ESTIMATION OF HAZARDOUS AIR POLLUTANT EMISSIONS FROM MUNICIPAL SEWER SYSTEMS

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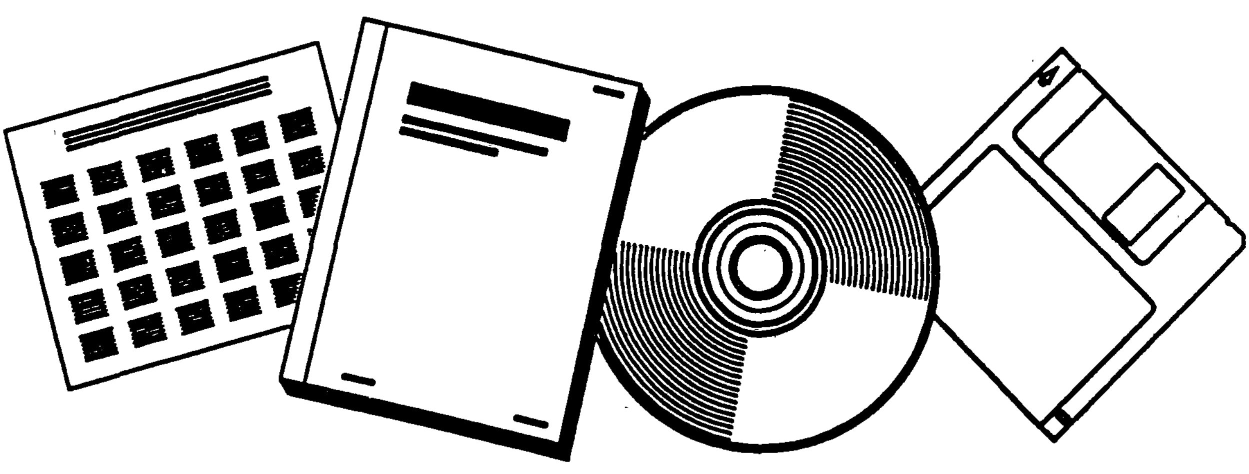

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ABSTRACT

Emissions from municipal sewers are usually omitted from both volatile organic compound and hazardous air pollutant (HAP) emission inventories. This omission may result from a lack of appreciation for the potential emissions impact and/or inadequate emissions estimation procedures. This paper presents results of efforts to estimate HAP emissions from sewers in a large U. S. city. An approach was developed and implemented that used EPA's National Pollutant Discharge Effluent System (NPDES) data as the basis for estimating HAP discharges to municipal sewers. The Collection Organic Release Algorithm (CORAL+) model was used with these data to estimate city-wide HAP emissions from sewers. The results showed that the sewer HAP emissions are likely to be equal to or greater than those from the city's wastewater treatment facilities. The sewer HAP emissions estimate of over 270 megagrams per year (300 tons per year) for the city was expected to underestimate sewer emissions, since sewer *effluent* wastewater concentration data from NPDES were used to formulate the estimate.

INTRODUCTION

Wastewater discharges to municipal sewer systems contain many compounds that are among the 189 hazardous air pollutants (HAPs) that the U. S. Environmental Protection Agency (EPA) is required to estimate and control if emitted into air, according to the Clean Air Act Amendments of 1990 (CAAA). Based on experience with industrial wastewater treatment and collection systems, there is a potentially high level of volatile HAP emissions from municipal sewer systems (sewers) before wastewater enters municipal wastewater treatment facilities [POTWs (publicly owned treatment works)]. Emissions from sewers are usually ignored in HAP emission inventories.[1] This omission may be partly a result of the lack of appreciation for the potential emissions impact, but may also be due to inadequate emissions estimation procedures. This paper reports on a method that was developed to estimate HAP emissions from municipal sewers that uses generally available data. The method was used to predict sewer emissions for a large U. S. city. For perspective, the HAP emissions predicted for sewers in the city were compared to estimates of HAP emissions from other sources, such as POTWs, and to sewer emissions that have been measured in other cities.

NOMENCLATURE

Nomenclature that is typically used to describe components of a municipal sewer system includes:

Manhole--A covered opening in the ground at surface level that provides maintenance access to sewer lines. Manhole covers are usually perforated (four or more holes) so that sewer gas escapes to the atmosphere with the cover in place.

Reach--A segment of the sewer line. In municipal systems, reaches are generally closed to the atmosphere except for the manhole vents.

Drop--A structure that serves as the junction of two or more sewer lines where the upstream pipeline enters the chamber at a higher elevation than the exit for the downstream pipeline. In most municipal systems, drops are closed except for the manhole vents above the drop.

Lift station--A junction of two or more sewer lines where the wastewater is lifted to a higher elevation by a pump or hydraulic lift.

MODELS AVAILABLE TO ESTIMATE EMISSIONS FROM MUNICIPAL SEWERS

Six models were found that could be used to predict emissions from sewers:

- BACT/LAER-IWW/MRE (Manhole regression equation from the Industrial Wastewater--Best Available Control Technology/Lowest Achievable Emission Rate document);[2]
- BASTE (Bay Area Sewage Toxics Emissions);[a]
- CHEMDAT7;[3]
- CORAL+ (Collection Organic Release Algorithm);[b]
- SIMS (Surface Impoundment Modeling System);[4] and
- WATER8.[5]

Of these six models, only two (BASTE and CORAL+) were not developed by the EPA; these models were also the only models of the six listed above that were specifically created to address municipal wastewater emissions. The EPA models were primarily created to address on-site industrial emissions and, in some cases, used industrial data to develop the models. Although the authors of WATER8 state that the model can be used with either municipal or industrial sewers, only industrial sewer data were used to develop the model.

Vents in reach manholes and drop structures are the most frequently found sewer emissions points in municipal sewers. In municipal sewer systems, most sewer components outside of the POTWs are enclosed, but vented to the atmosphere. The sewer system components addressed by each model are noted in Table 1. Components likely to be part of a municipal sewer system are also noted in Table 1. The EPA models, in general, address sewer components that are more likely to be included in an industrial sewer system than in a municipal sewer system. Only four models, BACT/LAER-IWW/MRE, BASTE, CORAL+, and WATER8, can be used to estimate HAP emissions from municipal sewer components.

METHOD TO ESTIMATE HAP EMISSIONS FROM MUNICIPAL SEWERS

The goal for this study was to provide a method to estimate HAP emissions from municipal sewers that state and local air pollution agencies can use to develop a sewer emissions inventory from available data. Of course, the most accurate means of estimating HAP emissions from sewers would be to obtain air measurement data on a continuous basis. Because of the extensive area over which sewers are located, this approach would be highly impractical. Even the continuous measurement of wastewater concentration data, the second best approach to providing sewer emissions estimates, would also be difficult to implement on a large scale.

In the absence of measurement data, a method was developed that can be used to estimate sewer HAP emissions from relatively available data and one of the sewer models discussed above. This method is described and demonstrated for a large U. S. city.

Description of the Method

The method developed to estimate HAP emissions from sewers relies on three components:

- Sewer wastewater HAP concentration data;
- Sewer physical and operating data; and
- A model that relates the above two data components to emissions.

Since most regions don't regularly measure sewer concentrations, the industrial wastewater discharge data reported to EPA's Toxic Release Inventory System (TRIS), under the authority of the Superfund Amendments Reauthorization Act, were used to provide one estimate of HAP inputs to sewer wastewater. Another source of data was influent POTW wastewater measurements performed for the National Pollution Discharge Effluent System (NPDES).

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[a] Developed by R. L. Corsi and available from the Bay Area Air Toxics (BAAT) group, c/o CH2MHill, Inc., Oakland, CA 96404

[b] Developed by R. L. Corsi and available from Enviromega, Ltd., Hamilton, Ontario, Canada. L9J 1K3

TRIS data are available in terms of annual chemical discharge (by total weight) into sewer wastewater, on a per-facility basis. Unfortunately, TRIS data do not include residential and commercial wastewater inputs to the sewer system, since these sources are not required to report to TRIS. Therefore, the use of TRIS data will underestimate sewer HAP emissions for areas where residential and commercial wastewater are significant contributors to the municipal sewer system. TRIS also does not include six of the 189 HAPs; one of the six, hexane, is a commonly used chemical that may be a significant sewer input in some areas.

Influent POTW wastewater concentration data are required to be reported annually to the NPDES for 111 priority pollutants as defined by the Clean Water Act. Frequently, data for other pollutants in the wastewater are also provided by the methods used to test the priority pollutants. Of the 111 priority pollutants, only 46 are HAPs; therefore, the HAP coverage of the NPDES data is expected to be low as compared to the universe of 189 potential HAPs and the 183 HAPs reported to TRIS. Within the 46+ HAP coverage, the NPDES data, however, are expected to be more representative of a municipal sewer system than TRIS data, since measurements are taken from wastewater that is composed of industrial, commercial, and residential sewer inputs. Although, since NPDES data are usually obtained from only one annual wastewater sample, the data may or may not represent the annual average wastewater concentration entering a POTW. Nevertheless, the NPDES data represent the HAP wastewater concentrations *after* sewer emissions occur, since the POTWs are downstream of the sewer emission points. If NPDES data are used to predict sewer emissions, the estimate may be much lower than if wastewater samples could be taken at the influent points in the sewer system.

The CORAL+ model was chosen as the model to estimate HAP emissions from sewers, since this model was developed from municipal sewer studies and provided emissions estimates for both reach manholes and drops. Of the six available models listed earlier, CORAL+ is only capable of estimating emissions from a single section of the sewer (a reach) and a single drop.[a] In order to estimate sewer emissions for an entire region, the CORAL+ model was first used to estimate emissions from a single reach manhole and drop, and then scaled up to the municipal level with information on the number of reach manholes and drops in the city.

The following sewer physical and operating data were needed to use the CORAL+ model and to scale up the individual reach and drop manhole emissions to the city level:

- Total length of sewer pipeline;
- Average wastewater velocity in reach;
- Average reach diameter;
- Average wastewater depth in a reach;
- Average wastewater depth in a drop;
- Average reach slope;
- Reach ventilation rate or air/water volume ratio;
- Approximate frequency of occurrence of reach and drop manholes, per length of sewer pipeline;
- Average drop diameter; and
- Vertical distance from surface to reach and drop.

These data were found to be available either from municipal sewer authorities or by estimating from literature values.

Sewer HAP Emissions for a Large U. S. City

The method described above was used with both 1989 TRIS data and 1989 NPDES data for a U. S. city (hereafter referred to as the "City") to estimate sewer HAP emissions. The City has a population of approximately 5 million and covers 2,259 square kilometers (872 square miles).

TRIS Data--The 1989 TRIS data for the City are shown in the second column in Table 2.[8] There were 40 HAPs identified as discharges into the City sewer system. The total amount of each HAP discharged from all facilities ranged from 0.02 to 766 megagrams (Mg) (0.03 to 842 tons), and the total amount of all HAPs discharged equalled 2,543 Mg (2,797 tons). The concentration of each HAP in the City's sewer wastewater was estimated by dividing the annual amount of each HAP discharge reported to TRIS summed for all facilities in the City by the volume of wastewater processed by the municipal treatment system (per year). The wastewater volume was assumed to be the sum of the annual influent wastewater volumes for all POTWs in

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[a] A "city" model is under development at this time.

the City's sewer system (5.5 million cubic meters per day or 1,443 million gallons per day [MGD]).[a] The calculated sewer wastewater concentrations of the 40 HAPs are shown in the third column of Table 2. The concentrations ranged from 0.014 to 381 micrograms per liter (µg/L), for a total HAP concentration of 1,260 µg/L for the City's wastewater.

NPDES Data--HAP wastewater concentration data were obtained for the City from annual NPDES reports of influent wastewater concentrations for all POTWs in the City in 1989.[7] The City-wide HAP wastewater concentrations were estimated from the average of the concentrations for each POTW weighted by the wastewater volume treated at each facility. The estimated City-wide HAP wastewater concentrations are shown in Table 3. There were 24 HAPs identified in the influent to the City POTWs. The weighted HAP concentrations ranged from 0.01 to 381 micrograms per liter (µg/L) for a total HAP concentration of 1,056 µg/L.

Table 3 also shows the wastewater concentrations calculated for these same HAPs from TRIS data (from Table 2). This comparison reveals that of the 24 HAPs measured in the City's POTW influent wastewater for NPDES, 14 were also found in the City's TRIS reports. The 10 HAPs missing from the TRIS reports are likely to be (solely) components of the commercial and residential wastewater in the City. The NPDES-reported wastewater concentration of these 10 HAPs, however, were only 4 percent of the total POTW wastewater concentration for all 24 HAPs and, therefore, were not expected to be major contributors to the municipal sewer emissions.

The data in Table 3 also show that the TRIS-calculated concentrations were greater than the NPDES values for only 4 out of the 14 HAPs that were identified in both NPDES and TRIS data for the City. For the other 10 HAPs, the NPDES wastewater concentrations were greater than the TRIS wastewater concentrations, by factors of 2 to 1,659. These 10 HAPs were believed to represent a major portion of the unaccounted-for contribution to the sewers from commercial and residential wastewater. Note that some uncertainty is associated with both the TRIS and NPDES data. This uncertainty may be as high as a factor of 10 on a plant-by-plant basis.

Sewer Physical and Operating Data--Table 4 shows the sewer physical and operating values that were used to estimate the City sewer emissions with the CORAL+ model. These values were estimated from information obtained from the City's sewer engineers, assumptions about the sewer system, or calculations made from one or both of these sources. In many cases, an average value was used in the model if only a range of values was available. The source or method of obtaining these data is also shown in Table 4.

Model Estimates--Estimates of HAP emissions from the City sewers were obtained using the CORAL+ model, sewer physical and operating data, and the two sets of HAP input data described above. These emissions are shown in Table 5.

Using the TRIS data, the estimated total sewer HAP emissions were approximately 27 Mg per year (30 tons per year [tpy]) for the 40 HAPs identified in TRIS for the City. Reach emissions comprised 42 percent of the total estimated emissions; drop emissions comprised 58 percent. Using the NPDES data, the estimated total sewer HAP emissions were 278 Mg per year (306 tpy) for the 14 HAPs identified with NPDES sampling (and also identified in TRIS data). Reach emissions comprised 52 percent of the total estimated emissions; drop emissions comprised 48 percent.

Table 5 also shows that the 14 HAPs included in both TRIS and NPDES reports account for 98 percent of the TRIS-reported HAPs, therefore the NPDES data were believed to have included the HAPs that comprised the majority of the quantity of sewer influent pollutants. For this reason, and because the NPDES data are a reflection of industrial, residential, and commercial wastewater discharges, the sewer HAP emissions estimate from NPDES data was thought to be the more representative sewer HAP emissions estimate.

The total sewer HAP emissions calculated from NPDES data were 10 times the amount estimated for the same HAPs with TRIS data. This factor, although large, implies an even larger true value, since the NPDES data were taken from city wastewater *after* emissions from the sewer system occurred. If the sewer system were a single point source, both the TRIS and NPDES estimates would enable the sewer system to qualify as a major HAP emission source under Title III of the CAAA through both of the applicable criteria: one HAP with an emission rate over 9 Mg per year (10 tpy) and combined HAP emission rates over 23 Mg per year (25 tpy).

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[a] The total annual wastewater flow was estimated from the sum of the wastewater volumes treated per day in the City POTWs, multiplied by 365 days per year.

Sources of Uncertainty in the Sewers Emissions Estimate

There are three primary sources of uncertainty in this sewers emissions estimate:

- The sewer wastewater HAP concentration data;
- The scaling of reach manhole and drop emissions to the City level; and
- The average values used as sewer physical and operating data.

The primary source of uncertainty in the sewers emissions estimate is thought to be the sewer HAP concentration data; i.e., the extent to which the NPDES data underestimate sewer wastewater concentrations. More work is needed to determine the correlation of NPDES wastewater measurements (POTW influent) to sewer influent wastewater concentrations or to obtain a better source of sewer influent data.

COMPARISON OF PREDICTED SEWER HAP EMISSIONS TO PREDICTED HAP EMISSIONS FROM POTWS AND OTHER AREA SOURCES IN THE CITY

This portion of the paper compares the estimate of the City sewer emissions, obtained with the method described above, to estimates of HAP emissions for other area sources in the City. In particular, estimates of HAP emissions from POTWs were compared to the sewer estimates developed in this study in order to observe the relative magnitude of emissions from each of these two components of a wastewater handling and treatment system. Comparisons were also made to estimates of emissions from two common urban area sources--graphic arts and dry cleaning--in the City. The methods used to obtain these estimates are also described below.

Comparison to POTW Emissions Estimates

The City sewer emissions estimates developed in this paper were first compared to estimates of POTW emissions, since the sewer system and POTW are both parts of the municipal sanitary system. In HAP emissions inventories, the POTW is usually the only component of the municipal sanitary system that is addressed.[1] This comparison, then, will show whether the omission of sewer emissions neglects a significant contributor of HAP emissions in a municipality.

Two estimates of HAP emissions from POTWs in the City were obtained using different methods. The first estimate of HAP emissions from POTWs was obtained using an emission inventory approach,[a] where an activity factor in terms of the amount of wastewater treated was multiplied by generic emission factors developed for 15 HAPs in a number of wastewater treatment processes that were thought to be part of a typical POTW. The generic emission factors were developed from test data from another U. S. city and were obtained from EPA's Factor Information Retrieval System (FIRE) data base.[8] Using this approach, the total estimated HAP emissions from POTWs in the City were 94 Mg per year (103 tpy). The estimated emissions for the 15 HAPs are shown in Table 6. The weaknesses in the emissions inventory approach to estimating POTW emissions were (1) the applicability of the typical POTW configuration to the City's POTW configuration, and (2) the applicability of the 15 HAPs to the City's wastewater treatment system. The sewer emissions estimate from NPDES, at 278 Mg per year (306 tpy), was three times the total POTW emissions estimated with this first approach.

A second estimate of POTW emissions was obtained using a 20-percent volatilization factor with HAP discharge data reported to TRIS.[6] The total HAP emissions from POTWs using this approach were estimated to be 504 Mg per year (554 tpy). The sewer emissions estimate obtained with NPDES data[6] was over half of the 504 Mg per year (554 tpy) POTW emissions estimate obtained with the 20-percent volatilization factor approach. The two sewer and POTW emissions estimates are shown in Table 7. A simple volatilization approach to estimating POTW emissions has many obvious drawbacks, such as the inability to account for the different types of treatment processes used at POTWs and the degree of volatility of each HAP.

Since the NPDES estimate is a low estimate based on sewer wastewater *effluent* concentrations, the true sewer emissions are likely to be equal to if not greater than POTW emissions, considering the POTW emissions estimates obtained with these two methods.

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[a]Described in an EPA report scheduled for publication early in 1995.

Comparison to Graphic Arts and Dry Cleaning Area Source Emissions Estimates for the City

The City's sewer emissions estimates were also compared to air emissions estimated for graphic arts and dry cleaning operations. This comparison was made to show the relative contribution of sewer emissions as compared to other area sources that are typically found in the urban setting. An emission inventory approach[a] was also used to estimate HAP emissions from graphic arts and dry cleaning area sources in the City. The graphic arts area sources emissions estimate was obtained using a *per capita* emission factor, with the estimated City population being the activity factor. The total HAP emissions estimated for graphic arts area sources in the City using this method were 1,522 Mg per year (1,674 tpy). For dry cleaning, a per employee emission factor was multiplied by the estimated number of employees in area sources in the City to estimate HAP emissions. Using this method, the total HAP emissions estimated for dry cleaning area sources in the City were 3,101 Mg per year (3,411 tpy).

The HAP emissions estimated for graphic arts and dry cleaning area sources in the City using the emission inventory approach, at 1,522 and 3,101 Mg per year (1,674 and 3,411 tpy), respectively, were greater than both TRIS and NPDES sewer emissions estimates. Although the sewer emissions estimated with NPDES data were only 9 and 18 percent of the emissions estimated for dry cleaning sources and graphic arts, respectively, the sewers emissions estimate from NPDES is likely to underestimate the sewer emissions impact. Therefore, sewer emissions may be comparable to emissions from these other area sources, if true sewer emissions were known. Table 7 shows the HAP emissions estimates from the City sewers, POTWs, and two area source categories produced with the various emissions estimation methods.

COMPARISON OF CITY SEWER EMISSIONS TO DATA FOR OTHER CITIES

Estimates of sewer gas HAP concentrations in the City, obtained with CORAL+, were compared to measurements of sewer gas HAP concentrations reported in the literature for other municipal sewer systems. Table 8 shows the predicted City sewer gas concentrations for four HAPs (benzene, ethylbenzene, toluene, and xylene) from the two sewer emissions data sources used in this study as compared to measurements of sewer gas reported in the literature for reach manholes in California;[9] Toronto, Canada;[10,11] and London, England.[12] Note that data for no more than three of the four HAPs were reported in each literature source.

The measured gas concentration data ranged from 0.18 to 170 parts per million (ppm). The sewer gas concentrations calculated with NPDES data were comparable in magnitude to some of the measured data, and ranged from 1.4 to 5.1 ppm. This comparison supports the opinion presented here that the sewer HAP emissions estimate obtained with NPDES data was a more realistic estimate of sewer emissions for the City than the estimate obtained with TRIS data; also, that the NPDES data may also have underestimated the sewer HAP emissions for the City, since the data from the literature were in general higher than the NPDES data. However, the literature measurement data may have been obtained at points in the sewer system where high concentrations of HAP emissions were likely to occur (i.e., near industrial discharges). The lower values for the City would then reflect the results of averaging the data over the entire City sewer system.

CONCLUSIONS AND RECOMMENDATIONS

A method was developed to estimate sewer HAP emissions from readily available sewer physical and operating data and one of the models available to predict sewer emissions. The method was used with POTW influent wastewater concentration data from NPDES, with the CORAL+ model. Wastewater HAP concentration data obtained from the NPDES reports were thought to be more representative of sewer conditions than TRIS data, because the NPDES data were a reflection of industrial, residential, and commercial wastewater discharges. The CORAL+ model was chosen because it is the only model that can be used to predict emissions from reaches and drops, frequent emission points in municipal sewer systems.

The method developed here was used to estimate sewer emissions for a large U. S. city. The estimated sewer HAP emissions for the city, at 278 Mg per year (306 tpy), were believed to be a low estimate, since NPDES data are POTW *influent* and sewer *effluent* measurements. This sewer emissions estimate showed that sewer HAP emissions are a significant component of the total urban HAP wastewater emissions (sewer emissions plus POTW emissions), and are likely to be greater than POTW emissions. Sewer HAP emissions may also be comparable to emissions from other area sources, such as dry cleaning and graphic arts. Since the sewer emissions estimated here are more likely to be emitted from manholes near the sources' discharge

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[a]Described in an EPA report scheduled to be published early in 1995.

to the sewer and not spread evenly around the city, there also is potentially a significant threat to public health from individual emissions points throughout the sewer system.

REFERENCES

1. Telecon. Darcy Campbell, Radian Corporation, Research Triangle Park, North Carolina, with Julian Jones, Air and Energy Engineering Research Laboratory, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. April 1, 1993. Evaluation of air toxics inventories from selected urban areas.

2. Elliott, J. and S. Watkins. Industrial Wastewater Volatile Organic Compound Emissions--Background Information for BACT/LAER Determinations. EPA-450/3-90-004 (NTIS PB90-194754). U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. January 1990.

3. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF)--Air Emissions Models Documentation. EPA-450/3-87-026 (NTIS PB88-198619). U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. December 1987.

4. Watkins, S. Surface Impoundment Modeling System (SIMS) User's Manual. EPA-450/4-89-013a (NTIS PB90-141227). U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. September 1989.

5. Personal Communication from F. Elaine Manning, Office of Air Quality Planning and Standards, Emission Standards Division, to Julian W. Jones, Air and Energy Engineering Research Laboratory, on estimation of air emissions from airflow in wastewater collection systems (WATER8 Model). U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. November 30, 1993.

6. Memorandum. Calvin Overcash, EC/R, Inc. Durham, North Carolina, to Eric Crump, Emission Standards Division, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. Summary of the Toxic Release Inventory System. January 28, 1993.

7. Letter. Metropolitan Water Reclamation District of the City to Donna Lee Jones, Radian Corporation, transmitting 1989 NPDES data for the City. July 14, 1994.

8. U.S. Environmental Protection Agency. Factor Information Retrieval (FIRE) System Database, Version 3.0. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. March 1994.

9. Chang, D. P. Y., E. D. Schroeder, and R. L. Corsi. Emissions of Volatile and Potentially Toxic Organics from Sewage Treatment Plants and Collection Systems. CARB A5-127-32. California Air Resources Board, Sacramento, California. 1987.

10. Quigley, C., P. Martos, and R. L. Corsi. VOC Emissions from a Municipal Sewer Interceptor. 86th Air and Waste Management Association Annual Meeting. Denver, Colorado. 93-WA-72A.03. June 1993.

11. Whitmore, A., R. L. Corsi, J. Shepherd, and D. Thompson. Examining Gas-Liquid Mass Transfer of Volatile and Semi-volatile Organic Compounds along Sewer Reaches. Proc. 85th Air and Waste Management Association Annual Meeting. Kansas City, Missouri. 1992.

12. Reid, J. M. and M. McEvoy. Monitoring Sewer Atmospheres for Organic Vapors. J. Institute of Water and Environmental Management. 1(2) 161. 1987.

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TABLE 1. SEWER COMPONENTS ADDRESSED BY THE MODELS

Model	Manholes[a]	Drops[a]		Lift Stations		Junction Boxes	Drains		Sumps		Open Conduits
		Open	Closed[a]	Open	Closed[a]		Open	Closed	Open	Closed	
BACT/LAER-IWW	X			X		X	X		X		
BASTE		X	X								
CHEMDAT7				X		X			X		
CORAL+	X	X	X								X
SIMS				X		X			X		
WATER8	X			X	X	X			X	X	X

[a] Likely component of a municipal sewer system.

TABLE 2. SEWER WASTEWATER HAP CONCENTRATION DATA FOR THE CITY ESTIMATED FROM TRIS REPORTS

Compound	TRIS 1989 Reported Sewer Discharge,[a] Mg (tons)	Calculated Wastewater Concentration,[b] µg/L
Acrylamide	0.15 (0.16)	0.07
Aniline	277(304)	137
Benzene	9.1(10)	4.5
Benzyl chloride	0.12 (0.13)	0.06
Bis(2-ethylhexyl) phthalate	0.12 (0.13)	0.06
Cadmium compounds	0.35 (0.38)	0.17
Carbon disulfide	12 (13)	5.9
Chromium compounds	8.5 (9.3)	4.2
Cobalt compounds	0.16 (0.18)	0.08
Cresols	696 (766)	346
Cyanide compounds	3.7 (4.1)	1.9
Dibutyl phthalate	0.35 (0.39)	0.18
Dichloromethane	0.45 (0.50)	0.23
Diethanolamine	1.7 (1.8)	0.82
Epichlorohydrin	0.12 (0.13)	0.06
Ethyl acrylate	0.12 (0.13)	0.06
Ethylbenzene	1.1 (1.3)	0.57
Ethylene glycol	21 (23)	10.4
Formaldehyde	14 (15)	7
Glycol ethers	83 (92)	44
Hydrogen chloride	766 (842)	381
Hydrogen fluoride	0.12 (0.13)	0.06
Hydroquinone	0.43 (0.47)	0.21
Lead compounds	1.9 (2.1)	0.94
Manganese compounds	5.2 (5.8)	2.6
Methanol	147 (162)	73
4,4-methylenedianiline	0.12 (0.13)	0.06
Methyl ethyl ketone	0.23 (0.25)	0.11
Methyl isobutyl ketone	0.12 (0.13)	0.06
Methyl methacrylate	0.12 (0.13)	0.06
Naphthalene	0.38 (0.42)	0.19
Nickel compounds	4.7 (5.1)	2.3
2-nitropropane	0.68 (0.75)	0.34
Phenol	464 (510)	231
Phosphorous	0.12 (0.13)	0.06
Propylene oxide	0.12 (0.13)	0.06
Toluene	6.2 (6.8)	3.1
1,1,1-trichloroethane	8.6 (9.4)	4.3
Vinyl acetate	0.02 (0.03)	0.014
Xylenes	7.9 (8.7)	3.9
TOTAL	2,543 (2,797)	1,260

[a] Reference 6.

[b] From annual TRIS data[a] divided by annual POTW volumes estimated from daily POTW flowrates.

TABLE 3. COMPARISON OF SEWER WASTEWATER HAP CONCENTRATIONS CALCULATED FROM NPDES AND TRIS DATA FOR THE CITY

HAP	Calculated Wastewater Concentration, µg/L	
	NPDES Data[a]	TRIS Data[b]
Aniline	91	137
Benzene	8	4.5
Bis(2-ethylhexyl)phthalate	26	0.1
Carbon disulfide	4	5.9
Chlorobenzene	1	NP[c]
Chloroform	6	NP
Cresol	270	346
Dibenzofuran	1	NP
Dibutylphthalate	7	0.2
Dichlorobenzene (1,4)	3	NP
Dichloromethane	381	0.2
Dimethylphthalate	0.3	NP
Ethylbenzene	17	0.6
Isophorone	3	NP
Methyl ethyl ketone	13	0.1
Naphthalene	14	0.2
Phenol	83	231
Polychlorinated biphenyls	0.5	NP
Polycyclic aromatic hydrocarbons	21	NP
Styrene	0.01	NP
Toluene	35	3.1
Trichlorobenzene (1,2,4)	0.3	NP
Trichloroethane (1,1,1)	11	4.3
Xylenes	60	3.9

[a] From NPDES reports of measured POTW influent wastewater concentrations, weighted by individual POTW wastewater volume[7].

[b] From TRIS reports of discharges to sewer wastewater and total wastewater volume to the POTWs in the city[8].

[c] Not present in TRIS reports.

TABLE 4. CASE STUDY SEWER PHYSICAL AND OPERATING DATA FOR A LARGE U. S. CITY[a]

Parameter	Data		Source of Information
Drop height	4.6 15	meters feet	City-supplied data
Drop diameter	1.8 6	meters feet	City-supplied data
Drop tailwater depth	0.91 3	meters feet	Assumed as 40 percent of reach height/diameter
Number of drops	2,000		City-supplied data
Number of reach manholes	4,000		City-supplied data
Reach air/water volume fraction	0.015	dimensionless	Calculated from reach ventilation rate and wastewater flowrate
Reach diameter	2.3 7.5	meters feet	City-supplied data
Reach length	183 600	meters feet	City-supplied data
Reach manhole gas volume	15.6 551	cubic meters cubic feet	Calculated from manhole diameter and reach height, as a cylinder
Reach slope	0.1	percent	Assumed, based on literature
Reach type	closed		Assumed, based on municipal scenario
Reach ventilation rate	10	turnovers per day (TO/D)	Assumed, based on literature
Roughness coefficient	0.015	dimensionless	Based on concrete pipes
VOC concentration in ambient air	0	ppm	Assumed, based on literature
Wastewater depth/height	1.1 3.6	meters feet	From reach diameter and assumption that reach is half-full; consistent with Manning's formula (for turbulent flow of water in open channels) and hydraulic parameters
Wastewater flowrate	243,381 8,591,349	cubic meters per day cubic feet per day	Calculated from wastewater velocity provided; assumed reach half-full
Wastewater temperature	20	°C	Assumed, based on literature

[a] The city contains approximately 5 million people and covers 2,259 square kilometers (872 square miles).

TABLE 5. ESTIMATE OF SEWER HAP EMISSIONS FROM THE CITY USING TRIS AND NPDES DATA

	Sewer Emissions, Mg per year (tpy)		
	TRIS DATA		
Compound	All Data	NPDES Matched	NPDES DATA
Carbon disulfide	10 (11)	10 (11)	6.9 (7.6)
1,1,1-trichloroethane	6.8 (7.5)	6.8 (7.5)	17 (19)
Xylenes	3.2 (3.5)	3.2 (3.5)	51 (56)
Benzene	3.2 (3.5)	3.2 (3.5)	5.7 (6.3)
Toluene	2.4 (2.7)	2.4 (2.7)	28 (31)
Methanol	0.44 (0.49)		
Ethylbenzene	0.37 (0.40)	0.37 (0.40)	14 (15)
Cresols	0.10 (0.11)	0.10 (0.11)	0.07 (0.08)
Dichloromethane	0.08 (0.09)	0.08 (0.09)	154 (169)
Phosphorous	0.06 (0.07)		
Methyl isobutyl ketone	0.05 (0.06)		
Phenol	0.05 (0.06)	0.05 (0.06)	0.02 (0.02)
Aniline	0.04 (0.05)	0.04 (0.05)	0.03 (0.03)
Naphthalene	0.01 (0.02)	0.01 (0.02)	1.1 (1.2)
Methyl methacrylate	0.01 (0.02)		
2-nitropropane	0.01 (0.01)		
Methyl ethyl ketone	0.005 (0.005)	0.005 (0.005)	0.51 (0.56)
Propylene oxide	0.003 (0.004)		
Benzyl chloride	0.003 (0.003)		
Ethyl acrylate	0.003 (0.003)		
Vinyl acetate	0.001 (0.001)		
Formaldehyde	4E-04 (4E-04)		
Epichlorohydrin	3E-04 (4E-04)		
Hydrogen fluoride	2E-04 (3E-04)		
Glycol ethers*	2E-03 (3E-03)		
Dibutyl phthalate	8E-06 (9E-06)	8E-06 (9E-06)	4E-04 (4E-04)
Ethylene glycol	3E-06 (4E-06)		
Bis(2-ethylhexyl) phthalate	3E-06 (3E-06)	3E-06 (3E-06)	9E-04 (1E-03)
Hydroquinone	5E-08 (6E-08)		
Acrylamide	3E-09 (3E-09)		
Diethanolamine	2E-10 (2E-10)		
4,4-methylenedianiline	0		
Cadmium compounds	0		
Chromium compounds	0		
Cobalt compounds	0		
Cyanide compounds	0		
Hydrogen chloride	0		
Lead compounds	0		
Manganese compounds	0		
Nickel compounds	0		
TOTAL	27 (30)	26 (29)	278 (306)

*Ethylene glycol was used to represent this group of compounds.

TABLE 6. ESTIMATE OF HAP EMISSIONS FROM THE CITY'S POTWS USING AN EMISSIONS INVENTORY APPROACH[a]

HAP	POTW Emissions, Mg per year (tpy)
Benzene	3.2 (3.6))
Carbon tetrachloride	21.9 (24.1)
Chloroform	12.1 (13.3)
Dichlorobenzene	2.5 (2.7)
1,4-Dioxane	0.10 (0.11)
Formaldehyde	2.5 (2.8)
Methylene chloride	10.1 (11.1)
Perchloroethylene	7.9 (8.7)
Styrene	1.2 (1.4)
Toluene	9.5 (10.5)
1,1,1-Trichloroethane	5.6 (6.2)
Trichloroethylene	5.8 (6.4)
Vinyl chloride	1.3 (1.4)
Vinylidene chloride	2.6 (2.8)
Xylenes	7.3 (8.0)
Total	94 (103)

[a]Described in an EPA report scheduled to be published early in 1995.

TABLE 7. COMPARISON OF CITY SEWER HAP EMISSIONS ESTIMATES TO EMISSIONS ESTIMATES FOR OTHER AREA SOURCES IN THE CITY

Area Source	Method of Estimating Emissions	Estimated HAP Emissions, Mg per year (tpy)
Sewers	CORAL+ with TRIS data	27 (30)
Sewers	CORAL+ with NPDES data	278 (306)
POTWs	Emissions inventory approach[a]	94 (103)
POTWs	Simple volatilization factor approach[b]	504 (554)
Graphic Arts	Emissions inventory approach[a]	1,522 (1,674)
Dry Cleaning	Emissions inventory approach[a]	3,101 (3,411)

[a] Decribed in an EPA report scheduled to be published early in 1995.
[b] Reference 6.

TABLE 8. COMPARISON OF THE CITY'S PREDICTED SEWER GAS HAP CONCENTRATIONS TO MEASURED VALUES IN OTHER CITIES

	Sewer Gas Concentration, ppm					
	City					
Compound	TRIS	NPDES	California[a]	London[b]	Toronto[c]	Toronto[d]
Benzene	0.27	2.0	4.4-5.8	52	--	--
Ethylbenzene	0.01	1.4	--	--	0.18-1.8	4
Toluene	0.19	3.2	4.4-5.8	170	8-17	44
Xylenes	0.01	5.1	--	--	1.4	31

[a] In an industrialized municipal sewer system. Reference 9.
[b] In a municipal sewer with small quantities of industrial wastewater. Reference 12.
[c] In a municipal sewer system. Reference 10.
[d] In a large municipal sewer with industrial discharge. Reference 11.