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QUANTIFICATION OF METHANE EMISSIONS AND DISCUSSION OF NITROUS OXIDE, AND AMMONIA EMISSIONS FROM SEPTIC TANKS, LATRINES, AND STAGNANT OPEN SEWERS IN THE WORLD

Prepared for

Policy and Program Evaluation Division

Prepared by

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Research Triangle Park, NC 27711

FOREWORD

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ABSTRACT

This study is a first attempt to estimate global and country-specific methane (CH_4) emissions from open sewers and on-site wastewater treatment systems, including latrines and septic sewage tanks. It is the follow-up of an earlier report that includes CH_4 and N_2O estimates from treated industrial and domestic wastewater. This study uses an emission factor that expresses CH_4 emissions in terms of removed Chemical Oxygen Demand ($COD_{removed}$).

Combined global CH_4 emissions from latrines, septic sewage tanks, and stagnant, open sewers are estimated to be 29 teragrams per year (Tg/yr), with lower and upper bound ranges of 14 and 49 Tg/yr. These ranges reflect boundaries in the parameters that could be quantified through measurements, i.e., the emission factor and COD loadings. Major uncertainties in the estimates are associated with the degrees to which wastewater in developing and eastern European countries is treated in latrines or septic tanks, or removed by sewer. Also, the amount of wastewater that is discharged into stagnant, open sewers and the degree to which anaerobic decomposition takes place in these sewers are highly uncertain.

Latrines in rural areas of developing countries such as China and India are believed to be the single most significant source of methane, accounting for roughly 12 Tg/yr. Total emissions from stagnant, open sewers are estimated at around 10 Tg/yr. Trends in these emissions in the future will likely be driven by changes due to health considerations. Although significant gains have been made in the provision of sanitation services in cities, these efforts have been nullified by rapid urban population growth. In rural areas of developing countries, lack of sanitation is not likely to become a significant health problem and no trends towards other sanitation systems are expected. Consequently, both rural latrines and urban stagnant, open sewers are expected to remain significant sources of methane emissions in the future.

An appendix to this report includes a discussion of nitrogen cycle effects in these systems to qualify ammonia (NH_3) and nitrous oxide (N_2O) emissions from these systems. It was concluded that these systems are not likely to contribute any significant quantity of NH_3 and N_2O to the atmosphere.

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APPCD	Air Pollution Prevention and Control Division
BOD	Biochemical Oxygen Demand
CH_4	Methane
CO	Carbon Dioxide
COD	Chemical Oxygen Demand
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared
GHG	Greenhouse Gas
g/cap/day	gram per capita per day
mg/l	milligram per liter
NH_3	ammonia
NH_4^+	ammonium
N_2O	Nitrous Oxide
OPM/TM	Open Path Monitoring Transect Method
POTW	Publicly Owned Treatment Works
Tg/yr	Teragram per year
VOC	Volatile Organic Compound
WWT	Wastewater Treatment

CHAPTER 1
INTRODUCTION AND BACKGROUND

Many wastewater management and treatment systems, including sewers, centralized wastewater treatment plants, as well as off-site treatment systems, such as septic sewage systems and latrines, are suspected of being significant sources of methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3). Methane is an important greenhouse gas (GHG), while N_2O is a secondary GHG. Ammonia is a gas that plays an important role in acid rain and small airborne particle formation, as well as in nitrogen deposition.

In the United States, the Air Pollution Prevention and Control Division (APPCD), National Risk Management Research Laboratory, Office of Research and Development of the U.S. Environmental Protection Agency (EPA), has been managing a program to develop estimates of GHG emissions from waste sources, including wastewater sources, and to compile information on cost-effective control technologies. As a first step in assessing the relative importance of wastewater as a source for CH_4 emissions, APPCD conducted a desk study in 1991 - 1992, which was summarized in a Report to Congress (USEPA, 1994). The study targeted anaerobic lagoons as the primary source of suspected CH_4 emissions from wastewater.

From this initial study, APPCD concluded that major data limitations existed for quantifying actual emissions from wastewater sources including the fraction of wastewater subject to anaerobic decomposition, and the outflow and composition of industrial wastewater. APPCD initiated a field test program to develop more accurate GHG emission factors based on actual emission measurements and to improve country-specific activity data for industrial and domestic wastewater treatment (WWT). The field test program involved the use of the open path monitoring/transect method (OPM/TM) technique with Fourier Transform Infrared (FTIR) spectroscopy to measure emissions from two beef processing plants, one chicken processing plant, and two facultative municipal WWT lagoons. Wastewater and process data were collected during the tests to allow for the development of emission factors. The field test results and discussion are documented in Eklund and LaCosse (1997). In conjunction with the field tests, research was undertaken to improve the quality of available activity data. Findings and country-specific and global CH_4 and N_2O estimates from treated wastewater are documented in a report entitled: "Estimates of Global Greenhouse Gas Emissions from Industrial and Domestic Wastewater Treatment" (Doorn, et al., 1997), produced under EPA Contract No. 68-D4-0100. The executive summary of this report is included as Appendix A. In the text, this report is referred to as the "Emissions-from-WWT report."

One of the findings from the treated wastewater study was that anaerobically degrading wastewater that is not treated at centralized WWT facilities may be a significant source of GHG emissions. Such wastewater sources include decentralized (on-site) anaerobic treatment systems, such as latrines and septic sewage tanks, as well as wastewater in stagnant, anaerobic sewers in developing countries. This study estimates CH_4 emissions from these sources, using the emission factor and methodology for treated domestic sewage from the Emissions-from-WWT report. Furthermore, this report provides background information and country- or region-specific activity data on various on-site treatment and sewer systems.

Because sanitation system choice and availability is strongly dependent on population density and per capita income, this study differentiates between country-specific rural, urban high-income, and urban low-income population groups. For example, in developing countries, high-income urban populations usually have access to some convenient type of sewage disposal system, whereas the urban low-income population may have little or no access. In rural areas, which have low population densities, there is less urgency for a sewage treatment or removal system from a sanitation perspective; people may use on-site systems or the surrounding fields. Also, the per capita cost for sewer infrastructure is inversely proportional to population density.

Also, this report includes a discussion of nitrogen cycle effects in septic tanks, latrines, and stagnant, open sewers on NH_3 and N_2O emissions (Appendix B). Because of the complex pathways of organic nitrogen decomposition, nitrogen emissions could not be quantified. However, knowledge of the nitrogen cycle in septic tanks, latrines, and stagnant, open sewers suggests that anaerobic wastewater in these systems does not contribute any significant quantity of NH_3 and N_2O to the atmosphere. This discovery indicates that the estimation of global GHG and NH_3 emissions can safely overlook the production of NH_3 and N_2O from septic tanks, latrines, and stagnant, open sewers at a global level.

CHAPTER 2
RESIDENTIAL, DOMESTIC, AND INDUSTRIAL WASTEWATER

Metcalf & Eddy (1991) define residential wastewater as the spent water originating from all aspects of human sanitary water usage, consisting of wastewater from toilets, baths, kitchens, and laundry-rooms. (Note that this definition does not express the source of the wastewater. Hence, residential wastewater also includes wastewater that is generated as a result of human sanitary water usage at home, at the work place, or at recreational facilities, such as restaurants, theaters, or sports clubs.)

Domestic (or municipal[1]) wastewater is defined as all wastewater that is discharged into municipal sewers to be removed from the premises and to be treated at a central municipal WWT plant[2] or disposed of via an outfall. Domestic wastewater sources include non-point sources, such as greengrocers, butchers, bakers, and workshops. In addition, a certain amount of raw or semi-treated industrial wastewater is often discharged into municipal sewers. In countries with adequate regulations and enforcement, industrial discharges to municipal sewers are limited to those kinds of wastewater that are treatable at the local POTW. These types of wastewater would include wastewater from the food and beverage industry, the textile industry, and from certain sectors of the organic chemicals industry. In other countries the situation may be radically different and industrial wastewater may be discharged indiscriminately into municipal sewers (Doorn et al., 1997).

Quantification of the fraction of industrial organic BOD and/or chemical oxygen demand (COD) in residential wastewater is difficult. The amount of wastewater COD in absolute and in relative terms (per unit of output or per liter of wastewater), is highly variable and depends on the type of product and industrial process. Industries that produce limited wastewater COD outflows may be permitted to direct all outflow to municipal sewers, whereas industries with large wastewater COD outflows in the same country are more likely to be required to apply on-site WWT. The establishment of on-site treatment may be regulatory driven or it may be company policy for other reasons, such as public image maintenance. Also, depending on local regulations and the enforcement thereof will vary from country to country and certain corporations may apply comprehensive on-site WWT in some countries, whereas the same corporations may apply no or limited WWT in other countries for the same industrial process (Doorn, et al., 1997).

The fraction of COD removed from the industrial wastewater stream depends on the type of treatment system. The primary treatment system of some plants may be designed to remove most or all

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1 The terms municipal and domestic wastewater often are used interchangeably throughout the literature.

2 Municipal WWT plants are often referred to as publicly owned treatment works (POTW) in the United States.

organic COD, e.g., when the COD has remaining commercial value as is the case with sugar. Conversely, other primary treatment systems may be designed to remove only inorganic solids or toxic compounds and deliberately leave the organic COD in the wastewater stream for treatment at the municipal WWT plant. In addition, the type of treatment will depend on the geographic location of the industry. For example, industrial processes that require large amounts of process water and that produce large quantities of wastewater (e.g., pulp and paper mills) are likely to be located near a fresh water source, such as a river or lake. The location on the river bank also allows for convenient discharge of the wastewater, be it raw or purified. In this situation, the plant is unlikely to release wastewater to municipal sewers.

Included in the Emissions-from-WWT report are estimates for the quantity of COD that is discharged to city sewers for different industrial categories for the major producing countries. These estimates cannot easily be combined with the data for municipal wastewater from the same report because the most populous countries (which produce the most residential wastewater COD) are not necessarily equal to the countries with the highest wastewater COD output per industrial category. In order to estimate the contribution of industrial COD to municipal sewers, it was decided to use the global average. The quantity of COD from industrial wastewater that is discharged into municipal sewers around the world is estimated at 18 Tg/yr (Emissions-from-WWT report, Table 18, COD-to-City-Sewers column); data from Table 17 and 19 in the Emissions-from-WWT report were combined to estimate the total global residential COD per year that is discharged into municipal sewers, i.e., 73 Tg/yr. Accordingly, this report uses 18/73 or 25 percent for the overall fraction of industrial wastewater COD in municipal sewers.

Domestic wastewater that has not received indiscriminate industrial discharges typically contains only components that are organic in nature (carbohydrates, lipids, proteins, soaps) and may be considered somewhat homogeneous. An indication of the average composition of U.S. municipal wastewater is given in Table 2-1.

TABLE 2-1. Typical Composition of Fresh Domestic U.S. Wastewater

COMPONENT	RANGE (mg/l)*	RANGE (g/cap/day)**	COMPONENT	RANGE (mg/l)*	RANGE (g/cap/day)**
Solids, Total	730 - 1,180	277 -448	Organic Carbon, Total	200 - 500	76 - 190
Dissolved, Total	400 - 700	152 - 266	Chemical oxygen Demand (COD)	550 - 700	209 - 266
Mineral	250 - 450	95 - 171	Total Nitrogen	40 - 50	15 - 19
Organic	150 - 250	57 - 95	Organic	15 - 20	6 - 8
Suspended	180 - 300	68 - 114	Free ammonia	25 - 30	10 - 11
Mineral	40 - 70	15 - 27	Nitrates and nitrites	0	0
Organic	140 - 230	53 - 87	Phosphorus, Total	10 - 15	4 - 6
Total Settleable Solids	150 -180	57 - 68	Chlorides	50 - 60	19 - 23
Five day biochemical oxygen demand (BOD_5)	160 - 280	61 - 106	Alkalinity (as calcium carbonate)	100 - 125	38 - 48
VOC's	< 1		Oil and Grease	90 - 110	34 - 42
Typical pH	7.0 - 7.5				

Based on Mullick (1987).
* milligrams per liter.
** grams per capita per day. Assumed water consumption of 100 gal. (380 liter) per capita. Assumed medium use of garbage disposals, moderate income population.

As did the Emissions-from-WWT report, this report uses daily per capita organic loadings rates to quantify residential and domestic organic wastewater outflow. Residential daily per capita BOD loadings depend on diet, metabolism, and body weight, as well as cleansing, bathing, laundering, and food preparation habits, including the use of kitchen garbage disposals. Table 2-2 includes available BOD and COD loadings for residential wastewater in different regions in the world, including those from the Emissions-from-WWT report. In the table, the per capita BOD loadings used in the Emissions-from-WWT report reflect the lower range of the loadings from Mullick (1987) and Laak (1980). Based on the data represented in Table 2-2 it was estimated that the ratio between municipal wastewater BOD and organic COD is approximated at 2.5.

2.1 EFFECT OF INCOME AND URBANIZATION

As mentioned in the Introduction and Background Section, this report distinguishes between rural, urban high-income, and urban low-income populations, because availability and choice of sewage disposal system are dependent on income and population density. According to the World Bank's World Development Report on Poverty (1990) in Bartone (1994), about one quarter of the world's urban population lives in absolute poverty and many more live in substandard conditions. In this report, 75 percent of the urban population for most developing countries has been classified as low-income, which is higher than what is indicated by the aforementioned Report on Poverty. The choice of this value is based on expert judgment by the authors and reflects relative sanitary conditions only and should not be construed as an indication of other factors that determine poverty or privation. For countries in "Other Asia" a low-income fraction of 50 percent is used instead of 75 percent. This region includes many oil-producing countries, which are assumed to have a larger middle- and high-income- class compared to other developing Asian countries. For developed and eastern European countries, the distinction between urban high-income and low income was not made.

Table 2-3 provides country-specific population and urbanization data (from UNEP, 1993), as well as BOD and COD loading rates. The COD ranges (g/cap/day) from Table 2-2 were converted into the low, mean, and high estimates of "Total COD Generation" (Tg/yr) by multiplying by the population (P) and by 365 (days/year).

TABLE 2-2 Available BOD_5 and COD Loadings for Municipal Wastewater in Different Regions in the World

REGION OR COUNTRY	WASTE	BOD_5 LOADING (g/cap/day)	COD LOADING (g/cap/day)	REFERENCE
USA	Excreted	27 ± 8	70 ± 20	Laak (1980), Mullick (1987)
	Toilet tissue	10 ± 5	40 ± 20	
	Bath, laundry, kitchen wastewater	± 50	± 90	
	Total residential	87 ± 25	200 ± 50	
USA	Total residential wastewater (use for septic tanks, cess pools, and latrines.)	65 ± 15	160 ± 70	from Doorn, et al. (1997)
Developing countries		35 ± 10	90 ± 40	
Eastern Europe		45 ± 10	110 ± 45	
OECD (ex. U.S.)		60 ± 15	140 ± 65	
USA	Total wastewater (use for stagnant sewers)		200 ± 87	25% added for industrial wastewater (only for city sewers)
Developing countries			113 ± 50	
Eastern Europe			138 ± 56	
OECD countries (ex. U.S.)			175 ± 81	

TABLE 2-3. COUNTRY-SPECIFIC POPULATION, URBANIZATION, AND RESIDENTIAL WASTEWATER BOD/COD GENERATION DATA

Country	Population (P) (million)	Fraction of Population (U) that is Rural	Urban total	Urban high-income	Urban low-income	BOD Generation (g/cap/day)	Total COD Generation (COD) (Tg/yr) low	mean	high
AFRICA									
Nigeria	127	0.65	0.35	0.09	0.26	35+/-10	3	4	5
Egypt	59	0.56	0.44	0.11	0.33	35+/-10	1	2	2
Kenya	28	0.76	0.24	0.06	0.18	35+/-10	1	1	1
South Africa	43	0.51	0.49	0.12	0.37	40+/-10	1	2	2
Zimbabwe	12	0.71	0.29	0.07	0.22	40+/-10	0	0	1
Other Africa	492	0.60	0.40	0.10	0.30	35+/-10	11	16	20
ASIA									
China	1,238	0.74	0.26	0.07	0.20	35+/-10	28	40	51
India	931	0.74	0.26	0.07	0.20	35+/-10	21	30	38
Indonesia	201	0.71	0.29	0.07	0.22	35+/-10	5	6	8
Pakistan	135	0.68	0.32	0.08	0.24	35+/-10	3	4	6
Bangladesh	128	0.84	0.16	0.04	0.12	35+/-10	3	4	5
Japan	126	0.23	0.77	0.77	0	55+/-15	5	6	8
Other Asia	726	0.50	0.50	0.25	0.25	35+/-10	17	23	30
EUROPE									
Russia	150	0.34	0.66	0.66	0	50+/-10	5	7	9
Germany	81	0.28	0.72	0.72	0	60+/-15	3	4	6
United Kingdom	58	0.11	0.89	0.89	0	60+/-15	2	3	4
France	58	0.27	0.73	0.73	0	60+/-15	2	3	4
Italy	58	0.31	0.69	0.69	0	60+/-15	2	3	4
Other OECD	113	0.20	0.80	0.80	0	60+/-15	5	6	8
Other Europe	217	0.35	0.65	0.65	0	60+/-15	9	12	15
NORTH AMERICA									
United States	263	0.25	0.75	0.75	0	65+/-15	13	17	20
Canada	29	0.23	0.77	0.77	0	60+/-15	1	2	2
LATIN AMERICA AND CARIBBEAN									
Brazil	161	0.25	0.75	0.19	0.56	35+/-10	4	5	7
Mexico	94	0.27	0.73	0.18	0.55	35+/-10	2	3	4
Others	225	0.25	0.75	0.19	0.56	35+/-10	5	7	9
AUSTRALIA AND NEW ZEALAND									
Australia	18	0.15	0.85	0.85	0	60+/-15	1	1	1
TOTAL	5,770						154	212	270

CHAPTER 3

ON-SITE TREATMENT SYSTEMS AND OPEN SEWERS

This section describes different on-site treatment systems and provides information on the extent to which they are used throughout the world. Also included is background information that defines the degree to which each system is anaerobic. In addition, this section provides country- or region-specific activity data on the availability of sewer systems, as well as a discussion on the possible anaerobicity of sewers.

3.1 ON-SITE TREATMENT SYSTEMS

On-site treatment systems include standard latrines, septic sewage systems, and systems that require some type of manual collection, such as bucket latrines. The use of septic sewage systems is common in rural and suburban areas throughout most countries in the world, including eastern Europe and the United States. Latrines are widely used in developing countries. Below, the most common on-site treatment systems are introduced.

3.1.1 Septic Tanks, Aqua Privies, and Cesspools

All these systems consist of a water-filled tank in which solids are allowed to settle (Rybczynski, 1979). They can receive wastewater from one or several dwellings. In a cesspool, the liquid waste is presumed to soak away. When the cesspool is fitted with an outlet pipe, it is indistinguishable from a septic tank or aqua privy. The effluent from an aqua-privy usually flows to a soak-away area, but may also be fed into a sewer system (Feachem and Cairncross, 1978). Aqua privies and cesspools are not very common compared to septic tanks (WHO/UNICEF, 1993) and are excluded from further discussion.

A septic tank is a horizontal, continuous-flow, one-story sedimentation tank that accepts all wastewater from an individual dwelling or a group of houses, including bath-, kitchen-, and laundry-water. The wastewater is allowed to flow slowly to permit settleable suspended matter to settle to the bottom, where it is retained until anaerobic decomposition is established. Digested solids will form a permanent sludge at the bottom of the tank and require periodic removal with a vacuum truck. (Depending on the size of the tank and the number of users, pumping should be done every couple of years.) Gases resulting from anaerobic composition, including CH_4, carbon dioxide (CO_2), and hydrogen sulfide, are vented from the septic tank through a vent stack or through the effluent outlet pipe. Recommended retention time for the wastewater in the tank is one to three days (Burks and Minnis, 1994).

Effluent from the septic tank consists of partially treated wastewater that still contains most non-settleable (dissolved and suspended) solids. It is discharged below the ground surface into a drainage field that is composed of a gravel and/or sand bed that is permeable to the effluent and to air. The drainage field is designed to provide secondary treatment by natural processes in the soil. These processes are physical, chemical, and biological. The soil acts as a filter, as well as an adsorption mechanism to remove remaining solids, nutrients, and pathogens. In addition, aerobic organisms in the soil digest the organic effluent matter (RHI, 1992). The combination of septic tank and drainage field is referred to as a septic sewage system.

The BOD_5 removal efficiency in a septic tank is around 50 percent, whereas, the organic solids removal efficiency is around 80 to 90 percent (Metcalf & Eddy, 1991). The discrepancy between the two numbers can be explained by the dissolved BOD, which is not removed in the septic tank.

3.1.2 Standard Latrines

Standard pit latrines are traditional "hole in the ground" solutions that consist of an enclosed structure and a squatting plate above the hole, which may be either dug or bored (referred to as "bore-hole latrines"). Simple pit latrines are prone to smell and fly problems and in many cases the design has been modified to reduce these problems. Improvements include latrines with vent pipes (VIP latrines) or offset pits to enable hand flushing (pour flush latrines). Pits are used until full, then either abandoned and relocated, or emptied and reused. The pits are unlined but may be reinforced, for example, by using oil drums with the tops and bottoms removed. Liquids are presumed to soak away and solids decomposition can be classified as anaerobic (Burks and Minnis, 1994). In this study, latrines are assumed to have an efficiency of 100 percent.

Latrines may serve individual households or larger groups of up to several hundred people and may be fitted with several squatting plates and partitions for privacy (World Bank, 1979; Rybczynski, 1979; Feachem and Cairncross, 1978). These systems are widely used throughout rural and urban settings in developing countries (WHO/UNICEF, 1993).

3.1.3 Bucket Latrines/Nightsoil Collection, Vault Latrines

These systems have in common the need for regular emptying. One of the oldest and generally least hygienic systems used in urban areas is the bucket latrine. A squatting slab or seat is placed directly above a bucket to collect excreta. The bucket location is at the outside wall of the dwelling and is accessible from the street or alley. The bucket is emptied every day or every several days by a sweeper who manually carries the bucket to a transfer or collection station. Vault latrines are more convenient and hygienic than bucket latrines because they allow for a water seal. Excreta plus small amounts of water for flushing are stored in sealed vaults under or beside the house. These vaults are emptied about once every two weeks by vacuum truck (or by hand-dipping if the infrastructure does not allow for motorized transport) (Feachem and Cairncross, 1978; Foster, 1980).

Until the late 1970s, bucket and vault latrine systems were widespread in urban locations in eastern Asia, including Japan, Taiwan, China, Korea, and Malaysia. Also, bucket latrines were fairly popular in African cities and towns. For example, between 50 to 80 percent of residential sewage in four cities in Japan was collected as nightsoil, and in Kumasi, Ghana, a city of 500,000 inhabitants (in 1978), 50 percent of the population made use of bucket latrines (World Bank, 1979). Traditionally, the nightsoil would be sold to local farmers as fertilizer, however, demand for nightsoil has decreased significantly. As an alternative disposal method, nightsoil would be trenched for land treatment or fed into city sewer lines to be treated at the local WWT plant (World Bank, 1979). Nevertheless, with ever-increasing pressure on civil services, due to rapid urbanization, lack of operating funds, and modernization of agriculture, many nightsoil collection systems have broken down and septage is dumped uncontrolled into the nearest wetland, manhole, or open sewer (Bartone, 1990). In addition, bucket latrines are widely seen as undesirable because of their unsanitary nature (World Bank, 1979).

Biological degradation in a bucket latrine, and especially in a vault, may be partially anaerobic. However, in the short time frame before collection, the nightsoil is not likely to undergo significant degradation. Depending on the disposal method, the collected nightsoil may still be a source of CH_4, for example if it is dumped into an open anaerobic sewer. Assessment of the actual fraction of nightsoil that may degrade anaerobically would, at best, be a coarse guess.

3.1.4 Extent of Use of On-Site Treatment Systems

3.1.4.1 Developing Countries

Figure 3-1 provides an overview of global sanitation coverage by technology type based on a survey from 82 developing countries (WHO/UNICEF, 1993). Technology types specified in the WHO/UNICEF survey are: house connection and small bore sewer, septic (sewage) system, various types of latrines, and "other." The survey distinguishes between urban high-income, urban low-income, and rural populations, but does not define the income cut-off [3,4]. The WHO/UNICEF survey does not include information on the disposal method or possible off-site treatment, i.e., it is unclear if sewered wastewater is treated at a WWT plant or disposed of via an outfall.

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3 It is assumed that the urban-high income is represented by the upper and middle classes, which typically are small for developing countries. The urban low-income population is represented by the slum dwellers and other lower classes. The rural population is also expected to be low-income.

4 The WHO/UNICEF document includes data for different continents and geographical areas, i.e., Africa, Western Asia, Asia & Pacific, and Latin America & Caribbean. These data have been incorporated into the spreadsheets used to calculate emissions.

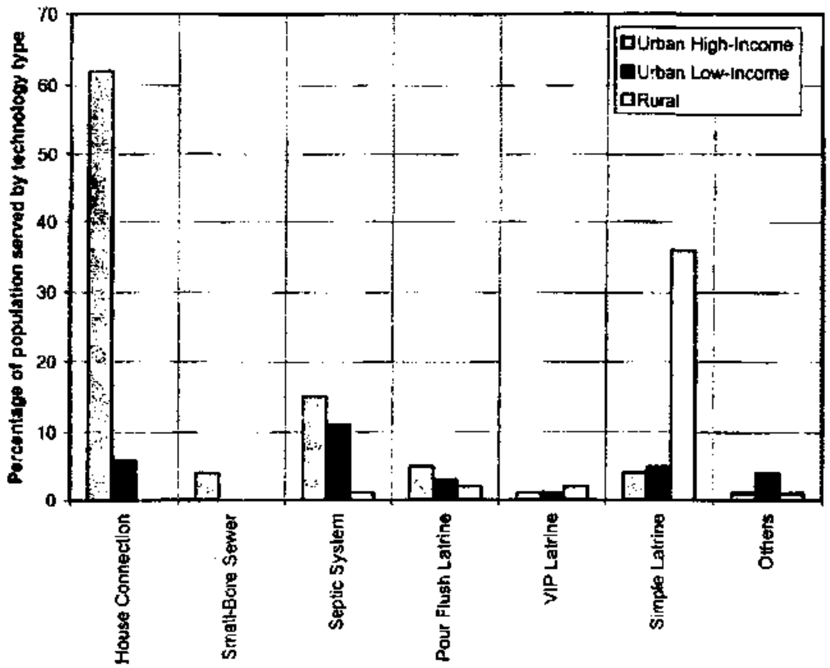

Figure 3-1. Overview of Global Sanitation by Technology Type for 82 Developing Countries

According to Figure 3-1, 92 percent of the urban high-income population in the surveyed countries has some type of coverage, compared to only 30 percent of the urban low-income population and 42 percent of the rural population. Consequently, 70 percent of the urban low-income population and 58 percent of the rural population has no access to a sanitation system. Wastes from these populations are assumed to be disposed of indiscriminately in the environment where it will likely degrade aerobically and not contribute to CH_4 emissions. People in rural areas may perhaps build out-houses over a lake or stream or they may use designated areas of the surrounding bush (Marks, 1993).

The category "Others" in Figure 3-1 was not specified in the text. It was assumed by the authors that this category includes bucket latrines/nightsoil collection systems and vault latrines by default. This category is one percent for high-income populations and less than five percent for the low-income and rural groups. Because bucket latrines/nightsoil collection systems and vault latrines play a minor role, they are not considered further as significant potential GHG sources.

3.1.4.2 Developed Countries

Table 3-1 includes comprehensive data on urban and rural sewerage coverage and the use of on-site disposal systems for European countries, including Turkey, and Israel (WHO, 1990; Artemel, 1995). In WHO (1990) on-site disposal systems are classified as either "adequate" and "inadequate," but these terms were not defined in the text. It was assumed by the authors that septic sewage systems are considered adequate, and that cesspools and latrines are considered inadequate on-site disposal systems. According to Table 3-1, most European urban residents have home sewer connections. Only in Greece, Hungary, Poland, Romania, and the former Yugoslavia septic sewage systems are being used by more than 10 percent of the urban population. Eastern European sewage treatment and disposal data were based on anecdotal data from Poland (Jocewicz, 1997). Urban Poland has a sewer infrastructure that accepts 90 to 100 percent of domestic sewage. A small amount of urban residents may make use of septic tanks (five percent). Only 40 percent of rural residents have sewer connections. The use of septic tanks is widespread in rural Poland (80 percent) and latrines are also in use. The respondents had different views on the degree to which sewered wastewater is treated. Estimates vary from 50 to 95 percent. It is believed that the situation is better for urban sewage. The best guess is that between almost 70 and 95 percent of urban domestic sewage is treated, whereas, about 50 percent of rural sewered wastewater is treated.

The status of WWT is different for rural Europe compared to urban Europe. In rural areas, the use of septic sewage systems is widespread. In many countries more than 50 percent of the rural population uses septic sewage systems. It is important to note that the rural population in Europe is relatively small, because most countries are highly urbanized (Table 2-3). Therefore, the total population that does not use sewers for wastewater disposal is also relatively small. Cesspools and/or latrines are still being used in rural areas in some European countries, including Albania, Hungary, Romania, former Yugoslavia, and the former Union of Soviet Socialist Republics (USSR).

TABLE 3-1. SEWAGE DISPOSAL AND TREATMENT FOR EUROPE, TURKEY AND ISRAEL

COUNTRIES	Urban	Sewerage Coverage and On-site Treatment RURAL			Sewerage Coverage and On-site Treatment URBAN			WWT*				DISCHARGE TREATED WW TO			DISCHARGE RAW SEWAGE TO		
All units in percent		Sewer	Sept Tank	Inade-quate	Sewer	Sept Tank	Inade-quate	None	Prim.	Sec.	Tert.	Sea	Surface waters	Land	Sea	Surface waters	Land
Albania	36	50	40	10	90	5	5										
Austria	58	20	80		100			10	5	80	5		100			100	
Belgium	96	54	46		98	2		55	45								
Bulgaria	68	56	40	4	85	1	14	56	45								
Czechoslovakia (former)	77	55	40	5	85	10	5	34	2	64			98	2		85	15
Denmark	85	1	99		99	1		5	25	65	5						
Finland	60	10	90		91	9		1		1	99	49	51		3	97	
France	73	63	37		100			60	40			20		80	25		75
Germany (DDR) (former)	85	70	30		91	9											
Germany (FRG) (former)	85	86	14		97	3			11	81	8						
Greece	63	54	40	6	60	35	5	82	18			95	5		60	40	
Hungary	64	5	80	15	76	20	4	4	10	82	4		99	1		99	1
Iceland	91	100	0		100			90	10			96	4				
Ireland	57	23	74	3	99	1		30	15	54	1	10	90		38	12	
Israel	65	60	40		93	7		10	15	70	5		52	48	10	90	
Italy	69	58	42		96	4		70									
Luxembourg	84	93	7		100			8	8	84			100			100	
Netherlands	89	18	82		100			15	7	75	3	5	95			100	
Norway	75	0	100		94	6		23	9	34	34	70	29	1	96	4	
Poland	62	43	50	7	79	16	5	37	40	23							
Portugal	34	9	86	5	83	12	5	55	20	23	2	34	65	1	42	43	15
Romania	54	14	76	10	73	22	5	20	18	62			80	20		100	
Spain	78	40	60		100			74	17	9							
Sweden	84	70	30		100				1	23	76	46	54				
Switzerland	62	82	18		100			17		28	55		100			100	
Turkey	61	20	65	15	56	36	8	70	14	16	0	50	45	5	1	7	92
USSR (former)	66	60	30	10	90	10											
United Kingdom	89	89	11		100				10	80	10						
Yugoslavia (former)	56	33	57	10	84	12	4	27	54	11	9						

Sources: WHO (1990); and Artemel (1995) for Turkey.

* Primary WWT consists of processes such as sedimentation and screening.
Secondary WWT is biological treatment.
Tertiary WWT may consist of chemical processes, reoxidation, chlorination, etc.

Twenty-five percent of the total U.S. population uses septic sewage systems for sewage treatment (U.S. Department of Commerce, 1990), whereas, the degree of urbanization is 75 percent. In this study it is assumed that 90 percent of the rural population of the United States uses septic sewage systems. Only eight percent of the rural population has sewer connections and the remaining two percent is assumed to use latrines. Septic tanks are used by five percent of urban U.S. inhabitants. These ratios were also adopted for Canada and Australia.

3.2 SEWER SYSTEMS

A conventional (closed) sewer is defined as an artificial, usually underground conduit for carrying off sewage and/or rainwater run-off. Sewers that are built solely for the purpose of carrying off rainwater are called storm sewers. Storm sewers do not contain significant loadings of organics and are, therefore, not considered to be potential GHG emission sources. Typically, a closed sewer system consists of a service line that runs from the dwelling to a collector in the street. The collector carries the sewage by gravity to an interceptor sewer. If topography dictates, the collector sewer may discharge to a pump station, which transports the sewage via a force main to another collector or interceptor at a higher elevation. Ultimately, the collection system delivers the sewage to a wastewater treatment plant or discharges the sewage in a river, lake, ocean, or other natural system.

Sewer lines do not necessarily transport sewage to a WWT plant. Instead they may also serve outfalls that discharge into an ocean, sea, lake, or river. Outfalls are used all over the world for the disposal of untreated or semi-treated wastewater. In many countries outfalls are used to dispose of wastewater that is either untreated or has received some type of preliminary or primary treatment (Proctor, 1989; Andreadakis et al., 1993). For example, an outfall that serves part of Rio de Janeiro, Brazil, dumps six cubic meters per second (136 million gallons per day) of raw wastewater into the Atlantic Ocean (Jordaõ and Leitaõ, 1990).

Sewers may be open or closed (covered or underground). In most developed countries and in high-incom urban areas in other countries, sewers are usually closed and underground. Underground location is most sanitary and prevents the accumulation of solid debris, such as trash, branches or rocks. Wastewater in closed, underground sewers is not subject to insolation and will stay relatively cool, compared to surface water, including water in open sewers. In urban areas in developing countries and some developed countries, sewer systems often consist of networks of canals, gutters, and ditches, which are referred to as open sewers.

The United Nations and some other international organizations labeled the period between 1980 and 1990 "The International Drinking Water Supply and Sanitation Decade." During this period, substantial absolute advances were made in providing more people from developing countries with adequate drinking water facilities. (Rotival, 1987.) Also, many improvements were made in the level of sanitation in different areas of the world, however these were often outpaced by urban population growth. The relative success in providing cities with water has generated greater volumes of both domestic and industrial wastewater to be managed. As cities densify, the per household volumes of wastewater exceed the infiltration capacity of local soils and require some other drainage system. (Bartone, 1994.) Hence, cities in arid areas in developing countries also can be expected to have open sewers, although these sewers will have less flow than similar sewers that accept substantial amounts of rain water.

3.2.1 Extent of Sewerage

In many developing countries, sewerage infrastructure does not reach large sections of the population (see Figure 1). Especially in rural areas and urban slums, sewerage is virtually non-existent (WHO/UNICEF, 1993; Draaijer, 1994 in Doorn et al., 1997). The lack of sewerage in rural areas in developing countries is rarely a large pollution or sanitation problem because the population density is low. However, in urban areas lack of adequate sanitation and sewerage can easily become a health issue and may also result in serious degradation of the environment. When wastewater is not sewered off or treated in adequate on-site systems, it accumulates in the direct environment, where it will degrade over time and likely contribute to the pollution of ground and surface water.

Official statistics on the extent of sewerage often do not acurately represent the actual situation. For example, the section of the urban low-income population that consists of slum dwellers may not be included in the count, thereby increasing the ratio of people with adequate sanitation coverage.[5] Also, official publications may not account for inadequate or malfunctioning sewer or treatment systems (Bartone, 1990).

In Africa in the mid-eighties, only 14 percent of the population had a sewerage connection. In Latin America and the Middle East, official figures indicate that 41 percent of the urban population has sewers (capitals and other large cities have 50 to 85 percent; for secondary cities this number is 10 percent). In Asia and the Pacific, less than 20 percent of the total urban population has sewer-to-house connections. (Bartone, 1990; WHO/UNICEF, 1993.) For reasons mentioned earlier in this Chapter these numbers should be treated with caution.

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5 Sanitation is defined as a sanitary means of excreta disposal and sanitation coverage is the proportion of the population with access to a sanitary facility for human excreta disposal in the dwelling or within a convenient distance from the user's dwelling.

3.2.1.1 Potential for Anaerobic Decomposition in Sewers

Anaerobic biodegradation reaction kinetics in open sewers depends on multiple parameters including, residence time, water temperature, and dissolved oxygen content. No qualitative data were found that pertain particularly to wastewater behaviour in open sewers. It may be expected, however that dissolved oxygen in fresh sewage can be depleted within a few hours (Hulshoff-Pol, 1986 in Doorn, et al., 1997). As a result, actual CH_4 generation resulting from anaerobic degradation may also start within a similar time frame, because active anaerobic organisms are already present in the sewage. In developing countries, open sewers are often clogged with debris, partially or entirely blocking the flow of wastewater and thereby increasing the residence time. In addition, many developing countries have a sunny, tropical climate, leading to relatively high water temperatures in open sewers. Consequently, wastewater in open sewers in many developing countries is likely to be septic and a likely source for CH_4 emissions. This conclusion is supported by anaecdotal evidence from Wiegant and Kalker, 1994; Draaijer, 1994; and Doppenberg, 1994, (all in Doorn et al., 1997) who provide anecdotal evidence that wastewater in many open sewers in various developing countries is practically stagnant, and brownish or black in color, and is visibly emitting gases. In this report it is assumed that 75 percent of wastewater in open sewers in developing countries will degrade anaerobically. This number is based on professional judgment by the authors using the anecdotal evidence provided above. The remaining 25 percent may degrade aerobically or not at all, due to the presence of compounds that are toxic to the pertinent bacteria.

It is unclear if closed municipal sewers in developed countries are also a source of CH_4. Although, closed sewers are typically designed to avoid anaerobic conditions to prevent hydrogen sulfide generation, anaerobic conditions can develop in certain sections of the sewer system, for instance, pump station wet wells and force mains which have no head space. A Research Triangle Institute (RTI) field study found CH_4 emissions at manholes in sewers in Durham, North Carolina. As part of the RTI study, a preliminary estimate of CH_4 emissions from sewers was developed, based on the estimated total number of manholes in the United States: roughly 0.16 Tg/yr (Thorneloe, 1997). Additional research is required to produce a more reliable CH_4 emissions estimate from closed sewers and this possible source category is not considered further in this study.

Excessive discharge of organics in rivers, lakes, or wetlands of limited capacity may also lead to local anaerobic conditions, but these conditions are not likely to cause CH_4 emissions. The reason is that rivers, lakes, or wetlands that are receptacles for anoxic organic wastewater are presumed to have a facultative top-layer, preventing these emissions. Also, organics discharged into oceans are unlikely to produce anaerobic GHGs emissions because the salt water environment is not conducive to anaerobic bacteria and other chemical and/or biochemical degradation mechanisms are likely to prevail (Wiegant and Kalker, 1994 in Doorn et al., 1997).

3.2.2 Extent of Centralized Treatment

For most countries in the world except for European countries, data from the Emissions-from-WWT report were used to quantify the extent of centralized WWT. New data were found for European countries, including Turkey, and Israel (see Table 3-1). Unfortunately, these data do not distinguish between rural and urban populations, nor do they include information on the former USSR. Because most European countries are largely urbanized, the country data were copied for the urban population and for the rural population engineering judgement was used.

According to Table 3-1, which includes data from 1990, many countries, including France, Greece, Portugal, Italy, and Spain, do not treat most of their municipal wastewater. However, in recent years the situation in southern and western Europe has begun to improve. Under pressure from European Union regulations, countries with bad WWT track records have started campaigns to improve the state of their WWT. In addition, countries in southern Europe, such as Spain, Greece, and Turkey, have been spurred to improve and increase local WWT due to economic pressure from the tourist industry (World Water and Environmental Engineering, 1992). These recent changes have not been reflected in the numbers and their possible impact will be discussed in the "Methane Emission Estimates and Uncertainties" and "Trends" sections.

CHAPTER 4

METHANE EMISSION ESTIMATION METHODOLOGY, ACTIVITY DATA, AND GLOBAL AND COUNTRY-SPECIFIC CH_4 EMISSION ESTIMATES

4.1 METHODOLOGY

Methodologies and activity data used to estimate CH_4 emissions from treated wastewater and the resulting CH_4 emissions estimates are documented in the Emissions-from-WWT report. This report includes CH_4 emission estimates for wastewater that is not centrally treated at a POTW or industrial WWT plant. In this report, the methodology for estimating CH_4 emissions for domestic wastewater from the Emissions-from-WWT report was modified to improve the CH_4 emission estimates for wastewater that is not centrally treated. The expanded methodology differentiates between three separate source categories: septic tanks, latrines, and stagnant, open sewers. The methodology was modified to distinguish between urban high-income, urban low-income, and rural populations, because sewage disposal and/or treatment options available to the three different categories vary considerably (see Figure 3-1). The distinction between urban high-income and urban low-income was not made for developed or eastern European countries, because income differences (as reflected in sanitation provisions) are less pronounced in these countries.

The comprehensive methodology used in this report to estimate CH_4 emissions from domestic wastewater that is not centrally treated for country *c* is represented by the equation below. Subscripts *c*, *s*, and *u* denote country or group of countries, treatment or disposal system (stagnant, open sewers, septic tanks, and latrines), and population-income group (urban high, urban low, rural-low), respectively.

$$CH_4\ Emissions_c = EF \times P_c \times BOD_c \times M \times \sum_u \sum_s [\, U_c \times T_{csu} \times (1 + I) \times AF_{cs} \,] \quad (Tg/yr)$$

where:

EF	=	emission factor, 0.3 ± 0.1 gram CH_4 per gram COD removed;
P_c	=	country population (from Table 2-3);
BOD_c	=	country-specific per capita BOD generation (g/day) (from Table 2-3);
M	=	conversion from BOD (g/cap/day) to COD (Tg/yr) (from Table 2-3);
U_c	=	population-income group fraction (from Table 2-3);
T_{csu}	=	degree of utilization of treatment or disposal system;
I_s	=	correction for industrial BOD/COD (I_s = 0.25 for sewers only), (see page 4);
AF_{cs}	=	degree to which BOD/COD is degrading anaerobically in system *s*.

4.2 ACTIVITY DATA

Tables 4-1, 4-2, and 4-3 include comprehensive, country-specific activity data for rural, urban-high, and urban-low populations, respectively. In the following text, the assumptions used in these tables are discussed and the data sources summarized.

- Table 4-3 (urban low-income) contains no data for European and developed countries, because for these countries the differentiation between urban high-income and urban low-income populations was not made. Information on the urban populations for these countries is condensed in Table 4-2.
- Emissions-from-WWT-columns in Table 4-1 (rural) and Table 4-3 (urban low-income) contain only zeroes, because it is assumed that for rural and low-income populations all sewered wastewater is discharged without treatment, i.e., there are no WWT plants.
- To account for industrial COD discharged with residential wastewater into open sewers, the COD_c quantity is multiplied by $I = 1.25$ (see page 4). For latrines and septic systems, $I = 0$, because these systems do not accept industrial wastewater.
- For most developing countries, except rural Latin America, the degree of utilization of specified treatment or disposal system for each income group (T_{csu}) is primarily based on WHO/UNICEF (1993). World Bank (1979) provided additional comprehensive information from site studies in South Korea, Taiwan, Indonesia, Malaysia, Sudan, Nigeria, Ghana, Zambia, Colombia, and Nicaragua. Data for latrine use in rural Latin America are based on World Bank (1979). WHO (1990) includes data for Israel and Turkey. Engineering judgment by the authors was complemented with anecdotal information on South Korea, China, and Turkey, to develop T_{csu} estimates for these three countries.
- For the urban high-income populations in developing countries, it was assumed by the authors that some type of sewage treatment or removal system exists (i.e., the "None" category in Table 4-2 is zero).
- For the urban low-income populations in developing countries (Table 4-3), it is assumed by the authors that 20 percent of human waste ends up on the ground or is directly disposed of into surface water (e.g., rivers or lakes). In either case it will not contribute to CH_4 emissions. For the same urban low-income populations, with the exception of "Other Asia" between 34 and 53 percent of human waste is assumed to accumulate in open sewers or gutters. For "Other Asia" the fraction of waste that is sewered is assumed to be higher, 68 percent, because this category includes many oil producing and exporting countries, where sewer infrastructure is assumed to be better than in other Asian countries.

TABLE 4-1. COUNTRY-SPECIFIC WASTEWATER TREATMENT PRACTICES AND METHANE EMISSIONS FOR RURAL POPULATION

Country	Municipal WW Disposal (Tcs)					Septic Tanks				Latrines				(Open) Sewers			
	Septic Tank	Latrine	Other	(Open) Sewer	None	AFcs	COD (anaerobic) (Tg/yr)			AFcs	COD (anaerobic) (Tg/yr)			AFcs	COD (anaerobic) (Tg/yr)		
	(%)	(%)	(%)	(%)	(%)	(-)	low	mean	high	(-)	low	mean	high	(-)	low	mean	high
<u>AFRICA</u>																	
Nigeria	2	28	4	10	56	0.5	0.0	0.0	0.0	1.0	0.5	0.7	0.9	0.8	0.2	0.2	0.3
Egypt	2	28	4	10	56	0.5	0.0	0.0	0.0	1.0	0.2	0.3	0.4	0.8	0.1	0.1	0.1
Kenya	2	28	4	10	56	0.5	0.0	0.0	0.0	1.0	0.1	0.2	0.2	0.8	0.0	0.1	0.1
South Africa	10	28	4	10	48	0.5	0.0	0.0	0.0	1.0	0.2	0.2	0.3	0.8	0.1	0.1	0.1
Zimbabwe	10	28	4	10	48	0.5	0.0	0.0	0.0	1.0	0.1	0.1	0.1	0.8	0.0	0.0	0.0
Other Africa	2	28	4	10	56	0.5	0.1	0.1	0.1	1.0	1.9	2.6	3.4	0.8	0.6	0.9	1.1
<u>ASIA</u>																	
China	0	47	50	0	3	0.5	0	0	0	1.0	9.8	13.8	17.7	0.8	0.0	0.0	0.0
India	0	47	10	10	33	0.5	0	0	0	1.0	7.4	10.3	13.3	0.8	1.5	2.1	2.7
Indonesia	0	47	0	10	43	0.5	0	0	0	1.0	1.5	2.1	2.8	0.8	0.3	0.4	0.6
Pakistan	0	47	0	10	43	0.5	0	0	0	1.0	1.0	1.4	1.8	0.8	0.2	0.3	0.4
Bangladesh	0	47	0	10	43	0.5	0	0	0	1.0	1.2	1.6	2.1	0.8	0.2	0.3	0.4
Japan	20	0	50	30	0	0.5	0.1	0.1	0.2	1.0	0.0	0.0	0.0	0.0	0	0	0
Other Asia	5	30	10	36	19	0.5	0.2	0.3	0.4	1.0	2.5	3.5	4.5	0.8	2.8	3.9	5.0
<u>EUROPE</u>																	
Russia	30	10	0	60	0	0.5	0.2	0.3	0.5	1.0	0.2	0.2	0.3	0.0	0	0	0
Germany	20	0	0	80	0	0.5	0.1	0.1	0.2	1.0	0	0	0	0.0	0	0	0
United Kingdom	11	0	0	89	0	0.5	0.0	0.0	0.0	1.0	0	0	0	0.0	0	0	0
France	37	0	0	63	0	0.5	0.1	0.2	0.2	1.0	0	0	0	0.0	0	0	0
Italy	42	0	0	58	0	0.5	0.2	0.2	0.3	1.0	0	0	0	0.0	0	0	0
Other OECD	50	0	0	50	0	0.5	0.2	0.3	0.4	1.0	0	0	0	0.0	0	0	0
Other Europe	50	10	0	40	0	0.5	0.8	1.0	1.3	1.0	0.3	0.4	0.5	0.0	0	0	0
<u>NORTH AMERICA</u>																	
United States	90	2	0	8	0	0.5	1.5	1.9	2.3	1.0	0.1	0.1	0.1	0.0	0	0	0
Canada	90	2	0	8	0	0.5	0.1	0.2	0.2	1.0	0.0	0.0	0.0	0.0	0	0	0
<u>LATIN AMERICA AND CARIBBEAN</u>																	
Brazil	0	45	0	10	45	0.5	0	0	0	1.0	0.4	0.6	0.7	0.8	0.1	0.1	0.2
Mexico	0	45	0	10	45	0.5	0	0	0	1.0	0.3	0.4	0.5	0.8	0.1	0.1	0.1
Others	0	45	0	10	45	0.5	0	0	0	1.0	0.6	0.8	1.0	0.8	0.1	0.2	0.2
<u>AUSTRALIA AND NEW ZEALAND</u>																	
Australia	90	2	0	8	0	0.5	0.0	0.1	0.1	1.0	0.0	0.0	0.0	0.0	0	0	0
TOTAL (Tg/yr)							3.7	5.0	6.2		28.2	39.4	50.6		6.3	8.8	11.3

Totals may not equal sums of individual numbers due to rounding.

(continued)

TABLE 4-1. COUNTRY-SPECIFIC WASTEWATER TREATMENT PRACTICES AND METHANE EMISSIONS FOR RURAL POPULATION (CONTINUED)

	WWT Plant						Methane Emissions (Tg/yr)											
Country	Raw Discharge	To WWTP	AFcs	COD (anaerobic) (Tg/yr)			Septic Tanks			Latrines			(Open) Sewers			WWT Plant		
	(%)	(%)	(-)	low	mean	high	low	mean	high	low	mean	high	low	mean	high	low	mean	high
AFRICA																		
Nigeria	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.0	0.1	0.1	0.0	0.0	0.0
Egypt	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0
Kenya	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	100	0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Zimbabwe	100	0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Africa	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	1.4	0.1	0.3	0.5	0.0	0.0	0.0
ASIA																		
China	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.1	7.1	0.0	0.0	0.0	0.0	0.0	0.0
India	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.1	5.3	0.3	0.6	1.1	0.0	0.0	0.0
Indonesia	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.1	0.1	0.1	0.2	0.0	0.0	0.0
Pakistan	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.7	0.0	0.1	0.1	0.0	0.0	0.0
Bangladesh	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.8	0.0	0.1	0.2	0.0	0.0	0.0
Japan	20	80	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Asia	100	0	0.5	0.0	0.0	0.0	0.0	0.1	0.1	0.5	1.0	1.6	0.6	1.2	2.0	0.0	0.0	0.0
EUROPE																		
Russia	80	20	0.4	0.1	0.1	0.1	0.0	0.1	0.2	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Germany	10	90	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United Kingdom	20	80	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
France	70	30	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Italy	70	30	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other OECD	40	60	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Europe	80	20	0.1	0.0	0.0	0.0	0.2	0.3	0.5	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
NORTH AMERICA																		
United States	0	100	0.1	0.0	0.0	0.0	0.3	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canada	0	100	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LATIN AMERICA AND CARIBBEAN																		
Brazil	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.0	0.0	0.1	0.0	0.0	0.0
Mexico	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Others	100	0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.0	0.1	0.1	0.0	0.0	0.0
AUSTRALIA AND NEW ZEALAND																		
Australia	20	80	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL (Tg/yr)				0.2	0.3	0.3	0.7	1.5	2.5	5.6	11.8	20.2	1.3	2.6	4.5	0.0	0.1	0.1

Totals may not equal sums of individual numbers due to rounding.

TABLE 4-2. COUNTRY-SPECIFIC WASTEWATER TREATMENT PRACTICES AND METHANE EMISSIONS FOR URBAN HIGH-INCOME POPULATION

	Municipal WW Disposal (Tcs)					Septic Tanks				Latrines				(Open) Sewers			
Country	Septic Tank	Latrine	Other System	(Open) Sewer	None	AFcs	COD (anaerobic) (Tg/yr)			AFcs	COD (anaerobic) (Tg/yr)			AFcs	COD (anaerobic) (Tg/yr)		
	(%)	(%)	(%)	(%)	(%)	(-)	low	mean	high	(-)	low	mean	high	(-)	low	mean	high
AFRICA																	
Nigeria	32	31	0	37	0	0.5	0.0	0.1	0.1	1.0	0.1	0.1	0.1	0.75	0.1	0.1	0.2
Egypt	15	5	10	70	0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.50	0.1	0.1	0.1
Kenya	32	31	0	37	0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.75	0.0	0.0	0.0
South Africa	15	15	0	70	0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.50	0.1	0.1	0.1
Zimbabwe	15	15	0	70	0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.50	0.0	0.0	0.0
Other Africa	32	31	0	37	0	0.5	0.2	0.3	0.3	1.0	0.3	0.5	0.6	0.75	0.4	0.5	0.7
ASIA																	
China	18	8	7	67	0	0.5	0.2	0.2	0.3	1.0	0.1	0.2	0.3	0.50	0.8	1.1	1.4
India	18	8	7	67	0	0.5	0.1	0.2	0.2	1.0	0.1	0.2	0.2	0.75	0.9	1.2	1.6
Indonesia	18	8	0	74	0	0.5	0.0	0.0	0.1	1.0	0.0	0.0	0.0	0.75	0.2	0.3	0.4
Pakistan	18	8	0	74	0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.75	0.2	0.2	0.3
Bangladesh	18	8	0	74	0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.75	0.1	0.1	0.1
Japan	0	0	10	90	0	0.5	0	0	0	1.0	0	0	0	0.00	0	0	0
Other Asia	18	8	0	74	0	0.5	0.4	0.5	0.7	1.0	0.3	0.5	0.6	0.50	1.9	2.7	3.4
EUROPE																	
Russia	10	0	0	90	0	0.5	0.2	0.2	0.3	1.0	0	0	0	0.00	0	0	0
Germany	5	0	0	95	0	0.5	0.1	0.1	0.1	1.0	0	0	0	0.00	0	0	0
United Kingdom	0	0	0	100	0	0.5	0	0	0	1.0	0	0	0	0.00	0	0	0
France	0	0	0	100	0	0.5	0	0	0	1.0	0	0	0	0.00	0	0	0
Italy	4	0	0	96	0	0.5	0.0	0.0	0.1	1.0	0	0	0	0.00	0	0	0
Other OECD	2	0	0	98	0	0.5	0.0	0.0	0.1	1.0	0	0	0	0.00	0	0	0
Other Europe	20	0	0	80	0	0.5	0.6	0.8	1.0	1.0	0	0	0	0.00	0	0	0
NORTH AMERICA																	
United States	5	0	0	95	0	0.5	0.2	0.3	0.4	1.0	0	0	0	0.00	0	0	0
Canada	5	0	0	95	0	0.5	0.0	0.0	0.0	1.0	0	0	0	0.00	0	0	0
LATIN AMERICA AND CARIBBEAN																	
Brazil	0	20	0	80	0	0.5	0.0	0.0	0.0	1.0	0.1	0.2	0.2	0.75	0.5	0.7	0.9
Mexico	0	20	0	80	0	0.5	0.0	0.0	0.0	1.0	0.1	0.1	0.1	0.75	0.3	0.4	0.5
Others	0	20	0	80	0	0.5	0.0	0.0	0.0	1.0	0.2	0.3	0.3	0.75	0.7	1.0	1.3
AUSTRALIA AND NEW ZEALAND																	
Australia	5	0	0	95	0	0.5	0	0	0	1.0	0	0	0	0.00	0.0	0.0	0.0
TOTAL (Tg/yr)							2.1	2.9	3.7		1.5	2.1	2.7		6.2	8.7	11.1

Totals may not equal sums of individual numbers due to rounding.

(continued)

TABLE 4-2. COUNTRY-SPECIFIC WASTEWATER TREATMENT PRACTICES AND METHANE EMISSIONS FOR URBAN HIGH-INCOME POPULATION (CONTINUED)

Country	WWT Plant						Methane Emissions (Tg/yr)											
	Raw Discharge	To WWTP	AFcs	COD (anaerobic) (Tg/yr)			Septic Tanks			Latrines			(Open) Sewers			WWT Plant		
	(%)	(%)	(-)	low	mean	high	low	mean	high	low	mean	high	low	mean	high	low	mean	high
AFRICA																		
Nigeria	90	10	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Egypt	80	20	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kenya	60	40	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	60	40	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zimbabwe	60	40	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Africa	90	10	0.5	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.1	0.2	0.3	0.0	0.0	0.0
ASIA																		
China	90	10	0.5	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.2	0.3	0.6	0.0	0.0	0.0
India	90	10	0.5	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.2	0.4	0.6	0.0	0.0	0.0
Indonesia	80	20	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0
Pakistan	90	10	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Bangladesh	90	10	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Japan	10	90	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0	0	0				0.0	0.1	0.1
Other Asia	90	10	0.5	0.2	0.2	0.3	0.1	0.2	0.3	0.1	0.1	0.2	0.4	0.8	1.4	0.0	0.1	0.1
EUROPE																		
Russia	40	60	0.4	0.7	1.0	1.3	0.0	0.1	0.1	0	0	0				0.1	0.3	0.5
Germany	10	90	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0	0	0				0.0	0.0	0.1
United Kingdom	0	100	0.1	0.1	0.1	0.2	0	0	0	0	0	0				0.0	0.0	0.1
France	60	40	0.1	0.0	0.0	0.1	0	0	0	0	0	0				0.0	0.0	0.0
Italy	70	30	0.1	0.0	0.0	0.0	0	0	0	0	0	0				0.0	0.0	0.0
Other OECD	30	70	0.2	0.5	0.7	0.8	0.0	0.0	0.0	0	0	0				0.1	0.2	0.3
Other Europe	40	60	0.2	0.6	0.7	0.9	0.1	0.2	0.4	0	0	0				0.1	0.2	0.4
NORTH AMERICA																		
United States	0	100	0.1	0.5	0.6	0.7	0.0	0.1	0.2	0	0	0				0.1	0.2	0.3
Canada	0	100	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0	0	0				0.0	0.0	0.0
LATIN AMERICA AND CARIBBEAN																		
Brazil	95	5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.4	0.0	0.0	0.0
Mexico	95	5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.0	0.0	0.0
Others	95	5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.5	0.0	0.0	0.0
AUSTRALIA AND NEW ZEALAND																		
Australia	0	100	0.1	0.0	0.0	0.0	0	0	0	0	0	0				0.0	0.0	0.0
TOTAL (Tg/yr)				3.1	4.2	5.3	0.4	0.9	1.5	0.3	0.6	1.1	1.2	2.6	4.5	0.6	1.3	2.1

Totals may not equal sums of individual numbers due to rounding.

TABLE 4-3. COUNTRY-SPECIFIC WASTEWATER TREATMENT PRACTICES AND METHANE EMISSIONS FOR URBAN LOW-INCOME POPULATION

Country	Municipal WW Disposal (Tcs)					Septic Tanks				Latrines				Open Sewers			
	Septic Tank	Latrine	Other System	(Open) Sewer	None	AFcs	COD (anaerobic) (Tg/yr)			AFcs	COD (anaerobic) (Tg/yr)			AFcs	COD (anaerobic) (Tg/yr)		
	(%)	(%)	(%)	(%)	(%)	(-)	low	mean	high	(-)	low	mean	high	(-)	low	mean	high
AFRICA																	
Nigeria	17	24	5	34	20	0.5	0.1	0.1	0.1	1.0	0.2	0.3	0.3	0.8	0.2	0.3	0.4
Egypt	17	24	5	34	20	0.5	0.0	0.1	0.1	1.0	0.1	0.1	0.2	0.5	0.1	0.1	0.2
Kenya	17	24	5	34	20	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.8	0.0	0.1	0.1
South Africa	17	24	5	34	20	0.5	0.0	0.0	0.1	1.0	0.1	0.1	0.2	0.5	0.1	0.1	0.2
Zimbabwe	17	24	5	34	20	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Other Africa	17	24	5	34	20	0.5	0.3	0.4	0.5	1.0	0.8	1.1	1.5	0.8	1.1	1.5	1.9
ASIA																	
China	14	10	3	68	5	0.5	0.4	0.5	0.7	1.0	0.6	0.8	1.0	0.5	2.3	3.3	4.2
India	14	10	3	53	20	0.5	0.3	0.4	0.5	1.0	0.4	0.6	0.7	0.8	2.1	2.9	3.7
Indonesia	14	10	3	53	20	0.5	0.1	0.1	0.1	1.0	0.1	0.1	0.2	0.8	0.5	0.7	0.9
Pakistan	14	10	3	53	20	0.5	0.1	0.1	0.1	1.0	0.1	0.1	0.1	0.8	0.4	0.5	0.7
Bangladesh	14	10	3	53	20	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.1	0.8	0.2	0.2	0.3
Japan*																	
Other Asia	8	7	6	69	10	0.5	0.2	0.2	0.3	1.0	0.3	0.4	0.5	0.5	1.8	2.5	3.2
EUROPE																	
Russia																	
Germany																	
United Kingdom																	
France																	
Italy																	
Other OECD																	
Other Europe																	
NORTH AMERICA																	
United States																	
Canada																	
LATIN AMERICA AND CARIBBEAN																	
Brazil	0	40	0	40	20	0.5	0	0	0	1.0	1	1	1	0.8	0.8	1.1	1.4
Mexico	0	40	0	40	20	0.5	0	0	0	1.0	0	1	1	0.8	0.4	0.6	0.8
Others	0	40	0	40	20	0.5	0	0	0	1.0	1	2	2	0.8	1.1	1.5	1.9
AUSTRALIA AND NEW ZEALAND*																	
Australia										1.0	0	0	0				
TOTAL (Tg/yr)							1.4	2.0	2.8		5.2	7.2	9.3		11.1	15.5	19.9

Totals may not equal sums of individual numbers due to rounding.

(continued)

TABLE 4-3. COUNTRY-SPECIFIC WASTEWATER TREATMENT PRACTICES AND METHANE EMISSIONS FOR URBAN LOW-INCOME POPULATION (CONTINUED)

URBAN LOW	WWT Plant						Methane Emissions (Tg/yr)											
Country	Raw Discharge	To WWTP	AFcs	COD (anaerobic) (Tg/yr)			Septic Tanks			Latrines			(Open) Sewers			WWT Plant		
	(%)	(%)	(-)	low	mean	high	low	mean	high	low	mean	high	low	mean	high	low	mean	high
AFRICA																		
Nigeria	100	0	0.5	0	0	0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.2	0	0	0
Egypt	100	0	0.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0	0	0
Kenya	100	0	0.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
South Africa	100	0	0.2	0	0	0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0	0	0
Zimbabwe	100	0	0.2	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Other Africa	100	0	0.5	0	0	0	0.1	0.1	0.2	0.2	0.3	0.6	0.2	0.5	0.8	0	0	0
ASIA																		
China	100	0	0.5	0	0	0	0.1	0.2	0.3	0.1	0.2	0.4	0.5	1.0	1.7	0	0	0
India	100	0	0.5	0	0	0	0.1	0.1	0.2	0.1	0.2	0.3	0.4	0.9	1.5	0	0	0
Indonesia	100	0	0.5	0	0	0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.4	0	0	0
Pakistan	100	0	0.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0	0	0
Bangladesh	100	0	0.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0	0	0
Japan																		
Other Asia	100	0	0.5	0	0	0	0.0	0.1	0.1	0.1	0.1	0.2	0.4	0.8	1.3	0	0	0
EUROPE																		
Russia																		
Germany																		
United Kingdom																		
France																		
Italy																		
Other OECD																		
Other Europe																		
NORTH AMERICA																		
United States																		
Canada																		
LATIN AMERICA AND CARIBBEAN																		
Brazil	100	0	0.5	0	0	0	0.0	0.0	0.0	0.2	0.3	0.6	0.2	0.3	0.6	0	0	0
Mexico	100	0	0.5	0	0	0	0.0	0.0	0.0	0.1	0.2	0.3	0.1	0.2	0.3	0	0	0
Others	100	0	0.5	0	0	0	0.0	0.0	0.0	0.2	0.5	0.8	0.2	0.5	0.8	0	0	0
AUSTRALIA AND NEW ZEALAND																		
Australia																		
TOTAL (Tg/yr)				0.0	0.0	0.0	0.3	0.6	1.0	1.0	2.2	3.7	2.2	4.6	8.0	0	0	0

Totals may not equal sums of individual numbers due to rounding.

- Total T_{cs} for sewer connections in urban China is slightly higher than for other populous Asian countries, including India, Indonesia, Pakistan, and Bangladesh. The Chinese government places relatively high emphasis on civil infrastructure (expert judgment by the authors). Additional information on China regarding the construction of WWT facilities was found in Zhongxiang and Yi (1991).
- In Table 4-2, sewer connection (T_{cs}) numbers for high-income urban Egypt, Zimbabwe, and South Africa are 70 percent, which is higher than for other African countries. Mancy (1993) states that Cairo, Egypt, has a sewer network which was built under colonial rule and during the era of Soviet aid in the sixties and seventies.
- Zimbabwe and South Africa also historically have had better sewer infrastructure for their urban high-income populations than most other African countries (Marks, 1993).
- Most T_{cs} information for European countries came from WHO (1990). Anecdotal information for Poland and its neighbors is from Jocewicz (1997).
- Information on Japan is from World Bank (1979). According to this document, nightsoil collection was widespread until the mid-seventies throughout Japan. For example, the city of Kyoto (1.5 million inhabitants) relied heavily on nightsoil collection (80 percent). Nightsoil was collected by vacuum truck. Bartone (1990) and World Bank (1979) state that, in the countries that traditionally relied heavily on nightsoil collection, there has been a steady decline in the use of collection and reuse systems with the modernization of agriculture. As no recent data were found that specifically pertain to present-day Japan, it was assumed by the authors that nightsoil collection systems in Japan also have become increasingly unpopular. Accordingly, it was estimated that in Japan in urban areas the nightsoil collection systems have been largely replaced by sewer connections (90 percent), and that in rural areas, 50 percent of the population have stopped using nightsoil collection in favor of sewer connections or septic tanks.
- In the United States, 25 percent of the total population use septic systems (U.S. Department of Commerce, 1990). It was assumed by the authors that 90 percent of the rural population are dependent on septic tanks, compared to five percent of the urban population. (The United States is 75 percent urbanized.) The same T_{cs} values were used for Canada and Australia.
- Values for the degree to which on-site WWT systems and open sewers are anaerobic (AF_{cs}) are based on various references, anecdotal evidence, and engineering judgment. Septic tanks are estimated to accommodate anaerobic degradation of approximately 50 percent of influent COD, while latrines were assumed to be 100 percent anaerobic. AF_{cs} for open sewers in most developing countries was assumed to be 75 percent, based on expert judgment by the authors. As mentioned

earlier, China, Egypt, Zimbabwe, and the countries of "Other Asia" are assumed to have slightly higher AF_{cs} values (50 percent) because sewer infrastructure is assumed to be somewhat better.

- All sewers in developed countries are assumed to be closed sewers and AF_{cs} for these closed sewers is, hence negligible. (As mentioned earlier, this source category is not considered in this report.).
- The AF_{cs} values for WWT plants are from the Emissions-from-WWT report, page 48, Table 17.

4.3 METHANE EMISSION ESTIMATES AND UNCERTAINTIES

Country-specific CH_4 emission estimates for rural, urban-high, and urban-low populations for stagnant, open sewers, septic systems, latrines, and WWT plants are included in Tables 4-1, 4-2, and 4-3. Global CH_4 emissions from the targeted source categories are estimated at 29 Tg/yr. Note that substantial uncertainties are associated with this number. Figure 4-1 summarizes global emission estimates for the different source categories. According to Figure 4-1, latrines in rural areas are the most significant source, emitting 12 Tg/yr. China and India account for about 60 percent of global CH_4 emissions from latrines in rural areas (Table 4-1). Also, emissions from stagnant, open sewers in urban, as well as in rural areas, are significant, i.e., 10 Tg/yr. The default estimate for CH_4 emissions from WWT plants is included for comparison purposes only. The 1.3 Tg/yr emission rate is similar to the estimate in Doorn, et al. (1997).

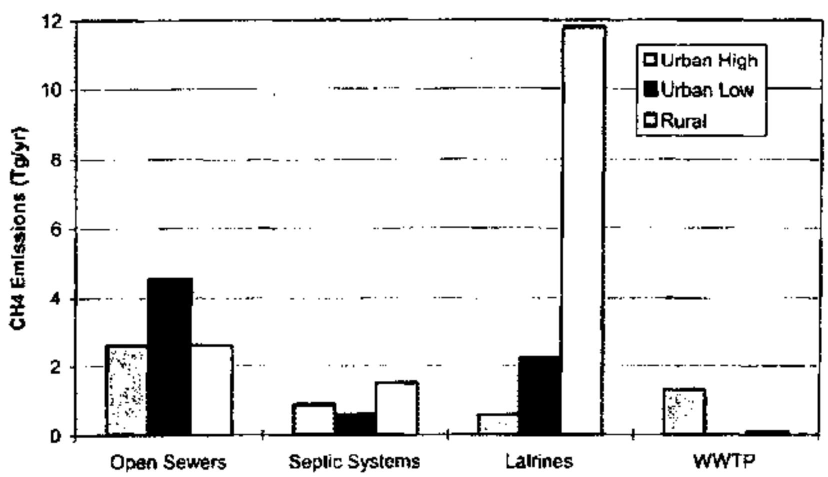

Figure 4-1: Global Estimates of CH_4 Emissions from Stagnant, Open Sewers, Septic Tanks, Latrines, and WWT Plants

The above CH_4 emission estimates should be seen only as preliminary and substantial research would be needed to reduce the level of uncertainty associated with these preliminary numbers. The mathematical uncertainty in this global emission estimate consists of the uncertainty in the emission factor (0.3 ± 0.1 g CH_4/g $COD_{removed}$) and the uncertainty in the BOD loading (Table 2-2). In a mathematical sense, the total CH_4 emissions estimate may hence be expressed as 29 with lower and upper boundaries of 14 and 49 Tg/yr, to reflect the uncertainties associated with these two parameters. Other significant uncertainties are associated with the activity data used in this report and could only be defined qualitatively. Therefore, the lower and upper bound values may be too conservative to reflect all uncertainties associated with the estimates. Uncertainties in the various parameters used to estimate the CH_4 emissions are discussed in the ensuing text.

- The degrees to which wastewater in developing countries is treated in latrines or septic tanks, or removed by sewer, per income group is primarily based on WHO/UNICEF (1993). Data in this document are from a survey to which 82 developing countries responded. It is likely that significant uncertainties are associated with these data, because the questions in the survey may have been misinterpreted or the data may have been flattered. In addition, the definitions for different WWT systems may not have been consistently interpreted by the respondents of the surveys. Nevertheless, there is qualitative evidence in sparse other literature, as well as anecdotal information that was used as a qualitative verification of the ratios to which each type of treatment system is used. As mentioned, emissions from latrines in rural China and India are estimated to be most significant and follow up work could be focused on verification of the degree of use of latrines in these countries.
- Urbanization rates and country-specific populations are from UNEP (1993) and are believed to be relatively accurate. However, recent increases in population and urbanization shifts are not reflected. This report uses the same criteria as WHO/UNICEF (1993) for classifying the population as either rural, urban low-income, and urban high-income. For the countries that were not included in WHO/UNICEF (1993), the distinction between urban low-income and urban high-income was based on engineering judgment.
- Bartone (1990) states that in Latin America and the Middle East, in capitals and other large cities 85 percent of the urban population may have sewer connections compared to only 10 percent in secondary cities. First, these numbers are likely to reflect only the situation for urban high-income residents. Secondly, sanitation coverage and choice is apparently dependent on city size, status or function. Country capitals, especially in east European or developing countries may well receive preferential treatment and may have better wastewater collection and treatment systems than secondary cities. This phenomenon has not been accounted for in the estimates, because urbanization data do not differentiate among different types of urban areas or cities.
- Other uncertainties are associated with the amount of wastewater that is discharged into open sewers. Whereas, data for high-income populations may be fairly accurate, quantification of sewer use for

low-income populations is very difficult. Low-income urban populations may make use of communal toilets that may be fitted with some kind of sewer line, however, this line may not necessarily be connected to a WWT plant. Instead, it may merely discharge into the nearest gutter or canal.

- One of the assumptions used in this study is that low-income humans with no access to sanitary facilities will attempt to keep their direct environment as clean as they can, just like anyone else. Accordingly, they will attempt to remove their body wastes from the premises. The most convenient method is to use some type of open sewer or other body of water, such as a river. Data that specifically pertain to open sewers and gutters, and the amount of waste that accumulates in them, are practically non-existent. The reason is that the existing literature and research are focused on the treatment or disposal systems themselves. As a result, the quantification of the wastes that remain outside of these systems (end up in a gutter, canal, or field) can only be by default. Accordingly, the estimates of the fraction of waste that accumulates in open sewers has an unknown degree of uncertainty.
- Another source of uncertainties is the degree to which open sewers in developing countries are anaerobic and will emit CH_4. This will depend on retention time and temperature, and on other factors including the presence of a facultative layer and possibly components that are toxic to anaerobic bacteria (e.g. certain industrial wastewater components). Based on anecdotal evidence, an unknown number of stagnant, open sewers in developing countries may well be 100 percent anaerobic. This percentage was adjusted downward to 75 percent for most countries, however, to account for factors that may impede (total) anaerobic degradation (based on best professional judgment by the authors). In follow-up studies, the degree of uncertainty could be reduced by laboratory testing to determine the actual retention time that is needed for full anaerobic degradation and the factors that impede anaerobic degradation. China and India are among the largest contributors to CH_4 emissions from stagnant, open sewers. More accurate data for these two countries are needed to improve the quality of the estimates.
- The degree to which latrines and septic tanks are anaerobic is less of an uncertainty than the degree to which open sewers are anaerobic. Latrines are very likely 100 percent anaerobic and septic tanks were assumed to be 50 percent anaerobic (see Chapter 3). Simple field tests for septic tanks and a laboratory test for latrines can be used to verify these assumptions.
- The amount of industrial COD that is discharged into open or closed municipal sewers for each country is very difficult to quantify. This quantity will depend on the size, type and scale of the industrial process and the local regulations and their enforcement. Some countries may be highly industrialized, whereas others are not. But, even in developing countries with low overall levels of

industrialization, one is likely to find semi-industrial food processing facilities that can make significant contributions to organic waste loadings in open sewers. A default value of 25 percent was used to account for industrial organic COD co-discharged with domestic COD. This value is based on global industrial wastewater data from the Emissions-from-WWT report.

4.4 TRENDS

In rural areas, where lack of sanitation is not a significant health problem, no large changes in the use of sanitation options are anticipated that would have a significant influence on CH_4 emissions. In many urbanized areas in developing countries, inadequate disposal of industrial and domestic wastewater has become a major health, as well as an environmental issue. Although significant gains have been made in the provision of sanitation services, the influx of migrants into cities has nullified most efforts. In the next two decades the global urban population will continue to increase. It is estimated that in this time frame, the number of persons living in cities in developing countries will double, increasing by nearly 1.3 billion. The rapid growth of cities and concentration of population lead to ever increasing amounts of human wastes to be managed safely. The relative success in providing cities with water generates greater volumes of wastewater to be managed, both domestic and industrial. As cities densify, the per household volumes of wastewater exceed the infiltration capacity of local soils, implying that wastewater removal will increasingly be by open sewer (Bartone, 1994). Increasing open sewer capacity is likely to lead to increasing CH_4 emissions.

In developing countries traditional sanitation and WWT projects funded with foreign aid have generally not provided the expected results. A survey of 223 municipal WWT plants in Mexico (installed capacity equal to 15 percent of total sewage outflow) revealed that 45 percent of the plants were out of service and 35 percent suffered severe operational problems. A World Bank study in Algeria showed that 33 out of 42 plants were out of service. Experience in Korea with nightsoil treatment plants has been similar with respect to operational difficulties (Bartone, 1990). The situation with existing sewer lines is unlikely to be much better. It is likely that many sewers in developing countries, as well as in eastern European countries are in need of repair.

Apart from limited financial resources, there are also other barriers to improving the current wastewater disposal and treatment situation in developing countries. Mancy (1993) writes that: "while the need of financial resources is indisputable, it seems that sociostructural and institutional variables are the limiting factors; there exists compelling evidence that the major constraints in Egypt, as well as in the majority of the less developed areas of the world, are not the lack of technology or financial resources; the new outlook for the future should emphasize capacity building, which entails the ability to develop, utilize and sustain the available resources; local communities (and their inhabitants) should not only participate in the planning and implementation of WWT projects, but they should also pay for the development and sustainment of these services." Thus, in addition to the financial and infrastructural barriers that exist, it may be expected that the implementation of the social infrastructure, as described by Mancy, in which sanitation service consumers are able and willing to pay, may further slow down the badly needed improvements.

It can be concluded that the wastewater disposal and treatment situation in developing countries is likely to get worse over the next two decades. In some cities, effects of the lack of WWT have started to reach intolerable proportions. Perhaps catastrophic events such as cholera epidemics or toxification of the local drinking water supply may spur drastic changes that will influence the current global trend. Notable exceptions are developing countries that have recently experienced significant economical growth and are beginning to have the financial means and political will to invest in wastewater infrastructure to address their pollution problems. These countries, often dubbed "Newly Industrialized Countries" include, Taiwan, Singapore, South Korea, and perhaps Chile and parts of Indonesia.[6] (Doppenberg, 1994 in Doorn et al., 1997.)

The problems associated with the lack of WWT are not limited to the developing world, but also include the countries of the former Soviet Union, and most eastern European countries. Also, for these countries no significant improvements in domestic WWT are expected in the near future, due to lack of funds (Draaijer, 1994 in Doorn et al., 1997). There are few exceptions, such as the former German Democratic Republic, which has had access to West German financial and technical support. Also, possibly Czechia, Slovenia, Hungary, and Poland are experiencing significant economical growth that may enable them to finance improved WWT on a significant scale.

Short-term improvements in regard to WWT can be expected only from developed countries that don't have existing comprehensive WWT, including Belgium, Spain, Greece, and Turkey. These countries are under pressure from the European Union which pushes for uniform and rigorous water and effluent quality regulations for its members and candidate members. For example, pressure to meet such EU regulations (in this case 90 percent reduction of load) has forced Spain to clean up its act (World Water and Environmental Engineering, 1992).

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6 Unfortunately, with the recent economic crisis in parts of east Asia this argument may have lost much of its validity.

CHAPTER 5

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APPENDIX A

EXECUTIVE SUMMARY OF "ESTIMATES OF GLOBAL GREENHOUSE GAS EMISSIONS FROM INDUSTRIAL AND DOMESTIC WASTEWATER TREATMENT."

Doorn, M.R.J., Strait, R.P., Barnard, W.R., and B. Eklund. 1997. Prepared for USEPA, Air Pollution Prevention and Control Division. Research Triangle Park, North Carolina. EPA-600/R-97-091, NTIS PB98-106420. September 1997.

Project Officer: Susan A. Thorneloe, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, Research Triangle Park, NC 27711

INTRODUCTION

To improve global estimates of greenhouse gas (GHG) emissions from WWT, EPA's APPCD initiated a field test program to develop GHG emission factors based on actual emissions measurements and to improve country-specific activity data for industrial and domestic WWT. The field test program involved the use of the open path monitoring/transect method (OPM/TM) technique with Fourier Transform Infrared (FTIR) spectroscopy to measure emissions from anaerobic waste lagoons at two beef processing plants, one chicken processing plant, and facultative lagoons at two POTWs. The field tests and results are documented in a separate report: Eklund and LaCosse, 1997.[7] In conjunction with the field test program, research was undertaken to improve the quality of the country-specific activity data, which included a search of the most recent literature and interviews with U.S. and European wastewater experts.

The Emissions-from-WWT-report summarizes the findings of the field tests and provides emission factors for CH_4 and N_2O from WWT. Also, the report includes country-specific activity data on industrial and domestic WWT, which were used to develop country-specific emission estimates for CH_4 and N_2O. The report concludes that WWT is unlikely to be a significant source of VOCs and CO_2 emissions. Also, the report provides background information on WWT systems and discusses the effect of water and ambient air temperature on CH_4 emissions and COD removal rates in anaerobic lagoons.

[7] References used in this summary are provided in the Reference section of the report

FIELD TESTS

Using FTIR spectroscopy, OPM/TM was used to determine emission rates. A large data set was generated, and up to 300 separate, valid, five-minute-average emission rate determinations were made at a given site. Typical detection limits were about 0.1 g/sec for most compounds, except for CO_2, which had a minimum detection limit of about 150 g/sec. The high detection limit for CO_2 was due to high background concentrations.

At all three meat processing plants, large amounts of CH_4 were measured downwind of the WWT system. The field tests detected significant N_2O emissions only from the anaerobic waste lagoons at the chicken processing plant. No N_2O emissions were detected from the anaerobic waste lagoons at the two beef processing plants or the facultative lagoons at the two POTWs. Surprisingly, no emissions of any GHG were detected from the facultative POTW lagoons. However, it is highly probable that CO_2 was being generated, but at levels too small to detect given the high background levels of CO_2 and the measurement variability.

With the help of activity factors provided by the plant operators and from the wastewater analyses, emission factors were developed for each site. An estimate of the uncertainty of the emission factors was developed through standard error propagation methods. The derived emission factors all appear to be reliable to within a factor of two, based on random error in the measurements, and assuming that the sites and samples accurately represent the population of interest.

EMISSION FACTORS AND METHODOLOGY

Average CH_4 emission factors based on theoretical models and on empirical industrial digester data are between 0.11 and 0.25 g/g COD. The average CH_4 emission factor derived from the field tests range from 0.26 to 0.96 g/g COD. The most likely explanation for the fact that the average APPCD field test emission factors are higher is that the field test emission rates also account for CH_4 emissions from COD that had been deposited in the sludge during past winters, when anaerobic microbial activity is low. In the report, an emission factor of 0.3 ± 0.1 g/g COD was used to develop CH_4 emission estimates. This factor reflects the upper end of the range of factors based on theoretical models and empirical digester data, as well as the lower end of the range of the factors developed from the field test results. The range for the emission factor (i.e., $\pm$ 0.1 g CH_4/g $COD_{(removed)}$) is based on expert judgment and accounts for the uncertainties associated with the use of COD and the extrapolation to different types of wastewater. This emission factor is believed to be conservative (i.e., on the high side).

The report uses two separate N_2O emission factors. The first emission factor (0.09 g N_2O/g $COD_{removed}$) is based on the field test at the chicken processing plant and reflects a completely anaerobic environment. It was used to estimate emissions from domestic sewage, and meat, poultry, fish, and dairy processing wastewater that is degrading under anaerobic conditions. The second emission factor (5.1 g/capita/yr) is based on literature studies and pertains to anoxic processes (denitrification) as a part of conventional domestic WWT.

The equation below was used to estimate CH_4 emissions from industrial wastewater. The methodology is also applicable for estimating N_2O emissions from anaerobic WWT.

$$CH_4\ Emissions = EF \times \Sigma_i \Sigma_c (P_{ic} \times Q_i \times COD_i \times TA_{ic} / 100) \times 10^{-12}\ (Tg/yr)$$

where:	EF	=	Emission factor (g CH_4 or g N_2O/g $COD_{removed}$);
	P_{ic}	=	Industry- and country-specific output [Megagrams per year (Mg/yr)];
	Q_i	=	Wastewater produced per unit of product (m^3/Mg);
	COD_i	=	Organics loading removed (g/m^3);
	TA_{ic}	=	Percentage of COD in wastewater treated anaerobically (%);
	Subscript *c*	denotes country;	
	subscript *i*	denotes industrial category within country c.	

Initially, 23 industrial categories were identified as the potentially most significant dischargers of wastewater with high organic COD loading. Country-specific annual industrial output data for these industrial categories were obtained from the United Nations' Industrial Statistical Yearbook. Typical wastewater generation rates expressed in cubic meters per Mg of product (m^3/Mg) and representative COD loadings were obtained from various literature sources.

TA_{ic} expresses the country- or region-specific fraction of wastewater for each industrial category that is treated at the industrial site under anaerobic conditions. Very little literature data were found to determine values for TA_{ic}; therefore, the TA_{ic} values are based mainly on anecdotal information from interviews with wastewater experts. In general, only a small fraction of wastewater is treated, even in several "developed" countries. Except for meat processing plants, industrial WWT is usually aerobic. Nevertheless, anaerobic conditions are expected to exist in certain sections of the plant (i.e., sludge storage) or due to mismanagement (e.g., overloading or underaerating of lagoons).

The equation on page 38 was adapted to estimate CH_4 emissions from domestic wastewater:

$$CH_4\ Emissions = EF \times \Sigma_c (P_c \times 365 \times COD_c \times TA_c / 100) \times 10^{-12} \quad (Tg/yr)$$

where:	EF	=	Emission factor (g CH_4/g $COD_{removed}$);
	P_c	=	Country population;
	COD_c	=	Country-specific per capita COD generation (g/day); and
	TA_c	=	Country-specific percentage of COD in wastewater treated anaerobically.

The methodology uses per capita COD generation rates (COD_{dc}), which were obtained from various literature sources. The country-specific fraction of COD that is treated anaerobically (TA_{dc}) was again based on anecdotal information. As with industrial WWT, only a small fraction of domestic wastewater is treated. In countries that do have comprehensive WWT, the WWT is likely to be primarily aerobic.

GHG EMISSION ESTIMATES

Table A-1 summarizes the Global CH_4 and N_2O estimates for domestic and industrial WWT. CH_4 emissions from industrial WWT are estimated to be between 0.6 and 6.1 teragrams per year (Tg/yr) with a mean value of 2.4 Tg/yr. The biggest contributor to industrial CH4 emissions from WWT is the pulp and paper industry in developing and eastern European countries. Although pulp and paper wastewater typically is treated aerobically, it is assumed that 15 percent of the COD in pulp and paper wastewater in developing and eastern European countries decomposes under anaerobic conditions as a result of poor wastewater management practices. The second principal contributor to CH_4 emissions from WWT is the meat and poultry processing industry.

Earlier estimates for global CH_4 emissions from industrial WWT are significantly higher (i.e., between 26 and 40 Tg/yr) (USEPA 1994). The emissions in this report are lower for two reasons: iron and steel manufacturing and petroleum refining are excluded as significant categories, and the fraction of wastewater degrading anaerobically is significantly lower for most remaining categories. (In USEPA 1994 it was assumed that between 10 and 15 percent of wastewater degrades anaerobically.)

TABLE A-1. Summary of Global GHG Estimates for Domestic and Industrial WWT

GHG	SOURCE	LOWER BOUND (Tg/yr)	AVERAGE (Tg/yr)	UPPER BOUND (Tg/yr)	REMARKS
CH_4	Industrial WWT	0.6	2.4	6.1	
CH_4	Domestic WWT	0.6	1.3	2.1	
N_2O	Domestic Activated Sludge WWT		0.004		These are rough estimates. No lower and upper bounds are available.
N_2O	Domestic Anaerobic WWT		0.5		
N_2O	Anaerobic WWT at beef, dairy, poultry and, fish, processing industry		0.24		

CH_4 emissions from domestic WWT are estimated to be between 0.6 and 2.1 Tg/yr with a mean value of 1.3 Tg/yr. Earlier estimates for global CH_4 emissions from domestic WWT are 2.3 Tg/yr (USEPA 1994). Russia is believed to be the largest contributor. In many developing countries, very little domestic wastewater is treated. Although much wastewater may end up "on the ground," significant amounts of this domestic wastewater also may be discharged into open sewers and ditches where it may degrade anaerobically. Consequently, CH_4 emissions from untreated domestic wastewater may be many times higher than those of treated domestic wastewater.

Global N_2O emissions from conventional domestic WWT are estimated at 0.004 Tg/yr. Estimated global N_2O emissions from anaerobic domestic WWT are 0.5 Tg/yr. Wastewater from the meat, poultry, fish, and dairy processing industries is expected to contain substantial amounts of bound nitrogen. Global N_2O emissions from this source category are estimated at 0.24 Tg/yr. Emissions for the United States are estimated to be 0.12 Tg/yr. In comparison, current U.S. estimates for total N_2O emissions are 0.4 Tg/yr and do not include WWT. These estimates are associated with large uncertainties and are, at best, an indication of the relative significance of this source category.

UNCERTAINTIES

The specific uncertainties associated with the development of the field test emission factors, such as the representativeness of the test sites and suitability of the test procedures, are discussed in the field test report. The emission factors express CH_4 and N_2O emissions per mass of $COD_{removed}$ as a surrogate for the amount of available organic carbon or nitrogen in the wastewater. The ratio of COD to actual degradable organic loading varies for different types of wastewater and is a source of uncertainty.

For both industrial and domestic wastewater, large relative uncertainties are associated with quantifying the overall extent of global WWT. Also, the quantification of the fraction of the wastewater that may decompose under anaerobic conditions is uncertain.

The estimates for industrial wastewater, furthermore, depend on quantification of the wastewater outflow and concentration per unit of product. Q_i and COD_i values depend on the product, the production process, and the efficiency of the process. The type and efficiency of the industrial process are likely to be dependent on plant scale, availability and cost of water, lo. al water and wastewater regulations, and the degree of enforcement. For these reasons, it is expected that significant errors are associated with the extrapolation of data.

APPENDIX B

SUMMARY OF NITROGEN CYCLE EFFECTS ON AMMONIA AND NITROUS OXIDE EMISSIONS FROM SEPTIC TANKS, LATRINES, AND STAGNANT OPEN SEWERS

INTRODUCTION

The relatively large concentration of nitrogen present in domestic wastewater necessitates an understanding of the nitrogen cycle within septic tanks and other methods of dealing with human waste, such as latrines and stagnant, open sewers. Canter and Knox (1985) determined that an average of 38 mg/l of Total Kjeldahl Nitrogen (TKN) is present in influent wastewaters of septic tanks serving single households. Of this 38 mg/l, 12 mg/l or 32 percent was found to be in the form of ammonium (NH_4^+). Metcalf & Eddy (1991) report that total nitrogen in domestic wastewater ranges from 20 mg/l to 85 mg/l (Tchobanoglous and Burton, 1991).

The presence of these concentrations of nitrogen in domestic sewerage is associated with a complex set of nitrogen inputs into the "average" wastewater. One source of organic nitrogen in domestic wastewater is the decomposition of animal and plant proteins in the digestive tract. The death and decomposition of fecal bacteria both within the digestive tract and following expulsion also contributes nitrogen to domestic wastewater. In addition, the human body excretes nitrogenous wastes in the form of urea. Additional sources of nitrogen may be found as a result of the use of household cleaning products and other chemical sources that are household-specific.

AMMONIA OR REDUCED NITROGEN

Septic Tank Reduced Nitrogen

Despite the complexity of influent nitrogen sources, bacterial processes convert most nitrogen in domestic wastewater to reduced nitrogen (Metcalf & Eddy, p. 1040). Reduced nitrogen is a relative term used in this memo to discriminate between forms of oxidized nitrogen, such as nitrite and nitrate, and types of nitrogen without bonds with negative ions. Examples of reduced nitrogen are ammonia (NH_3) and NH_4^+. The only exception to the prevalence of reduced nitrogen in domestic wastewater would be nitrate that was present in the potable water used for domestic purposes. Because the preponderance of nitrogen in domestic wastewater is reduced nitrogen, this section will focus on the fate of reduced nitrogen in aqueous, anaerobic systems. This fate is both microbially mediated and determined by chemical properties of the water.

Microbial mediation of the fate of reduced nitrogen in water is dependent on the types of bacterial populations present as a direct result of the presence or absence of oxygen as a terminal electron acceptor. In the presence of oxygen, bacterial nitrification converts reduced nitrogen first to nitrite, and then to nitrate (Brock and Madigan, 1988). Septic tank influent and the water within septic tanks are largely anaerobic because the rate of biotic oxygen usage outstrips the rate of atmospheric oxygen transfer into the wastewater. Because the microorganisms responsible for nitrification are obligately aerobic, nitrification is an unlikely fate for reduced nitrogen in domestic wastewater. Under anaerobic conditions, reduced nitrogen is stable in a microbiological sense (Brock and Madigan, 1988).

The pH is the most important chemical factor involved in the fate of reduced nitrogen in septic tanks. The chemical property of pH determines the speciation of reduced nitrogen in aqueous systems. At pH levels above 7, the equilibrium of the following reactions are displaced to the left.

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$

or

$$NH_3 + H^+ \leftrightarrow NH_4^+$$

Below pH 7, NH_4^+ is predominant (Tchobanoglous and Burton, 1991). Hem (1989) states that the transformation of aqueous ammonia (NH_3) in solution to the NH_4^+ ion is half complete at pH 9.24. Because the pH of septic tanks is expected to be close to neutral (see Table B-1), reduced nitrogen is predominantly present as the NH_4^+-ion. The importance of this reaction equilibrium in determining the fate of reduced nitrogen during septic tank wastewater treatment is that gaseous NH_3 is volatile and NH_4^+ is not (Sundstrom and Klei, 1979).

Due to the microbiological stability of reduced nitrogen in anaerobic environments and the chemical tendency of NH_3 to become the nonvolatile NH_4^+-ion at pH values typical of septic tanks (pH = 7 ± 1), NH_3 emissions from these on-site wastewater treatment systems are anticipated to be negligible. This hypothesis is supported by the work of many researchers who have studied the fate of NH_4^+ in the effluent of septic tanks. Aravena et al. (1993) in Gerritse et al. (1995) state that nitrogen leaches from the studied septic tank into the soil mainly as NH_4^+ and then is oxidized to nitrate. Canter and Knox (1985) state that, due to the prevalence of anaerobic conditions in septic tanks, organic nitrogen is converted to NH_4^+. In discussing the fate of nitrogen in septic tank effluent, Ritter and Eastburn (1988) state that, "under saturated conditions, NH_4^+-nitrogen would eventually be leached to the ground water." Whelan and Titamnis (1982) concur that NH_4^+ is the predominant form of nitrogen in septic tank effluent due to the anaerobic nature of these wastewater treatment systems. During their studies of the fate of nitrogen in septic tank effluent, all of these researchers established that septic tanks achieve very little nitrogen removal from domestic wastewater.

Table B-1. Septic Tank Influent and Effluent pH Values from Two Sources

REFERENCE	SAMPLE SOURCE	pH (standard units)
Whelan and Titamnis, 1982	5 Septic Tank Effluents (Mean ± Standard deviation)	6.6 ± 0.1 7.4 ± 0.1 7.0 ± 0.1 6.9 ± 0.2 6.9 ± 0.3
Canter and Knox, 1985	Septic Tank Influent (85% of the time less than)	7.15 - 8.7

The fate of NH_4^+-ions leaving septic tanks seems well established. These NH_4^+-ions are available for uptake and conversion to organic nitrogen by soil bacteria during incorporation into bacterial proteins. More important, the NH_4^+-ions in septic tank effluent also undergo the nitrification process in aerobic soils which support the necessary bacterial communities. Nitrate contamination of groundwater as a result of the nitrification of septic tank effluent is well documented. Plant uptake and the bacterial denitrification processes are the ultimate fate of septic tank nitrogen that has been converted to nitrate.

Reduced Nitrogen In Latrines And Stagnant, Open Sewers

Though no data have been located, the chemical and microbiological characteristics associated with septic tanks are believed to be prevalent in both latrines and stagnant open sewers. Both of these forms of wastewater are expected to be anaerobic and to be neutral or acidic with regard to pH. Both of these chemical characteristics suggest that the fate of reduced nitrogen in latrines and stagnant, open sewers does not involve gaseous nitrogenous emissions.

NITROUS OXIDE

Nitrous Oxide from Septic Tanks

The potential for the release of nitrous oxide (N_2O) from septic tanks is also of interest. Nitrous oxide results from the incomplete reduction of nitrate during a bacterial process called denitrification (Brock and Madigan, 1988). By definition, denitrification is not possible in the absence of nitrate, which serves microorganisms as an alternative terminal electron acceptor in the absence of oxygen. Though septic tanks represent suitable environments for denitrification because they are anaerobic, the concentration of nitrate in the tank is expected to be limited. Only the nitrate present in the potable water associated with domestic life, or present as a result of the introduction of a chemical into the potable water (i.e. photographic development) would be available to facilitate denitrification. In most developed countries, nitrate concentrations in potable water supplies are monitored and in some cases regulated due to the negative human health aspects associated with elevated concentrations of nitrate. Without consistent, substantial concentrations of nitrate, denitrification does not take place. Because septic tanks do not support denitrification in the absence of nitrate, N_2O emissions from septic tanks will be negligible.

The NH_4^+-ions present in septic tank effluent could undergo nitrification to form nitrate in aerobic soil surrounding the drain field and then be transported to regions that would support denitrification and lead to the formation of N_2O. This type of nitrogen fate would be highly site specific and a significant lag time would be expected for the transport and bacterial conversion necessary to form N_2O.

Nitrous Oxide from Latrines and Stagnant, Open Sewers

As with septic tanks, N_2O emissions from latrines and stagnant, open sewers would be dependent on the availability of nitrate to serve as a terminal electron acceptor. Also, nitrate concentrations in any water added to latrines and open sewers along with the actual waste will be the primary source of nitrate in these anaerobic systems. Though the extent of nitrate in water added to latrines and open sewers is not documented here, the potential for nitrate to be present in water used for these purposes is much greater in areas of the world that rely on latrines and stagnant sewers as means of handling domestic wastewater. This higher potential for the presence of significant nitrate concentrations is associated with the expected primitive state of enforced drinking water regulations in countries where open sewers are used to transport domestic wastewater.

As with NH_4^+-ions in septic tank drain field effluent, NH_4^+-ions seeping into soils surrounding unlined latrines and open sewers could undergo nitrification to nitrate. If transported to a subsurface area where anaerobic conditions prevail, the nitrate formed in this manner could undergo denitrification and subsequently result in the emission of N_2O. This fate of nitrogen would be equally site specific and could also be accompanied by a substantial time lag between the expulsion of the waste and the emission of N_2O gas.

SUMMARY AND CONCLUSION

Data associated with the operation of septic tanks and scientific judgment were used to generate an understanding of the nitrogen cycle associated with on-site septic tank treatment of domestic wastewater. This nitrogen cycle characterization can be applied to latrines and stagnant, open sewers because the microbiological and chemical conditions are expected to be identical to the conditions within septic tanks. Knowledge of the nitrogen cycle in septic tanks, latrines, and stagnant, open sewers suggests that anaerobic wastewater does not contribute any significant quantity of NH_3 and N_2O to the atmosphere. This discovery indicates that the estimation of nitrogenous air emissions can safely overlook the production of NH_3 and N_2O from septic tanks, latrines, and open sewers at a global level.

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16. ABSTRACT The report gives results of a first attempt to estimate global and country-specific methane (CH4) emissions from sewers and on-site wastewater treatment systems, including latrines and septic sewage tanks. It follows a report that includes CH4 and nitrous oxide (N2O) estimates from treated industrial and domestic wastewater. The study uses an emission factor that expresses CH4 emissions in terms of removed Chemical Oxygen Demand. Combined global CH4 emissions from latrines, septic sewage tanks and stagnant open sewers are estimated to be 29 Tg/yr, with lower and upper bound ranges of 14 and 49 Tg/yr, respectively. These ranges reflect boundaries in the parameters that could be quantified through measurements; i.e., the emission factor and Chemical Oxygen Demand loadings. Major uncertainties in the estimates are associated with the degrees to which wastewater in developing and eastern European countries is treated in latrines or septic tanks, or removed by sewer. Also, the amount of wastewater that is discharged into stagnant open sewers and the degree to which anaerobic decomposition takes place in these sewers are highly uncertain. Latrines in rural areas of developing countries such as China and India are believed to be the single most significant source of CH4, accounting for roughly 12 Tg/yr.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Ammonia	Pollution Control	13B	
Emission	Greenhouse Effect	Stationary Sources	14G	04A
Septic Tanks		Latrines		
Sanitary Sewers		Open Sewers		
Methane			07C	
Nitrogen Oxide (N2O)			07B	

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