Trichlorobenzene	0.74 kg/kg in influent	EPA FIRE (FIRE 6.23)
Trichloroethylene	1.24 kg/kg in influent	EPA FIRE (FIRE 6.23)
Vinyl chloride	1.62 kg/kg in influent	EPA FIRE (FIRE 6.23)
Volatile organic compounds	1.07 kg/1000 m3 influent	EPA FIRE (FIRE 6.23)
Xylene	1.1 kg/kg in influent	EPA FIRE (FIRE 6.23)

## Group 2: Process-Specific Emission Factors

### Emission Factors for Air Release from Headworks Screening

Emission factors for air release from headworks screening at municipal wastewater treatment plants are compiled in Table D-3. The source classification code (SCC) for headworks screening is 5-01-007-07. Data obtained from the EPA's Factor Information REtrieval Data System (FIRE6.23) provide controlled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed. These emission factors were derived from testing results at ducted headworks' facilities and a wet scrubber was used as a control device.

**TABLE D-3 – EMISSION FACTORS FOR AIR RELEASE FROM HEADWORKS SCREENING AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-07)**

NPRI SUBSTANCE	AIR-EMISSION FACTOR CONTROLLED BY WET SCRUBBER		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.78	$6.5 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	< 0.049	$< 4.06 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Chlorine	559.0	4.66	EPA FIRE (FIRE 6.23)
Chloroform	0.22	$1.83 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Dichloromethane	0.049	$4.09 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Ethylbenzene	0.086	$7.13 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Toluene	0.080	$6.71 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.046	$3.84 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Xylene	0.086	$7.19 \times 10^{-4}$	EPA FIRE (FIRE 6.23)

### Emission Factors for Air Release from Aerated Grit Chamber

Emission factors for air release from an aerated grit chamber at municipal wastewater treatment plants are compiled in Table D-4. The source classification code (SCC) for aerated grit chamber is 5-01-007-15. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed, except the emission factor for *p*-dichlorobenzene that is expressed as a mass fraction.

**TABLE D-4 – EMISSION FACTORS FOR AIR RELEASE FROM AERATED GRIT CHAMBER AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-15)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.43	$3.56 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Chloroform	0.073	$6.077 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
<i>p</i> -Dichlorobenzene	$1.50 \times 10^{-3}$ kg/kg	$1.50 \times 10^{-3}$ lb/lb	EPA FIRE (FIRE 6.23)
Dichloromethane	0.15	$1.287 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
<i>p</i> -Dioxane	$1.80 \times 10^{-3}$	$1.50 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$2.16 \times 10^{-4}$	$1.80 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Styrene	$6.60 \times 10^{-4}$	$5.50 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Toluene	0.32	$2.642 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.034	$2.80 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Xylene	0.10	$8.75 \times 10^{-4}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Primary Settling Tank**

Emission factors for air release from a primary settling tank at municipal wastewater treatment plants are compiled in Table D-5. The source classification code (SCC) for primary settling tank is 5-01-007-20. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-5 – EMISSION FACTORS FOR AIR RELEASE FROM PRIMARY SETTLING TANK AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-20)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.065	$5.40 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	1.1	$9.00 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Chloroform	1.8	$1.50 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	1.5	$1.29 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Formaldehyde	0.026	$2.133 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Styrene	0.13	$1.10 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Toluene	0.19	$1.56 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.35	$2.90 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	0.016	$1.30 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Xylene	0.23	$1.897 \times 10^{-3}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Diffused Air-Activated Sludge**

Emission factors for air release from diffused air-activated sludge at municipal wastewater treatment plants are compiled in Table D-6. The source classification code (SCC) for diffused air-activated sludge is 5-01-007-31. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-6 – EMISSION FACTORS FOR AIR RELEASE FROM DIFFUSED AIR-ACTIVATED SLUDGE AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-31)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.080	$6.67 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	0.025	$2.10 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Chloroform	2.1	$1.73 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	2.4	$1.973 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
p-Dioxane	0.053	$4.40 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Formaldehyde	0.013	$1.048 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Toluene	0.26	$2.17 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.50	$4.154 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Xylene	0.42	$3.533 \times 10^{-3}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Mechanical Mix, Air-Activated Sludge**

Emission factors for air release from mechanical mix, air-activated sludge at municipal wastewater treatment plants are compiled in Table D-7. The source classification code (SCC) for mechanical mix, air-activated sludge is 5-01-007-32. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-7 – EMISSION FACTORS FOR AIR RELEASE FROM MECHANICAL MIX, AIR-ACTIVATED SLUDGE AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-32)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Carbon tetrachloride	0.22	$1.80 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Chloroform	3.0	$2.50 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	0.11	$9.40 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Toluene	0.079	$6.60 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Xylene	0.014	$1.20 \times 10^{-4}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Pure Oxygen-Activated Sludge**

Emission factors for air release from pure oxygen-activated sludge at municipal wastewater treatment plants are compiled in Table D-8. The source classification code (SCC) for pure oxygen activated sludge is 5-01-007-33. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-8 – EMISSION FACTORS FOR AIR RELEASE FROM PURE OXYGEN-ACTIVATED SLUDGE AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-010-07-33)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	$4.56 \times 10^{-4}$	$3.80 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	$8.52 \times 10^{-4}$	$7.10 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Chloroform	$9.98 \times 10^{-3}$	$8.32 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Dichloromethane	$8.64 \times 10^{-3}$	$7.20 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$3.48 \times 10^{-5}$	$2.90 \times 10^{-7}$	EPA FIRE (FIRE 6.23)
Styrene	$5.88 \times 10^{-4}$	$4.90 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Toluene	$1.04 \times 10^{-3}$	$8.64 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	$1.63 \times 10^{-3}$	$1.36 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	$3.72 \times 10^{-4}$	$3.10 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Xylene	$1.40 \times 10^{-3}$	$1.17 \times 10^{-5}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Trickling Filter**

Emission factors for air release from a trickling filter at municipal wastewater treatment plants are compiled in Table D-9. The source classification code (SCC) for trickling filter is 5-01-007-34. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed. Air flow is countercurrent through filter media.

**TABLE D-9 – EMISSION FACTORS FOR AIR RELEASE FROM TRICKLING FILTER AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-34)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.19	$1.60 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Chloroform	2.2	$1.80 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	1.1	$8.95 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Formaldehyde	0.065	$5.40 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Styrene	0.72	$6.023 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Toluene	6.1	$5.05 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.33	$2.78 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	1.0	$8.50 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Xylene	6.7	$5.59 \times 10^{-2}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Secondary Clarifier**

Emission factors for air release from an uncovered secondary clarifier at municipal wastewater treatment plants are compiled in Table D-10. The source classification code (SCC) for secondary clarifier is 5-01-007-40. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-10 – EMISSION FACTORS FOR AIR RELEASE FROM SECONDARY CLARIFIER AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-40)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.017	$1.40 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	$9.00 \times 10^{-4}$	$7.50 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Chloroform	$9.48 \times 10^{-3}$	$7.90 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Dichloromethane	0.011	$9.067 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
p-Dioxane	$2.88 \times 10^{-3}$	$2.40 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$1.80 \times 10^{-4}$	$1.50 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Toluene	$2.92 \times 10^{-3}$	$2.433 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Xylene	$2.21 \times 10^{-3}$	$1.84 \times 10^{-5}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Tertiary Filters**

Emission factors for air release from uncovered tertiary filters at municipal wastewater treatment plants are compiled in Table D-11. The source classification code (SCC) for tertiary filters is 5-01-007-50. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed, except the emission factor for formaldehyde, which is expressed as a mass fraction.

**TABLE D-11 – EMISSION FACTORS FOR AIR RELEASE FROM TERTIARY FILTERS AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-50)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	$4.80 \times 10^{-4}$	$4.00 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Chloroform	0.013	$1.06 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Dichloromethane	$3.31 \times 10^{-3}$	$2.76 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$2.70 \times 10^{-7}$ kg/kg	$2.70 \times 10^{-7}$ lb/lb	EPA FIRE (FIRE 6.23)
Toluene	$1.25 \times 10^{-3}$	$1.044 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	$1.01 \times 10^{-3}$	$8.40 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Xylene	$6.96 \times 10^{-4}$	$5.80 \times 10^{-6}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Chlorine-Contact Tank**

Emission factors for air release from a chlorine-contact tank at municipal wastewater treatment plants are compiled in Table D-12. The source classification code (SCC) for chlorine contact tank is 5-01-007-60. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed, except the emission factors for carbon tetrachloride, chlorine, trichloroethylene and vinyl chloride, which are expressed as mass fractions.

**TABLE D-12 – EMISSION FACTORS FOR AIR RELEASE FROM CHLORINE CONTACT TANK AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-60)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.017	$1.39 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	$< 9.90 \times 10^{-7}$ kg/kg	$< 9.90 \times 10^{-7}$ lb/lb	EPA FIRE (FIRE 6.23)
Chlorine	$3.28 \times 10^{-3}$ kg/kg	$3.28 \times 10^{-3}$ lb/lb	EPA FIRE (FIRE 6.23)
Chloroform	0.057	$4.766 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Dichloromethane	$5.16 \times 10^{-3}$	$4.30 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Ethylbenzene	0.025	$2.10 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$2.40 \times 10^{-4}$	$2.00 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Toluene	0.020	$1.668 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	$1.67 \times 10^{-6}$ kg/kg	$1.67 \times 10^{-6}$ lb/lb	EPA FIRE (FIRE 6.23)
Vinyl chloride	$2.21 \times 10^{-6}$ kg/kg	$2.21 \times 10^{-6}$ lb/lb	EPA FIRE (FIRE 6.23)
Xylene	0.46	$3.85 \times 10^{-3}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Dechlorination**

Emission factors for air release from dechlorination at municipal wastewater treatment plants are compiled in Table D-13. The source classification code (SCC) for dechlorination is 5-01-007-61. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as either pounds of a substance emitted per one million gallons of wastewater processed or pounds of a substance emitted per pound of wastewater processed.

**TABLE D-13 – EMISSION FACTORS FOR AIR RELEASE FROM DECHLORINATION AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-61)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	$7.50 \times 10^{-1}$ kg/kg	$7.50 \times 10^{-1}$ lb/lb	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	1.00 kg/kg	1.00 lb/lb	EPA FIRE (FIRE 6.23)
Chloroform	$2.075 \times 10^{-1}$ kg/kg	$2.075 \times 10^{-1}$ lb/lb	EPA FIRE (FIRE 6.23)
Dichloromethane	$3.96 \times 10^{-4}$	$3.30 \times 10^{-6}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$2.967 \times 10^{-1}$ kg/kg	$2.967 \times 10^{-1}$ lb/lb	EPA FIRE (FIRE 6.23)
Styrene	$6.40 \times 10^{-1}$ kg/kg	$6.40 \times 10^{-1}$ lb/lb	EPA FIRE (FIRE 6.23)
Toluene	$8.64 \times 10^{-5}$	$7.20 \times 10^{-7}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	$8.04 \times 10^{-5}$	$6.70 \times 10^{-7}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	$1.32 \times 10^{-5}$	$1.10 \times 10^{-7}$	EPA FIRE (FIRE 6.23)
Xylene	$2.88 \times 10^{-5}$	$2.40 \times 10^{-7}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Gravity Sludge Thickener**

Emission factors for air release from a gravity sludge thickener at municipal wastewater treatment plants are compiled in Table D-14. The source classification code (SCC) for gravity sludge thickener is 5-01-007-71. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-14 – EMISSION FACTORS FOR AIR RELEASE FROM GRAVITY SLUDGE THICKENER AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-71)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Chloroform	1.64	$1.37 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	1.57	$1.312 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Formaldehyde	$6.00 \times 10^{-3}$	$5.00 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Styrene	$1.44 \times 10^{-3}$	$1.20 \times 10^{-5}$	EPA FIRE (FIRE 6.23)
Toluene	0.33	$2.75 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.42	$3.50 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	0.090	$7.50 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Xylene	0.15	$1.25 \times 10^{-3}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Dissolved Air Flotation Sludge Thickener**

Emission factors for air release from a dissolved air flotation sludge thickener at municipal wastewater treatment plants are compiled in Table D-15. The source classification code (SCC) for dissolved air flotation sludge thickener is 5-01-007-72. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-15 – EMISSION FACTORS FOR AIR RELEASE FROM DISSOLVED AIR FLOTATION SLUDGE THICKENER AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-72)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.36	$3.00 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	8.76	$7.30 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Chloroform	1.28	$1.069 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	17.4	$1.45 \times 10^{-1}$	EPA FIRE (FIRE 6.23)
Formaldehyde	0.068	$5.70 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Toluene	1.88	$1.565 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.26	$2.20 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	1.10	$9.20 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Xylene	0.42	$3.50 \times 10^{-3}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Anaerobic Digester**

Emission factors for air release from an anaerobic digester at municipal wastewater treatment plants are compiled in Table D-16. The source classification code (SCC) for anaerobic digester is 5-01-007-81. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-16 – EMISSION FACTORS FOR AIR RELEASE FROM ANAEROBIC DIGESTER AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-81)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	36.9	$3.08 \times 10^{-1}$	EPA FIRE (FIRE 6.23)
Chloroform	0.17	$1.40 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Dichloromethane	1.02	$8.471 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Formaldehyde	0.034	$2.80 \times 10^{-4}$	EPA FIRE (FIRE 6.23)
Styrene	1.06	$8.80 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Toluene	96.4	$8.033 \times 10^{-1}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	2.95	$2.463 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Vinyl chloride	20.3	$1.695 \times 10^{-1}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	0.29	$2.40 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Xylene	99.5	$8.293 \times 10^{-1}$	EPA FIRE (FIRE 6.23)



**Emission Factors for Air Release from Belt-Filter Press**

Emission factors for air release from a belt-filter press at municipal wastewater treatment plants are compiled in Table D-17. The source classification code (SCC) for belt filter press is 5-01-007-91. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-17 – EMISSION FACTORS FOR AIR RELEASE FROM BELT-FILTER PRESS AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-91)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	6.00	$5.00 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Chloroform	1.32	$1.10 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Dichloromethane	1.64	$1.367 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Formaldehyde	7.96	$6.64 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Toluene	6.45	$5.38 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Trichloroethylene	11.8	$9.80 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Xylene	3.40	$2.833 \times 10^{-2}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Sludge Centrifuge**

Emission factors for air release from a sludge centrifuge at municipal wastewater treatment plants are compiled in Table D-18. The source classification code (SCC) for sludge centrifuge is 5-01-007-92. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-18 – EMISSION FACTORS FOR AIR RELEASE FROM SLUDGE CENTRIFUGE AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-92)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
Benzene	0.22	$1.84 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Carbon tetrachloride	0.19	$1.60 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Chloroform	0.67	$5.60 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Dichloromethane	0.64	$5.32 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Formaldehyde	1.36	$1.132 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Styrene	0.37	$3.10 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Toluene	213.3	1.778	EPA FIRE (FIRE 6.23)
Trichloroethylene	0.20	$1.70 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Vinyl chloride	0.56	$4.675 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Vinylidene chloride	0.86	$7.20 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Xylene	1.58	$1.314 \times 10^{-2}$	EPA FIRE (FIRE 6.23)

**Emission Factors for Air Release from Sludge-Drying Bed**

Emission factors for air release from a sludge-drying bed at municipal wastewater treatment plants are compiled in Table D-19. The source classification code (SCC) for sludge-drying bed is 5-01-007-93. The data obtained from the EPA's Factor Information REtrieval Data System (FIRE 6.23) provide uncontrolled air-emission factors expressed as pounds of a substance emitted per one million gallons of wastewater processed.

**TABLE D-19 – EMISSION FACTORS FOR AIR RELEASE FROM SLUDGE-DRYING BED AT MUNICIPAL WASTEWATER TREATMENT PLANTS (SCC: 5-01-007-93)**

NPRI SUBSTANCE	UNCONTROLLED AIR-EMISSION FACTOR		REFERENCE
	kg/MILLION M <sup>3</sup>	lb/MILLION GALLONS	
BBenzene	0.34	$2.80 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Dichloromethane	0.68	$5.70 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Formaldehyde	0.14	$1.20 \times 10^{-3}$	EPA FIRE (FIRE 6.23)
Toluene	0.16	$1.30 \times 10^{-2}$	EPA FIRE (FIRE 6.23)
Xylene	1.32	$1.10 \times 10^{-2}$	EPA FIRE (FIRE 6.23)

**Group 3: Substance-Specific Emission Factors****Emission Factors for Nitrogen Oxides**

The emission factor for nitrous oxide (N<sub>2</sub>O), the most common of nitrogen oxides emitted to air from sewage-treatment facilities, is found to vary in a wide range. Significant discrepancies have been observed between plant data and laboratory studies (Barton and Atwater, 2002). As a result, an estimate has been recommended which ranges between 0.002 and 0.02 kg N<sub>2</sub>O-N/kg sewage-N produced with an average value of 0.01 kg N<sub>2</sub>O-N/kg sewage-N (Mosier et al., 1998, in Barton and Atwater, 2002). In other words, the recommended emission factor assumes that 1% of wastewater nitrogen will be emitted as N<sub>2</sub>O-N. This value has been used for the EPA's national greenhouse gas inventory (EPA, 1999, in Barton and Atwater, 2002).

The emission factor for N<sub>2</sub>O has also been reported on a per-capita basis. Measurements around an activated sludge process at a domestic wastewater treatment plant in Japan indicated that the N<sub>2</sub>O emission rate was in the range of 0.43 to 1.89 g N<sub>2</sub>O per person per year (Kimochi et al., 1998). The concentration of dissolved N<sub>2</sub>O in the aeration tanks was low at 0.5 to 4 mg/L and the N<sub>2</sub>O generated was always released to the atmosphere through aeration. Another study of a treatment plant consisting of both primary and secondary processes reported a higher rate at 3.2 g N<sub>2</sub>O per person per year (Peter et al., 1995, in Kimochi et al., 1998).

**Emission Factors for Volatile Organic Compounds (VOCs)**

Many NPRI substances are volatile organic compounds (VOCs) and the air emission factor for each individual VOC emitted during the entire course of wastewater collection and treatment is a function of the volatility of that compound (EPA-453/D-92-016c, 1992). VOCs can be classified into four groups according to their volatilities — low volatility, medium volatility, medium-high volatility and high volatility. Summarized in Table D-20 are empirical values of VOC air-emission factors obtained from statistic analysis of operation data and measurements of various wastewater streams at synthetic organic chemical manufacturing industry facilities. Although the data presented in Table D-20 are based on industrial wastewater facilities, they may provide reference values for municipal wastewater systems if no other data are available.

**TABLE D-20 – AIR-EMISSION FACTORS FOR VOLATILE ORGANIC COMPOUNDS EMITTED DURING ENTIRE COURSE OF WASTEWATER COLLECTION AND TREATMENT (EPA-453/D-92-016C, 1992)**

VOLATILE ORGANIC COMPOUND	AIR-EMISSION FACTOR (MASS EMITTED/MASS INPUT)
Low volatility	0.03
Medium volatility	0.19
Medium-high volatility	0.25
High volatility	0.68

Air-emission factors for several VOCs have been compiled by Environment Australia, 1999 (Table D-21). These emission factors were obtained from various sources, including the U.S. Pooled Emissions Estimation Program (PEEP) and Environment Canada. They are associated with both aerated and non-aerated processes.

**TABLE D-21 – AIR-EMISSION FACTORS FOR VOCs FROM AERATED AND NON-AERATED WASTEWATER PROCESSES(ENVIRONMENT AUSTRALIA, 1999, P.43)**

SUBSTANCE	AIR-EMISSION FACTOR (KG/KG OF WASTEWATER)					
	AERATED GRIT CHAMBERS		SEDIMENTATION		TERTIARY FILTRATION	
	PEEP	ENVIRONMENT CANADA	PRIMARY	SECONDARY	QUIESCENT	BACKWASH
Benzene	0.032	0.011	0.39	0.0	0.00085	0.0
Chloroform	0.0037	0.0029	0.0	0.0021	0.00055	0.11
Tetrachloroethylene	0.0068	0.0023	0.0	0.0008	0.0027	1.0
Styrene	0.0013	0.0	0.0039	0.0	0.00085	0.0
Trichloroethylene	0.010	0.0021	0.034	0.00083	0.0027	0.11
Toluene	0.0013	0.0070	0.0039	0.0	0.00085	0.0
Xylenes	0.00025	0.0057	0.0039	0.0	0.00085	0.0
Formaldehyde	0.0	0.0	0.0	0.0	0.35	0.0

#### Emission Factors for Ammonia

In a report prepared for the EPA, Battye et al., 1994, reviewed and compiled literature data published between 1985 and 1994 on ammonia-emission factors. The data included the 1985 U.S. National Acid Precipitation Assessment Program (NAPAP) emission inventory which utilized an emission factor of 2.2 kg NH<sub>3</sub>/10<sup>6</sup> litres (19 lb NH<sub>3</sub>/10<sup>6</sup> gallons) treated for publicly-owned treatment works (POTWs) (Battye et al., 1994, p.6-4). The NAPAP factor was developed based on the 1984 Needs Survey, which included influent and effluent NH<sub>3</sub> concentrations for more than 850 wastewater facilities nationwide, and on studies of NH<sub>3</sub> stripping from treatment plants (Warn et al., 1990, in Battye et al., 1994, p.6-4). The data reviewed and compiled by Battye et al., 1994, also included the Hot Spot Toxic Inventory for the State of California which provided NH<sub>3</sub> emission factors reported for three sources of treatment plants. These sources are aerobic digestion, primary settling and sludge thickening. It should be noted that in the original report an aerobic digester was incorrectly coded as an entire plant, and a sludge thickener as an aeration tank. The NAPAP factor and the factors reported in California are summarized in Table D-22.

**TABLE D-22 – AMMONIA EMISSION FACTORS FOR PUBLICLY-OWNED TREATMENT WORKS (BATTYE ET AL., 1994, P.6-4)**

SOURCE	AVERAGE NH <sub>3</sub> EMISSION FACTOR (RANGE)	
	kg/10 <sup>6</sup> LITERS TREATED	lb/10 <sup>6</sup> GALLONS TREATED
NAPAP - entire plant	2.2	19
California - aerobic digester	1.93 (0.012-5.39)	16.1 (0.099-45)
California - primary settling	0.00023	0.0019
California - sludge thickener	14 (0.00066-29)	120 (0.00552-240)

#### Emission Factors for Mercury

Mercury has been detected in sewage sludge by Guo and Bassner, 1996. The mercury concentration in sewage sludge samples analyzed was in the range of 1.2 to 3.3 mg/g sludge (dry basis).

Mercury has also been detected in effluent from facultative lagoons. Araujo et al., 1996, reported the mercury concentration in effluent from facultative ponds in the range of 0.75 and 2.70 mg/L and that from subsequent maturation ponds in the range of 0.73 and 2.14 mg/L. The observed overall mercury removal efficiency was 1.1-72.5%. In the meantime, the mercury concentration in sludge of facultative ponds was found at 0.238 mg/kg (dry basis) and that in sludge of maturation ponds at 0.04-0.23 mg/kg. Some kinds of algae have been identified that show strong adsorption affinities for mercury.



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## Appendix E

# Mass Balance Methods

### Mass Balance Principle

The mass balance method is an application of the law of mass conservation to a wastewater process or configuration. It is used to estimate release or transfer based on input-output difference corrected for quantities formed and transformed within a process or configuration.

A generic equation used for mass balance method is:

$$E = M_{\text{input}} - M_{\text{output}} + M_{\text{formation}} - M_{\text{transformation}} \quad \text{EQ E-1}$$

where:

E	=	annual release or transfer of a substance from a wastewater process or from a configuration, tonne/yr
$M_{\text{input}}$	=	total input quantities of a substance into a wastewater process or configuration, tonne/yr
$M_{\text{output}}$	=	total output quantities of a substance from a wastewater process or configuration excluding the release or transfer being estimated, tonne/yr
$M_{\text{formation}}$	=	total quantities of a substance formed within a wastewater process or configuration, tonne/yr
$M_{\text{transformation}}$	=	total quantities of a substance removed by chemical transformation within a wastewater process or configuration, tonne/yr

The above equation is valid if no substance is accumulated within a process or configuration. If a substance is accumulated in a process or configuration (such as for the lagoon configurations in section 2.4, processes 3a and 3b), the final release or transfer must be corrected by subtracting the total accumulated quantity from the release or transfer estimated by the equation.

The equation can be simplified depending on the behaviour of a substance within a wastewater process or configuration. Considering the function of each wastewater process or configuration, substances can be grouped into three categories:

- substances neither formed nor transformed
- substances formed, and
- substances transformed.

### Application to Substances Neither Formed Nor Transformed

For substances neither formed nor transformed within a wastewater process or configuration, the equation for the mass balance method is simplified to:

$$E = M_{\text{input}} - M_{\text{output}} \quad \text{EQ E-2}$$

where:

E	=	annual release or transfer of a substance from a wastewater process or from a configuration, tonne/yr
$M_{\text{input}}$	=	total input quantities of a substance into a wastewater process or configuration, tonne/yr
$M_{\text{output}}$	=	total output quantities of a substance from a wastewater process or configuration excluding the release or transfer being estimated, tonne/yr

Substances considered neither formed nor transformed are relative to wastewater processes or configurations. Metals, such as copper, cadmium, chromium, etc., are neither formed nor transformed within all individual processes and configurations. All other substances also remain chemically unchanged within physical processes as well as the preliminary and primary configurations. Table E-1 summarizes the applicability of the equation.

**TABLE E-1 – APPLICABILITY OF MASS BALANCE EQUATION CONCERNING SUBSTANCES NEITHER FORMED NOR TRANSFORMED**

		METALS	ORGANIC SUBSTANCES	INORGANIC SUBSTANCES
Wastewater Process	Screening	✓	✓	✓
	Grit removal	✓	✓	✓
	Chemical flocculation	✓	✓	✓
	Primary sedimentation	✓	x	x
	Activated sludge	✓	x	x
	Extended aeration	✓	x	x
	Sequencing batch reactor	✓	x	x
	Oxidation ditch	✓	x	x
	Rotating biological contactor	✓	x	x
	Trickling filter	✓	x	x
	Secondary clarification	✓	✓	✓
	Nitrogen removal	✓	x	x
	Phosphorus removal	✓	x	x
	Aerobic or anaerobic digestion	✓	x	x
	Aerated lagoon	✓	x	x
	Aerobic-facultative lagoon	✓	x	x
	Facultative lagoon	✓	x	x
	Anaerobic lagoon	✓	x	x
	Chlorine disinfection	✓	✓	x
	Dechlorination	✓	✓	x
	UV disinfection	✓	✓	✓
	Ozone disinfection	✓	✓	x
	Dissolved air flotation	✓	✓	✓
	Solids thickening	✓	✓	✓
	Gravity settling	✓	✓	✓
	Belt thickening	✓	✓	✓
Centrifuge thickening	✓	✓	✓	
Wastewater Configuration	Preliminary – mechanical plant	✓	✓	✓
	Primary – mechanical plant	✓	x	x
	Other configurations containing biological treatment	✓	x	x

✓ - applicable

x - not applicable

**Application to Substances Formed**

For substances which can be formed within a wastewater process or configuration, the equation for the mass balance method takes the following form:

where:

$$E = M_{\text{input}} - M_{\text{output}} + M_{\text{formation}} \quad \text{EQ E-3}$$

$E$  = annual release or transfer of a substance from a wastewater process or from a configuration, tonne/yr

$M_{\text{input}}$  = total input quantities of a substance into a wastewater process or configuration, tonne/yr

$M_{\text{output}}$  = total output quantities of a substance from a wastewater process or configuration excluding the release or transfer being estimated, tonne/yr

$M_{\text{formation}}$  = total quantities of a substance formed within a wastewater process or configuration, tonne/yr

Substances which have been identified to be formed are limited. Total residual chlorine and chloroform are common substances formed during chlorine disinfection. Nonylphenol is produced from nonylphenol ethoxylates during biological treatment. Nitrogen oxides are formed during nitrogen-removal processes.

#### Application to Substances Transformed

For substances which are removed by chemical transformation within a wastewater process or configuration, the equation for the mass balance method takes the following form:

$$E = M_{\text{input}} - M_{\text{output}} - M_{\text{transformation}} \quad \text{EQ E-4}$$

where:

E	=	annual release or transfer of a substance from a wastewater process or from a configuration, tonne/yr
$M_{\text{input}}$	=	total input quantities of a substance into a wastewater process or configuration, tonne/yr
$M_{\text{output}}$	=	total output quantities of a substance from a wastewater process or configuration excluding the release or transfer being estimated, tonne/yr
$M_{\text{transformation}}$	=	total quantities of a substance removed by chemical transformation within a wastewater process or configuration, tonne/yr

There are numerous substances which are removed by chemical transformation. These substances include organic compounds, ammonia, nitrate ion, etc. They are removed primarily by biological treatment. As a result, the equation concerning substances transformed should be used for all biological processes and configurations containing biological treatment.





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## Appendix F

# Engineering Calculations

Engineering calculations rely on use of engineering correlations and data relevant to a wastewater process for determination of release and/or transfer of a substance from the process. The engineering calculation approach can be straightforward, as in the case of using removal efficiency to determine the amount of heavy metal in sludge removed from a chemical flocculation process. It can also be complicated if sophisticated process modelling is involved, dealing with numerous variables such as operating conditions, substance properties, mass transfer, thermodynamics and chemical reactions. The level of effort involving process modelling for emission estimating normally warrants use of emission-estimating software (such as WATER9 offered by the EPA).

Described below are two common engineering principles used for emission and/or transfer estimation — Removal Efficiency Principle and Mass Transfer Principle.

### Removal Efficiency Principle

Removal efficiencies are derived from common engineering data obtained from process operations. Removal efficiencies for various types of pollutants are available for many wastewater processes, as given in Table F-1 (Droste, 1997, p.233). The removal efficiency for a specific substance in a given process may be obtained in the literature and can be used in release-estimation calculations. General removal efficiency data (Table F-1) are recommended when substance-specific data are not available.

Heavy metals are considered unchanged chemically as they undergo a treatment process. Such metals include antimony, arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, silver, vanadium and zinc. Generally, these metals (except for mercury) do not emit to air, but transfer from a liquid phase to a solid phase with the latter being removed with sludge and contained in biosolids.

The quantities of a heavy metal in effluent and sludge from a wastewater process can be estimated using its removal efficiency by using the following equations:

$$E_{\text{eff}} = C_i \times Q \times t_{\text{op}} \times (1 - f_{\text{removal}}) \times 10^{-6} \text{ tonne/g} \quad \text{EQ F-1}$$

$$E_{\text{sludge}} = C_i \times Q \times t_{\text{op}} \times f_{\text{removal}} \times 10^{-6} \text{ tonne/g} \quad \text{EQ F-2}$$

where:

$E_{\text{eff}}$	=	annual release of a heavy metal by effluent, tonne/yr
$E_{\text{sludge}}$	=	annual release of a heavy metal by sludge, tonne/yr
$C_i$	=	heavy metal concentration in wastewater influent, g/m <sup>3</sup>
$Q$	=	daily volume of wastewater treated, m <sup>3</sup> /d
$t_{\text{op}}$	=	operation days during a reporting year, d/yr
$f_{\text{removal}}$	=	removal efficiency for metals (ratio of $E_{\text{sludge}}$ to influent tonne/yr)

Where  $E_{\text{sludge}}$  for heavy metals is known from biosolids data, equations F-1 and F-2 can be used to estimate the concentration of a substance in the influent ( $C_i$ ), so the quantity released in the effluent may then also be estimated. The removal efficiency of a substance from the wastewater stream ( $f_{\text{removal}}$ ) to sludge may be estimated based on operational data of the reporting facility or from literature data (as indicated in Table F-1, following). To put equation F-2 another way, the removal efficiency for heavy metals is the ratio of the quantity of substance in the sludge to the total quantity in the influent within a given time.

For substances other than heavy metals, removal-efficiency data can also be used to estimate release and/or transfer, but where substances are transformed by the process or released to air, calculations must take this into account. These substances, such as volatile organic compounds (VOCs), ammonia and hydrogen sulphide, are soluble in wastewater and are transformed to other compounds during treatment. They may be released to effluent, sludge, and/or to air, if volatile. The total release, however, is less than the total input because of chemical transformation. The quantity of these substances can be described by the mass balance equation:

$$E_{\text{eff}} + E_{\text{sludge}} + E_{\text{air}} + E_{\text{transformed}} = (C_1 \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g}) \quad \text{EQ F-3}$$

where:

$$\begin{aligned} E_{\text{eff}} &= \text{annual release and/or transfer by effluent, tonne/yr} \\ E_{\text{sludge}} &= \text{annual release and/or transfer by sludge, tonne/yr} \\ E_{\text{air}} &= \text{annual release to air, tonne/yr} \\ E_{\text{transformed}} &= \text{annual amount transformed, tonne/yr} \\ C_1 &= \text{substance concentration in wastewater influent, g/m}^3 \\ Q &= \text{daily volume of wastewater treated, m}^3/\text{d} \\ t_{\text{op}} &= \text{operation days during a reporting year, d/yr} \end{aligned}$$

The removal efficiency from the perspective of effluent results, can be expressed as:

$$f_{\text{removal}} = (E_{\text{sludge}} + E_{\text{air}} + E_{\text{transformed}}) / (C_1 \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g}) \quad \text{EQ F-4}$$

Where  $E_{\text{air}}$  can be estimated from emission factors or monitoring data (or is not applicable),  $E_{\text{transformed}}$  is believed to be relatively small, and removal efficiency can be estimated from literature values. Calculation of the quantity released to water in the effluent can be determined by the following calculation:

$$E_{\text{eff}} = (C_1 \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g}) \times (1 - f_{\text{removal}}) \quad \text{EQ F-5}$$

Note that equation F-3 applies where substances are transformed to reduce the quantity of the NPRI substance through the process. In cases where the wastewater process transforms other substances to increase the quantity of an NPRI substance, the quantity of the substance can be described by the equation:

$$E_{\text{eff}} + E_{\text{sludge}} + E_{\text{air}} = (C_1 \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g}) + E_{\text{transformed}} \quad \text{EQ F-6}$$

Where variables are as indicated for EQ F-3, above.

**TABLE F-1 – POLLUTANT-REMOVAL EFFICIENCIES OF WASTEWATER TREATMENT PROCESSES (DROSTE, 1997, P.233)**

TREATMENT PROCESS	AMMONIA NITROGEN	INORGANIC NITROGEN	SULPHIDES	VOLATILE ORGANIC COMPOUNDS (VOCs)	HEAVY METALS
Coagulation, flocculation, sedimentation	N/A	N/A	N/A	N/A	60-100%
Primary sedimentation	N/A	N/A	N/A	N/A	0-60%
Sedimentation following biological treatment	N/A	N/A	N/A	N/A	60-100%
Sedimentation following biological treatment with chemical addition to influent	N/A	N/A	N/A	N/A	60-100%
Conventional aerobic treatment	0-20%	0-20%	90-100%	60-100%	N/A
Biological denitrification	60-100%	60-100%	90-100%	60-100%	N/A
Low-loading trickling filter	60-100%	0-20%	90-100%	60-100%	N/A
High-loading trickling filter	0-20%	0-20%	60-100%	60-100%	N/A
Anaerobic treatment	0-20%	0-20%	N/A	60-100%	N/A
Disinfection	20-90%	N/A	60-100%	N/A	N/A
Air stripping	60-100%	N/A	60-100%	60-100%	N/A
Carbon adsorption	20-90%	0-20%	60-100%	N/A	60-100%

N/A: not applicable

### Mass Transfer Principle

The mass transfer principle for engineering estimation can be useful for estimating releases of volatile substances to air. Mass transfer is a fundamental mechanism for air emission, and is applicable to many uncovered wastewater collection and treatment units (Elliott and Watkins, 1990). These units are surface impoundments and open top tanks, such as junction boxes, lift stations and sumps in wastewater collection systems, and clarifiers or aeration

tanks in wastewater treatment systems. In such units, wastewater is in contact with ambient air and volatile substances dissolved in the wastewater tend to escape to the ambient air to reach their equilibrium concentrations. Since the ambient air is constantly replenished by wind and/or aeration, the equilibrium concentrations will never be reached. As a result, volatile substances are continuously emitted to the ambient air.

The mass transfer principle is commonly based on a two-film resistance theory. The theory assumes that the resistance to mass transfer exists at the interface between the liquid (wastewater) and vapour (ambient air) phases. As a volatile substance is emitted to the ambient air, it must overcome both liquid and gas film resistances.

According to the two-film resistance theory, the annual air emission of a volatile substance from an uncovered wastewater collection or treatment unit can be estimated by the equation:

$$N_a = K \times 3600 \text{ s/hr} \times 24 \text{ hr/d} \times t_{op} \times C_L \times A \times 10^{-6} \text{ tonne/g} \quad \text{EQ F-7}$$

where:

$$\begin{aligned} N_a &= \text{annual air emission of a substance, tonne/yr} \\ K &= \text{overall mass transfer coefficient of a substance from liquid to gas, m/s} \\ t_{op} &= \text{operation days during a reporting year, d/yr} \\ C_L &= \text{concentration of a substance in bulk liquid, g/m}^3 \\ A &= \text{surface area of wastewater in contact with ambient air, m}^2 \end{aligned}$$

The overall mass transfer coefficient (K) is determined based on the liquid and gas mass transfer coefficients by the equation:

$$1/K = 1/k_L + 1/(K_{eq}k_G) \quad \text{EQ F-8}$$

where:

$$\begin{aligned} k_G &= \text{gas phase mass transfer coefficient, m/s} \\ k_L &= \text{liquid phase mass transfer coefficient, m/s} \\ K_{eq} &= \text{equilibrium constant, dimensionless, defined as } K_{eq} = H/(RT) \\ H &= \text{Henry's law constant of a substance in water, atm-m}^3/\text{gmol} \\ R &= \text{gas constant, } 8.21 \times 10^{-5} \text{ atm-m}^3/\text{gmol-K} \\ T &= \text{temperature, K} \end{aligned}$$

There are three variables which need to be evaluated further when the mass transfer principle is used for air-emission estimation. These variables are concentration of a substance in bulk liquid ( $C_L$ ); liquid phase mass transfer coefficient ( $k_L$ ); and gas phase mass transfer coefficient ( $k_G$ ). They are functions of material properties and unit operating conditions.

Tables F-2 and F-3 show two sets of equations and data used for estimating air emissions from non-aerated units and turbulent-flow units, respectively. This subject has been dealt with in detail by Elliott and Watkins, 1990, as well as in an Australian Emission Estimation Technique Manual for Sewage and Wastewater Treatment (Environment Australia, 1999). The data compiled in Table F-2 for non-aerated units are particularly applicable to primary and secondary clarifiers and various lagoons, while those compiled in Table F-3 are applicable to junction boxes in which flow turbulence and mixing can be approximated by mechanical agitation.

TABLE F-2 – ENGINEERING ESTIMATING METHOD FOR AIR EMISSIONS FROM NON-AERATED UNITS

DATA TYPE RESULTS	PARAMETER ANNUAL AIR EMISSION ( $N_a$ )	ESTIMATING EQUATION OR DATA $N_a = K t_{op} C_L A$	UNITS TONNE/YR
Mass Transfer Coefficients	Overall mass transfer coefficient (K)	$1/K = 1/k_L + 1/(K_{eq} k_G)$	m/s
	Liquid phase mass transfer coefficient ( $k_L$ )	$k_L = 2.78 \times 10^{-6} (D_w/D_{ether})^{2/3}$ ( $U_{10} < 3.25$ m/s, all $d_e/D$ values)	
		$k_L = (2.605 \times 10^{-9} d_e/D + 1.277 \times 10^{-7} U_{10}^2 (D_w/D_{ether})^{2/3})$ ( $U_{10} > 3.25$ m/s, $14 < d_e/D < 51.2$ )	m/s
		$k_L = 2.61 \times 10^{-7} U_{10}^2 (D_w/D_{ether})^{2/3}$ ( $U_{10} > 3.25$ m/s, $d_e/D > 51.2$ )	
		$k_L = 1.0 \times 10^{-6} + 144 \times 10^{-4} U^{*2.2} Sc_L^{-0.5}$ ( $d_e/D < 14$ , $U_{10} > 3.25$ m/s, $U^* < 0.3$ )  $k_L = 1.0 \times 10^{-6} + 34.1 \times 10^{-4} U^{*2} Sc_L^{-0.5}$ ( $d_e/D < 14$ , $U_{10} > 3.25$ m/s, $U^* > 0.3$ )	
	Gas phase mass transfer coefficient ( $k_G$ )	$k_G = 4.82 \times 10^{-3} U_{10}^{0.78} Sc_G^{-0.67} d_e^{-0.11}$	m/s
Characteristic Parameters	Schmidt number for a substance in gas ( $Sc_G$ )	$Sc_G = m_G / (r_G D_G)$	dimensionless
	Schmidt number for a substance in liquid ( $Sc_L$ )	$Sc_L = m_L / (r_L D_w)$	dimensionless
	Substance concentration in bulk liquid ( $C_L$ )	$C_L = Q C_i / (KA + Q)$	g/m <sup>3</sup>
	Equilibrium constant ( $K_{eq}$ )	$K_{eq} = H / (RT)$	dimensionless
	Wind speed factor ( $U^*$ )	$U^* = 0.01 U_{10} (6.1 + 0.63 U_{10})^{0.5}$	m/s
	Liquid surface area (A)	facility-specific data	m <sup>2</sup>
	Substance concentration in influent ( $C_i$ )	facility-specific data	g/cm <sup>3</sup>
	Unit effective diameter ( $d_e$ )	facility-specific data	m
	Liquid depth (D)	facility-specific data	m
	Wastewater flow (Q)	facility-specific data	m <sup>3</sup> /s
	Operation days per year ( $t_{op}$ )	facility-specific data	d/yr
	Temperature (T)	facility-specific data	K
	Wind speed at 10 metres above liquid surface ( $U_{10}$ )	facility-specific data	m/s
Material Property Data	Diffusions coefficient of ether in water ( $D_{ether}$ )	universally available	cm <sup>2</sup> /s
	Diffusions coefficient of a substance in gas ( $D_G$ )	universally available	cm <sup>2</sup> /s
	Diffusion coefficient of a substance in water ( $D_w$ )	universally available	cm <sup>2</sup> /s
	Henry's law constant of a substance in water (H)	universally available	atm-m <sup>3</sup> /gmol
	Gas constant (R) $8.21 \times 10^{-5}$ atm-m <sup>3</sup> /gmol-K	atm-m <sup>3</sup> /gmol-K	
	Gas viscosity ( $m_G$ ) universally available	g/cm-s	
	Liquid viscosity ( $m_L$ ) universally available	g/cm-s	
	Gas density ( $r_G$ ) universally available	g/cm <sup>3</sup>	
Liquid density ( $r_L$ ) universally available	g/cm <sup>3</sup>		

TABLE F-3 – ENGINEERING ESTIMATING METHOD FOR AIR EMISSIONS FROM UNITS AERATED BY FLOW TURBULENCE

DATA TYPE RESULTS	PARAMETER ANNUAL AIR EMISSION ( $N_a$ )	ESTIMATING EQUATION OR DATA $N_a = K t_{op} C_L A$	UNITS TONNE/YR
Mass Transfer Coefficients	Overall mass transfer coefficient (K)	$1/K = 1/k_L + 1/(K_{eq} k_G)$	m/s
	Liquid phase mass transfer coefficient ( $k_L$ )	$k_L = 8.22 \times 10^{-9} J P^{1.024} T^{-20-273}$	
		$(Q_t \times 10^6) (M_L / (V a_v r_L)) (D_w / D_{O_2})^{0.5}$	m/s
	Gas phase mass transfer coefficient ( $k_G$ )	$k_G = 4.82 \times 10^{-3} U_{10}^{0.78} S_{C_G}^{-0.67} d_e^{-0.11}$	m/s
Characteristic Parameters	Schmidt number for a substance in gas ( $Sc_G$ )	$Sc_G = m_G / (r_G D_G)$	dimensionless
	Substance concentration in bulk liquid ( $C_L$ )	$C_L = Q C_i / (KA + Q)$	g/m <sup>3</sup>
	Equilibrium constant ( $K_{eq}$ )	$K_{eq} = H / (RT)$	dimensionless
Operation Data	Specific liquid surface area ( $a_v$ )	$a_v = A / V \text{ ft}^{-1}$	
	Aeration rate (J)	empirical data: 3 lb O <sub>2</sub> /hr-hp	lb O <sub>2</sub> /hr-hp
	Power input (P)	$P = r_p AD$	hp
	Specific power input ( $r_p$ )	empirical data: 0.5-1 hp/1 000 ft <sup>3</sup>	hp/1 000 ft <sup>3</sup>
	Agitated volume (V)	$V = r_a AD$	ft <sup>3</sup>
	Liquid surface area (A)	facility-specific data	m <sup>2</sup>
	Substance concentration in influent ( $C_i$ )	facility-specific data	g/cm <sup>3</sup>
	Equipment effective diameter ( $d_e$ )	facility-specific data	m
	Liquid depth (D)	facility-specific data	m
	Wastewater flow (Q)	facility-specific data	m <sup>3</sup> /s
	Oxygen transfer correction factor ( $Q_t$ )	empirical data: 0.83	dimensionless
	Liquid fraction agitated ( $r_a$ )	facility-specific data	dimensionless
	Operation days per year ( $t_{op}$ )	facility-specific data	d/yr
	Temperature (T)	facility-specific data	K
	Wind speed at 10 metres above liquid surface ( $U_{10}$ )	facility-specific data	m/s
Material Property Data	Diffusions coefficient of a substance in gas ( $D_G$ )	universally available	cm <sup>2</sup> /s
	Diffusion coefficient of a substance in water ( $D_w$ )	universally available	cm <sup>2</sup> /s
	Diffusion coefficient of oxygen in water ( $D_{O_2}$ )	universally available	cm <sup>2</sup> /s
	Henry's law constant of a substance in water (H)	universally available	atm-m <sup>3</sup> /gmol
	Molecular weight of water ( $M_L$ )	universally available	g/gmol
	Gas constant (R) $8.21 \times 10^{-5}$	atm-m <sup>3</sup> /gmol-K	atm-m <sup>3</sup> /gmol-K
	Gas viscosity ( $m_G$ )	universally available	g/cm-s
	Gas density ( $r_G$ )	universally available	g/cm <sup>3</sup>
	Liquid density ( $r_L$ )	universally available	g/cm <sup>3</sup>



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## Appendix G

### Behaviour of NPRI Substances in Specific Wastewater Processes

Following is compiled literature data on characteristics of various wastewater treatment processes and the fate of NPRI substances in each process. For simplification, NPRI substances commonly found in releases from municipal wastewater treatment plants are grouped into the following categories:

- volatile organic compounds (e.g., toluene, styrene, ethylbenzene, etc.);
- volatile inorganic compounds (e.g., ammonia, nitrogen oxides, hydrogen sulphide, sulphur dioxide, etc.), and
- heavy metals (e.g., copper, cadmium, mercury, nickel, etc.).

#### Wastewater Collection Units

Various volatile NPRI substances are released to air from many wastewater collection units. These units include drains, inspection covers, trenches, sumps, junction boxes and lift stations (Beck et al., 2000, Chem. Eng.; EPA-453/D-92-016c, 1992, p.5-5). Volatile NPRI substances emitted are:

- volatile organic compounds (VOCs) (e.g., toluene and styrene);
- hydrogen sulphide ( $H_2S$ ); and
- ammonia.

They are present in wastewater and emitted to air by volatilization. Banister et al., 1999, found that a significant source of  $H_2S$  gas emission in sewers is drop structures such as interceptor drop maintenance holes, joint structures, forcemain discharges and wet-well drops in sewer-pumping stations. These structures create turbulent flow which causes air emissions.

Ammonia,  $H_2S$ , methane and carbon dioxide can be formed during wastewater collection. The formation is a result of aerobic and/or anaerobic mineralization of organic waste (Kerri et al., 1989, in Devai and Delaune, 2000).  $H_2S$  is formed under anaerobic conditions by microbial decomposition of sulphur-containing organic matter or from reduction of mineral sulphites and sulphates (Hayes, 1999).

Mercury and several other heavy metals have been detected in sewage sludge by Guo and Bassner, 1996. The mercury concentration in sewage sludge samples analyzed was in the range of 1.2 to 3.3 mg/g sludge (dry basis). Other heavy metals measured were copper at 330-550 mg/g, nickel at 35-120 mg/g, lead at 72-150 mg/g and zinc at 1100-2800 mg/g.

Methane and carbon dioxide can be emitted during sludge handling. Czepiel et al., 1993, reported that sludge-holding tanks were a source of air emissions of methane and carbon dioxide at a municipal wastewater treatment plant in Durham, NH. The emission rate from these tanks containing sludges from grit chambers, primary settling tanks and secondary clarifiers was 63 kg/yr for methane and 21 t/yr for carbon dioxide, accounting for 15% of the total methane emission and 5.4% of the total carbon dioxide emission, respectively.

Ammonia can be emitted to air during sludge handling. Kogan and Torres, 1997, (in DeHollander, 1998) identified solids-handling units as a major source of ammonia emission at a treatment plant.

#### Mechanical Screening and Grit Removal

Volatile NPRI substances can be emitted to air and are also expected to be present in both wastewater treated and screenings removed during mechanical screening. Air emissions occur by volatilization because the screening operation is performed in the open atmosphere. Those emitted by volatilization include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide. These substances are water soluble and are, therefore, contained in treated wastewater as well as trapped in screenings through liquid carry-over and/or solid adsorption.

Methane and carbon dioxide can emit from grit chambers. Czepiel et al., 1993, reported that grit chambers (aerated and non-aerated) were a dominant source of methane emission at a municipal wastewater treatment plant in Durham, NH. The plant consisted of both primary and secondary treatment processes and the methane emission rate was 57 kg/yr, accounting for 35% of the plant total. The air emission of carbon dioxide from the grit chambers was, on the other hand, minor at a rate of 3.9 t/yr which accounted for 1.3% of the plant total.

### **Primary Sedimentation**

Primary sedimentation is designed to remove readily-settleable solids and floating material (Grites and Tchobanoglous, 1998, p.300). It can remove 50-70% suspended solids and 25-40% BOD.

Both nitrogen and phosphorus can be removed by primary sedimentation. The removal is about 20% for nitrogen and 10% for phosphorus (Grites and Tchobanoglous, 1998, p.434-435).

Volatile NPRI substances can be emitted to air and are also expected to be present in both wastewater treated and primary sludge removed during primary sedimentation. Air emissions occur by volatilization because the primary sedimentation operation is performed in the open atmosphere. Those emitted by volatilization include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide. These substances are water soluble and are therefore contained in treated wastewater as well as being trapped in sludge through liquid carry-over and/or solid adsorption.

Heavy metals are commonly concentrated in sludge and are also present in effluent in trace amounts.

### **Secondary Clarifier**

Volatile NPRI substances can be emitted to air and are also expected to be present in both wastewater treated and secondary sludge removed during secondary clarification. Air emissions occur by volatilization because a secondary clarifier is open to the atmosphere. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels. These substances are water soluble and can therefore be contained in treated wastewater as well as trapped in secondary sludge through liquid carry-over and/or solid adsorption.

Heavy metals are commonly concentrated in sludge and are also present in effluent in trace amounts.

### **Chemical Flocculation**

Mercury can be removed by sulphide addition, which results in formation of highly-insoluble mercury sulphide and is the most common precipitation treatment (Patterson, 1975, p.149). Precipitation may possibly be combined with flocculation and separation by gravity settling, filtration or dissolved-air flotation. Removal of mercury by coagulation has been reported for a variety of mercury-containing wastewater streams. Coagulants employed include aluminum sulphate (alum), iron salts and lime. The process has been applied successfully to both organic and inorganic mercury. Conventional precipitation systems employing sulphide and flocculating aids are capable of yielding mercury levels of 10-20 mg/L.

Volatile NPRI substances can be emitted to air during chemical flocculation. Air emissions occur by volatilization because the flocculation operation is conducted in the open atmosphere. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels.

### **Dissolved Air Flotation**

Volatile NPRI substances can be emitted to air and are also expected to be present in both wastewater treated and solids removed during dissolved air flotation. Air emissions occur because of both volatilization and air stripping. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels. These substances are water soluble and can, therefore, be contained in treated wastewater as well as trapped in solids through liquid carry over and/or solid adsorption.

### **Activated Sludge: Conventional**

Volatile NPRI substances can be emitted to air in an activated sludge process aeration vessel. Air emissions occur because of volatilization and air stripping. Those emitted may include: 1) volatile organic compounds, i.e., toluene and styrene; 2) ammonia; and 3) hydrogen sulphide, depending upon their inlet concentration levels.

Organic NPRI substances are expected to decompose in an activated sludge process. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

Nonylphenol is an NPRI substance which can be formed in an activated-sludge process. Nonylphenol ethoxylates are precursors for the formation.



Nitrous oxide ( $N_2O$ ) is a nitrogen oxide substance which can be generated in an activated sludge process incorporating nitrogen removal. Kimochi et al., 1998, reported air emissions of  $N_2O$  from an activated sludge process during either nitrification or denitrification.

Methane and carbon dioxide can be emitted from an activated-sludge process. Czepiel et al., 1993, reported that aerated secondary treatment tanks were the principal source of air emissions of methane and carbon dioxide at a municipal wastewater treatment plant in Durham, NH. The plant consisted of both primary and secondary treatment processes. The emission rate from the aerated secondary treatment tanks was 220 kg/yr for methane and 360 t/yr for carbon dioxide, accounting for 51% of the total methane emission and 92% of the total carbon dioxide emission, respectively.

**Activated Sludge: Oxidation Ditch**

Volatile NPRI substances can be emitted to air in an oxidation ditch. Air emissions occur because of volatilization and air stripping. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels.

Organic NPRI substances are expected to decompose in an oxidation ditch. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

Nonylphenol is an NPRI substance which can be formed in an oxidation ditch. Nonylphenol ethoxylates are precursors for the formation.

**Activated Sludge: Sequencing Batch Reactor**

Volatile NPRI substances can be emitted to air from a sequencing batch reactor. Air emissions occur because of volatilization and air stripping. Those emitted may include volatile organic compounds (i.e., toluene and styrene), 2) ammonia and hydrogen sulphide, depending on their inlet concentration levels. Liao and Lee, 1997, (in DeHollander, 1998) predicted VOC emission rates from a sequencing batch reactor under various operating conditions.

Organic NPRI substances are expected to decompose in a sequencing batch reactor. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

Nonylphenol is an NPRI substance which can be formed in a sequencing batch reactor process. Nonylphenol ethoxylates are precursors for the formation.

Nitrous oxide ( $N_2O$ ) is a nitrogen oxide substance which can be generated in a sequencing batch reactor. Okayasu et al., 1997, (in Barton and Atwater, 2002) found that as much as 40% of nitrogen removed from a sequencing batch reactor was emitted as  $N_2O$ . Most of this emission occurred during a low-dissolved oxygen period. Park et al., 2001, also reported significant air emissions of  $N_2O$  from a sequencing batch reactor during the aerobic phase.

**Activated Sludge: Extended Aeration**

Volatile NPRI substances can be emitted to air in an extended-aeration process. Air emissions occur because of volatilization and air stripping. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels.

Organic NPRI substances are expected to decompose in an extended-aeration process. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

Nonylphenol is an NPRI substance which can be formed in an extended-aeration process. Nonylphenol ethoxylates are precursors for the formation.

### **Trickling Filter**

Carbon dioxide is an NPRI substance generated as a by-product from a trickling filter. Biomass in the form of slime grows on the media of a trickling filter (Stephenson and Blackburn, Jr., 1998, p.282). As wastewater passes over the slime, nutrients and oxygen diffuse into the slime and carbon dioxide diffuses out of the slime along with other by-products.

Volatile NPRI substances can be emitted to air from a trickling filter. Air emissions occur because of volatilization and air stripping. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels. The fate of VOCs in trickling filters has been studied by Parker et al., 1996c, (in Dawson and Beyerlein, 1997).

Organic NPRI substances are expected to decompose in a trickling filter. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

Nonylphenol is an NPRI substance which can be formed in a trickling filter. Nonylphenol ethoxylates are precursors for the formation.

### **Rotating Biological Contactors**

Volatile NPRI substances can be emitted to air in a rotating biological contactor. Air emissions occur by volatilization because the contactor is open to the atmosphere. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending upon their inlet concentration levels. Parker et al., 1996c, (in Dawson and Beyerlein, 1997) found that VOC emissions by volatilization from rotating biological contactors could be affected by many parameters, including recycle rate, hydraulic loading and rotational speed.

Organic NPRI substances are expected to decompose in a rotating biological contactor. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

Nonylphenol is an NPRI substance which can be formed in a rotating biological contactor. Nonylphenol ethoxylates are precursors for the formation.

### **Anaerobic Digestion**

Several NPRI substances are generated during anaerobic digestion. The digestion process produces three output streams — digester gas, digestion effluent and digested sludge (Fresenius et al., 1989, p.869). Anaerobic digester gas typically contains 65-70% methane (CH<sub>4</sub>), 30-35% carbon dioxide (CO<sub>2</sub>), and trace amounts of hydrogen sulphide (H<sub>2</sub>S).

Several NPRI substances are also found in the anaerobic digestion effluent. They include ammonium ion (400-1 100 mg N/L), phosphate (200-2 500 mg PO<sub>4</sub><sup>-3</sup>/L), and manganese in the form of potassium permanganate (500-200 mg KMnO<sub>4</sub>/L) (Fresenius et al., 1989, p.873).

Mercury has been detected in anaerobic digester gas. A study of a sewage-treatment plant in Goteborg, Sweden, (Sommar et al., 1999) found that the total mercury in anaerobic digester gas ranged from 119 to 162 ng/m<sup>3</sup>. It consisted of dimethylmercury at 55-93 ng/m<sup>3</sup> and elemental mercury at 65-88 ng/m<sup>3</sup>. The feed sludge to the digester contained 5% solids and had a mercury concentration of 1-2 mg/g dry sludge.

### **Aerobic Lagoons**

Volatile NPRI substances can be emitted to air in an aerobic lagoon and are also expected to be present in the effluent and bottom sludge. Air emissions occur by volatilization because the lagoon is open to the atmosphere. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels. These substances are water soluble and can therefore be contained in the effluent as well as trapped in the bottom sludge through its water content and/or solid adsorption.

Organic NPRI substances are expected to decompose in an aerobic lagoon. Examples of such substances are benzene, toluene, styrene and xylene. Final decomposition products are primarily carbon dioxide and water. The extent of decomposition varies from substance to substance.

#### **Facultative Lagoons**

Nitrogen is removed in facultative lagoons. The removal mechanism appears to be the result of a combination of ammonia volatilization, algal uptake, nitrification/denitrification, sludge deposition and adsorption onto bottom soils (Grites and Tchobanoglous, 1998, p.532). Nitrogen removal in facultative lagoons is in the range of 43-82% for an influent nitrogen concentration of 14-50 mg/L.

Mercury has been detected in effluent from facultative lagoons. Araujo et al., 1996, reported the mercury concentration in effluent from facultative ponds in the range of 0.75 and 2.70 mg/L and that from subsequent maturation ponds in the range of 0.73 and 2.14 mg/L. The observed overall mercury removal efficiency was 1.1-72.5%. The mercury concentration in sludge of facultative ponds was found at 0.238 mg/kg (dry basis) and that in sludge of maturation ponds at 0.04-0.23 mg/kg. Some kinds of algae have been identified that show strong adsorption affinities for mercury.

Volatile NPRI substances can be emitted to air in a facultative lagoon and are also expected to be present in the effluent and bottom sludge. Air emissions occur by volatilization because the lagoon is open to the atmosphere. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels. These substances are water-soluble and can therefore be contained in the effluent as well as trapped in the bottom sludge through its water content and/or solid adsorption.

Organic NPRI substances are expected to decompose in a facultative lagoon. Examples of such substances are benzene, toluene, styrene and xylene. The extent of decomposition varies from substance to substance.

#### **Chlorine Disinfection**

Chloroform, trichloroethylene and tetrachloroethylene are formed as a result of wastewater chlorination. These substances were detected in chlorinated wastewater at many treatment plants in Ontario (Glaze and Henderson, 1975; Grove et al., 1985; Supply and Services Canada, 1993, p.11).

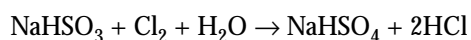
Chlorine gas can be emitted to air during chlorine disinfection if chlorine is used as a disinfecting agent.

Volatile NPRI substances can be emitted to air and are also expected to be present in disinfected wastewater during chlorine disinfection. Air emissions occur by volatilization because the disinfection is conducted in the open atmosphere. Those emitted may include volatile organic compounds (i.e., toluene and styrene), ammonia and hydrogen sulphide, depending on their inlet concentration levels. These substances are water soluble and can therefore be contained in the disinfected wastewater.

#### **Dechlorination**

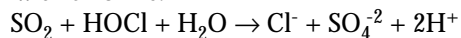
Sulphur dioxide is the only NPRI substance which may be used during dechlorination, according to literature data. Dechlorination involves removal of free and combined residual chlorine that remains after chlorination to reduce the toxic effect of chlorinated effluent (Grites and Tchobanoglous, 1998, p.854; Droste, 1997, p.223). Sulphites are a common class of dechlorination agents which include sodium bisulphite ( $\text{NaHSO}_3$ ) and sodium metabisulphite ( $\text{Na}_2\text{S}_2\text{O}_5$ ). Sulphur dioxide ( $\text{SO}_2$ ), sodium thiosulphate ( $\text{Na}_2\text{S}_2\text{O}_3$ ), and granular activated carbon have also been used for dechlorination.

Hydrochloric acid and ammonium ion are two NPRI substances which may be formed during dechlorination. When sodium bisulphite is added to wastewater, residual chlorine is converted into hydrochloric acid (Grites and Tchobanoglous, 1998, p.859):

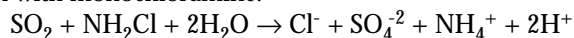


When sulphur dioxide is added to wastewater, both hydrochloric acid and ammonium ion are formed as a result of reactions of sulphur dioxide with free chlorine, monochloramine and dichloramine (Grites and Tchobanoglous, 1998, p.854).

Reaction with chlorine:



Reaction with monochloramine:



#### **Ultraviolet (UV) Disinfection**

The literature data obtained suggest there is no formation of NPRI substances during UV disinfection. Because UV light is not a chemical agent, no toxic residuals are produced (Grites and Tchobanoglous, 1998, p.872; Droste, 1997, p.530). However, certain chemical compounds may be altered by UV radiation, but it appears that the compounds formed are harmless or are broken down into more innocuous forms.

#### **Ozone Disinfection**

The literature data obtained suggest there is no formation of NPRI substances during ozone disinfection. Because ozone decomposes rapidly, no chemical residual persists in the treated effluent. In ozone disinfection, an ozone dosage is usually 0.5 to 2.0 ppm and a residual ozone concentration of 0.3 to 0.4 ppm can be maintained for four minutes (Stephenson and Blackburn, Jr., 1998, p.242).

#### **Gravity Thickeners**

Volatile NPRI substances can be emitted to air and are also expected to be present in effluent and thickened sludge from a gravity thickener. Air emissions occur by volatilization because the gravity thickening is conducted in the open atmosphere.

Heavy metals are commonly concentrated in sludge and also present in effluent in trace amounts.

#### **Centrifuge Thickening**

Volatile organic compounds are mostly concentrated in solids. The amount of VOCs captured in solids could be in the range of 14-53% of the total VOC output, while the air emission was small at about 2% (Monteitch and Bell, 1998, in D'Amato, II, and DeHollander, 1999).

Heavy metals are commonly concentrated in sludge and also present in effluent in trace amounts.

#### **Belt Thickening**

Belt thickening is a sludge-dewatering process using various press and filter systems. Common systems include vacuum belt filters, automatic plate and frame presses, gravity belt presses, and belt presses with combinations of pressure and vacuum devices (Stephenson and Blackburn, Jr., 1998, p.139). Some filter presses can approach 100% solids' removal efficiency and produce dewatered sludge containing 40-60% solids (Fresenius et al., 1989, p.903). This means that the filtered liquid can be free of solids.

Volatile organic compounds are mostly concentrated in solids. The majority of VOCs could be captured in filter cake, while the amount present in filtrate and wash water was less than 5% of the total VOC output and the air emission was also small at about 2% (Monteitch and Bell, 1998, in D'Amato, II, and DeHollander, 1999).

Heavy metals are commonly concentrated in sludge and also present in effluent in trace amounts.

#### **Biofiltration**

Volatile organic compounds and hydrogen sulphide are removed from waste gas streams by biofiltration. Biofilters can remove 83% of total VOCs and more than 90% of hydrogen sulphide, while biotrickling filters remove as little as 11% of total VOCs and more than 87% of hydrogen sulphide (Torres and Basrai, 1998, in D'Amato, II, and DeHollander, 1999).

## Appendix H Calculation Examples

### Example 1 - Annual Release and Transfer of Ammonia from a Facility with a Biological Nitrogen-Removal Process

A wastewater treatment facility contains conventional aerobic treatment and treats 50 000 m<sup>3</sup>/d wastewater. The raw wastewater has an average ammonia concentration at 26 mg/L. The facility discharges the treated wastewater to a receiving water body and is operated 365 days during a reporting year.

#### Identification of Release and Transfer Streams

The wastewater treatment facility generates two release streams and one transfer stream. The two release streams are air emission and effluent discharge, and the transfer stream is biosolids. Since all biosolids generated are transferred for off-site processing, there is no release to land.

#### Determination of Ammonia Air Emission by Emission Factor

The air emission of ammonia from the facility is estimated using the emission-factor method. The uncontrolled emission factor for ammonia air release from municipal wastewater treatment plants has been reported at 2.2 g/m<sup>3</sup> of wastewater treated (Appendix D, Table D-22). According to the emission-factor method, the annual air emission of ammonia from the facility is determined as follows:

$$\begin{aligned} E_{\text{air}} &= F'_{\text{uncontrol}} \times Q \times t_{\text{op}} \times (1 - f) \times 10^{-6} \text{ tonne/g} && \text{(EQ D-3)} \\ &= 2.2 \text{ g/m}^3 \times 50\,000 \text{ m}^3/\text{d} \times 365 \text{ d/yr} \times (1 - 0) \times 10^{-6} \text{ tonne/g} \\ &= 40.2 \text{ tonne/yr} \end{aligned}$$

where:

$$\begin{aligned} E_{\text{air}} &= \text{annual air emission of ammonia, tonne/yr} \\ F'_{\text{uncontrol}} &= 2.2 \text{ g/m}^3 \text{ of wastewater treated (uncontrolled emission factor)} \\ Q &= 50\,000 \text{ m}^3/\text{d (daily volume of wastewater treated)} \\ t_{\text{op}} &= 365 \text{ d/yr (operation days during a reporting year)} \\ f &= 0 \text{ (emission control equipment efficiency)} \end{aligned}$$

#### Quantity of Ammonia Contained in Biosolids

The quantity of ammonia contained in biosolids is approximated based on engineering estimation. The ammonia removal efficiency by a conventional aerobic treatment facility ranges from 0% to 20% (Appendix F, Table F-1), and an estimate of 10% is assumed for the facility. It is also assumed that the quantity of ammonia transformed in the conventional system is small. With these assumptions, the quantity of ammonia in the sludge is calculated as follows:

$$\begin{aligned} f_{\text{removal}} &= (E_{\text{sludge}} + E_{\text{air}} + E_{\text{transformed}}) / (C_i \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g}) && \text{(EQ F-4)} \\ &= (E_{\text{sludge}} + 40.2 + 0) / (26 \text{ g/m}^3 \times 50\,000 \text{ m}^3/\text{d} \times 365 \text{ d/yr} \times 10^{-6} \text{ tonne/g}) \\ E_{\text{sludge}} &= 47.45 \text{ tonne/yr} - 40.2 \text{ tonne/yr} \\ &= 7.25 \text{ tonne/yr} \end{aligned}$$

where:

$$\begin{aligned} E_{\text{sludge}} &= \text{annual quantity of ammonia in the sludge, tonne/yr} \\ C_i &= 26 \text{ g/m}^3 \text{ (ammonia concentration in wastewater influent)} \\ Q &= 50\,000 \text{ m}^3/\text{d (daily volume of wastewater treated)} \\ t_{\text{op}} &= 365 \text{ d/yr (operation days during a reporting year)} \\ f_{\text{removal}} &= \text{ammonia removal efficiency} \end{aligned}$$

This example demonstrates that EPA emission factors for air are large (compare the volume of ammonia released through sludge with that of air). If monitoring data are available for influent, effluent and sludge concentrations, air emissions may be more reliably estimated through the mass balance technique.

**Aqueous Release of Ammonia**

The aqueous release of ammonia is estimated by the equation:

$$\begin{aligned}
 E_{\text{eff}} &= (C_i \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g}) (1 - f_{\text{removal}}) && \text{(EQ F-5)} \\
 &= 474.5 \text{ tonne/yr} (1 - 0.1) \\
 &= 427.0 \text{ tonne/yr}
 \end{aligned}$$

**Summary**

Summarized in Table EX-1 are calculation results for annual release and transfer of ammonia from the reporting facility.

**TABLE EX-1 – CALCULATION RESULTS FOR ANNUAL RELEASE AND TRANSFER OF AMMONIA FROM A FACILITY WITH A BIOLOGICAL NITROGEN-REMOVAL PROCESS**

ON-SITE RELEASE			OFF-SITE TRANSFER	TOTAL
AIR	WATER	LAND		
40.2 tonne/yr	427.0 tonne/yr	0	7.25 tonne/yr	474.5 tonne/yr

**Example 2 - Annual Release and Transfer of Phenol from an Activated Sludge Facility**

An activated-sludge facility treats about 470 000 m<sup>3</sup>/d wastewater and discharges the effluent to a receiving water body. It also generates dewatered sludge which is transferred for off-site processing. The facility consists of both primary and secondary (activated sludge) treatment processes and is operated 365 days during a reporting year.

**Identification of Release and Transfer Streams**

The facility generates two release streams and one transfer stream. The two release streams are air emissions and effluent discharge. Air emissions occur within uncovered processes, such as primary sedimentation and secondary clarification. Any remaining phenol after biological treatment is released to effluent. The transfer stream results from production of dewatered sludge, which is transferred off-site for processing. It can contain a trace amount of phenol. There is no on-site release to land as all thickened sludge generated is transferred off site.

**Determination of Aqueous Release by Measurement Data**

The effluent discharged was measured once a month over a one-year period for phenol concentration and volume flow. The measurement data are presented in Table EX-2a. The daily release rate of phenol for each measurement event is determined by multiplying the concentration by the flow rate. The average daily release rate over a year is determined to be 29.7 kg/d, which is an arithmetic mean of all 12 measurement events. Also calculated are the average effluent flow rate at 470 850 m<sup>3</sup>/d and the average concentration in effluent at 0.063 g/m<sup>3</sup> (ppm).

**TABLE EX-2A– MEASUREMENT DATA OF PHENOL CONCENTRATION IN EFFLUENT AND EFFLUENT FLOW FROM AN ACTIVATED-SLUDGE FACILITY**

DATE	EFFLUENT FLOW (m <sup>3</sup> /d)	PHENOL CONCENTRATION IN EFFLUENT (g/m <sup>3</sup> )	DAILY RELEASE (kg/d)
Jan.8	445 775	0.062	27.6
Feb.12	461 625	0.063	29.1
Mar.10	473 150	0.068	32.2
Apr.15	481 350	0.059	28.4
May 9	483 925	0.058	28.1
Jun.13	489 525	0.059	28.9
Jul.11	475 600	0.061	29.0
Aug.10	473 025	0.062	29.3
Sept.8	463 575	0.064	29.7
Oct.12	465 525	0.065	30.3
Nov.10	468 075	0.068	31.8
Dec.8	458 950	0.069	31.7
Average	470 850	0.063	29.7

The annual release of phenol to the receiving water body is determined as follows:

$$\begin{aligned} E_{\text{eff}} &= R_{\text{eff}} \times t_{\text{op}} \times 10^{-3} \text{ tonne/kg} && \text{(EQ C-1)} \\ &= 29.7 \text{ kg/d} \times 365 \text{ d/yr} \times 10^{-3} \text{ tonne/kg} \\ &= 10.84 \text{ tonne/yr} \end{aligned}$$

where:

$$\begin{aligned} E_{\text{eff}} &= \text{annual aqueous release, tonne/yr} \\ R_{\text{eff}} &= 29.7 \text{ kg/d (average aqueous release rate)} \\ t_{\text{op}} &= 365 \text{ d/yr (operation days during a reporting year)} \end{aligned}$$

#### Determination of Transfer by Engineering Estimation

The amount of phenol transferred to the thickened sludge is determined by engineering estimation based on literature data. The treatment plant produces 108,300 kg/d of dewatered sludge (based on the production rate of 0.23 kg (dry)/m<sup>3</sup> of wastewater treated). The dewatered sludge contains 90% water. Considering there are little literature data on phenol adsorption in sludge solids, it is assumed that phenol is not adsorbed in solids and is only present in the water portion of the thickened sludge, at the same concentration as that in effluent (0.063 ppm). Based on the above assumptions, the amount of phenol in the dewatered sludge is calculated based on the water in the sludge:

$$\begin{aligned} E_{\text{sludge(water)}} &= R_{\text{sludge(water)}} \times t_{\text{op}} \times 10^{-3} \text{ tonne/kg} && \text{(EQ C-1)} \\ &= (C_{\text{eff}} \times Q_{\text{sludge}} \times S_{\text{water}}/r_{\text{water}} \times 10^{-3}) \times t_{\text{op}} \times 10^{-3} \text{ tonne/kg} && \text{(from EQ C-5)} \\ &= 0.063 \text{ g/m}^3 \times 108,300 \text{ kg/d} \times 0.90 / 1000 \text{ kg/m}^3 \times 365 \text{ d/yr} \times 10^{-6} \\ &= 0.002 \text{ tonne/yr} \end{aligned}$$

#### Determination of Air Emission by Emission Factor

The air emission of phenol from the facility is estimated by the emission factor method as follows:

$$\begin{aligned} E_{\text{air}} &= F_{\text{uncontrol}} \times C_i \times Q \times t_{\text{op}} \times (1 - f) \times 10^{-6} \text{ tonne/g} && \text{(EQ D-2)} \\ &= 0.0018 \text{ g/g} \times 0.316 \text{ g/m}^3 \times 470 \text{ 850 m}^3/\text{d} \times 365 \text{ d/yr} \times (1 - 0) \times 10^{-6} \text{ tonne/g} \\ &= 0.10 \text{ tonne/yr} \end{aligned}$$

This example calculation shows that the amounts of phenol released to air and transferred to the thickened sludge are small.

#### Summary

Summarized in Table EX-2b are calculation results for annual release and transfer of phenol from the activated-sludge facility.

**TABLE EX-2B – CALCULATION RESULTS FOR ANNUAL RELEASE AND TRANSFER OF PHENOL FROM AN ACTIVATED-SLUDGE FACILITY**

ON-SITE RELEASE			OFF-SITE TRANSFER	TOTAL
AIR	WATER	LAND		
0.10 tonne/yr	10.84 tonne/yr	0	0.002 tonne/yr	10.942 tonne/yr

#### Example 3 - Annual Release of Copper from a Chemical Flocculation Process

A chemical flocculation process treats 100 000 m<sup>3</sup>/d wastewater which has a copper influent concentration of 0.3 ppm. The copper is removed from the wastewater by chemical flocculation. The effluent is discharged to a receiving river and the thickened sludge is transported off site to be landfilled. The process is operated 365 days during a reporting year.

**Identification of Release and Transfer Streams**

The chemical flocculation process has two release streams — effluent and thickened sludge. Because copper is a non-volatile substance under normal process conditions, it is not emitted to air so its air emission is zero. Most copper is removed in sludge, which is landfilled off site. Some copper, on the other hand, remains soluble in liquid after chemical flocculation and is released to the receiving river via the effluent. There is no release of copper to land on site.

**Determination of Transfer by Engineering Estimation**

Copper is a common heavy metal removed by chemical flocculation. The removal efficiency of chemical flocculation for heavy metals is in the range of 60-100% (Appendix F, Table F-1). An average efficiency of 80% is assumed for the process and used to calculate the amount of copper removed and captured in sludge. The transfer off site through thickened solids is determined as follows:

$$\begin{aligned} E_{\text{sludge}} &= C_i \times Q \times t_{\text{op}} \times f_{\text{removal}} \times 10^{-6} \text{ tonne/g} && \text{(EQ F-2)} \\ &= 0.3 \text{ g/m}^3 \times 100\,000 \text{ m}^3/\text{d} \times 365 \text{ d/yr} \times 0.8 \times 10^{-6} \text{ tonne/g} \\ &= 8.76 \text{ tonne/yr} \end{aligned}$$

where:

$$\begin{aligned} E_{\text{sludge}} &= \text{annual quantity of copper in the sludge, tonne/yr} \\ C_i &= 0.3 \text{ g/m}^3 \text{ (copper concentration in wastewater influent)} \\ Q &= 100\,000 \text{ m}^3/\text{d} \text{ (daily volume of wastewater treated)} \\ t_{\text{op}} &= 365 \text{ d/yr} \text{ (operation days during a reporting year)} \\ f_{\text{removal}} &= 80\% \text{ (removal efficiency)} \end{aligned}$$

**Determination of Aqueous Release by Mass Balance**

The mass balance method is used to determine the aqueous release of copper.

$$\begin{aligned} E_{\text{eff}} &= M_{\text{input}} - M_{\text{output}} && \text{(EQ E-2)} \\ &= C_i \times Q \times t_{\text{op}} \times 10^{-6} \text{ tonne/g} - E_{\text{sludge}} \\ &= 0.3 \text{ g/m}^3 \times 100\,000 \text{ m}^3/\text{d} \times 365 \text{ d/yr} \times 10^{-6} \text{ tonne/g} - 8.76 \text{ tonne/yr} \\ &= 10.95 \text{ tonne/yr} - 8.76 \text{ tonne/yr} \\ &= 2.19 \text{ tonne/yr} \end{aligned}$$

where:

$$\begin{aligned} E_{\text{eff}} &= \text{annual aqueous release, tonne/yr} \\ C_i &= 0.3 \text{ g/m}^3 \text{ (copper concentration in wastewater influent)} \\ Q &= 100\,000 \text{ m}^3/\text{d} \text{ (daily volume of wastewater treated)} \\ t_{\text{op}} &= 365 \text{ d/yr} \text{ (operation days during a reporting year)} \\ E_{\text{sludge}} &= 8.76 \text{ tonne/yr} \text{ (land release determined previously)} \end{aligned}$$

**Summary**

Summarized in Table EX-3 are calculation results for annual release and transfer of copper from the chemical flocculation process.

**TABLE EX-3 – CALCULATION RESULTS FOR ANNUAL RELEASE OF COPPER FROM A CHEMICAL FLOCCULATION PROCESS**

ON-SITE RELEASE			OFF-SITE TRANSFER	TOTAL
AIR	WATER	LAND		
0 tonne/yr	2.19 tonne/yr	0	8.76 tonne/yr	10.95 tonne/yr

**Example 4 - Annual Air Emission of Toluene from a Primary Clarifier**

A primary clarifier (non-aerated) removes suspended solids from wastewater at a flow rate of 10 000 m<sup>3</sup>/d. Both the effluent and the sludge produced are sent to subsequent processes for further treatment. Toluene is present in the wastewater influent at a concentration of 10 ppm and emitted to air during the operation of the clarifier.



**Identification of Release and Transfer Streams**

The primary clarifier contains three output streams — air emission, effluent and sludge. Since the effluent and the sludge produced are sent to subsequent processes for further treatment, air emission is the only release stream of concern for this example.

**Determination of Air Emission by Engineering Estimation**

The annual air emission of toluene from the primary clarifier is estimated based on the mass transfer of toluene in a non-aerated aqueous system in contact with air. (Details on the application of the mass transfer principle to air emission estimation are provided by Elliott and Watkins (1990) and in an Australian Emission Estimation Technique Manual for Sewage and Wastewater Treatment (Environment Australia, 1999).) The emission is estimated in the following steps.

**Step 1 – Determination of Characteristic Parameters**

Characteristic parameters in this example include Schmidt numbers, equilibrium constant and wind speed factor. These parameters are evaluated using the process operating conditions and material properties listed in Table EX-4. The calculation results are also given in the same table.

The Schmidt number for toluene in liquid phase ( $Sc_L$ ) is calculated according to its definition:

$$\begin{aligned} Sc_L &= m_L / (r_L D_L) \\ &= (8.93 \times 10^{-3} \text{ g/cm-s}) / (1 \text{ g/cm}^3 \times 8.60 \times 10^{-6} \text{ cm}^2/\text{s}) \\ &= 1038 \text{ (dimensionless)} \end{aligned}$$

The Schmidt number for toluene in gas phase ( $Sc_G$ ) is calculated according to its definition:

$$\begin{aligned} Sc_G &= m_G / (r_G D_G) \\ &= (1.81 \times 10^{-4} \text{ g/cm-s}) / (1.20 \times 10^{-3} \text{ g/cm}^3 \times 8.70 \times 10^{-2} \text{ cm}^2/\text{s}) \\ &= 1.734 \text{ (dimensionless)} \end{aligned}$$

The equilibrium constant for toluene in an air-water system ( $K_{eq}$ ) is calculated according to its definition:

$$\begin{aligned} K_{eq} &= H / (RT) \\ &= 6.68 \times 10^{-3} \text{ atm-m}^3/\text{gmol} / (8.21 \times 10^{-5} \text{ atm-m}^3/\text{gmol-K} \times 298 \text{ K}) \\ &= 0.273 \text{ (dimensionless)} \end{aligned}$$

The wind speed factor  $U^*$ , defined as a function of wind speed  $U_{10}$  (4.47 m/s), is determined to be

$$\begin{aligned} U^* &= 0.01 U_{10} (6.1 + 0.63 U_{10})^{0.5} \\ &= 0.01 \times 4.47 \times (6.1 + 0.63 \times 4.47)^{0.5} \\ &= 0.1335 \text{ (m/s)} \end{aligned}$$

**Step 2 – Determination of Mass Transfer Coefficients**

The overall mass transfer coefficient for toluene from wastewater to the air above the liquid surface is computed based on individual liquid and gas mass transfer coefficients. These individual coefficients are empirically correlated with various characteristic parameters. For the wind speed  $U_{10} = 4.47 \text{ m/s} < 3.25 \text{ m/s}$ , the diameter-to-depth ratio  $d_e/D = 5.19 < 14$ , and the wind speed factor  $U^* = 0.1335 < 0.3$ , the liquid phase mass transfer coefficient ( $k_L$ ) is determined by the Mackay-Yeun empirical correlation (Elliott and Watkins, 1990, p.205; Environment Australia, 1999, p.27):

$$\begin{aligned} k_L &= 1.0 \times 10^{-6} + 144 \times 10^{-4} \times (U^*)^{2.2} \times (Sc_L)^{-0.5} \\ &= 1.0 \times 10^{-6} + 144 \times 10^{-4} \times 0.1335^{2.2} \times 1038^{-0.5} \\ &= 6.32 \times 10^{-6} \text{ (m/s)} \end{aligned}$$

The gas phase mass transfer coefficient for toluene in water ( $k_G$ ) is determined by the Mackay-Matasugu empirical correlation (Elliott and Watkins, 1990, p.205; Environment Australia, 1999, p.27):

$$\begin{aligned} k_G &= 4.82 \times 10^{-3} \times (U_{10})^{0.78} \times (Sc_G)^{-0.67} \times (d_e)^{-0.11} \\ &= 4.82 \times 10^{-3} \times 4.47^{0.78} \times 1.734^{-0.67} \times 22.3^{-0.11} \\ &= 4.82 \times 10^{-3} \times 3.215 \times 0.692 \times 0.711 \\ &= 0.0076 \text{ (m/s)} \end{aligned}$$

The overall mass transfer coefficient (K) is then determined from the liquid and gas phase mass transfer coefficients ( $k_L$  and  $k_G$ , respectively) by the equation:

$$\begin{aligned} 1/K &= 1/k_L + 1/(K_{eq}k_G) \\ &= 1/(6.32 \times 10^{-6} \text{ m/s}) + 1/(0.273 \times 0.0076 \text{ m/s}) \\ &= (158228 + 482.0) \text{ s/m} \\ K &= 6.30 \times 10^{-6} \text{ m/s} \end{aligned}$$

### Step 3 – Determination of Toluene Concentration in Bulk Liquid

For a non-aerated process, the toluene concentration in the bulk liquid is determined by the equation:

$$\begin{aligned} C_L &= QC_i/(KA + Q) \\ &= (0.1157 \text{ m}^3/\text{s}) \times (1 \times 10^{-5} \text{ g/cm}^3) \times (10^6 \text{ cm}^3/\text{m}^3) / \\ &\quad (6.30 \times 10^{-6} \text{ m/s} \times 390.6 \text{ m}^2 + 0.1157 \text{ m}^3/\text{s}) \\ &= 9.79 \text{ g/m}^3 \end{aligned}$$

### Step 4 – Estimation of Air Emission

The annual air emission of toluene is determined by the overall mass transfer equation:

$$\begin{aligned} N_a &= Kt_{op}C_LA \\ &= (6.30 \times 10^{-6} \text{ m/s} \times 3600 \text{ s/hr} \times 24 \text{ hr/d}) \times 300 \text{ d/yr} \times 9.79 \text{ g/m}^3 \times 390.6 \text{ m}^2 \times 10^{-6} \\ &\quad \text{tonne/g} \\ &= 0.624 \text{ tonne/yr} \end{aligned}$$

Finally, the mass fraction of toluene emitted to air is obtained by dividing the annual air emission by the total input to the clarifier.

$$\begin{aligned} f_e &= N_a/(QC_it_{op}) \\ &= (0.624 \text{ tonne/yr}) / (0.1157 \text{ m}^3/\text{s} \times 3600 \text{ s/hr} \times 24 \text{ hr/d} \times 300 \text{ d/yr} \times 1 \times 10^{-5} \text{ g/cm}^3 \times 10^6 \\ &\quad \text{cm}^3/\text{m}^3 \times 10^{-6} \text{ tonne/g}) \\ &= 0.0208 \text{ (mass fraction)} \end{aligned}$$

### Summary

Engineering calculations are performed to determine the air emission of toluene from the clarifier. The air emission is determined to be 0.62 tonne/yr. Summarized in Table EX-4 are clarifier operating conditions, material properties, and calculation results. A nomenclature for symbols used is also provided in Table EX-4.

**TABLE EX-4 – ENGINEERING CALCULATION RESULTS FOR ESTIMATING AIR EMISSION OF TOLUENE FROM A PRIMARY CLARIFIER**

SECTION	PARAMETER	NOTATION	VALUE
Operating Conditions	Liquid surface area	A	390.6 m <sup>2</sup>
	Clarifier diameter	d <sub>e</sub>	22.3 m
	Liquid depth in clarifier	D	4.3 m
	Diameter-to-depth ratio	d <sub>e</sub> /D	5.19 (dimensionless)
	Wastewater volume flow	Q	0.1157 m <sup>3</sup> /s
	Toluene concentration in influent	C <sub>i</sub>	10 ppm (1×10 <sup>-5</sup> g/cm <sup>3</sup> )
	Operating temperature	T	298 K (25°C)
	Wind speed at 10 m above liquid surface	U <sub>10</sub>	4.47 m/s
	Operation days per year	t <sub>op</sub>	300 d/yr
Material Properties	Molecular weight of toluene	M <sub>toluene</sub>	92.0 g/gmol
	Diffusion coefficient of toluene in water	D <sub>L</sub>	8.60×10 <sup>-6</sup> cm <sup>2</sup> /s
	Diffusion coefficient of toluene in air	D <sub>G</sub>	8.70×10 <sup>-2</sup> cm <sup>2</sup> /s
	Henry's law constant of toluene in water	H	.68×10 <sup>-3</sup> atm-m <sup>2</sup> /gmol
	Gas constant	R	8.21×10 <sup>-5</sup> atm-m <sup>3</sup> /gmol-K
	Water density	μ <sub>L</sub>	1 g/cm <sup>2</sup>
	Water viscosity	m <sub>L</sub>	8.93×10 <sup>-3</sup> g/cm-s
	Air density	μ <sub>G</sub>	1.20×10 <sup>-3</sup> g/cm <sup>3</sup>
Air viscosity	m <sub>G</sub>	1.81×10 <sup>-4</sup> g/cm-s	
Calculated Parameters	Schmidt number for toluene in liquid	Sc <sub>L</sub>	1038 (dimensionless)
	Schmidt number for toluene in gas	Sc <sub>G</sub>	1.734 (dimensionless)
	Equilibrium constant for toluene in air-water system; K <sub>eq</sub> =H/(RT)	K <sub>eq</sub>	0.273 (dimensionless)
	Wind speed factor, defined as a function of wind speed: U* = 0.01U <sub>10</sub> (6.1 + 0.63U <sub>10</sub> ) <sup>0.5</sup> , m/s	U*	0.1335 m/s
	Liquid phase mass transfer coefficient	k <sub>L</sub>	6.32×10 <sup>-6</sup> m/s
	Gas phase mass transfer coefficient	k <sub>G</sub>	0.0076 m/s
	Overall mass transfer coefficient of toluene from liquid phase to gas phase	K	6.30×10 <sup>-6</sup> m/s
	Toluene concentration at gas-liquid interface	C <sub>L</sub>	9.79 g/m <sup>3</sup>
	Emission Results Annual air emission of toluene from clarifies	N <sub>a</sub>	0.624 tonne/yr
	Emission factor for toluene	f <sub>e</sub>	0.0208 tonne emitted per tonne in influent



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## Appendix I

# Emission Estimating Software

Several emission-estimating computer-based programs are identified from the literature and internet. Summarized in Table I-1 are these programs and their supplier information.

**TABLE I-1 – EMISSION-ESTIMATING SOFTWARE FOR WASTEWATER FACILITIES**

SOFTWARE	SUPPLIER INFORMATION
WATER9	EPA, tel: 919-541-5610, web: <a href="http://www.epa.gov/ttn/chief/software/water">http://www.epa.gov/ttn/chief/software/water</a>
TOXCHEM+ and SEAM	Enviromega, 7 Innovation Dr., Flamborough, ON, Canada L9H 7H9, tel: 905-689-4410, web: <a href="http://www.enviromega.com">http://www.enviromega.com</a>
BASTE	No information obtained on supplier
PAVE	Contact EPA for further information
CORAL+	Predecessor to SEAM
FATE	No information available from initial search
PEEP	No information available from initial search

### **WATER9 (treatment and collection)**

WATER9 is a Windows-based computer program for estimating air emissions from wastewater collection, storage, treatment and disposal facilities. It was developed by the U.S. EPA and is a publicly-available computer program which can be downloaded from the EPA Clearinghouse for Inventories and Emission Factors (CHIEF) system at <http://www.epa.gov/ttn/chief/software/water>.

For technical support or more information, a hotline can be reached at 919-541-5610.

WATER9 is a significant upgrade of features offered by three previous computer programs, WATER8, CHEM9, and CHEMDAT8. It contains a set of model units (e.g., collection systems and aerated basins) that can be linked together to model an entire facility and provide emission estimates for each individual substance present in wastewater. WATER9 can be used to evaluate a full facility that contains multiple wastewater inlet streams, multiple collection systems and complex treatment configurations. Many of the emission models contained in its previous version (WATER8) are also presented in a spreadsheet form in CHEMDAT8 (EPA, 1997, p.5.4-2).

Emission estimates made by the WATER9 package are based on various mass transfer and biodegradation models. These models are discussed in an EPA document entitled "Air Emissions Models for Waste and Wastewater" (EPA, 1994) as well as in the Australian Emission Estimation Technique Manual for Sewage and Wastewater Treatment (Environment Australia, 1999). WATER9 contains a database of many substances emitted to air, and also allows for a non-database substance to be specified by users. When estimating the air emission of a substance, a user must select the compound from the database and specify its concentration in the wastewater.

Many studies have been conducted on previous versions of WATER9 (i.e., WATER7 and WATER8.) For example, modelled emission results were obtained using WATER8 from an industrial wastewater treatment facility in Oklahoma City, OK (Hall, 1998, in D'Amato, II, and DeHollander, 1999). Tata et al., 1994, (in Dawson and Beyerlein, 1996) studied emissions of volatile organic compounds from seven water-reclamation facilities in the Chicago, IL, area and found that WATER7 consistently over-predicted VOC emission rates. Soszynski et al., 1997, (in DeHollander, 1998) further reported that WATER8 predicted higher VOC emissions than measured results from aerated grit chambers at two large water-reclamation plants in the greater Chicago area. Ferro and Pincince, 1996, (in Dawson and Beyerlein, 1997) also found that WATER8 over-predicted VOC emissions from wastewater treatment plants.

Comparative studies have also been conducted between WATER8 or WATER7 and other leading programs. Soszynski et al., 1997, (in DeHollander, 1998) reported similar estimates of VOC emissions from aeration basins based on WATER8, TOXCHEM+ and BASTE, but found that WATER8 yielded higher VOC emissions from aerated grit chambers than the other two programs. In a study of WATER7, TOXCHEM, BASTE and PAVE, Schroy, 1997, (in DeHollander, 1998) found that PAVE predicted effluent concentration most accurately, whereas WATER7 predicted stripping most accurately.

**TOXCHEM+ (version 3, treatment and collection)**

TOXCHEM+ is an EPA-approved, emission-estimating program. It is used to determine emissions of contaminants (organic and metallic) from wastewater treatment and collection systems (Environmental Expert, 2002). It is particularly suited for synthetic/organic chemical, pharmaceutical, and pulp and paper industries. TOXCHEM+ was developed by the Wastewater Technology Centre of Environment Canada and Enviromega (Shine, 1996) and is commercially available from Enviromega (7 Innovation Dr., Flamborough, ON, Canada L9H 7H9, tel: 905-689-4410, Web site: <http://www.enviromega.com>).

The principle used by TOXCHEM+ for emission estimation is based on modelling the fate of pollutants in treatment and collection systems. This includes sorption to solids, volatilization to air, and biodegradation in liquid. TOXCHEM (the previous version of TOXCHEM+) includes both steady-state and dynamic models to predict locations and quantities of VOC emissions within a wastewater treatment facility, Melcer et al., 1994a, (in Dawson and Beyerlein, 1996). It contains a database of more than 200 substances and allows for user-specified substances.

Many studies have been conducted on the use of TOXCHEM+ and the previous version, TOXCHEM. A study by Oppelt et al., 1998, (in D'Amato, II, and DeHollander, 1999) concluded that TOXCHEM was effective in estimating quantities of biodegraded VOCs, with the exception of hexane. Ferro and Pincince, 1996, (in Dawson and Beyerlein, 1997) indicated that TOXCHEM+ over-predicted actual VOC emissions. Soszynski et al., 1997, (in DeHollander, 1998) recommended use of TOXCHEM+ as a screening tool for determining annual VOC emissions from municipal sewage treatment plants, with direct measurement advised if VOC emission rates are close to or exceed regulatory limits.

**SEAM (version 3, collection only)**

SEAM is a sewer emission assessment model for estimating emissions of VOCs and hazardous air pollutants from wastewater collection systems. It is supplied by Enviromega, the same provider as for TOXCHEM+. SEAM was developed for the Chemical Manufacturers' Association (now American Chemistry Council) and can estimate emissions from the following processes:

- process drain
- water seal
- open and closed reaches
- open and closed drop structures
- lift station, and
- air treatment device.

**BASTE (treatment only)**

BASTE is a computer-based model for estimating emissions from sewage treatment plants (EPA, 1997, p.5.4-2). It was developed by a cooperative investigation of 20 wastewater agencies in the San Francisco Bay area of California (Shine, 1996).

BASTE is structured to allow significant flexibility in simulating a wide range of treatment processes (EPA, p.5.4-2). It can simulate the fate of organic compounds in well-mixed to plug-flow reactors and diffused bubble to surface aeration. It is also capable of estimating emissions from weirs and drop structures.

Many studies have been conducted on the use of BASTE. Ferro and Pincince, 1996, (in Dawson and Beyerlein, 1997) indicated that BASTE over-predicted actual VOC emissions. Soszynski et al., 1997, (in DeHollander, 1998) recommended use of BASTE as a screening tool for determining annual VOC emissions from municipal sewage treatment plants, with direct measurement advised if VOC emission rates are close to or exceed regulatory limits.

No information has been obtained on the supplier of BASTE.

**PAVE (treatment only)**

PAVE is a computer-based model for simulating the fate of contaminants in both surface-aerated and diffused air-activated sludge systems (EPA, 1997, p.5.4-2). The model was developed for the Chemical Manufacturers' Association (now American Chemistry Council).

PAVE offers a selection of biological kinetic models (EPA, 1997, p.5.4-2). These models are based on traditional kinetic processes for biological reactors and perform traditional calculations of dissolved-oxygen concentration and waste-activated sludge flow. They work with substances of low volatilities and therefore may be limited by gas-phase mass transfer. In contrast, most other programs use oxygen as a mass transfer surrogate in their models so that only liquid-phase mass transfer resistance is considered.

No information has been obtained on the supplier of PAVE.

**CORAL+ (collection only)**

CORAL+ was a model that predicted emissions from sewer reaches based on actual data from field experiments (EPA, 1997, p.5.4-2). CORAL+ is the predecessor to SEAM and allowed for continuous or slug discharge to sewers, variation in flow depth and temperature, sewer physical conditions, and retardation of mass transfer by gas accumulation in the sewer headspace. CORAL+ estimated emissions based on ventilation input rates and patterns. It also estimated losses at sewer-drop structures.

**FATE**

Shine, 1996, indicates that FATE was a model developed by the EPA's Office of Research and Development (ORD) for estimating emissions from wastewater systems. The model is however not found at the EPA ORD's Web site. Further search indicates that there is little information available from the literature and Internet on this tool.

**PEEP**

Shine, 1996, indicates that PEEP (Pooled Emission Estimation Program) was a model developed by a cooperative investigation of 30 wastewater agencies in California. Little information is however found from the literature and Internet on this tool.

