# POLLUTION PREVENTION AND MANAGEMENT STRATEGIES FOR DIOXINS IN THE NEW YORK/NEW JERSEY HARBOR

**August 2006**

**by**
**Gabriela R. Muñoz**
**Marta A. Panero (NYAS)**

**with a preface by**
**Dr. Charles W. Powers**
***Chair of the Harbor Consortium***

New York Academy of Sciences
New York, New York

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# PREFACE

From the early days of the Harbor Project, when the initial list of contaminants to be studied was being debated, there was the most discussion about dioxins. Everyone agrees that dioxins are a very toxic group of contaminants known to be found in the Harbor and to negatively impact fish and wildlife. Although there are many dioxins, it is 2,3,7,8 tetrachlorodibenzo-dioxin (also known as 2,3,7,8 TCDD) that is the most toxic and that has attracted the most attention. But the Harbor Consortium members were also well aware of the difficulties in tracking a contaminant that is released, measured in the environment, and causes adverse impacts *all at extremely low concentrations* (for example, we estimate that local yearly releases of dioxins to air are *a few hundred grams or less* as compared to mercury, of which local releases to air are in the range of 1,900 *kilograms*—that is, nearly 20,000 times more mercury than dioxin). Although dioxin emissions from several well-known sources (e.g., the Diamond Alkali Superfund site) are fairly well characterized, other emission sources are typically small and exceedingly diffuse. Furthermore, we realized that if we decided to address dioxins, we would be investigating a compound that was never intentionally manufactured; and yet we would be still trying to apply our "industrial ecology" (IE) approach. Industrial ecology has proven most useful for estimating emissions of compounds that are part of the current, or at least clearly definable, economic structure of a region.[1] Balancing the importance of this contaminant type as a continuing threat to the Harbor against the difficulty in tracking its sources, the Consortium decided to address dioxins later in the project's evolution—after we had already honed our IE and other environmental assessment tools. Having successfully addressed three other toxicants, we were ready for dioxins! Their importance to the overall Harbor health and the role of pollution prevention goals and techniques in improving that Harbor health were, however, never in question.

Among dioxins, 2,3,7,8 TCDD is the most toxic and has been identified as carcinogenic in humans. Several other dioxins are included on U.S. EPA's list of top 20 hazardous substances. Incineration and combustion generate a broad spectrum of dioxins, while herbicide manufacture generated mainly 2,3,7,8 TCDD. Dioxins persist in the environment and are now ubiquitous, found at low levels in air, water, soil, and sediments. Further compounding the risk from exposure to dioxins in the environment is their potential to accumulate through the food chain. Nationally, the main route of *human* exposure to dioxins is via ingestion of contaminated biota (mainly meat, dairy products, fish and other marine biota). The relationship between dioxin releases into the environment and the subsequent pathways to accumulation in animal receptors is key to understanding how best to intervene and develop a pollution prevention (P2) strategy. However, the routes from dioxins released to the environment to dioxins found in pigs, cows, chickens, fish, and human breast milk are neither simple nor direct. While levels of dioxins in the Harbor have been decreasing over the last 30 years, in several areas of the NY/NJ Harbor and in coastal waters dioxins have been found in fish, crustaceans, and shellfish at levels of real concern. Dioxins and other contamination in the region have resulted in advisories against eating fish and shellfish from Harbor waters.

The deeper we got into this work, the more we realized that the question of how dioxins impact the health of the Harbor actually has two quite different answers—in effect, two entirely different stories. On the one hand, the dioxins issue can be seen as one in which both source and adverse effects are localized to specific parts of the Harbor. Many of the advisories can be directly tied to releases from the Diamond Alkali Superfund site and other historical industrial activities along the Passaic River. Serious questions remain about both the extent of movement of these contaminants—into Newark Bay, the Hackensack basin, and, more broadly, into the wider Harbor (these are matters of continuing assessment)—and about the nature and extent of the needed remediation. Surely, the heaviest concentrations of dioxins we are seeing in Harbor organisms are in major part caused by these larger-scale releases of dioxins. Despite the ongoing technical and legal issues involved, this story is relatively easy to tell—and it is told in press releases, media stories, and telecommunications features. But, in fact, this part of the dioxin story renders most of the citizens of the bi-state Harbor Watershed area as bystanders and observers.

But the document you are about to read also portrays a second, different picture—the rest of the

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1. I recognize that the Consortium, in including PCBs (see [219]), had already addressed a contaminant that had long since been banned. Still, most PCBs had, when created, been intentionally produced in a variety of specific compounds to achieve very specific purposes.

story, as it were. As already noted, with dioxins we are in most cases tracking complex and diffuse exposure pathways of a contaminant that is inadvertently produced from many different sources in very small amounts. Quantifying dioxin emissions from several sources (e.g., structure fires, forest fires) is extremely difficult, if not impossible; and yet these sources cannot be ignored because their adverse impacts, when they finally do get to us, typically can occur at very low concentrations. Pursuing this second story is like following a barely discernible, twisting, and turning path and it requires patience, persistence, and technical competence. Finding a needle in a haystack is simple by comparison. But it turns out that "the rest of the story" directly or indirectly involves most of us in the Watershed, in very diverse ways.

Hence, as you will also clearly see from this document, impacts to the Harbor can also be linked to a very wide range of local activities taking place across the entire Watershed and inadvertently generating dioxins. It is important to note that our understanding of dioxins in the Harbor itself comes from ongoing and consistent long-term monitoring of the Harbor waters, sediments, and organisms as well as a commitment regionally to fund research on myriad issues relating to the transport and fate of dioxins. We have probably the largest and most detailed data set in the world for this Harbor, and we have a responsibility to the area's residents to continue this monitoring effort to understand what impact the actions we take are having on the Harbor.

The dioxin story is somewhat similar to the story of mercury as it unfolded for the Consortium. Once production and import of mercury batteries was banned and batteries became a much smaller source of mercury to the environment, pollution prevention efforts switched to the remaining sources—in the case of our region, the Consortium considered dental offices and hospitals. And now with dioxins we have again found that the NY/NJ Harbor Watershed may be different from other regions in terms of sources. While there appear to be significant releases from open burning in our Watershed, it is also possible that a major source may be fires, both in buildings and in the processing and storage of solid waste at landfills, transfer stations, dumpsters, and recycling centers. We discover this same pattern with each new toxicant: the focus on large-quantity generators may be important, but the cumulative impact of numerous small-quantity generators (like the dental and medical facilities for mercury and capacitors for PCBs) can equal or exceed that of the large-quantity generators when the entire system of contaminant flows is considered.

While the toxicity of specific dioxin congeners and dioxin-like PCBs is debated and discussed, we have stayed true to the original Consortium goals of identifying pollution prevention actions for all dioxins. Again, taking a more precautionary approach as we did with our cadmium recommendations, until the science is better able to distinguish the true environmental and health impacts of the various dioxin compounds, we have called for citizen and institutional awareness and interventions to monitor and address the extraordinary diversity of things we can all do to further reduce the dioxin burden and create a more healthy Harbor.

In sum, in this report we have again looked beyond the proverbial "elephant in the room," as we did with the PCBs report. We have a major Superfund site *within* the Harbor Watershed where dioxins are the major contaminant—in fact, we have the nation's largest 2,3,7,8 TCDD site. With PCBs, the General Electric site was upstream of our Harbor but was clearly a major source (although by no means the only source) of PCBs to the Harbor. Here, the Consortium looked directly at the Passaic issues and agreed to encourage those who must still resolve the major and obvious dioxin problems to move forward diligently and with alacrity. And then it went beyond the headlines and continued to assess responsibility and recommend actions for the broader community whose actions impact the "rest of the story."

The issuing of this report means that we have again built a consensus within the diverse group of remarkable people who form this unprecedented Consortium. For five years, guided by the Academy's able staff and their technical consultants and pro bono advisors, the growing number and diversity of Consortium members have worked through complex technical issues to assess the significance of new and existing sources of still one more contaminant in and into the Harbor. And then, astonishingly, we reached a consensus about a very significant set of diverse recommendations. I remain in awe of the fact that we have built such a culture within the Consortium. It is extraordinary, if not unique. My hope is that the ripples from this Consortium's work will continue to extend more and more broadly to the diverse institutions and people whose enjoyment of and economic dependence on a healthy Harbor ultimately depend on their willingness to understand and participate in the Harbor's protection.

Charles W. Powers
*Chair*

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# GLOSSARY OF TERMS

| | |
|---|---|
| **µg** | Microgram ($10^{-6}$ grams) |
| **2,4,5-T** | 2,4,5 Trichlorophenoxyacetic acid |
| **2,4-D** | 2,4-Dichlorophenoxyacetic acid |
| **ACRC** | Ag Container Recycling Council |
| **AF&PA** | American Forest and Paper Association |
| **Ag** | Agricultural |
| **AHR** | Aryl hydrocarbon receptor |
| **Al** | Aluminum |
| **AMSA** | Association of Metropolitan Sewerage Agencies |
| **AOCs** | Areas of concern |
| **AOX** | Adsorbable organic halides |
| **APCD** | Air pollution control device |
| **API** | American Petroleum Institute |
| **As** | Arsenic |
| **BAF** | Bioaccumulation factor |
| **BCF** | Bioconcentration factor |
| **BDD/Fs** | Brominated dioxins and furans |
| **BFR** | Brominated flame retardants |
| **Bit** | Bituminous |
| **BMPs** | Best management practices |
| **BSAF** | Biota-Sediment Accumulation Factor |
| **C&D** | Construction and demolition |
| **CAA** | Clean Air Act |
| **CANA** | Cremation Association of North America |
| **CARB** | California Air Resources Board |
| **CARP** | Contaminant Assessment and Reduction Project |
| **CCA** | Chromated copper arsenate |
| **CCIA** | Cumberland County Improvement Authority |
| **Cd** | Cadmium |
| **CDD/Fs** | Chlorinated dioxins and furans |
| **CDDs** | Chlorinated dibenzo-para-dioxins |
| **CDFs** | Chlorinated dibenzo furans |
| **CEC** | Commission for Environmental Cooperation |
| **CFR** | Code of Federal Regulations |
| **CHEJ** | Center for Health Environment and Justice |
| **CI** | Activated carbon injection |
| **CKD** | Cement kiln dust |
| **$Cl_2$** | Chlorine gas |
| **CNG** | Compressed natural gas |
| **ConEd** | Consolidated Edison of New York |
| **Cr** | Chromium |
| **Cu** | Copper |
| **CWA** | Clean Water Act |
| **DEICs** | Diesel emission inspection centers |
| **DfE** | Design for the environment |
| **DFO** | Distillate fuel oil |
| **DIFM** | Do it for me's |
| **DIY** | Do it yourselfers |
| **DL** | Detection limit |
| **DLC** | Dioxin-like compound |
| **DSI** | Dry sorbent injection |
| **EAF** | Electric arc furnace |
| **EC** | Elemental chlorine |
| **ECF** | Elemental chlorine free |
| **EDC** | Ethylene dichloride |
| **EF** | Emission factor |
| **EIA** | Energy Information Association |
| **ELGs** | Effluent Limitations Guidelines |
| **EPR** | Extended producer responsibility |
| **EPRI** | Electric Power Research Institute |
| **ER-M** | Effects range-median |
| **ESP** | Electrostatic precipitator |
| **EU** | European Union |
| **Fe** | Iron |
| **FF** | Fabric filter |
| **FIFRA** | Federal Insecticide, Fungicide, and Rodenticide Act |
| **FO6** | Fuel oil No. 6 |
| **FOIA** | Freedom of Information Act |

## GLOSSARY OF TERMS (cont.)

| | |
|---|---|
| **FOIL** | Freedom of Information Law |
| **g** | Gram |
| **GCP** | Good combustion practices |
| **GLBTS** | Great Lakes Binational Toxics Strategy |
| **H2E** | Hospitals for a Healthy Environment |
| **HCB** | Hexachlorobenzene |
| **HCl** | Hydrochloric acid/Hydrogen chloride |
| **HCWH** | Health Care without Harm |
| **HDDVs** | Heavy-duty diesel vehicles |
| **Hg** | Mercury |
| **HPBA** | Hearth, Patio & Barbecue Association |
| **HpCDD** | Heptachloro dibenzodioxin |
| **HpCDF** | Heptachloro dibenzofuran |
| **HWI** | Hazardous waste incinerator |
| **HxCDD** | Hexachloro dibenzodioxin |
| **HxCDF** | Hexachloro dibenzofuran |
| **IARC** | International Agency for Research on Cancer |
| **IC** | Internal combustion |
| **IE** | Industrial Ecology |
| **IFCS** | Intergovernmental Forum on Chemical Safety |
| **IJC** | International Joint Commission |
| **IPCS** | International Programme on Chemical Safety |
| **IRMs** | Interim remedial measures |
| **I-TEQ** | International toxic equivalent |
| **Kow** | Octanol-water partition coefficient |
| **L** | Liter |
| **LaMPs** | Great Lakes Lakewide Management Plans |
| **lb** | Pounds |
| **LCA** | Life cycle analysis |
| **LCIA** | Life cycle impact assessment |
| **LEV** | Low-emission vehicle |
| **LFG** | Landfill gas |
| **LMOP** | Landfill Methane Outreach Program |
| **m** | Meter |
| **MACT** | Maximum available control technology |
| **MBWW** | Mass burn, water wall furnace |
| **MCU** | Modular combustion unit |
| **MedWI** | Medical waste incinerator |
| **mg** | Milligram ($10^{-3}$ grams) |
| **mmscfd** | Million standard cubic feet per day |
| **MSWI** | Municipal solid waste incinerator |
| **MW** | Megawatts |
| **NAS** | National Academy of Sciences |
| **NATO** | North Atlantic Treaty Organization |
| **NCASI** | National Council of the Paper Industry for Air and Stream Improvement, Inc. |
| **NDAMN** | National Dioxin Air Monitoring Network |
| **NESCAUM** | Northeast States for Coordinated Air Use Management |
| **ng** | Nanogram ($10^{-9}$ grams) |
| **NG** | Natural gas |
| **NGO** | Nongovernmental Organization |
| **NJ DEP** | New Jersey Department of Environmental Protection |
| **NJ DOT** | New Jersey Department of Transportation |
| **NJDA** | New Jersey Department of Agriculture |
| **NJTRWP** | New Jersey Toxics Reduction Workplan |
| **NMIM** | National Mobile Inventory Model |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NOX** | Nitrogen oxides control device |
| **NPDES** | National Pollutant Discharge Elimination System |
| **NPL** | National Priorities List |
| **NYAS** | New York Academy of Sciences |
| **NYC DEP** | New York City Department of Environmental Protection |
| **NYS DEC** | New York State Department of Environmental Conservation |

| | |
|---|---|
| **NYS DMV** | NYS Department of Motor Vehicles |
| **NYS DOH** | NY State Department of Health |
| **NYSERDA** | NYS Energy Research and Development Authority |
| **OCDD** | Octachloro dibenzodioxin |
| **OCDF** | Octachloro dibenzofuran |
| **OCS** | Octachlorostyrene |
| **OGV** | Ocean-going vessels |
| **OPRA** | Open Public Records Act |
| **P2** | Pollution prevention |
| **Pa** | Pascal (a unit of pressure) |
| **PAHs** | Polycyclic aromatic hydrocarbons |
| **PANYNJ** | Port Authority of NY and NJ |
| **PAYT** | Pay-as-you-throw |
| **PBDEs** | Polybrominated diphenyl ethers |
| **PBTs** | Persistent, bioaccumulative toxics |
| **PC** | Petroleum coke |
| **PCBs** | Polychlorinated biphenyls |
| **PCF** | Processed chlorine free |
| **PCP** | Pentachlorophenol |
| **PCS** | Permit Compliance System |
| **PeCDD** | Pentachloro dibenzodioxin |
| **PeCDF** | Pentachloro dibenzofuran |
| **pg** | Picogram ($10^{-12}$ grams) |
| **PICs** | Products of incomplete combustion |
| **PM** | Particulate matter |
| **POPs** | Persistent organic pollutants |
| **POTWs** | Publicly owned treatment works |
| **ppb** | Parts per billion ($\mu$g/kg) |
| **ppm** | Parts per million (mg/kg) |
| **ppt** | Parts per trillion (ng/kg) |
| **PRPs** | Potentially responsible parties |
| **PSAs** | Public service announcements |
| **PVC** | Polyvinyl chloride |
| **QA/QC** | Quality assurance and quality control |
| **RAPs** | Remedial action plans |
| **RCRA** | Resource Conservation and Recovery Act |
| **RFO** | Residual fuel oil |
| **RI/FS** | Remedial investigation/feasibility study |
| **RMW** | Regulated medical waste |
| **RUSLE** | Revised universal soil loss equation |
| **RWW** | Rotary, water wall combustor |
| **SARA** | Superfund Amendments and Reauthorization Act |
| **Sbit** | Sub-bituminous |
| **SD** | Standard deviation |
| **SDA** | Spray dryer absorber (same as dry scrubber) |
| **SE** | Standard error |
| **SIC** | Standard industrial classification |
| **SNCR** | Selective noncatalytic reduction for nitrogen oxides control |
| **SSI** | Sewage sludge incinerator |
| **SUV** | Sports utility vehicle |
| **T** | Metric ton (1,000 kg) |
| **TCDD** | Tetrachloro dibenzodioxin |
| **TCDF** | Tetrachloro dibenzofuran |
| **TCF** | Total chlorine-free |
| **TCLP** | Toxicity characteristic leaching procedure |
| **TDF** | Tire-derived fuel |
| **TEF** | Toxic equivalency factor |
| **TEQ** | Toxic equivalent |
| **TJ** | Tera Joule ($10^{12}$ J) |
| **TRI** | Toxics release inventory |
| **TSCA** | Toxic Substances Control Act |
| **U.S. DOE** | U.S. Department of Energy |
| **U.S. DOT** | U.S. Department of Transportation |
| **U.S. EPA** | U.S. Environmental Protection Agency |
| **U.S. FDA** | U.S. Food and Drug Administration |
| **U.S. FWS** | U.S. Fish and Wildlife Service |
| **UNECE** | United Nations Economic Commission for Europe |

## GLOSSARY OF TERMS (cont.)

| | |
|---|---|
| **UNEP** | United Nations Environmental Programme |
| **USACE** | U.S. Army Corps of Engineers |
| **USDA** | U.S. Department of Agriculture |
| **USGS** | U.S. Geological Survey |
| **USLE** | Universal soil loss equation |
| **USWAG** | Utility Solid Waste Activities Group |
| **VCM** | Vinyl chloride monomer |
| **VOCs** | Volatile organic compounds |
| **WC** | Waste coal |
| **WESPHIX** | Fly ash stabilization |
| **WHO** | World Health Organization |
| **WIP** | Waste in place |
| **WPCFs** | Water pollution control facilities |
| **WRDA** | Water Resources Development Act |
| **WS** | Wet scrubber |
| **WTC** | World Trade Center |

# EXECUTIVE SUMMARY

Dioxins, the fourth suite of contaminants chosen by the Harbor Consortium for a full industrial ecology (IE) pollution prevention (P2) analysis, were selected because of their impacts on fish and shellfish in the NY/NJ Harbor Watershed, their relatively high toxicity even at low concentrations, and their ubiquity in sediments in the Harbor, (e.g., the lower Passaic River and Newark Bay) and their potential impact on the Port of NY & NJ.

In contrast with the three contaminants previously studied by the Consortium (mercury, cadmium, PCBs), dioxins were never intentionally produced and therefore are not a commodity that can be tracked with trade and industrial statistics to help calculate flows of these contaminants through the economy. Instead we must rely on available emission inventories and/or estimate dioxin releases based on emission factors and level of activity.

But dioxins are similar to our previous contaminants in that most of the major sources of these contaminants to the environment have already been dealt with, and now the smaller sources become the focus of our efforts. And for dioxins, the major releases were from processes such as pulp and paper production and combustion processes. In the last 20 years, some of these emissions have been greatly curbed by MACT (maximum available control technology) requirements and technological advances in production without (or with different) chlorine compounds. This has brought us to the same point we have reached with our previous contaminants—namely, that our focus is now on more diffuse and generally smaller sources, as well as historical reservoirs (e.g., contaminated sites from activities in the past).

While the historical sources of dioxins to the environment continue to be addressed, there are several ongoing sources that have the potential to increase dioxin emissions. The relatively recent introduction of plastics in the agricultural and nursery industry has resulted in the open burning of some of these materials with the potential to release significant amounts of dioxins when they are burned with chlorine-containing materials.[2] Dioxins, in turn, can deposit locally and enter the human food chain through plant uptake by humans and animals. Agricultural plastics followed the same story as nickel-cadmium (Ni-Cd) batteries, with early promises of coupled recycling programs that have never or very slowly begun to materialize. Similarly, the steep rise in the use of PVC in all aspects of building and construction enhances the potential to release dioxins if the PVC materials are incinerated or burned, a not-so-uncommon occurrence during the management of demolition debris. And just recently has the nation begun a coherent effort to address the stockpiles of discarded tires around the country, only after several extremely large and persistent fires have occurred with a high likelihood of significant dioxin emissions.

This report has attempted to identify and quantify as many sources of dioxins to the region as possible; to try to categorize sources by their toxicity (there are 210 different dioxin compounds with a range of toxicities); and to assess their likelihood of impact on the Harbor. This last component is unique to this study and was undertaken because almost every dioxin emission estimate has a high degree of uncertainty associated with it. This uncertainty is a result of the difficulty in measuring dioxins, especially because of their low concentrations and because measuring emissions of a group of compounds that is always an unintentional byproduct of other processes is also very difficult and sometimes impossible (e.g., forest fires). Despite these constraints, this study and others have provided estimates for dioxin releases, and there are many regional, national, and international efforts to address dioxin pollution. Several case studies and pollution prevention programs for specific dioxin sources are described throughout the report and online at *http://www.nyas.org/programs/harbor.asp*.

More than 90% of the dioxin toxicity in the Harbor is accounted for by three dioxin compounds (2,3,7,8 TCDD, 2,3,7,8 TCDF, and 2,3,4,7,8-PeCDF). The first of these compounds, TCDD, is the most toxic of all of the dioxins and is the basis of the TEQ calculations. Based on congeners that seem to be contributing the most toxicity found in Harbor biota, the top ten priorities to reduce dioxin-like toxicity in the Harbor include:

- Proper management of PCB fluids, which inevitably contain dioxins, especially if the fluids have been in use. A full suite of recommendations for addressing PCBs were put forth in our previous pollution prevention report on PCBs [219].
- Reducing emissions from: waste burning (including both backyard burning and fires at

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[2] Chlorine is ubiquitous and may be found in crop residues, pesticide residues, and other refuse likely to be burned with the plastics.

facilities managing waste), landfill gas (LFG) management, structural fires, wood burning by industrial, commercial and electric facilities, steel recycling, and medical waste incineration

- Cleanup of PCB-contaminated sites as well as the dioxin-contaminated Diamond Alkali Superfund site

As did the previous reports, this report includes recommendations for pollution prevention and management for the dioxin emissions described for the NY/NJ Harbor Watershed, and these are summarized below. In many cases, a more detailed description of the P2 and management recommendations is given in the Dioxins Technical Report. For some of the largest sources a brief description of who might be best positioned to undertake the P2 effort is also identified.

## General Recommendations for Uncontrolled Burning

Given the importance of waste combustion in the generation of dioxins, we call for:

**Municipalities to develop comprehensive waste management plans to reduce the volume of waste to be managed.** Waste, including construction and demolition debris, is susceptible to purposeful or accidental combustion. A "zero waste" approach preserves resources, conserves energy and water, saves money, and reduces pollution, including greenhouse gases. Some strategies might include:

- Design for the environment in order to minimize waste generation and/or the use of hazardous materials in products and industrial processes [industries, in collaboration with universities and research institutions, and public interest groups].
- Evaluate the use of resources at preproduction stage, considering disposal options and their life-cycle costs and impacts [industries can take the lead].
- Emphasize pollution prevention and source reduction efforts (e.g., through a variety of policies, including procurement procedures).
- Reduce, reuse, recycle, including mandatory recycling programs, take-back programs, pay-as-you-throw (PAYT), encourage composting and other programs that divert recyclables items from the waste stream [state or municipal level, can be mandated or voluntary].
- Promote purchasing policies that favor products that do not contain or generate hazardous waste.

**More research *[by state and federal agencies, in collaboration with universities and research institutions]* is needed on:**

- Emission factors, to properly characterize current levels of dioxin (and other pollutants such as PAHs and PCBs) releases from all types of fires;
- The relative contribution of chlorinated materials (e.g., PVC) as well as copper and other metals (which catalyze dioxin formation) to dioxin emissions.

**Based on the research results, various groups *[state and federal regulatory agencies, public interest groups, non-governmental organizations (NGOs)]* should direct efforts to:**

- Minimize the use of materials likely to generate dioxins during combustion (consider both voluntary approaches and regulation on the national level),
- Review and update packaging laws (designed to reduce toxic materials from packaging) to include dioxin and dioxin precursors such as chlorine and PVC plastics,

## Specific Recommendations for the Major Combustion Processes (Uncontrolled and Controlled)

### Open burning of rural residential and agricultural waste:

- Provide adequate infrastructure and develop comprehensive waste management plans to properly dispose of or recycle residential and agricultural wastes [the states should take the lead on this].
- Education of local officials and the public, including farmers, about the need to prevent open burning, its hazards, and available alternatives for waste disposal [government agencies, agricultural extension, community groups].
- Require producers to devise waste management options before a product is introduced in the market and to be involved in implementation. Support the development of extended

producer responsibility programs [government agencies, NGOs, public interest groups].

- Offer incentives to stop burning garbage [local and state agencies, waste collectors, recycling centers].
- Regulation: institute and enforce a state-wide ban on open burning in NY, which will provide more incentives for proper waste management [state regulatory agencies].
- Close the NJ regulatory gap (state ban exempts 1- and 2-family homes).

**Fires during waste management:**

- Develop a central reporting system for all fires to allow for better management decisions [New York City could take the lead on this since a large portion of these fires occur here, but state-level programs would provide more comprehensive data].
- Reduce inputs of combustible materials to the waste stream by promoting recycling, reuse, and recovery of paper, wood, and plastic materials [government agencies, NGOs, public interest groups could all play a role in educational campaigns and setting up pilot waste reduction projects].
- Promote best management practices at all facilities dealing with waste, including transfer stations and recycling centers [government agencies, waste management organizations].

**Structural fires:**

- Promote awareness among architects, engineers, designers and other professionals about building materials that minimize the occurrence of fires as well as associated dioxin emissions.
- Promote fire prevention (e.g., fire departments and municipal authorities should periodically educate the public about fire prevention practices).

**Incinerators (general):**

*Recommendations for managers of these facilities:*

- Optimize conditions in the combustion chamber to ensure complete destruction of any dioxins in feed: high combustion temperatures, long residence times, and an adequate amount of oxygen.
- Rapidly cool down combustion gases to prevent dioxin generation during post-combustion.
- Minimize unavoidable dioxin releases by fitting the incinerators with proper air pollution control devices (APCDs) to trap all the particles (dioxins are typically adsorbed to particles).
- Minimize starts and stops, which can result in increased dioxin releases; have all pollution control devices running during start-up and shut down.
- Train solid waste operators on proper operating procedures to reduce dioxin emissions.

*Recommendations for regulatory agencies:*

- Monitor dioxins over long periods of operation including shutdown, start-up, and malfunctions/accidents to better characterize dioxin emissions during typical cycles of incinerator operations.
- Enforcement of federal requirements for dioxin emission controls for incinerators.

**Medical waste incinerators (MedWI)**

Given that regulated medical waste contains up to 15% of PVC materials (by weight), specific recommendations apply to health care managers, such as:

- Source reduction of chlorine-containing products and materials from the waste stream.
- Waste separation, to ensure that only "red bag" or infectious waste is sent to MedWI. Waste segregation results in cost savings because disposal of regulated waste is more expensive.
- Consider the use of alternative treatments for infected material such as microwave shredders, chemical shredders (sterilization by chemical agents), and autoclaving and shredding. Note that every alternative has its downside. For example, autoclaving may release steam with toxic chemicals that are present in the material being sterilized, such as formaldehyde.

**Landfill gas (LFG) flaring:**

- Promote collection and purification of LFG for use as natural gas substitute or utilizing LFG for energy production rather than flaring. Assist landfill operators with cost benefit analyses to determine the best options for their particular landfill. [This could be a local or state-run program undertaken by extension staff.]

**Wood combustion:**
Regulatory agencies (local, states) need to:

- Ensure that facilities permitted to burn wood are equipped with proper pollution control devices.
- Quantify the number of permits given to commercial wood burning operations and verify that the wood burned is not contaminated. [States would need to monitor this.]

### Recommendations for Products Containing Dioxin-like PCBs

Recommendations for products containing PCBs have been developed in a separate report: "Pollution Prevention and Management Strategies for Polychlorinated Biphenyls in the New York/New Jersey Harbor" [219]. All of the same recommendations would apply to dioxin-like PCBs.

### Recommendations for Secondary Metal Production

- Managers of metal recycling facilities, particularly those that recycle dirty scrap, should conduct regular testing of dioxin emissions. Testing results should be reported to the regulatory/monitoring agencies.
- Facilities must install APCDs if warranted.

### Recommendations Concerning Dioxin Remobilization from Contaminated Sites:

- The scientific community, government agencies, and other parties should continue to be engaged in characterizing dioxin pollution, remobilization from natural processes, impacts of dredging activities, and evaluation of treatment technologies for dredged materials, such as efforts at the Passaic River.
- Support continued funding and timely cleanup efforts at contaminated sites in the Watershed as well as specific recommendations as detailed in the Technical Report.
- To be able to estimate the flux of contaminants from on-land sites into the Harbor, we recommend further research at sites located close to water bodies within the Watershed. Based on the outcome of this research, more stopgap measures (e.g., physical barriers, runoff collection systems, etc.) may need to be employed to minimize releases until these sites are remediated. [This could be a joint collaboration between government agencies, universities, and other research institutions]
- To stop the ongoing remobilization of dioxins within the Harbor, support interim remedial actions as well as the development of permanent technical and managerial solutions that assure the simultaneous protection and development of the Harbor.

# SUMMARY OF FINDINGS

The Harbor Consortium chose dioxins[3] as the fourth contaminant to be addressed with a full industrial ecology (IE), pollution prevention approach. Our goal was to identify strategies to minimize sources of dioxin pollution to and within the NY/NJ Harbor. Thus, we have analyzed both ongoing and historical sources of dioxins to the Harbor and its watershed as well as mobilization within the Harbor.

The first step in this process was to develop a mass balance for the NY/NJ Harbor watershed (see Appendix A), in order to understand the large-scale flows of dioxins in and out of the Harbor. The second step involved the development of the dioxins industrial ecology assessment for the Harbor watershed (see Section C), which includes identifying all known ongoing sources of dioxins to the NY/NJ Harbor; developing emission estimates for each source; and providing a range of preliminary pollution prevention (P2) and best management practices (BMPs). The final step has been to integrate both assessments, together with toxicological information in order to present the information in a manner that facilitated the Harbor Consortium's discussion about P2 recommendations.

This "Summary of Findings" section focuses on the major sources of dioxins to the NY/NJ Harbor and summarizes the most important findings with respect to dioxins in this region. A full description of all of the identified sources is put forth in the Dioxins Technical Report. A synopsis of the pollution prevention recommendations can be found in the Executive Summary.

## Summary of Sources of Dioxins to the NY/NJ Harbor Watershed

We have used an industrial ecology approach to develop an inventory of dioxin releases from primary sources. We identify dioxin sources, their activity levels, and associated releases. Dioxins are unintended by-products of several processes including:

- Combustion of materials in the presence of a chlorine source;
- Synthesis of chlorinated chemicals;
- Pulp paper bleaching using chlorine or chlorine dioxide;
- Production, refining, and recycling of several metals.

The following sections describe more fully the processes that are responsible for the largest ongoing dioxin releases—namely, combustion processes (see Table 2). The final sections address the issues of dioxin remobilization and contaminated sites within the Harbor. These sites, although they are not strictly ongoing or "new" sources per se and not necessarily candidates for P2 recommendations, are included here because of their magnitude and impact on the Harbor.

### Combustion Sources

Dioxins can be emitted whenever carbon- and chlorine-containing materials are combusted together. There are three main mechanisms that generate dioxins:

- Release of dioxins present in the material being burned that are not destroyed by the combustion process;
- Formation from precursors that generate dioxins during combustion;
- *De novo* synthesis from carbon, hydrogen, oxygen, and chlorine, the building blocks of dioxins.

The largest and highest-priority release of dioxins for the Harbor results from combustion processes. This is generally true on a national level: open (uncontrolled) burning has been identified as the largest source of dioxins and is the focus of pollution prevention efforts nationally. The analysis for the NY/ NJ Harbor points to other uncontrolled burning sources—namely, structural fires and fires during solid waste management. There is significant uncertainty around these estimates, but based on the best available emission factors, these sources may be as important as open burning (backyard burning) to the Watershed and

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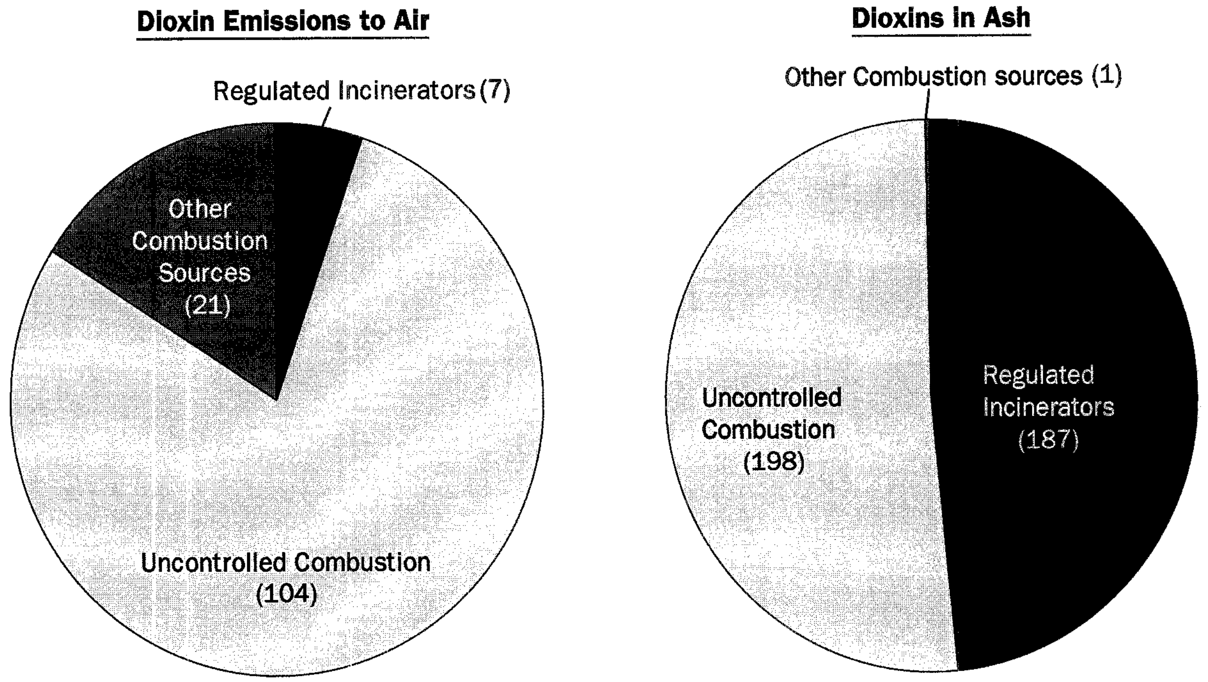
[3] Because dioxins comprise 210 different compounds (congeners), several approaches have been developed to try to coherently describe this suite of chemicals. Typically, dioxin concentrations are expressed in toxic equivalents (TEQ). Because dioxins and dioxin-like compounds typically occur as mixtures of varying composition in the environment, it has been historically difficult to evaluate risks to humans, fish, and wildlife [232,351]. The system of toxic equivalents (TEQs) has evolved as an aid in estimating the toxicity of these complex mixtures. It indicates the toxicity of a mixture of dioxin-like compounds by weighing the concentration of each congener by its toxicity relative to 2,3,7,8-TCDD. The relative toxicity of each congener is quantified by its Toxic Equivalency Factor (TEF), which "indicates an order of magnitude estimate of the toxicity of a compound relative to 2,3,7,8 TCDD" [351]. In this Summary of Findings section, all release estimates are given in TEQs. Dioxin toxicity and the TEQ approach are discussed in Section B of the Technical Report. Supplemental information on releases by congener is available at *http://www.nyas.org/programs/harbor.asp.*

**Figure 1. Dioxin Emissions to air and ash from combustion processes in the Watershed (g TEQ/yr)**



Figures show upper limit emissions. "Other combustion sources" include fossil fuel combustion in buildings, power plants, and on- and off-road engines, landfill gas flaring and combustion, and crematoria.

have a higher potential to impact the Harbor since the majority of these fires occur near the Harbor.

Releases of dioxins to air and ash from the major combustion processes in the Watershed are shown in Figure 1 and demonstrate the importance of uncontrolled combustion to emissions.

## Uncontrolled Combustion

Uncontrolled burning refers to accidental or intentional fires started by humans or due to natural processes where materials are burned without controls—in the open such as in agricultural fields, in barrels, or in other uncontrolled combustion devices. Examples include wildfires (which could be set by lightning or human activity, including arson and accidents), prescribed fires, garbage burning, and structural fires. Open burning of residential and agricultural waste typically takes place in rural communities and can impact the food supply (e.g., there are many dairy farms in New York), potentially affecting or exposing people, including the Watershed population. Characteristics of uncontrolled burning include low combustion temperatures, poor turbulence (i.e., mixing of combusted waste with air), and lack of air pollution control devices, resulting in incomplete combustion and contaminant generation. Many toxics can be released to air and remain in ashes and residues, including dioxins, PAHs, PCBs, particulate matter (PM), sulfur dioxide, and metals.

Uncontrolled combustion processes likely account for most of the local ongoing sources of dioxins to the Watershed. However, the associated uncertainties are large for both the extent of the processes (activity levels) and emission factors (EFs, the amount of dioxins emitted per mass combusted), in part because there is a wide range of possible conditions and materials that can be combusted. A breakdown of the estimated dioxin emissions associated with the known uncontrolled combustion sources in the Harbor Watershed are shown in Figure 2, followed by a more thorough description of the major sources.

### Open Burning of Residential and Agricultural Waste

Nationwide, industrial sources of dioxins have declined within the past 20 years because of enforcement of the Clean Air Act and Maximum Available Control Technology (MACT) emission controls. However, emissions from open burning have remained approximately the same. Thus attention has shifted to open burning because it is now one of the largest sources of dioxins to air. It is estimated that a single barrel burning household waste emits ~2,000 to 75,000 times as much dioxins as a modern municipal waste incinerator, per amount of waste burned [129].

Open burning of waste most commonly takes place in rural areas where farming also occurs. This has implications for local deposition of dioxins and the possibility that dioxins can enter the food supply. Agricultural activity in New York State represents ~2% of that of the US, with ~26% of statewide sales originating in counties within the Watershed. Animal production accounts for more than half of the farms in NY, and dioxins bioaccumulate in organisms including cattle, pigs, and poultry.

There are no simple solutions to burning on farms nationwide. The main reasons given by residents in rural communities for engaging in open burning are: (1) waste collection service is unavailable or inconvenient; (2) cost avoidance of waste collection services and/or tipping fees; (3) tradition; (4) desire to keep garbage out of the landfill.

Locally, we estimate that 8–30% of the domestic waste generated in rural areas is burned each year in NY (~150 to 500 thousand T/yr), almost half of which takes place in the Watershed.[4] This is estimated to be the single largest source of dioxins to air in the region **(1 – 37 g TEQ/yr)**. Even larger amounts of dioxins remain in the combustion residues, which are typically disposed of by either spreading or burying them in gardens and yards, dumping in ravines or creeks, or simply leaving them exposed to the elements and dispersed by the wind. These ashes in gardens can contaminate nearby surface waters.

**Figure 2. Relative releases of dioxins from uncontrolled sources in the Watershed (g TEQ/yr)**

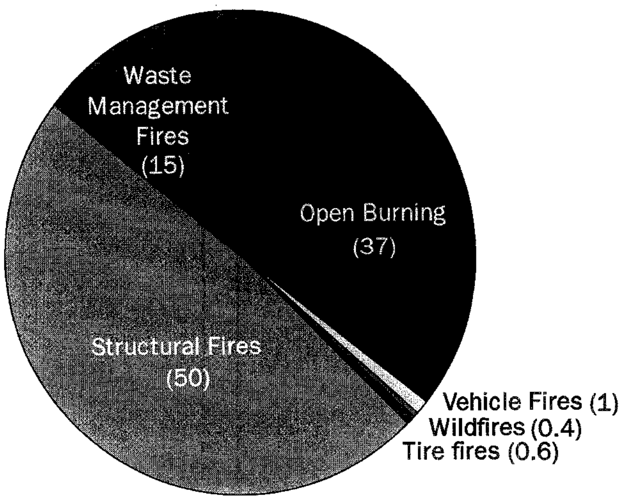


Figure shows upper limit emissions. Open burning refers to the purposeful burning of residential waste.

Available research[5] and our own consultative process[6] revealed that successful waste management plans are those that address all three pillars of open burning reduction efforts: regulatory/enforcement, education, and infrastructure.

### Structural Fires

Buildings contain many combustible materials (mainly wood and plastics) in the structure itself, in furniture, appliances, and other items. All of these can generate dioxins upon combustion—in particular, when chlorinated materials are burned. Chlorinated materials in buildings include polyvinyl chloride (PVC) or vinyl, textiles treated with chlorinated paraffins, paints, certain flame retardants, as well as bleach and other cleaning agents. PVC is of particular concern because it is widely used in construction materials (including siding, pipes, floors, windows, blinds, and electrical wires) and its use has been steadily increasing [14]. Items that may contain PVC include computers, furnishings, carpet backing, bath curtains, and toys. In addition, certain metals widely found in buildings, such as copper, are effective catalysts of dioxin synthesis.

Emission factors (EFs) for structural fires (the amount of dioxins emitted per mass combusted or per fire) are difficult to measure because of the variable conditions at each fire, including amounts and types of materials burnt as well as the duration of fire and combustion conditions. In addition, a significant challenge is to be able to capture the whole of dioxin emissions (in the gaseous phase, particulates or soot, and residues or ash). The vast majority of the experiments have focused on soot, assuming that this is the phase where most dioxins will be found. However, dioxins may be more prevalent in the gas phase (up to 90%). Given the uncertainties and measurement limitations, emission factor estimates for structural fires differ widely.

In 2001, ~43,500 structural fires occurred in NY and NJ. Based on the available EFs, we estimated that

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4. Open burning is deemed to be scant in NJ, mainly because of statewide regulations and enforcement.
5. Batelle Inc. Draft of Burn Barrel Case Studies (for the U.S. EPA and the Burn Barrel Working Group), September 7, 2005. Case studies are expected to be finalized by fall 2006.
6. The Harbor Project has organized a consultative "sector" process, including a meeting on October 26th, 2005, which included various representatives of federal, state, and local agencies, other parties working on reducing open burning, as well as those that oppose a ban on open burning activities.

this is possibly one of the largest sources of dioxins to air in the region, although the range is wide (**0.01 – 50 g TEQ/yr**). A similar amount of dioxins is also estimated to be associated with the ash resulting from these fires. In the case of structural fires, the ashes are typically collected and disposed of as municipal solid waste.[7] From the time a fire occurs until residues are collected a variable portion of the ashes can be dispersed by runoff (including from water to fight the fire) or wind.

Over 80% of these fires take place within the Watershed, and over 60% in New York City alone. Any dioxins deposited on impervious surfaces (widespread in urban and suburban areas) can be easily washed away and reach the Harbor or tributaries.[8] Consequently, we regard this source as highly likely to impact the Harbor.

### Fires at Waste Management Facilities

Fires may occur at various points during waste management activities, from dumpsters at commercial facilities or residences, to waste management facilities (e.g., transfer stations, recycling centers, and landfills). Although landfill fires are perhaps the least common of waste-related fires, when they occur their effect can be severe because they can be difficult to detect and/or extinguish.

Fires at landfills or facilities handling construction and demolition (C&D) waste have not been thoroughly studied, but they are of concern because some of the combustible materials have a high potential for releasing toxics: wood (including painted, treated and coated wood and wood products) and plastics (including PVC). Anecdotal information suggests that C&D landfills are at higher risk of significant fires than other landfills, and there have been many instances of fires lasting weeks or going undetected for long periods of time [343].

Fires during waste management can be initiated by a range of causes, including arson, disposal of smoldering materials, and spontaneous ignition of methane gas due to the heat released by waste decomposition. Of particular concern is shredder fluff generated at metal shredding facilities. This material is combustible and comes out of the shredder at high temperatures that may result in spontaneous ignition, whether at the facility or when sent to a landfill. Fluff may contain PVC and fire retardants and is also likely to be contaminated with PCBs, oils, and other materials that increase dioxin generation upon combustion. Fluff can also contain mercury (from switches in cars and appliances) [21], which will volatilize upon combustion.

In NY and NJ there are ~30–60 fires involving MSW each year and another 30–130 fires involving construction and demolition (C&D) waste. Approximately 60–70% of these take place within the Watershed, and approximately two-thirds of the fires in NY involve C&D waste. These fires are estimated to release **0.01 – 15 g TEQ/yr.** These estimates have two sources of uncertainty:

1. They are based on limited information on reported fire incidents.
2. The EFs are highly uncertain.

Nevertheless, these preliminary estimates suggest that fires during solid waste management might be one of the largest ongoing sources of dioxins in the region. Finally, many of these fires are taking place at transfer stations, recycling facilities, and/or landfills on the shores or close to the Harbor. Therefore, the potential for dioxins released during these fires to reach the Harbor is high to medium.

## Controlled Combustion

### Combustion of Waste at Regulated Incinerators

Incinerators release dioxins both to the air and to the ash residue. Emissions to air from stacks of varying but generally considerable heights[9] may allow dioxins to travel long distances. However, the closer to the Harbor an incinerator is, the more likely it is that dioxins will reach this water body. Emissions within the Watershed are particularly relevant because they can either deposit directly to streams and rivers connected to the Harbor or on land where runoff may eventually convey them to nearby water bodies. Over half of all dioxin emissions from incineration take place within the Watershed (where most hazardous waste and all medical waste incinerators operate). Many of the incinerators outside the Watershed are located in surrounding areas (e.g., several waste-to-energy [WTE] facilities are in Long Island, while those located in NJ are in the path of prevailing local winds). This suggests that the likelihood of local incinerator emissions reaching the Harbor is high.

Emission factor estimates generally do not account for nonroutine emissions—those associated with start-up and shut-down processes or accidents and mal-

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[7] As stated by Thomas Belton, Research Scientist, NJ DEP during a dioxins workgroup meeting. March 24, 2005.

[8] It is estimated that more than half of the rainwater that falls in typical urban areas (75% impervious cover) will end up as runoff [269].

[9] Some typical heights range from ~10 to 70 meters [137].

functions. It is expected that these emissions are actually higher than emissions during normal operations. "Constant" monitoring of dioxins over extended periods of operation, including during shut-down and start-up, is needed to better define emissions from incineration processes. Particles captured by air pollution control devices (APCDs) constitute the fly ash, which typically contains high levels of dioxins. Bottom ash is composed of residues that remain in the combustor and tends to be less contaminated. Data on the amounts of ash generated and their dioxin concentrations are scant. Although dioxins strongly bind to particles, mobilization of these particles might occur during storage or transport, or at the final destination (typically landfills, where they might be used as daily cover) carried either by wind or water runoff. Their likelihood to reach the Harbor is regarded as low, but further research is needed to confirm this.

There are several types of solid waste incinerators: municipal, hazardous, and sewage sludge. Most of the dioxins in municipal solid waste (MSW) combustion residues are associated with ash, but very low levels have been found in MSW wet scrubber effluents. Regionally only one MSW and three medical waste incinerators are equipped with wet scrubbers. Most of the local hazardous waste incinerators (HWI) are expected to generate liquid effluents. Waste water from sewage sludge incineration (SSI) is often reintroduced to the system, so no releases are expected [350]. Although this appears to be a minor source of dioxins, its relevance should be investigated, as liquid wastes (which could be treated) will likely be eventually discharged to water streams.

### Medical Waste Incinerators (MedWIs)

Today, there are only 5 MedWIs in the region,[10] all of them located in NJ, within the Watershed. Three of the incinerators are research facilities with no set limits on dioxin emissions, one of which has no active pollution control device (APCD) because it is considered to be a minor source. Dioxins from these facilities are about equally divided between emissions to air and ash (fly and bottom). Fly ash is sent to hazardous wastes landfills, while bottom ash goes to regular landfills. Virtually all of the ash is landfilled outside of the Watershed. According to our estimates, MedWIs are the largest controlled combustion sources of dioxins in the region, contributing **~2–4 g TEQ/yr** to the atmosphere.

## Other Combustion Sources

Many other combustion processes have the potential to release dioxins to the atmosphere. This section focuses on the two processes that are estimated to result in the largest dioxin releases:

- Landfill gas flaring and combustion;
- Wood combustion at industrial, commercial, and power generating facilities.

### Landfill Gas Flaring and Combustion

As municipal solid waste decomposes in landfills, it generates off-gases or landfill gas (LFG), which is composed mostly of methane and carbon dioxide [60,350], with trace components that were present in the original waste or generated during decomposition (e.g., chlorine and chlorine-containing compounds) [168].[11] Typically, these gases are piped to allow their release to the air, flared (burned at the top of the pipe), burned as an energy source, or upgraded to pipeline-quality gas [335]. These activities may reduce the risk of landfill fires (see section on waste management–related fires). Several factors control which of these strategies is employed, but it is likely that energy production from landfill gas is an underutilized energy resource.

Dioxins may be generated when landfill gases are burned. It is estimated that ~0.3–4.7 billion $m^3$ of LFG are flared in NY and NJ every year, while another 0.7 billion $m^3$ are burned by 30 operational landfill projects (mostly in internal combustion [IC] engines). Approximately 60–70% of this activity takes place within the Watershed. Emission factors for LFG flaring and combustion are based on limited measurements, but it is estimated that in NY and NJ **0.1 – 5 g TEQ/yr** is released to the air from these processes, and this source has a high-medium potential to affect the Harbor.

### Wood Combustion at Industrial, Commercial, and Power Generating Facilities

Many facilities burn wood to produce heat, steam, and/or electricity. The industrial sector accounts for 80% of wood combusted in the US [334]. The biggest consumers of wood fuel are the paper and the lumber and wood products industries [334]. Dioxin emissions from wood combustion span several orders of magnitude depending on the type of wood and furnace or boiler involved [126]. Clean wood emits the lowest amounts of dioxins, but emissions are much higher

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[10] When regulations were imposed on this sector, many facilities chose to close down rather than retrofit their incinerators. Some of the regulated medical waste generated in NY and NJ is managed by alternative methods such as autoclaving or chemical treatment, or is sent out of state for incineration or other treatment.

[11] These trace components include oxygen gas, hydrogen sulfide, halides, and organic compounds [60].

when wood that is contaminated, treated, painted, or contains large amounts of chlorine is burned [126]. In NY and NJ, only clean wood (i.e., wood that has not been painted or treated) is allowed to be burned, and no salt-laden wood is burned locally. Approximately 1.3–2.3 million T of wood are burned by commercial, electric, and industrial facilities in NY and NJ. Based on population distribution, we estimate that ~50% is burned in the Watershed. Even assuming that all the wood is clean, dioxin emissions to air are estimated to be important locally **(0.01–5 g TEQ/yr)**. Based on proximity to the Harbor and other factors, dioxins from this source are regarded as moderately likely to reach the Harbor.[12]

## Chlorinated Chemicals

The production, use, and disposal of chlorinated chemicals may generate and release dioxins. Several dioxin-contaminated sites have resulted from industrial production or use of these chemicals in the Watershed. The main chlorinated compound of concern in the Harbor Watershed region is polychlorinated biphenyls (PCBs).

**Polychlorinated Biphenyls (PCBs)**

PCB fluids always contain furans, a by-product of PCB production. However, the dioxin-like toxicity (TEQ) of PCB fluids is due mostly to coplanar PCBs [52]. Furans can form during normal use and when PCB fluids are exposed to heat. All used PCB fluids should be assumed to have dioxins and furans in excess of their original concentrations.

Approximately 3,000 T of PCBs are estimated to be still in use within the Harbor Watershed [219], resulting in ~10–20 kg being released annually in this region. We estimate that considerable amounts of dioxins **(0.2–28 g TEQ/yr)** and coplanar PCBs (an additional 3–400 g TEQ/yr) would be released together with these PCBs.[13] A good share of the dioxin-like compounds associated with PCBs comes from the disposal of small capacitors. These are generally landfilled as demolition debris, enter the MSW stream, or end up in metal shredders [219]. Although the PCBs (and furans) are initially confined within the capacitors, these could break during compaction, crushing during waste collection operations, or metal shredding [219]; and the contaminants could be remobilized via landfill leachate,[14] groundwater infiltration, or runoff from landfills [219].

## The Impact of Contaminated Sites in the Watershed on the Dioxin Inventory in the Harbor

Contaminated sites became significant to the study of inputs of dioxins to the Harbor because remobilization processes can carry dioxins from these sites into the Harbor. The National Priorities List (NPL) identifies 17 dioxin-contaminated sites in the Watershed region (2 in NY and 15 in NJ).[15] Twelve other sites contaminated with dioxins have been identified in NJ.[16] Remedial measures (by removal or containment of the contaminated materials) have taken place in at least four NPL and nine NJ sites. The remaining sites have not yet been remediated, or information on remediation activities has not been updated for several years. In addition, there are likely other dioxin-contaminated sites for which we have no information.[17]

**Influence of on-land contaminated sites:**

Given that dioxins are particle reactive, the most likely way to reach the Harbor from on-land contaminated sites would be through runoff and, to a lesser extent, wind erosion. Proximity to the Harbor will influence the probability of these dioxins entering the Harbor. Many of these sites are located close to bodies of water connected to the Harbor. Overall, the relevance of these sites will be, at a minimum, medium.

We have estimated dioxin runoff from three contaminated on-land sites by following an approach similar to that applied by the Delaware River Basin Commission for PCB runoff from contaminated sites on the Delaware River [46]. Soil loss according to the Revised Universal Soil Loss Equation (RUSLE) was combined with data on area of contamination and dioxin concentrations. A significant amount of dioxins **(~3 – 12g TEQ/yr)** was calculated to be contributed by these three sites alone (see Table 1). This puts in perspective the potential impact that the tens of con-

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[12] Estimates could be refined if emission factors were measured, or with detailed information on the types of boilers or furnaces used, whether they are fitted with APCDs, and the amount of wood burned in each facility, provided that appropriate EFs are developed for each scenario.

[13] This includes spills from transformers and capacitors in operation, and discarded small capacitors.

[14] Although many construction and demolition (C&D) landfills are unlined, those in NY must have at least a single composite liner with a leachate collection and removal system. In NJ, C&D debris is disposed of in MSW landfills.

[15] In addition, there is another NJ superfund site (W A Cleary) that is not listed in the NPL list.

[16] Data provided by Anne Hayton, Technical Coordinator, Bureau of Environmental Evaluation and Risk Assessment, Site Remediation Program, NJ DEP. Personal communication, March 6, 2006.

[17] Dioxins are not always measured for, especially if there are other known sources of contamination. To our knowledge, there has not been a systematic effort to identify dioxin-contaminated sites in New York.

## Table 1. Dioxins remobilized from selected contaminated land sites

| Site Name | Area (acres) | Soil loss (kg/acre/yr)† | Dioxin concentration (μg TEQ/kg)‡ | Dioxins in runoff (g TEQ/yr) |
|---|---|---|---|---|
| Bayonne Barrel & Drum | 16 | 1,996 | 20–900 | 1–9 |
| Standard Chlorine | 5.6 | 6,260 | 94 | 3 |
| Sherwin Williams | 0.4 | 5,080 | ~6–11§ | 0.006 |
| **Total for the 3 sites** | **22** | | | **3–12** |

† From RUSLE2

‡ Bayonne site: 17,000 cubic yards of soil contain 20 ppb TEQ, while ~6,000 cubic yards contain >80 ppb. The maximum concentration is 900 ppb. Based on this, we assumed that 74% of the site has dioxin concentrations ranging from 20 to 80 ppb and 26% of the site has 80–900 ppb.

§ Mean at each of two areas with dioxin contamination.

taminated sites may have collectively. Note that the RUSLE calculates soil delivery at the end of a slope. The amount that actually reaches a given water body will depend on the proximity to the Harbor, the presence and discharge location of catch basins, whether there are any barriers to contain runoff, and other site characteristics; therefore, these estimates have significant uncertainty.

### Summary: Processes Impacting the Dioxin Inventory of the New York/New Jersey Harbor Watershed

There are several factors that affect the movement of dioxins in the environment. In our Dioxin Technical Report, we have considered how these factors affect dioxin transport from their source to the Harbor. In order to rank the likelihood of a particular source reaching the Harbor we have classified them as having a low, medium, or high potential of reaching the Harbor (regardless of their magnitude).

Dioxins are hydrophobic, and, thus, insoluble in water. They are almost always attached to the organic fractions of soils and sediments, but transformation and transport processes can impact the way they move in the environment. The media of release (water, land, air) can impact the amount of dioxins that will reach the Harbor. For example, dioxins attached to particles in the atmosphere may be deposited inland and never impact the Harbor, or they may fall on an asphalt surface and be washed into a water body via the stormwater system. We have attempted to estimate the potential of any given release to reach the Harbor (see Table 2). As part of this estimate, we have evaluated specific factors that will impact the likelihood of atmospheric releases to reach the Harbor such as proximity to the Harbor; height of release (e.g., incinerator stacks versus burn barrel); prevailing winds; conditions of the surface where dioxins are deposited (impervious surfaces do not allow for water infiltration and facilitate transport by water of any substance deposited on these surfaces).

**Dioxins released to air** during combustion processes (involving some form of chlorine) represent the majority of *current primary* releases of dioxins to the environment. Once in the atmosphere, dioxins can be transported miles away (depending on the size of the particles to which they are attached) before eventually depositing on water bodies, soil, vegetation, and manmade infrastructures such as roads and buildings via wet or dry deposition. Dioxins in the gas phase can travel longer distances but are more prone to photochemical degradation. Dioxins attached to particles will eventually deposit on land or water; their travel distance governed by several factors, including rain (wet deposition), particle size, wind velocity, and height of emissions. Dioxins released to the atmosphere closer to the Harbor have a medium-to-high potential to reach the Harbor waters. The long-range transport potential of dioxins in air implies that sources that are not in the immediate vicinity of the Harbor may still impact it.

There is currently no data on the relative contribution of dioxins from geographical areas beyond the Watershed. However, experts consulted estimated that sources within the states of NY and NJ would likely capture most of the emissions reaching the Harbor.[18] Therefore, the technical report considers atmospheric sources of dioxins located within the states of NY and NJ—within and outside the Watershed region. Furthermore, applying pollution prevention measures outside NY and NJ will reduce emissions that might affect our Harbor, while local efforts can have a positive impact beyond our region.

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[18] In August 4, 2005 we held a consultative meeting with experts on the issue of long-range transport of dioxins and other toxics. A detailed discussion is provided in Section C of the Technical Report.

**Dioxins discharged *directly* to water** will tend to attach to suspended particles in the water or may enter the water body already sorbed to particles. These particles can travel varying distances before settling through the water column to the sediment surface. Sediments can be resuspended when disturbed and further transported. A small fraction of the dioxins still in dissolved form can be broken down by sunlight or UV light [232] or volatilize and enter the atmosphere. The shorter the distance from primary sources to the Harbor, the larger the potential for dioxins to reach this water balance.

**Dioxins released to land** tend to bind to soil particles (more strongly to soils with high organic matter content) and are generally assumed not likely to move down into the groundwater but could be mobilized with runoff and/or wind erosion. In general, the potential for remobilization once dioxins are deposited on land is estimated to be low to medium. Within the Harbor Watershed, the highest amounts of dioxins and coplanar PCBs were estimated to be released directly to land from PCB spills. Other direct sources to land are very small (e.g., application of sewage sludge and 2,4-D, releases from PCP-treated utility poles during use, improperly disposed of motor oil).

One way to constrain the estimates of releases from primary sources is to compare them to estimates of dioxins entering the Harbor via the main media of conveyance (e.g., deposition, tributaries, CSOs, stormwater runoff, etc.). Estimates of these loadings are given in the mass balance assessment.

### The Mass Balance

In an effort to understand how dioxins are entering and leaving the NY/NJ Harbor, a mass balance (see Appendix A) was constructed to quantify the major sources and sinks of dioxins (17 toxicologically relevant dioxin compounds; dioxin-like PCBs were included when data were available). The mass balance takes into account inputs to the Harbor from major media of conveyance such as rivers/tributaries, water pollution control facilities (WPCFs or POTWs), combined sewer overflows (CSOs), atmospheric deposition (wet and dry), absorption from the atmosphere (gas phase), stormwater runoff, and landfill leachate. Losses of dioxins from the Harbor occur via tidal exchange (with the Atlantic Ocean and Long Island Sound), volatilization to the atmosphere, dredging, and sedimentation.[19]

The following observations about inputs to, and losses from, the Harbor "box" can be made:

- The mass balance for the 17 dioxin congeners suggests that 3,940 (±750) g/yr enter the Harbor, while only 2,490 (±1,950) g/yr are lost, in terms of mass. This means that dioxins may be slowly building up in the Harbor.
- In terms of mass, OCDD accounts for ~80% of CDD/F inputs: 1,970 g/yr. This accounts for 0.6 g TEQ/yr or 7% of CDD/F TEQ loads (applying the newly revised mammalian TEFs [352]).[20]
- The mass balance also suggests that the more toxic dioxin compounds are leaving the Harbor at a faster rate than they are being added.
- Approximately 1.1 g/yr of the most toxic dioxin compound (2,3,7,8-TCDD) enters the Harbor (this does not necessarily account for runoff from contaminated sites) and about 12.8 g/yr is lost, mostly through dredging (8.5g/yr).

The mass balance points to the complexity of the system and suggests that dioxins are in a relatively dynamic state within the Harbor. From the mass balance, we get a clearer picture of loadings from wastewater treatment plants, CSOs, and runoff, which convey dioxins from point and diffuse primary sources. The mass balance also points out the impact of dredging on the system. As the input estimates become more refined, the individual dioxin compound data can be used to track the sources of these dioxins and provide a tool for prioritizing pollution prevention strategies.

### Impact of Remobilization Processes within the Harbor:

Remobilization processes from dioxin hotspots within the NY/NJ Harbor are an important contribution of dioxin toxicity levels and therefore cannot be ignored from this analysis. Not surprisingly, the starting point of many previous and ongoing dioxin studies is the Diamond Alkali Superfund Site. This site on the shore, with sediments of the lower Passaic River, has been identified as one of the worst dioxin pollution cases in the nation. The Diamond Alkali site is of particular concern both because the released material includes the most toxic dioxin compound (2,3,7,8 TCDD) and because it is located right at the mouth of the Harbor. However, until recently, there was limited information on the rates of dioxin remobilization from this

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[19] Sedimentation removes dioxins from the water column. However, it is not a true loss because, unless dredged, sediments remain within the Harbor. Therefore, sedimentation rates are presented for comparison, although this process is not considered an output.

[20] In this revised system (pending final publication), the TEF for OCDD was raised from 0.0001 to 0.0003 [352].

Superfund site and very little data about its relative importance compared to other sources. The following is a summary of the main information concerning dioxin remobilization in the Harbor:

1. A 1990 study estimated that between 4 to 8 kg of 2,3,7,8 TCDD may have been transported from the Passaic hotspot downstream into Newark Bay over a period of ~40 years, from 1948 to 1985 [17].
2. It is unknown how much of the estimated 4 to 8 kg in Newark Bay has already been removed via dredging operations, how much dioxin remains in this area, how much could be considered sequestered, and how much could be resuspended and thus become bioavailable.
3. The mass balance for dioxins indicates that the Harbor "box" (which includes the Diamond. Alkali site) is losing about ~13 g/yr of the 2,3,7,8-TCDD congener (8.5 g /yr via dredging) while only ~1.1 g/yr of this particular congener can be accounted for entering the Harbor. Thus, while the losses from the Harbor are made up of about 39% 2,3,7,8-TCDD on a TEQ basis, the inputs to the Harbor box are made of only 8% 2,3,7,8-TCDD on a TEQ basis. The imbalance in this congener indicates that either (1) there are unidentified sources of 2,3,7,8-TCDD to the Harbor or (2) that redistribution of historical deposits of 2,3,7,8-TCDD contamination (e.g., the Lower Passaic River "hotspots") within the Harbor are occurring.
4. Recent calculations estimate that ~20 – 30 kg of 2,3,7,8 TCDD are still contained in the Passaic hotspot [145]. Remobilization of Passaic sediments, primarily during high-discharge events, could deliver **~12 g/yr of 2,3,7,8 TCDD** [145] **(or ~14 g TEQ/yr)** to Newark Bay.
5. OCDD, the dioxin compound that contributes the largest mass to remobilization (~200 g/yr), accounts for 0.07 g TEQ/yr under the newly revised TEF system.

### Prioritizing sources:

Many different dioxin-like compounds are present in the NY/NJ Harbor, and all of these are still being released to the Harbor from various sources. However, of the dioxin-like PCB congeners typically found in the NY/NJ Harbor, only a few account for most of the potential toxicity to biota. Measurements of the suite of dioxins from the Harbor (in the Hudson River, POTW effluents, CSOs, runoff, sediments, water, fish, shellfish) indicate that several dioxin-like PCB congeners account for a significant amount of the toxicity. Possible sources of PCBs (containing dioxin-like PCBs and other contaminants) are released during management of PCB-containing fluids as well as soil and sediments mobilized from contaminated sites. Curbing PCB spills is therefore one of the top priorities to reduce dioxin emissions. So both dioxin emissions and PCB releases are prioritized for action based on toxicity.

We have developed a summary table (Table 2) of the major dioxin releases to the NY/NJ Harbor Watershed, and their likelihood to reach the Harbor. It lists dioxin releases in approximate order of quantity, with most of the releases being to air. Estimates of dioxins other than air emissions are provided in a separate column (for the Watershed only) described as "products and residues": in residues (e.g., incinerator ashes), end products (e.g., contained in paper), as well as those directly released to land and water. This table also includes the likelihood for dioxins to reach the Harbor (as high, medium, or low) and qualifies the data in terms of confidence (rating A, B, or C).[21] Figure 3 graphically displays this table's data (for the Watershed only).

As noted in the Executive Summary and the Preface, the focus of this report is to identify pollution prevention strategies for the remaining, ongoing sources of dioxins in the Harbor. Nevertheless, releases from contaminated sites as well as dioxin releases associated with PCBs are also included. The latter are a significant source to the Harbor and are discussed more fully in the Chlorinated Compounds section in the Technical Report. Pollution prevention recommendations have already been put forth for PCBs in the Consortium's PCB report [219], and their importance to the dioxin releases has been included in the prioritization of dioxin P2 efforts.

### Loadings from Ongoing Sources within the Harbor Watershed

Ongoing dioxin sources emitting to the atmosphere dominate primary releases within the Harbor Water-

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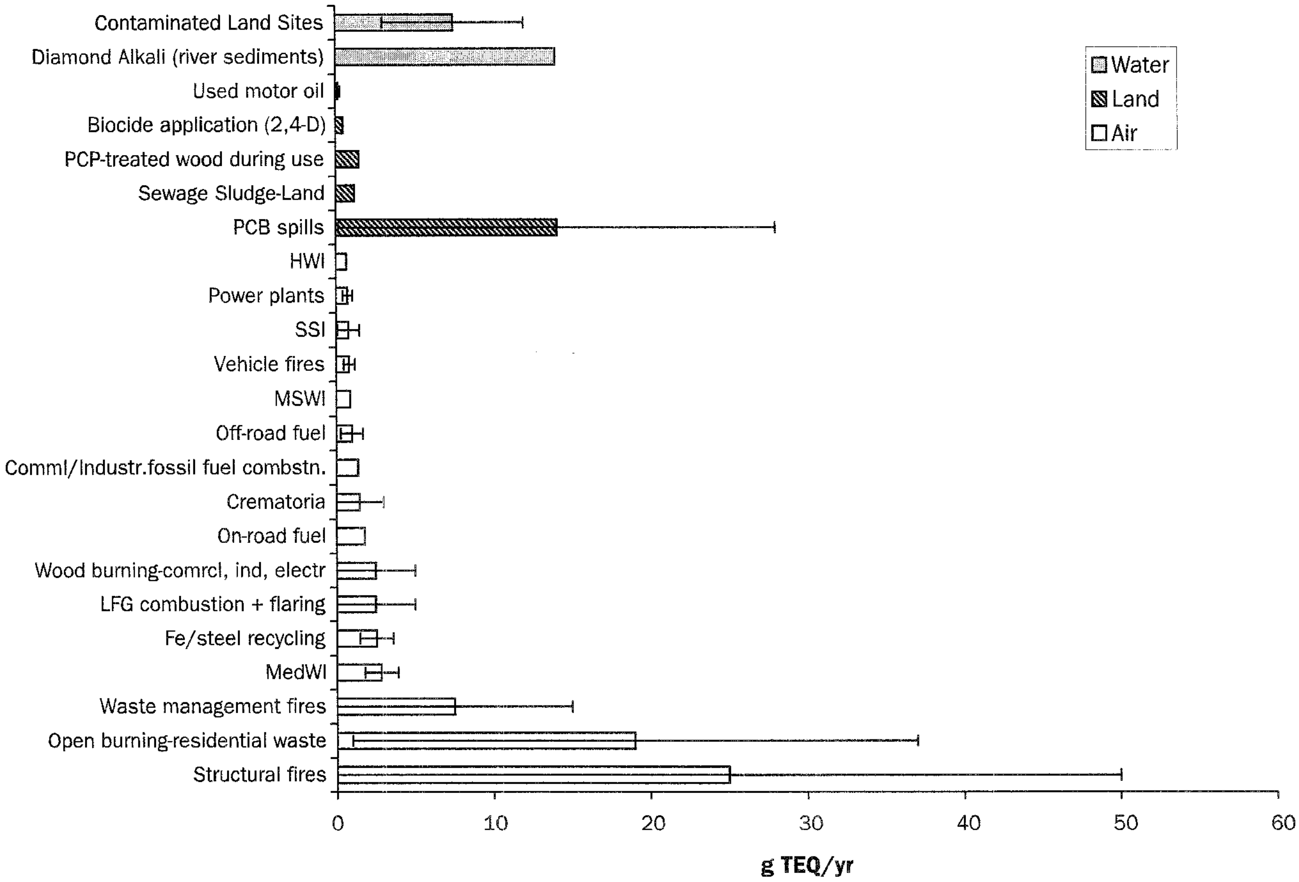
[21] In general, industrial sources for which activity level was known and facility-specific measurements were available were given a high confidence rating (A). Sectors for which EFs were based on numerous tests, but with no facility-specific data, were rated medium (B). Poorly characterized sources with uncertain activity levels and/or EFs were assigned a low confidence rating (C).

## Figure 3. Major dioxin sources within the NY/NJ Harbor Watershed



Emissions to air, water, and soil are represented by white, gray, and striped bars, respectively.

shed (~20 to 110 g TEQ/yr). Dioxin releases from most of the top 10 primary sources to the atmosphere and those most relevant from a toxicological standpoint have a high-medium potential to reach the Harbor, except for open burning of residential waste (medium-low). These emissions are dominated by uncontrolled combustion processes, which are the most uncertain both in terms of activity level and dioxin emission factors.

1. If we consider bioaccumulation rates in fish tissue (from recent sampling), it is apparent that three dioxin congeners should be prioritized (2,3,7,8 TCDD; 2,3,7,8 TCDF; and 2,3,4,7,8 PeCDF). The top 10 ongoing sources associated with these congeners are:
   1. PCB spills;
   2. Open burning of residential waste (medium-low potential to reach the Harbor);
   3. Structural fires;
   4. Fires at waste management facilities (including C&D waste);
   5. Landfill gas flaring and combustion;
   6. Iron and steel recycling;
   7. Wood burning by commercial, industrial, and power generating facilities;
   8. Medical waste incineration;
   9. On-road engines (internal combustion);
   10. Commercial/industrial fossil fuel combustion.
2. The mass balance indicates that **~15 g TEQ** enter the "harbor box" each year, through different media of conveyance. Direct air deposition to the relatively small area of the Harbor contributes only ~1.5 g TEQ/yr. However, it is estimated that dioxins released to air within the Watershed region deposit on land and are then mobilized towards the Harbor. The mass balance points out that:
   - Run-off contributes approximately 4.5 g TEQ/yr, which is consistent with estimates of wet and dry deposition on land within

## Table 2. Major dioxin sources to the NY/NJ Harbor

| | Air emissions (g TEQ/yr) | | | | Dioxins released to land & water, or in residues/products (Watershed only) | | | |
|---|---|---|---|---|---|---|---|---|
| Source | Watershed | NY+NJ | Potent. to reach Harbor | Confid. level (all estimates) | Dioxins (g TEQ/yr) | Type | Managmt. /fate | Potent. to reach Harbor |
| **Releases from Ongoing Sources** | | | | | | | | |
| PCB spills[¶] | — | — | — | C | 0.2–28 | | La | M |
| Structural fires | 0.01–50 | 0.01–60 | H | C | 0.04–24 | R | SW | M–L |
| Open burning of residential waste (NY only) | 1–37 | 4–96 | L | C | 30–173 | R | SW, La | L? |
| Waste management fires | 0.01–15 | 0.02–20 | M | C | ? | R | On-site | M–L |
| MedWI | 1.8–3.9 | 1.8–3.9 | H | A–B | 2 | R | LF | L? |
| Fe/steel recycling | 1.5–3.6 | 2.1–5.1 | H | B | 0.2 | R | | L? |
| LFG combustion and flaring | 0.09–5 | 0.2–9 | M | B–C | ? | | | |
| Wood burning-comrcl, ind, electr | 0.01–5 | 0.03–12 | M | C | ? | ? | ? | L |
| On-road fuel | 2 | 4 | H | B | — | — | — | — |
| Crematoria | 0.01–3 | 0.03–6 | H | C | 0.1 | R | La,W,CM | M–L |
| Comml/Industr.fossil fuel combstn. | 1 | 3 | H | C | ? | R | ? | L? |
| Off-road fuel | 0.3–1.7 | 0.4–3.7 | H | C | — | — | — | — |
| MSWI | 0.9 | 3 | H | A–B | 30–130 | R | LF, BA | L? |
| Vehicle fires | 0.5–1.2 | 0.7–1.5 | H | C | 0.2 | R | SW | M–L |
| SSI | 0.1–1.5 | 0.3–2.7 | H | B | 0.02–0.6 | R | SW | L? |
| Power plants | 0.4–1 | 1.3–3.4 | H | B | 0.2–0.7 | R | LF, BA | L? |
| HWI | 0.7 | 1 | H | A–B | 2–54 | R | LF | L? |
| Tire fires | 0.6 | 0.9 | M–L | C | ? | R | La, SW | L |
| Residential fossil fuel combustion | 0.6 | 1.2 | H | C | — | — | — | — |
| PCP-treated wood disposal * | 0.009–0.04 | 0.02–0.08 | M | C | 483 | R | LF, BA | L |
| Sewage Sludge-Land ** | — | — | — | B–C | 1.2 | R | SW, La | M–L |
| PCP-treated wood during use[†] | 0.3 | 0.6 | L | C | 1.5 | P | La | L |
| Biocide application (2,4-D) | — | — | — | C | 0.5 | | | |
| Used motor oil | — | — | — | C | 0.06–0.3 | P | WW, SW, La | M–L |
| Other | 2–4 | 5–9 | | | 1–2 | | | |
| **Subtotal** | **15–138** | **30–282** | | | **571–927** | | | |
| **Releases from "reservoirs"** | | | | | | | | |
| Diamond Alkali (river sediments) | — | — | — | C | ~14 (12)[§] | SS | | H |
| Contaminated Land Sites | — | — | — | C | > 3–12 | Runoff | | M–L |
| **Subtotal** | **—** | **—** | | | **> 17–26** | | | |

MSWI, municipal solid waste incinerators; MedWI, medical waste incinerators; HWI, hazardous waste incinerators; SSI, sewage sludge incinerators; R, residues; P, products; La, land; LF, landfill; WW, waste water; SW, solid waste; BA, beneficial applications; CM, contained in memorials; SS, suspended sediments. Confidence: A, high; B, medium; C, low. Potential to reach the Harbor: H, high; M, medium; L, low. * Air: assuming that 1–5% of the wood given to individuals was burned; residues: dioxins in poles taken out of service each year; ~19 kg TEQ are associated with poles in use. ** Amount land-applied and landfilled only. †Estimated yearly releases to air occur during useful life of poles; Residues: releases to soil during use. ¶ CDD/Fs only; coplanar PCBs add another 3–400 g TEQ/yr; PCBs still in use contain ~45 to 4,500 g TEQ CDD/Fs (7–370 kg with coplanar PCBs). §In parenthesis, 2,3,7,8 TCDD only.

the Watershed if 5% washes out to the water.

- Combined sewer overflow (CSO) contributes ~3.3 g TEQ/yr.
- The Hudson River contributes an estimated ~3.2 g TEQ/yr, while all the NJ rivers combined appear to contribute about ~1.7 g TEQ/yr.
- Coplanar PCBs would add another 8.3 g TEQ/yr from runoff, CSOs, Hudson River, and NJ river inputs.

All of the above account for ~95% of the dioxins entering the Harbor (effluents from wastewater treatment plants and absorption account for the balance).

The overwhelming majority of dioxins (whether released or associated with various waste streams) originates directly or indirectly in activities related to waste management and recycling of materials: PCB spills (e.g., from disposal of PCB products, including small capacitors entering the waste stream), open burning of residential and agricultural waste, fires associated with waste management (at MSW and construction and demolition landfills, as well as transfer and recycling centers), LFG flaring and combustion, waste combustion at regulated incinerators, tire fires, and used motor oil disposal. Releases could increase as the amount of dioxin-contaminated products or chlorinated materials sent to municipal solid waste and construction and demolition landfills increases. The amount of dioxins associated with residues is larger than the amount directly released to the environment from atmospheric sources. The available evidence points to the need to further investigate the fate of residues, to continue to look for alternatives to chlorinated materials and ways to keep them out of the waste stream, as well as to minimize the waste stream volume and its chlorine content.

In this document we have used limited regional information on dioxins in biota[22] to help prioritize actions leading to reduce inputs of dioxins to the Harbor. To more completely define the scope of the issue of dioxins and dioxin-like compounds in this region, the description of sources along with aspects of fate and transport should include sustained monitoring of the biota in both NY and NJ. Since the states provide advice on the limiting of fish consumption due to contamination by dioxins and other toxic substances [197], analyzing fish and other biota in a design focusing on selected sources (e.g., the Diamond-Alkali Superfund site) and suitable reference locations is needed on a relatively long-term and frequent basis. Effective monitoring requires a commitment to ensure adequate funding. Any monitoring project should answer the question, "How are we doing?" and would provide data for ecological receptors such as fish, and even humans, on the efficacy of controlling/remediating source conditions.

Finally, the U.S. EPA has conducted analyses of emissions from specific point sources and continues to improve emissions and EFs estimates as part of the Dioxin Reassessment.[23] Similar efforts are underway in other countries, and the issue of dioxin emissions continues to be researched. As more accurate EFs and monitoring data from individual industrial sources become available, these estimates can be refined.

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22. Much of the data came from NJ DEP, NYS DEC, and the Contaminant Assessment and Reduction Project (CARP).
23. The US EPA Dioxin Reassessment is in draft form. Although the document is publicly available, its findings cannot be cited or quoted until it is finalized and, therefore, can be considered to represent EPA's official position. In 1985, the U.S. EPA produced an initial assessment of risks to human health from dioxin exposure, and in 1991 the agency announced that it would conduct a reassessment of these risks [31]. An inventory of dioxin sources in the US was first published in 1994 as part of the draft Reassessment. This draft has undergone several reviews and significant updates and revisions. The latest version of the document includes dioxin inventories for 1987, 1995, and 2000. In July 2006, the National Academy of Sciences (NAS) released an evaluation of the EPA reassessment focusing on the risk characterization [31]. The NAS proposed several recommendations but encouraged the EPA to "finalize the current Reassessment as quickly, efficiently, and concisely as possible after addressing the major recommendations in this report" [31].

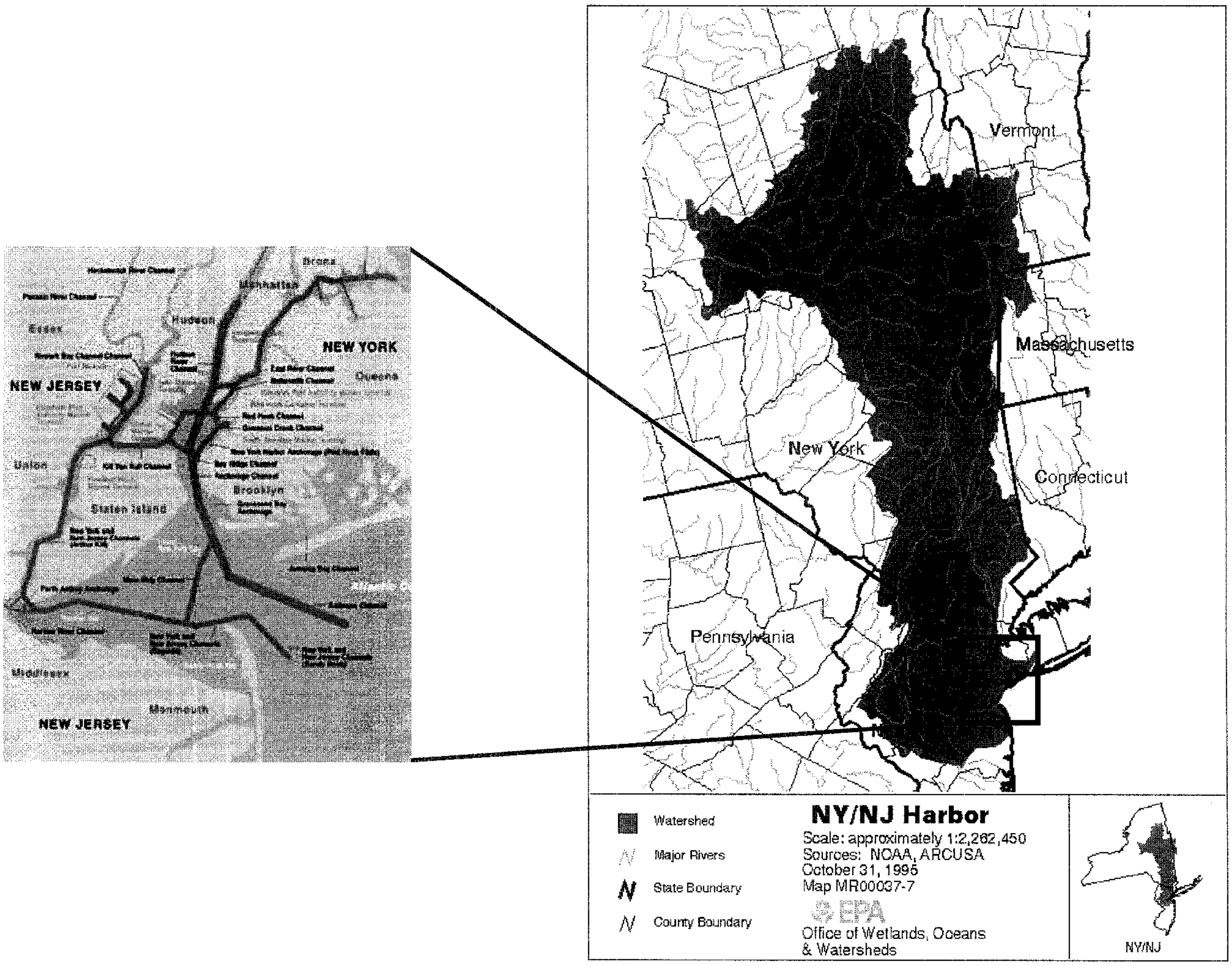
# TECHNICAL REPORT

## A. INTRODUCTION

Dioxins are the fourth contaminant to be addressed with a full industrial ecology (IE), pollution prevention approach by the Harbor Consortium. They are among of the most toxic compounds in the environment; several dioxin congeners are included on U.S. EPA's list of the top 20 hazardous substances. In contrast to the first three contaminants already considered by the Consortium (mercury, cadmium, and PCBs), dioxins were never a commodity, but are rather a by-product of different combustion and manufacturing processes.[24]

The first step in trying to identify the pathways of dioxins to the Harbor has been to develop a mass balance for the NY/NJ Harbor Watershed (see map in Figure A. 1), in order to understand the large-scale flows of dioxins in and out of the Harbor (the full mass balance is provided in Appendix A). The second step involves the development of the dioxins industrial ecology assessment for the Watershed. We have attempted to identify all ongoing sources of dioxins to the NY/NJ Harbor, estimate emissions for each source, and provide a picture of available measures or preliminary strategies leading to pollution prevention and best management recommendations to decrease dioxin pollution in the Harbor. Sources considered in-

**Figure A. 1. NY/NJ Harbor and Watershed**



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[24] In contrast to the other contaminants we have studied, there are no available trade and industrial statistics specific to dioxins to track flows of these contaminants through the economy.

clude combustion and production processes and products that continue to release dioxins to the regional environment, as well as historically contaminated sites that appear to contribute to the remobilization of dioxins within the Watershed region. Another unique aspect of dioxins in comparison to our previous studies is that the largest dioxin-contaminated site in the US (Diamond Alkali Superfund site) is situated within the Harbor itself. This means that we had to approach this project in a slightly different way than mercury, cadmium, and PCBs to ensure that we captured the full extent of the possible P2 strategies.

Section B provides a general background on dioxins including a brief summary of their toxicity and environmental impacts. In Section C we develop the Industrial Ecology assessment, identifying all of the known relevant sources, providing emissions factors for each sector whenever available, and calculating emissions estimates. Preliminary recommendations to prevent ongoing releases and remobilization of dioxins are also put forward in this section. The mass balance analysis, including a summary of main findings, is provided in Appendix A; Appendix B summarizes several cases of human exposure to dioxins; and minor local sources of dioxin are presented in Appendix C. Supplemental information on regulatory initiatives and other efforts to curb dioxin emissions, examples of educational efforts to curb open burning of residential waste, and congener-specific data is available online at *http://www.nyas.org/programs/harbor.asp.*

### Note on the Expression of the Data and Cautions on Its Use

In general, this report uses the term *dioxins* to refer to the 17 chlorinated dibenzo-para-dioxins (CDDs) and chlorinated dibenzofurans (CDFs)—CDD/Fs for short—that possess dioxin-like toxicity and have been assigned toxicity factors (see section B.2 on toxicity). The most toxic congener, 2,3,7,8-tetrachloro dibenzo-para-dioxin, is referred to as 2,3,7,8 TCDD and is used as the basis for the toxicity comparisons described below. Coplanar (or dioxin-like) PCBs may contribute a significant portion of dioxin-like toxicity to certain sources. Emissions of these PCB congeners were estimated for two of the sectors considered in this report (PCB fluids and sewage sludge). In the mass balance, dioxin-like compounds (DLCs) refers to CDD/Fs and coplanar PCBs.[25]

The ability to view the data in a variety of forms (i.e., mass versus TEQ) is useful because both concentration and toxicity matter for assessing the risk posed to humans and other biota.[26] However, because the available data can be expressed in many different ways, they are not always directly comparable. Moreover, data is often subject to uncertainties. Solving these uncertainties would require further sampling, which is often not done given associated costs.[27] For example, the mass balance provides a sense of the relative sizes of the major sources and sinks of dioxin-like compounds in the Harbor, but because of a lack of data, and related analytical issues, the values often have high levels of associated uncertainty. Similarly, the industrial ecology assessment also involves considerable uncertainties. Attempts to date to estimate dioxin releases at a local, national and global level have been impaired by insufficient data. The most important limitations in our knowledge of dioxin emissions include: (1) Some sources may have not yet been identified[28] (2) Some emission factors (EFs) may be based on a series of assumptions and/or approximations rather than on comprehensive tests[29] (3) The extent of dioxin testing is limited in part by the high costs. One particular concern is the fact that industrial facilities are not tested under no-routine operations (start-up, shut-down, and malfunctions), which may be responsible for a good proportion of dioxin emissions. (4) Dioxin emissions are highly dependent on process conditions and can span orders of magnitude, particularly for uncontrolled combustion.[30] (5) Difficulty in conducting source apportionment: The vast majority of the ongoing releases of dioxins in the region are to air, and detailed modeling is needed to determine to what extent these emissions will make their way to the Harbor.

Despite these caveats, when the mass balance is combined with the industrial ecology analysis, a picture of dioxin distribution and sources becomes clearer and provides a guide for what actions may be taken to continue reducing emissions of dioxins to the NY/NJ Harbor.

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[25] Strictly, this term refers to any substance with dioxin-like toxicity (see section B.1).

[26] Note, however, that other factors also affect risk; therefore, a detailed risk assessment would be a more rigorous approach to determine the benefits of addressing specific sources of dioxins. For instance, certain congeners have a greater tendency to bioaccumulate than do others. This may increase the risk associated with specific congeners, even if these are not the most prevalent or toxic in the environment. Another factor is bioavailability, where congeners that are more soluble in water can pose a greater risk to aquatic organisms than congeners that are bound to sediments.

[27] It is very expensive to complete dioxin assays from environmental sampling.

[28] For example, the estimated levels of global dioxin emissions cannot account for the levels observed in the environment. It has been speculated that there are important missing sources, such as conversion of PCP (pentachlorophenol) into dioxins in the atmosphere or that dioxins are remobilized from historical sources/reservoirs.

[29] For instance, most emission factors for off-road engines are based on motor vehicle engines.

[30] For uncontrolled combustion, the amount of material burned can be only roughly approximated, and the EFs are poorly characterized.

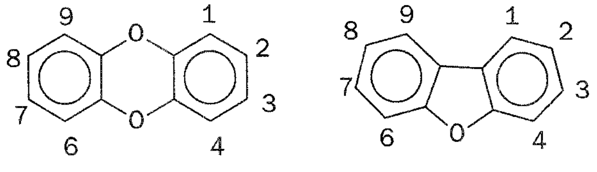
# B. GENERAL BACKGROUND ON DIOXINS

## B.1. Dioxins: General Characteristics and Background

Dioxin is the common name given to a family of chlorinated organic compounds: chlorinated dibenzo-para-dioxins (CDDs). Furan stands for chlorinated dibenzofurans (CDFs). These two groups of halogenated[31] aromatic hydrocarbons are commonly studied together, since they share many similarities: structure, sources, physical-chemical properties, and toxicity. Both are tricyclic (i.e., have three rings) and have 10 positions available for chlorine atoms (Figure B. 1). Based on the number and position of the chlorine atoms, 75 CDD and 135 CDF, different compounds (congeners) are possible. These substances are always found <u>as mixtures</u> of congeners and are commonly referred to as dioxins or CDD/Fs. Other compounds, with shapes similar to dioxins, exert their toxicity through the same mechanism [260] and are termed "dioxin-like compounds" (DLCs). This group of substances includes coplanar polychlorinated biphenyls (PCBs),[32] polychlorinated naphthalenes, and brominated and chlorinated/ brominated dioxins [260].[33]

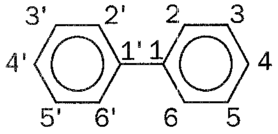
Dioxins are generally solids, with high melting points and very low water solubilities and vapor pressures [144]. These compounds have affinity for organic solvents and fats (i.e., they are lipophilic), which is reflected in their high octanol–water partition coefficients ($K_{ow}$), a parameter that relates to bioaccumulation.[34] In general, vapor pressure and water solubility decrease with increasing degree of chlorination while $K_{ow}$ (lipophilicity) increases. Therefore, dioxins associate with fatty tissues in organisms and tend to attach to sediments and soils (they are particle-reactive or "sticky"). Dioxins are quite stable in the environment and in organisms and have been classified as persistent organic pollutants (POPs) and persistent bioaccumulative toxics (PBTs).

**Figure B. 1. General structure of dioxins, furans, and PCBs**



**Dioxin** **Furan**

Each number indicates a position that can be occupied by a chlorine atom and is used to name the congener.



**PCB**

Chlorine atoms may occupy positions 2 to 6 and 2' to 6'. Dioxin-like PCBs may have one or no chlorine in ortho positions (2, 2', 6, and 6').

Dioxins were never intentionally manufactured, except for small quantities for research and analytical purposes. Instead, they are unintended by-products of several other processes,[35] including:

- Any combustion process: combustion of carbon or hydrocarbons (such as fossil fuels) in the presence of a chlorine source (either organic or inorganic);
- Synthesis of chlorinated chemicals (e.g., chlorine gas, chlorinated pesticides, and pentachlorophenol);
- Production, refining, and recycling of several metals including copper, aluminum, iron, and steel;

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31. Halogenated compounds are those that contain halogen atoms such as chlorine and bromine.
32. Of the 209 possible PCB congeners, 12 of them (those that are laterally substituted and have one or none chlorine atoms in ortho position—see Figure B. 1) are able to rotate the two benzene rings and adopt a flat configuration (both rings are in the same plane) and, thus, a shape similar to that of dioxins.
33. These compounds contain bromine instead of, or in addition to, chlorine and have been found in incinerator ash, residues after structural fires, and car exhausts. The toxicity of these compounds has been estimated to be similar to that of chlorinated dioxins, but their environmental half-lives are thought to be shorter and concentrations in the environment are believed to be lower than CDD/Fs [352]. Polybrominated diphenyl ethers (PBDEs), used as flame retardants, have been shown to degrade to brominated dibenzofurans under UV light and are widespread in the environment. Only CDD/Fs and coplanar PCBs have been assigned TEFs [352].
34. $K_{OW}$ "is the ratio of the concentration of a chemical in octanol and in water at equilibrium and at a specified temperature. Octanol is an organic solvent that is used as a surrogate for natural organic matter. This parameter is used in many environmental studies to help determine the fate of chemicals in the environment. An example would be using the coefficient to predict the extent a contaminant will bioaccumulate in fish" [347]. The higher the $K_{OW}$ (or log $K_{OW}$) the more affinity the substance has for organic matter and tends to sorb to sediments as opposed to dissolve in water.
35. Often, conditions that favor dioxin formation can also result in the generation of other toxic chemicals (the U.S. EPA considers dioxins as indicators of other chlorinated compounds). For instance, combustion processes will also generate polycyclic aromatic hydrocarbons (PAHs); certain industrial processes (e.g., chloralkali process, metal refining, and recycling) can produce chlorinated organic chemicals such as octachlorostyrene (OCS) and hexachlorobenzene (HCB) [288]. Therefore, measures that control dioxin sources may have the additional effect of reducing the inadvertent production of other toxics and vice versa.

- Pulp paper bleaching using chlorinated chemicals (after regulatory limits were established on dioxin emissions, most paper mills switched from elemental chlorine to chlorine dioxide —which generates less dioxins, while some mills phased out chlorine-based processes altogether).[36]

Chlorine (in any form, including chloride) has to be present in all of the above processes in order to generate dioxins. Chlorine[37] is ubiquitous in the environment (in living organisms, minerals, and in the atmosphere in trace amounts)[38] and can always be assumed to be present, for instance, when materials are combusted, even without human intervention (e.g., forest fires). However, environmental concentrations of dioxins soared starting in the mid-1930s [42] following a pattern similar to that of increases in production of chlorinated organic compounds [32]. This suggests that the vast majority of dioxins found in the environment today are related to human activity. This assumption is supported by the rather significant drop in air emissions after measures were taken to minimize releases from incinerators (historically the largest source of dioxins). Nowadays, uncontrolled combustion processes such as open burning of household trash or forest fires are becoming the major remaining source of dioxin emissions. Note that at least part of these emissions may be the result of remobilization of existing dioxins rather than new generation, or incomplete combustion of organochlorines (which act as dioxin precursors).

## B.2. Toxicity

The compound 2,3,7,8 TCDD is the most toxic dioxin congener and one of most toxic human-made substances. Even extremely low doses can cause illness or other adverse effects in humans, laboratory animals, and fish and wildlife. Other congeners present varying degrees of toxicity according to the number and position of chlorine atoms in the molecule. Lateral substitution (i.e., in positions 2, 3, 7, and 8, see Figure B. 1) by a halogen, such as chlorine, determines both bioaccumulation and biologic/toxic potential.[39] There are 17 dioxin congeners (7 dioxins and 10 furans) that are laterally substituted and thus possess dioxin-like toxicity. These 17 compounds are the focus of this report. A brief discussion of the toxic effects of dioxins is provided in the following two sections on human and wildlife toxicity.

Dioxins and dioxin-like compounds typically occur as mixtures of varying composition in the environment. As a result, it has been historically difficult to evaluate risks to humans, fish, and wildlife [232,351]. The system of toxic equivalents (TEQs) has evolved as an aid in estimating the toxicity of these complex mixtures. Note that although it is common to express dioxin emissions from their sources as TEQs, the dioxin TEQ of an abiotic matrix[40] says little about the impact of these mixtures on biota. However, "TEQ values can be used as relative measures between different abiotic samples, e.g., sediment and soil, to prioritize remedial actions" [351]. Strictly, TEFs should only be applied to concentrations in tissues of specific organisms, or concentrations in their food, after applying appropriate bioaccumulation factors [314,325]. The TEQs thus calculated would then reflect the toxicity of the dioxin mixtures to which the organisms are exposed.

Because all dioxin congeners share the same mode of action in vertebrates, the TEQ system[41] indicates the toxicity of a mixture of dioxin-like compounds by weighing the concentration of each congener to its toxicity relative to 2,3,7,8-TCDD. The relative toxicity of each congener is quantified by its Toxic Equivalency Factor (TEF), which "indicates an order of magnitude estimate of the toxicity of a compound relative to 2,3,7,8 TCDD" [351].

TEFs are determined by comparing the adverse effects[42] of specific congeners on different animal spe-

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[36] As long as dioxin limits are met, a mill may still use elemental chlorine as a bleaching agent.

[37] This element may exist in several chemical forms. Chlorine tends to form inorganic salts, where it is found as chloride ion ($Cl^-$), which is the most stable form and constitutes the vast majority of naturally occurring chlorine. Elemental chlorine is a gas ($Cl_2$), which is very reactive and is thus not found in nature as such. This gas can be produced from the electrolysis of table salt (chloralkali process). Chlorine can also be a part of organic compounds (organochlorines), most of which are human made. Certain organisms may produce small amounts of organochlorines, but this constitutes a minute fraction of the organochlorines found in the environment today.

[38] Chloride in the atmosphere originates mostly from salts in the ocean that are carried in mist and particles.

[39] 2,3,7,8 TCDD is the reference compound for other halogenated dioxins, furans, and biphenyls [32], and thus it is the most widely studied congener.

[40] For instance, releases from an incinerator stack, or the actual concentrations found in ambient samples.

[41] TEFs were first defined in 1989 by the North Atlantic Treaty Organization (NATO) for mammals only [102]. This scheme was referred to as International TEFs (I-TEFs). In 1998, the World Health Organization (WHO) modified mammalian TEFs [366] and developed new TEFs for birds and fish, reflecting the different susceptibility among species to specific congeners [351,366]. In 2005, the WHO revised mammalian TEFs. The new set of TEFs was released as this dioxin report was being finalized [352]. Final publication of these revised TEFs is pending.

[42] Only effects mediated by the aryl hydrocarbon receptor (AHR) are considered in this approach.

cies with that of 2,3,7,8-TCDD, which is assigned a reference TEF value of 1. Only certain dioxin congeners, those containing chlorine in positions 2, 3, 7, and 8, are assigned a TEF.[43] The TEQ of a dioxin mixture can be calculated by multiplying the concentration of each congener with its respective TEF and then summing this product over all congeners:[44]

$$TEQ = \sum_{i=1}^{n} TEF_i \cdot [Congener]$$

where n = number of congeners, $TEF_i$ = TEF of congener i, $[Congener]_i$ = concentration of congener i.

The main assumptions of the TEQ approach are: (1) All dioxin congeners have the same toxicity mechanism, and (2) toxic effects are additive.[45] The TEQ method provides a simple approach to dealing with and comparing the health risk of complex environmental mixtures by providing a single value for dioxins as opposed to a set of 17 values (one for each of the dioxin-like congeners). TEFs based on mammals (mainly rodents) are considered suitable to evaluate risk for humans [351].[46] According to the World Health Organization (WHO), "the TEF concept is still the most plausible and feasible approach for risk assessment of halogenated aromatic hydrocarbons with dioxin-like properties" [351].

Although this is the best available tool to deal with dioxins and there are studies validating the approach, this method has several inherent limitations [3] including: (1) the TEFs are derived from studies on animals; (2) the potency of toxic effects varies on different organs or systems, but this is not captured in the TEF ranking; (3) effects are likely to be overestimated for congeners that are more rapidly metabolized, and underestimated for those that are more slowly metabolized; (4) humans are exposed to many natural substances that exert toxicity by the same mechanism whose relative potency is not known.[47] Other limitations of the TEQ approach exist.[48] A downside of solely reporting data as TEQs is that valuable information regarding absolute congener concentrations as well as patterns (which can be used to track down sources) is lost.

Table B. 1 shows the 1989 NATO I-TEFs [366] and TEFs modified and expanded by the World Health Organization (WHO) in 1998 [351,366] and 2005 [352]. $WHO_{05}$ TEFs were not considered in this report except where noted because they became available as the document was being completed.

## Wildlife Toxicity

Aquatic organisms are exposed to dioxins through water, bottom and suspended sediment, and other organisms on which they prey [232].[49] The latter is the main source of dioxins to fish. Because dioxins are lipophilic, they associate with fatty tissues and bioaccumulate up the food chain.[50] Several parameters—which vary with the type of organism, tissue, and dioxin congener—are used to characterize bioaccumulation in biota according to the route of exposure:

1. The bioconcentration factor (BCF) indicates the concentration of a toxic in an organism relative to concentration in water and can be estimated from the $K_{ow}$ [3].[51]
2. Given the tendency of dioxins to associate with particles, most aquatic organisms will be exposed from sediments or food rather than water. Biota-sediment accumulation factors (BSAFs) are the ratio of lipid-adjusted contaminant concentration in an organism to the organic carbon-adjusted concentration in solids (sediment, fly ash, soil) [3].
3. The bioaccumulation factor (BAF) compares concentration in an organism relative to the food, water, and sediment [3].

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[43] The remaining congeners are assigned a TEF of zero.

[44] Details on TEQ calculation from Fennell [87]; see Appendix A.

[45] Other assumptions include: (3) the shape of the dose-response curve is the same for all congeners, and (4) the responsiveness of different animal species within a group (i.e., mammals, birds, or fish) is the same.

[46] Unlike mammals, fish have much lower or no responses to coplanar PCBs [351]. Also, invertebrates do not metabolize dioxin-like compounds and do not biomagnify them via their diet. As a result, concentrations in their tissues tend to be at equilibrium with their abiotic medium [325]. Therefore, organisms that feed on sediment-dwelling (benthic) invertebrates will be exposed to higher levels of dioxins than those feeding on surface-water (pelagic) invertebrates [325]. Elimination of dioxins also varies among species and is congener specific [325].

[47] However, these natural compounds are typically rapidly metabolized, and therefore their effects are short-lived.

[48] For instance, there is the issue of relative bioavailability: TEFs predict the relative toxicity of congeners in animal tissues or their diets and not relative bioavailability from abiotic matrices. Hydrophobic chlorinated organic pollutants like dioxins tend to sorb—sometimes very strongly—to particles, soil, and sediment in the environment; therefore, the fraction of the total contaminant concentration that is actually bioavailable may be very low. For example, 2,3,7,8 TCDD is not only the most toxic congener but is also likely to be more bioavailable from water to most species than many other dioxin congeners considered in this report.

[49] In addition to sediment particles, dioxins also attach to microscopic organisms.

[50] Only 2,3,7,8-substituted congeners bioaccumulate and biomagnify in vertebrates [232].

[51] For terrestrial species, the BFC is the contaminant concentration in the animal divided by the concentration in food.

**Table B. 1. TEFs for mammals, birds, and fish**

| Congener | | I-TEF (mammals only) | WHO$_{98}$-TEF | | | WHO$_{05}$-TEF |
|---|---|---|---|---|---|---|
| **Name** | **Number** | | **Mammals** | **Birds** | **Fish** | **Mammals** |
| 2,3,7,8-TCDD | 1 | 1 | 1 | 1 | 1 | 1 |
| 1,2,3,7,8-PeCDD | 2 | 0.5 | **1** | 1 | 1 | 1 |
| 1,2,3,4,7,8-HxCDD | 3 | 0.1 | 0.1 | 0.05 | 0.5 | 0.1 |
| 1,2,3,6,7,8-HxCDD | 4 | 0.1 | 0.1 | 0.01 | 0.01 | 0.1 |
| 1,2,3,7,8,9-HxCDD | 5 | 0.1 | 0.1 | 0.1 | 0.01 | 0.1 |
| 1,2,3,4,6,7,8-HpCDD | 6 | 0.01 | 0.01 | <0.001 | 0.001 | 0.01 |
| OCDD | 7 | 0.001 | **0.0001** | 0.0001 | <0.0001 | **0.0003** |
| 2,3,7,8-TCDF | 8 | 0.1 | 0.1 | 1 | 0.05 | 0.1 |
| 1,2,3,7,8-PeCDF | 9 | 0.05 | 0.05 | 0.1 | 0.05 | **0.03** |
| 2,3,4,7,8-PeCDF | 10 | 0.5 | 0.5 | 1 | 0.5 | **0.3** |
| 1,2,3,4,7,8-HxCDF | 11 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 1,2,3,6,7,8-HxCDF | 12 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 1,2,3,7,8,9-HxCDF | 13 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 2,3,4,6,7,8-HxCDF | 14 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 1,2,3,4,6,7,8-HpCDF | 15 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1,2,3,4,7,8,9-HpCDF | 16 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| OCDF | 17 | 0.001 | **0.0001** | 0.0001 | <0.0001 | **0.0003** |
| 3,4,4',5-TCB (81) | | | 0.0001 | 0.1 | 0.0005 | **0.0003** |
| 3,3',4,4'-TCB (77) | | | 0.0001 | 0.05 | 0.0001 | 0.0001 |
| 3,3',4,4',5-PeCB (126) | | | 0.1 | 0.1 | 0.005 | 0.1 |
| 3,3',4,4',5,5'-HxCB (169) | | | 0.01 | 0.001 | 0.00005 | **0.03** |
| 2,3,3',4,4'-PeCB (105) | | | 0.0001 | 0.0001 | <0.000005 | **0.00003** |
| 2,3,4,4',5-PeCB (114) | | | 0.0005 | 0.0001 | <0.000005 | **0.00003** |
| 2,3',4,4',5-PeCB (118) | | | 0.0001 | 0.00001 | <0.000005 | **0.00003** |
| 2',3,4,4',5-PeCB (123) | | | 0.0001 | 0.00001 | <0.000005 | **0.00003** |
| 2,3,3',4,4',5-HxCB (156) | | | 0.0005 | 0.0001 | <0.000005 | **0.00003** |
| 2,3,3',4,4',5'-HxCB (157) | | | 0.0005 | 0.0001 | <0.000005 | **0.00003** |
| 2,3',4,4',5,5'-HxCB (167) | | | 0.00001 | 0.00001 | <0.000005 | **0.00003** |
| 2,3,3',4,4',5,5'-HeCB (189) | | | 0.0001 | 0.00001 | <0.000005 | **0.00003** |

Sources: UNEP toolkit [350] and WHO [351] [352]. In bold, TEFs that changed with respect to the previous set.

Fish can bioconcentrate dioxins up to more than 100,000 times over the levels in water, with bioconcentration factors varying widely for different fish species and different dioxin compounds [3]. Freshwater aquatic invertebrates, marine invertebrates, shellfish, and birds have all been shown to bioaccumulate dioxins.

Some of the symptoms of acute poisoning by dioxins and dioxin-like compounds in animals include edema, hemorrhage, weight loss or reduced weight gain, suppression of the immune system, and accumulation of fat in the liver [232]. Dioxins, particularly 2,3,7,8 TCDD, are known to cause carcinogenic, teratogenic, mutagenic, reproductive, histopathologic, and immunotoxic effects in wildlife [56] by affecting the normal development and functioning of several systems [232]. Skin contact generally produces the same kinds of effects, plus skin lesions and skin cancer.

Some of the observed organism-specific effects of 2,3,7,8 TCDD include:[52]

- Aquatic organisms:
  - Fish:
    - Direct exposure: reduced growth, skin discoloration, fin necrosis, reduced resistance to infections, reduced swimming ability, hemorrhage.

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[52] For details regarding species, doses, and exposure time and method, see Eisler, 1986 [56].

    - Exposure as eggs: degeneration and necrosis of the liver, deformation of opercula and jaw, edema.
  - Mollusks: reduced reproduction.
- Birds: liver enlargement, weight loss, accumulation of uric acid, edema, reduced activity, weakness, muscular incoordination, spasms.
- Mammals: atrophy of the thymus with consequent decrease in immune response, stillbirths, decreased size of litter at birth, teratogenic effects (including cystic kidney, cleft palate, and deformation of the spinal cord).
  - Monkeys: weight loss, chloracne, nail loss, scaly and dry skin, weakness.
  - Rats: hormonal deficiencies including decreased testosterone levels in plasma and decreased weight of seminal vesicles, prostate gland, testes, and epididymis; cancer of the liver, pharynx, skin, lung, and thyroid.
  - Rabbits:[53] edema, hemorrhage, liver damage.
  - Horses:[54] gastric ulcers, lesions of the liver, lung, and kidney, skin hyperkeratosis.

The effects of exposure to dioxins can affect reproductive and developmental processes, which, in turn, will negatively impact the normal functions needed for survival [232]. Some of the effects of 2,3,7,8 TCDD measured in laboratory studies that can have ecotoxicological significance include lower body temperature, hearing deficits, learning deficits possibly related to brain damage, changes in rearing behavior, endometriosis,[55] and alteration of hormonal levels [232].

Very small amounts of dioxins can trigger negative effects. For instance, water concentrations of ~10–100 ppt 2,3,7,8 TCDD caused lesions and death in fish that had not been previously exposed to dioxins [223].[56] Doses of 2,3,7,8 TCDD causing death of 50% of the treated organisms ($LD_{50}$) can be as low as 1 $\mu$g/kg body weight for mink, up to 5,000 $\mu$g/kg for hamster [232].

Extremely high levels of dioxins have been measured in aquatic organisms around the lower Passaic River and Newark Bay [11,110,227]. Concentrations tend to be higher in the lower Passaic River and generally decrease in Newark Bay and New York Harbor [164]. More recently, total dioxins in Atlantic Tomcod liver[57] fish from Newark Bay/Hackensack River (1,109–1,736 ppt, wet weight) were found to be among the highest ever reported in any natural population [89].[58] The congener pattern was different from that found in areas of the Hudson River and was dominated (~50%) by tetra-CDDs, almost exclusively 2,3,7,8 TCDD, likely from the Diamond Alkali site [89].[59]

## Human Toxicity and Exposure Pathways

The most potent dioxin congener, 2,3,7,8 TCDD, has been shown to cause cancer in animals in several organs including the liver, thyroid, lung, skin, and soft tissues [321]. This compound was classified as a "group 1 carcinogen" (i.e., a human carcinogen) in 1997 by the International Agency for Research on Cancer (IARC),[60] and a wide range of effects have been observed in people exposed to 2,3,7,8 TCDD, including neurological effects. People exposed to high levels of 2,3,7,8 TCDD have exhibited chloracne and other dermatological manifestations,[61] liver damage, increased risk of diabetes, alterations of the thyroid function, and disorders of the kidneys and lungs.[62] Symptoms of human exposure include skin rash, headaches, dizziness, and digestive disorders [321]. Children seem to be more sensitive than adults, and exposure to dioxins in early childhood may also affect tooth development, resulting in a greater susceptibility to cavities [5].[63]

Figure B. 2 shows the contribution of different sources to daily intake of dioxins and dioxin-like PCBs

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[53] Exposed during the Seveso accident.

[54] Exposed after dioxin-contaminated oil was applied as dust suppressor in a riding arena in Missouri.

[55] Endometriosis is a condition where endometrium tissue (which lines the uterus) grows outside the uterus.

[56] The same species of fish from a dioxin-polluted area (Newark Bay) did not show lesions when exposed to the same concentrations. However, these fish tended to have greater incidence of liver parasites, liver neoplasia, and greater liver/body mass ratio, likely because of chronic exposure to dioxins [223].

[57] Measured in young-of-the-year fish, which move less and better represent local contamination.

[58] These levels are much higher than those known to trigger toxicity in tomcod and several other fish [89].

[59] Samples from main-stem Hudson River had lower levels (43–425 pg/g, wet weight) and were dominated by tetra CDFs, of which 30–100% was 2,3,7,8 TCDF. This congener is a cocontaminant of PCBs, a major congener of PVC combustion, and a by-product of chlorine-bleached pulp [89].

[60] The classification was based on limited evidence in humans, sufficient evidence in experimental animals, and extensive information on the mechanisms of action of 2,3,7,8 TCDD, which are common to both groups [255].

[61] Chloracne is an acne-like eruption of the skin which may appear weeks or months after exposure and usually recedes after exposure ends.

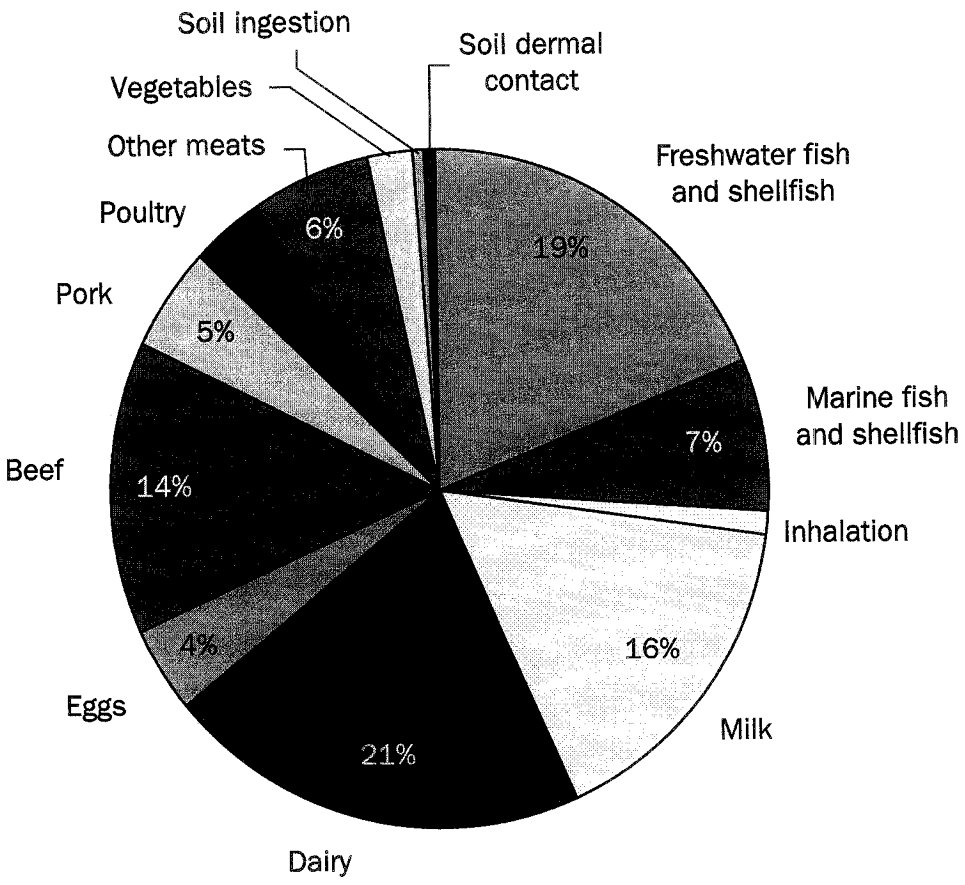
[62] Mostly in occupationally exposed groups (e.g., chemical workers and pesticide applicators) or communities exposed through contaminated food or chemical releases [321].

[63] There are effects that have been demonstrated in animals, but for which human data are inconclusive: diseases of the circulatory and immune systems, alterations of the reproductive system in adults, and developmental effects (including miscarriages, birth defects, dental effects, and decreased number of born males) [321].

in adults: Although dioxins can be absorbed by inhalation and skin contact, the main route of human exposure (making up ~95% of dioxin intake) is through ingestion of animal fats, where these compounds concentrate and bioaccumulate [3].[64] [65] The metabolism of dioxin compounds (i.e., the way the body rids itself of dioxins) is slow and results in excretion primarily via bile and feces.[66] Lactation is also an important way of elimination for breastfeeding mothers and a source of exposure for the infant [3].[67] Dioxins can also be transferred via the placenta.

Although diet is the main source of exposure to dioxins in the general population, occupational activities are a significant exposure pathway for workers involved in such activities as incineration; production, use, and disposal of chlorinated chemicals (e.g., certain pesticides); and paper and pulp mills [3]. Large-scale exposure has been caused by accidents, planned actions such as exposure during herbicide spraying in Vietnam, or indirectly through contaminated animal feed. Several of these exposure incidents are summarized in Appendix B. Although food contamination may occur in any country (because dioxins result from a wide range of common activities found across the globe), most food contamination cases have been reported in industrialized countries. This may be because industrialized countries monitor foods for contamination and have regulatory sampling for the

**Figure B. 2. Sources of dioxin and dioxin-like PCBs intake in adults**



Based on a graph provided by Erin Newman, Environmental Scientist, EPA Region 5.

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64. Another possible route of exposure to dioxins, PCBs, and other contaminants are fish oil supplements. For more information, visit *http://www.environmentaldefense.org/article.cfm?contentid=4362.*
65. The U.S. EPA, in its draft Dioxin Reassessment, has estimated the daily intake of dioxins and dioxin-like compounds in the adult population in ~40 pg TEQ/day [307]. Most of this amount (95%) comes from food, particularly from fish and shellfish, and beef (20 and 23%, respectively) [307]. Note that this publication has not been finalized and does not represent EPA's official position.
66. The half-life of 2,3,7,8 TCDD in the body is about 7 years. Half-lives have been estimated for other dioxins ranging from about 5 to 30 years. Octa CDD is not metabolized.
67. Most dioxins are released during the first few weeks of lactation. Second-born children can be exposed to 20–30% less dioxins from breast milk than first-born children. Milk contains a greater proportion of heavily chlorinated congeners.

detection of dioxins [367] and not necessarily because of a higher incidence of events. Other sources of exposure include cigarette smoke and automobile exhaust, especially diesel and leaded fuels.[68]

The main dietary sources are meat, dairy products, and fish. In particular, people in the Watershed can be exposed to dioxins not only from fish caught and consumed from the Harbor, but also from food that may or may not have been produced in our area. There are several dairy farms in NY State, many of which use agricultural plastics. Approximately 6,500 T of these plastics are estimated to be burned yearly in NY, potentially impacting dioxin levels in dairy products. Thus, any efforts made to curb dioxin releases in the Watershed will also have positive impacts nationwide.

Although dioxin levels in sediments in the Harbor have generally declined from the 1950s or 1960s to the early 1990s, some areas still show concentrations above the EPA guidance value for dioxins[69] [256]. Recent analyses of fish and shellfish tissue throughout the Harbor indicate that the NY State Department of Health (NYS DOH) criteria for 2,3,7,8 TCDD (10 pg/g) for the implementation of consumption advice was exceeded in several species in the Upper Bay and Raritan Bay, as well as in Newark Bay and the Passaic River [43].[70] Water samples throughout the Harbor exceed the NY State Department of Environmental Conservation (NYS DEC) Ambient Water Quality Standard (for protection of humans eating fish) of 0.0006 pg TEQ/L [134].

High concentrations of dioxins in fish, crustacea, and shellfish from the tidal Passaic River have resulted in advisories against consumption as well as bans on selling several species found throughout the Newark Bay complex (there is a ban on collecting, eating, or selling blue crabs from this area [192]).[71] In 1993, the State of New Jersey issued fish advisories based on dioxins and PCBs for all of its coastal waters, and these advisories remain in effect [328]. Specific water bodies under advisory include the Raritan and Newark Bay complexes (including the Kills, Hackensack River, and tidal tributaries) and the Passaic and Hudson Rivers [192]. Guidelines are more stringent for high-risk individuals such as pregnant women, childbearing-age women, and children, but most advise not to eat fish from these water bodies, or to limit consumption to 1–4 meals per year for certain species.[72] In 1994, New York State adopted fish advisories for some of its lakes and rivers, and in 1995 for coastal waters [328]. Six water bodies in NY (outside the Watershed) have advisories based on dioxins [197]. In the US, there are relatively few water bodies with fish advisories based on dioxins, but this is due, at least in part, to the high cost of dioxin analyses leading to limited monitoring [328]. Note that the issuance of fish advisories is just that—advice. Some in the fishing population choose to downplay or ignore them, are not aware of these advisories, or depend on fishing for survival and therefore eat the fish and shellfish they catch [151].

## B.3. What Happens to Dioxins after they are Released to the Environment

Dioxins are persistent compounds and are now ubiquitous in the environment; found at low levels in the air, water, soil, and sediments. Dioxins are typically below detection limits in US lakes and rivers, tap waters, and ocean waters because of their affinity with particles. In rare cases, unfiltered groundwater from areas of known dioxin contamination has detectable dioxin concentrations.

Dioxins enter the environment through air, water, and land; partition into and move across the different environmental compartments[73] (e.g., gas phase, aqueous phase, or sorption to particles); and are subject to weathering (degradation) processes. Figure B. 3 shows how dioxins can move between air, water, soil and sediments, and biota. In general, dioxins tend to be associated with solids rather than being freely dissolved in water or in gaseous form.

Fate and transport processes are congener-specific and will modify dioxin signatures after emitted from the source. As a result, congener patterns found in the environment, including biota, can be quite different from the profiles of the original sources. This needs to be taken into account when attempting to track the source of dioxin contamination at any given location.

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[68] Leaded fuel in motor vehicles for highway use was prohibited in the U.S. as of December 31, 1995 [80]. In 1992, 1.4% of the gasoline supply contained lead [59].

[69] Several pollutants have been assigned an Effects Range-Median (ER-M). This is the "median sediment concentration at which adverse biological effects have been observed." No such value has been established for dioxins; therefore, sediment concentrations were compared to the EPA guideline value, which is the "sediment concentration at which there is high risk for mammalian wildlife consuming food contaminated with dioxin" [256].

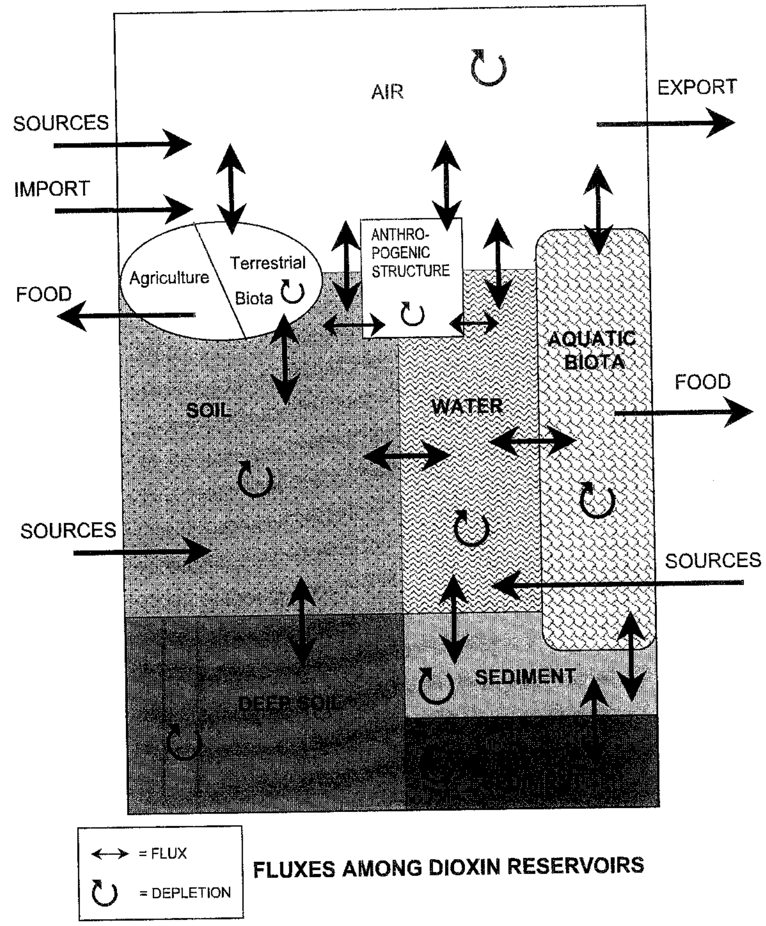
[70] The highest mean dioxin TEQs for fish muscle tissue were found in white perch in the Passaic River and Newark Bay (238 and 209 pg TEQ/g, respectively), which are at least 10 times higher than in other areas sampled [43].

[71] Striped bass, bluefish, eel, and crab are some of the species that have been identified as having high concentrations of contaminants and therefore have widespread advisories associated with them [171].

[72] For details, check the NJ DEP website on fish advisories *http://www.state.nj.us/dep/dsr/njmainfish.htm [192]*.

[73] Including transport by biota through trophic exchange and the movement through commerce of contaminated materials.

Figure B. 3. Pathways of dioxins in the environment



Source: U.S. EPA [289].

In the following paragraphs, we will describe the pathways of dioxin releases, which will allow us to qualitatively rank the likelihood of dioxins from different sources to reach the NY/NJ Harbor.

### Dioxins Emitted to Air

Releases to air can occur during combustion processes in which some form of chlorine is present.

Dioxins released to air will partition among the gas and particle phases. The lighter, more volatile dioxin congeners will have a greater tendency than the heavier ones to be in vapor phase, where they are more susceptible to degradation by light or hydroxy radical reactions. Mono- through tri-CDD/Fs, which are present almost exclusively in the gas phase, are likely to be removed rapidly from the atmosphere (within days). The tetra- to hexa-CDD/Fs are present in both phases,[74] while the heavier hepta- and octa-CDD/Fs are mostly associated with particles, which protect dioxins from degradation. Most congeners exhibiting dioxin-like toxicity will be predominantly particle bound. Dioxins in the atmosphere can be transported miles away before eventually depositing on water bodies, soil, and vegetation via wet or dry deposition.[75] Once deposited on land or water, dioxins may be carried into surface water bodies by erosion and runoff [320].

Because dioxins can be transported over long distances, sources that are not in the immediate vicinity of the Harbor can still impact it. The distance that dioxins are likely to travel before depositing will depend on many variables including the height of emissions (the higher the release, the farther away they can travel), particle size, wind speed, and precipitation. It is expected that air emissions from sources that are closer to the Harbor will have a greater impact than more distant ones. In an effort to quantify these long-range sources, we have estimated the geographical area of influence (airshed) for the Harbor.

### Determining the airshed area for the NY/NJ Harbor[76]

Many factors influence how far away and where dioxins will travel in the atmosphere after being released, including wind patterns and photochemical reactions

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74. For instance, estimates suggest that, of the tetra-CDDs present in the atmosphere, 20 to 60% are in the vapor phase, while hexa-CDD/Fs are about equally divided between the gas and particle phases.
75. If the vegetation is ingested by animals or humans, dioxins will enter the food chain. Dioxins deposited on vegetation can be remobilized when the material is burned. At least part of the dioxins released during forest fires, and wood burning in general, arise from previously deposited dioxins. Although some studies suggest that new dioxins are generated upon wood combustion [104], it is possible that this may be aided by deposition of other chlorinated chemicals.
76. We want to acknowledge the invaluable input, insights and suggestions of several experts we have consulted in order to better understand dioxin transport in the atmosphere: Paul Bartlett, CBNS, CUNY, Queens College; David Cleverly, Environmental Scientist, National Center for Environmental Assessment, U.S. EPA Headquarters; Mark Cohen, Physical Scientist, NOAA; Donna Fennell, Assistant Professor, Rutgers University; Bob Kelly, Air Programs Branch, EPA Region 2; Todd G. Nettesheim, Great Lakes National Program Office, USEPA Region 5; Chuck Powers, Consortium Chair; Leslie Shor, Research Assistant Professor, Vanderbilt University; Lisa Totten, Assistant Professor, Rutgers University; Dwain Winters, Dioxin Policy Project, EPA Headquarters.

leading to dioxin destruction.[77] The two main mechanisms that remove airborne toxics, including dioxins, from the atmosphere and limit their atmospheric lifetimes are: (1) chemical and photochemical destruction; and (2) wet and dry particle deposition on land and water surfaces [100]. The first mechanism affects low–molecular weight dioxins, which are mostly in the gas phase, while the second affects high–molecular weight dioxins that are attached to particles.[78] Note that dioxins (and chemicals in general) in the gas phase have the potential to travel longer distances but are, at the same time, more prone to degradation in the atmosphere. Dioxins associated with particles are protected from chemical and photochemical degradation but can settle rapidly if attached to heavy particles. On the other hand, small particles can remain suspended in the atmosphere for long periods.

In a 1990s study, it was determined that, although sources around the Great Lakes accounted for a good portion of dioxin deposition to this water body, some significant contributors were located in distant states, such as Florida and Utah [35]. The Great Lakes Binational Toxics Strategy (GLBTS) has been working on determining what regions contribute to atmospheric dioxin deposition to the Great Lakes.[79] A recent model study addressing deposition of dioxins to the Great lakes from sources in the US and Canada shows that "for Lakes Superior and Huron, between 20 and 40% of the deposition in 1995/1996 was due to sources at regional distances (400–1500 km) from the lakes while for the other three Lakes, local sources (within 100 km) contributed between 40 and 60% of the total dioxin deposition" [100]. Sources within North America, including Mexico and Canada, affect the Great Lakes, while sources further away have little influence.[80]

In trying to determine all relevant inputs of dioxins to the NY/NJ Harbor, we need to consider whether air emissions originating outside the Watershed or even beyond the states of NY and NJ (which we will call "transboundary") reach the Harbor, and what their relative contribution is in relation to local/regional sources.

In order to determine the area of the airshed, we take into consideration the following factors:

- Dioxin concentrations in air in urban areas tend to be greater than in rural areas. For instance, a study in Oklahoma City showed that air concentrations at the city center were about two times higher than in the rural surroundings. Concentrations dropped relatively rapidly with distance and reached background levels at about 160 km from the center of the city.[81]
- The biggest concern when addressing the influence of urban areas has been point sources. Point sources such as incinerators, which tend to concentrate in urban areas, used to dominate dioxin emissions; but these have been substantially reduced after the implementation of several regulations in the late 1990s. A big part of what remains in air concentrations nowadays is believed to result from the remobilization of past dioxin releases (commonly termed *diffuse sources*) or from uncontrolled combustion processes (burning of structures or waste).

Based on these considerations, we have decided to focus our industrial ecology assessment of atmospheric sources only within the states of NY and NJ, distinguishing those sources located in the Watershed. Although other sources beyond these two states may contribute to atmospheric loadings to the Harbor waters, we consider that our approach will capture most of the relevant emissions. Finally, applying our pollution prevention measures to other regions will address transboundary sources that might be contributing dioxins to the NY/NJ Harbor. At the same time,

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[77] For example, it has been estimated that over 70% of dioxins found in New Hampshire are not emitted by local sources, but are the result of long-range transport, resuspension of historical emissions, and nonanthropogenic sources [168]. This not only has implications regarding the delimitation of the NY/NJ Harbor airshed, but also is an indication of how emissions that do not immediately reach the Harbor can eventually affect it.

[78] Mono- through tri-CDD/Fs are present almost exclusively in the gas phase. However, these isomers are not part of the 17 dioxin-like congeners typically measured and have not been considered in our analyses. Hepta- and octa-CDD/Fs are almost exclusively bound to particles while tetra- to hexa-CDD/Fs are present in both phases (e.g., hexa-CDD/Fs are about equally divided between the gas and particle phases).

[79] The U.S EPA is currently conducting a model intercomparison project to determine which model will be used nationally as the standard for dioxin transport. Starting in 1998, the National Dioxin Air Monitoring Network (NDAMN) collected air samples from numerous sites around the country and analyzed them for dioxins. The program was suspended in December 2004 due to lack of funds. Erin Newman, Environmental Scientist, EPA Region 5. Personal communication, May 25, 2005.

[80] In contrast, other pollutants are transported globally, and a large portion of deposition in the Great Lakes originates in emissions from other countries. Ibid.

[81] The NY/NJ Harbor is surrounded by one of the largest metropolitan areas in the US, unlike the case of Oklahoma City, which is a relatively small city surrounded by rural land. The relevance of this and other similar studies is that it provides an estimation of the area of influence of dioxin sources. If we consider a 160-km–radius circular area centered in the Harbor, we will likely capture most relevant atmospheric sources. The question of why urban areas show higher dioxin levels has not been fully answered yet. One of the possible factors is vehicle emissions, which are concentrated in urban regions. Another possibility is resuspension of past emissions. Accidental fires (both structural and garbage-related fires) could possibly be an important factor.

efforts to decrease dioxin emissions in our region can have a positive impact on other areas.

### Dioxins Released to Land

Direct releases to land typically involve application of dioxin-containing residues (such as sewage sludge, pulp and paper mill sludge, and other wastes) or products (e.g., certain herbicides) and accidental spills or improper disposal of industrial wastes (e.g., releases at wood treatment facilities using pentachlorophenol).

Dioxins released to land will tend to bind to soil particles[82] and are generally assumed to be not likely to move down into the groundwater. However, laboratory studies showed that 2,3,7,8-TCDD moves readily through soil with waste oil and other organic liquids[83] and that mobility can also be enhanced by surfactants (e.g., detergents) [224,245,368] (as cited in [320]), for example at landfills, contaminated sites, and oil spills.[84] In addition, many hydrophobic toxics have been found to migrate downwards in soil associated with colloidal particles, increasing the risk of reaching groundwater [45].[85]

Erosion processes can remobilize dioxins attached to soil. Rain and irrigation water can carry soil particles, which can eventually reach nearby water bodies. Wind erosion can also detach soil particles, especially when dry, and transport them suspended in the atmosphere.[86] Given the low vapor pressure of dioxins, volatilization from land is not likely to be significant.

Transformations in the environment are typically slow, with photolysis being the fastest. For this reason, dioxins are degraded faster in the soil surface than in the subsurface. Management of dioxin-contaminated sediments and soil is complicated by their insolubility, their tendency to sorb to organic matter, and their long-term stability. Land disposal of dioxin-contaminated sediment is subject to restrictions under the Resource Conservation and Recovery Act (RCRA). Other regulations prohibit ocean disposal of sediments unless only trace amounts are present.

Plants can adsorb dioxins released to land, taking up small amounts directly through the roots;[87] and contaminated soil can adhere to their surface. Animals feeding on these plants can bioaccumulate dioxins in fat, their body tissues, and/or milk, with concentrations increasing up the food chain. Grazing animals are also likely to ingest varying amounts of soil.

### Dioxins Released to Water

Direct releases to water include effluents from pulp and paper mills, waste water treatment plants, chemical plants with dioxin-contaminated wastewater, and landfill leachate.

Dioxins entering water bodies will tend to attach to suspended particles in the water or may enter the water body already sorbed to particles. These particles can travel varying distances in the water, depending on the particle size and water movement, before they settle through the water column to the sediment surface. Once in the sediments, dioxins can be resuspended when disturbed (by storms and tides, biota, or dredging) and further transported. A small fraction of the dioxins still in dissolved form can be broken down by sunlight or UV light [232] or volatilize and enter the atmosphere.[88]

The transport mechanisms will affect the amount of dioxins released to the environment that will enter the Harbor, and by which media. The mass balance (Appendix A) provides a detailed analysis of loadings to the Harbor from the entire watershed and airshed, as well as outputs. A summary table of inputs and outputs is provided in Table B. 2.

### Prioritizing the Impact of Local Dioxin Sources to the Harbor

Given the general fate and transport properties of dioxins, and because so many activities have the potential to generate dioxins, it is important to ascertain which sources have a greater impact on the Harbor in order to establish priorities for action. A common

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[82] They will bind more strongly to soils with higher organic matter content.

[83] Examples of such organic cosolvents include alcohols and acetone [3,238]. Since these liquids are better solvents for dioxins and are at least partially soluble in water, they increase the solubility and mobility of dioxins.

[84] Subsurface migration of dioxins was also found at a pentachlorophenol (PCP) wood treatment plant in Pensacola, FL, in a water treatment sludge impoundment [90].

[85] Colloids are particles 1–10 nm and 2–10 µm in diameter. Because they are so small, their surface area is very large, making them very effective at sorbing particle-active toxics, including dioxins. Colloidal particles include minerals, organic matter, bacteria, and viruses. Some of the organic compounds shown to migrate associated with colloids in soils include pyrene (a PAH) and several biocides such as DDT, atrazine, prochloraz, and glyphosate [45].

[86] This phenomenon occurred at a massive scale with catastrophic consequences during the Dust Bowl in the 1930s. In this period, drought conditions affected the Great Plains region, and subsequent winds transported vast amounts of soil across the entire continent. A thick cloud of dust covered cities as far away as New York and Washington DC.

[87] Root vegetables, growing directly in contact with the soil have more chances of taking up organic contaminants in the soil such as DDT and chlordane [230].

[88] Microorganisms can dechlorinate dioxins in sediments under anaerobic conditions. This process removes chlorine from the molecules but does not significantly eliminate dioxins [232]. In addition, the rate of this mechanism in the environment is not clear: Studies typically involve incubating sediment samples after adding nutrients and compounds needed by the bacteria, at higher temperatures than those found in aquatic environments [232].

**Table B. 2. Summary of Harbor inputs and outputs of dioxin-like compounds**

| | Mass basis (g/year) | | TEQ basis (g TEQ/year) | |
|---|---|---|---|---|
| | CDD/Fs plus coplanar PCBs | CDD/Fs only† | CDD/Fs plus coplanar PCBs | CDD/Fs only† |
| **Inputs** | | | | |
| Hudson River | 6,420 | 694 (±43) | 5.2 | 3.2 (±0.34) |
| NJ rivers | 2,530 | 1,341 | 2.46 | 1.66 |
| WPCF | 944* | 123 (±49) | 2.2* | 0.9 (±0.38) |
| CSOs | 7,280 | 890 (±220) | 7.8 | 3.3 (±0.8) |
| Deposition | 386* | 106 (±42) | 1.3* | 1.3 (±0.5) |
| Absorption | 560* | 3 (±1.2) | 0.6* | 0. 5 (±0.2) |
| Runoff | 2,430 | 780 (±390) | 5.6 | 4.4 (±2.2) |
| Leachate | 37 | 1.7 (±0.6) | 0.02 | 0.01 (±0.004) |
| **Total Inputs** | **20,552*** | **3,940 (±750)** | **25*** | **15.2 (±4.4)** |
| **Outputs** | | | | |
| Tidal exchange (Atlantic) | 7,070 | 930 (±280) | 10.7 | 7.5 (±2.2) |
| Tidal exchange (Long Island Sound) | 5,140 | 360 (±180) | 11.9 | 9.2 (±4.6) |
| Volatilization | 18,450 | 12 (±6.8) | 7.7 | 2.5 (±1.4) |
| Dredging | 14,300* | 1,190 (±475) | 180* | 16 (±6.4) |
| **Sedimentation** | **33,200*** | **2,515 (±1,006)** | **440*** | **37 (±14.8)** |
| **Total outputs§** | **78,150*** | **2,490 (±1,950)** | **210*** | **35(±30)** |

NA = not available; * Data set is incomplete; † ± standard error.
§ Assuming dredging, but not sedimentation, is considered a loss from the Harbor.

approach to determine or estimate how dioxins (and other contaminants) move in the environment is through modeling. However, all models have a large associated uncertainty because they also rely on a series of assumptions and simplifications.

Dioxin sources near the Harbor can be prioritized based on three different criteria:

1. Amount of dioxins released;
2. Toxicity of the congeners released;
3. Likelihood of releases to reach the Harbor (fate and transport).

It is important to emphasize that these analyses have important limitations that will be detailed in the following three subsections. In particular, the greatest uncertainties are associated with uncontrolled combustion sources, which, at the same time, may represent the largest remaining dioxin emissions.

### 1. Amount of dioxins released

In this case, sources are ranked based solely on the amount of dioxins released. This could be expressed in total mass or in TEQs. This ranking approach makes sense particularly when the goal is to protect humans and the environment in large areas (e.g., an entire country).[89] When focusing on a smaller area such as the NY/NJ Harbor, the impact of each source will surely depend on factors other than sheer magnitude. However, the amount of emissions in the vicinity of the Harbor provides a straightforward first approximation to curbing the largest sources. An important limitation relates to the uncertainty associated with the development of dioxin inventories, especially emissions from uncontrolled combustion sources, which are very poorly characterized. The largest local sources, ranked by the level of releases, are shown in Table B. 3.

### 2. Toxicity of congeners released

A second possible criterion is to prioritize those sources releasing the highest amounts of congeners that account for most of the dioxin-like toxicity in Harbor biota. In addition to the above-mentioned uncertainties in dioxin emissions, other limitations of this approach include:

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[89] This was the approach taken by U.S. EPA and Europe. David Cleverly, Environmental Scientist, National Center for Environmental Assessment, U.S. EPA Headquarters. Personal communication, December 6, 2005.

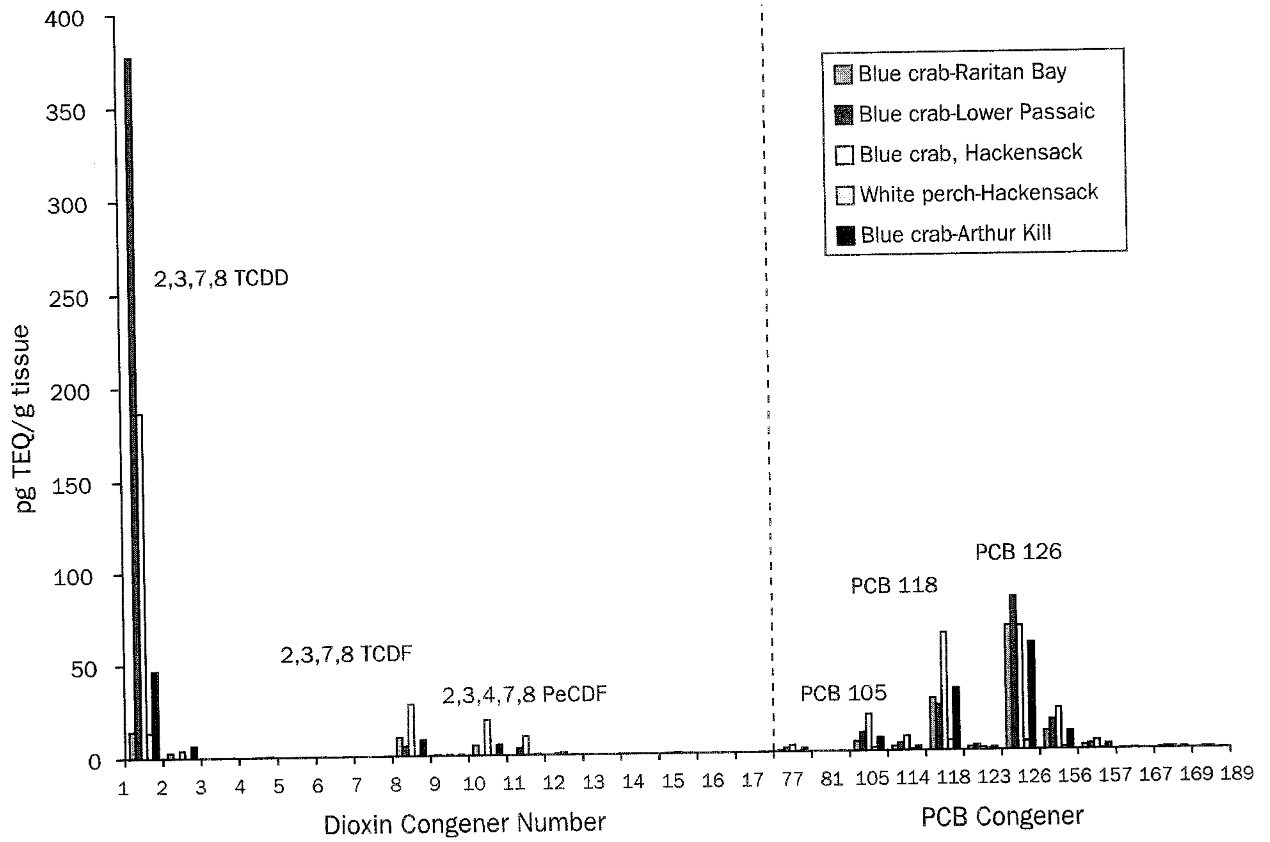
- Congener-specific data for dioxin sources are not always available.
- Congener profiles are typically uncertain. In particular, uncontrolled combustion sources are expected to vary widely and may not be associated with a "typical" emission profile.
- This approach does not consider whether emissions are likely to reach the Harbor.

As an indication of toxicity to humans eating contaminated biota from the Harbor, Figure B. 4 shows levels of dioxins and coplanar PCBs recently measured in whole fish tissue and blue crab hepatopancreas[90] collected from the Passaic and Newark Bay [191]. DLCs are expressed in mammalian TEQs.[91] Although absolute levels vary according to location and type of tissue, these data suggest that only a few of the dioxin-like congeners found in biota from the NY/NJ Harbor account for most of the potential toxicity to humans.

Figure B. 4 shows that coplanar PCBs—particularly PCB 126, 118, 105, 156, and 77—are important contributors to dioxin-like toxicity to mammals (including humans) consuming this biota. In the samples from the Raritan River and Arthur Kill, dioxin-like toxicity is clearly dominated by coplanar PCBs. Although their contribution to TEQs is lower, PCB, 114, and 157 were consistently detected in the samples.

PCB fluids contain significant amounts of coplanar PCBs. The major congeners found in Aroclors released locally are PCBs 118, 105, and 77. These releases have a medium potential to reach the Harbor (see section below). PCBs 118, 77, 105, and 156—in decreasing order of importance—account for most of the coplanar PCBs found in sewage sludge, although the portion of

**Figure B. 4. Dioxin-like compounds in fish and shellfish in the Passaic/Newark Bay area**



Source: NJ DEP (2006) [191]. Congener numbers are identified in Table B. 1. $WHO_{98}$ TEFs were used in this graph.

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[90] Organs with higher levels of lipids (e.g., crab hepatopancreas and fish liver) tend to have much higher concentrations of dioxin-like compounds. Note that the hepatopancreas is difficult to separate from the meat and will likely be consumed. Thus, it is relevant to consider this tissue as an indicator of human toxicity. When cooked, the hepatopancreas dissipates throughout the organism and in the cooking water, which may be consumed as a broth or ingredient for sauces. Anne Hayton, Technical Coordinator, Bureau of Environmental Evaluation and Risk Assessment, Site Remediation Program, NJ DEP. Comments submitted on April 10, 2006.

[91] $WHO_{98}$ TEFs were used, but the conclusions would remain unchanged if $WHO_{05}$ TEFs were applied.

sludge that is applied to land contains small amounts of dioxin-like compounds that are deemed to have a medium–low potential of reaching the Harbor (see section below). In both cases, PCB 126 is present in low concentrations (<1% of mass) but contributes most of the TEQ.[92]

The mass balance found all these toxicologically relevant PCB congeners as major components of coplanar PCBs in inputs from the Hudson River, POTW effluents, CSOs, and runoff. In each case, dioxin-like PCBs contributed to TEQ loadings at a similar or higher level than CDD/Fs. Coplanar PCBs released during management of PCB-containing fluids as well as soil and sediments mobilized from contaminated sites will be carried to the Harbor through one of these modes of conveyance. Although the PCB dataset is incomplete,[93] the mass balance suggests that atmospheric deposition is not a significant source of coplanar PCBs and that their contribution to TEQs is negligible (see Appendix A). In contrast, curbing PCB spills are one of the top priorities to reduce dioxin-like toxicity in the Harbor. Other recommendations for PCBs were put forth in our previous report on PCBs [219] and will not be discussed here.

Figure B. 4 shows that, in spite of some distinctions,[94] the trends are consistent throughout the Harbor:[95] Most of the CDD/F toxicity in biota samples is accounted for by (in decreasing order of importance) TCDD, TCDF, and 2,3,4,7,8-PeCDF, making up ≥93% of the total. Although typically making minor contributions to TEQs, HpCDD, OCDD, and 1,2,3,7,8-PeCDF are consistently detected in biota [43,191] (data not shown).[96] Based on these data, the prioritization criterion was based on the three main contributors to toxicity: TCDD, TCDF, and 2,3,4,7,8-PeCDF.

### 3. Likelihood to reach the Harbor

The third criterion consists in using information on the fate and transport of dioxins in the environment to qualify the relative likelihood of local dioxin emissions to reach the Harbor. The approach taken for our present analysis does not attempt to quantify the amount of dioxins reaching the NY/NJ Harbor from each source. Rather, sources are classified as having a low, medium, or high potential of reaching the Harbor, *regardless of their magnitude*, allowing an approximate ranking. A thorough modeling effort is needed in order to estimate actual dioxin fluxes to the Harbor.

The main limitations to the present approach are: (1) the factors affecting transport from the source to the Harbor are discussed only qualitatively; and (2) each factor involved in dioxin movement will be affected by many variables (e.g., distance traveled by pollutants from a source will depend on how high the plume rises, the type of material burned, and the atmospheric conditions at the moment). Therefore, great variability is expected.

The following factors have been considered in ranking the sources, in approximate order of importance:

1. **Proximity to the Harbor**: Available evidence suggests that the most dramatic effects of dioxins are typically felt in the vicinity (a few km at the most) of the source [141,360], although an important fraction of dioxins emitted to air may be able to travel 1,000s of km from the source [137,242] and these far-reaching dioxins will have a diffuse effect over a much larger area. Emissions closer to the Harbor are particularly relevant because the pathway is the shortest, most direct, and physically connected to it.
2. **Prevailing local winds**: Dioxins from sources located in the path of prevailing winds are more likely to be carried towards the Harbor.
3. **Type of surface** where dioxins are deposited have an effect on the amount available for remobilization: Dioxins deposited on land tend to stick to soil particles and have little mobility, except when land is disturbed. Dioxins on impervious surfaces such as asphalt are more mobile because water flows easily over these surfaces (e.g., stormwater runoff) washing away any substances or particles.
4. **Height of emissions**: This factor only affects the travel distance of that fraction of dioxins that is dispersed beyond the vicinity of the source. For that fraction, the higher the emission point, the farther dioxins may travel [137].

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[92] Data on congener patterns can be obtained at *http://www.nyas.org/programs/harbor.asp*.

[93] Of the most relevant congeners, data was available for PCBs 77, 105, 118, and 156.

[94] Concentrations of 2,3,7,8 TCDD are much higher in biota from the Passaic/Newark Bay than from other areas. Several furans are also elevated there. TCDF is higher in the Upper Hudson area than in other samples, while 1,2,3,4,6,7,8-HpCDF is high in the Upper Bay as well.

[95] The same trends were found in blue crab samples across the Harbor by the Contaminant Assessment and Reduction Project (CARP) [43] (Data provided by Dawn McReynolds, NYS DEC).

[96] The HpCDFs, 1,2,3,4,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,7,8,9-HxCDF, 2,3,4,6,7,8-HxCDF, and PeCDD are rarely or never detected, although the latter, when present, is an important contributor to TEQs.

In general, the highest likelihood of reaching the Harbor was assigned to sources closest to this water body, particularly those in the path of prevailing local winds, which may deposit directly on the Harbor or on impervious surfaces. The height of the emission was given less weight. All sources were evaluated using these criteria to determine their potential to reach the Harbor.

### Comparison of Prioritization Criteria

A comparison was made among the rankings resulting in each case. Ordering dioxin emissions according to the amounts of either total dioxins or the toxicologically relevant congeners is straightforward. The likelihood of reaching the Harbor cannot be evaluated in isolation, but has to be thought of as a complement or adjustment of one of the first two. In order to modify the quantity-based ranking, we assumed that 100%, 50%, and 10% of dioxins with a high, medium, and low potential to reach the Harbor, respectively, would eventually get there.

Table B. 3 shows dioxin emissions (for total TEQ or TEQ of the three congeners driving toxicity in Harbor biota) for the largest sources within the Watershed.

Table B. 3 shows that source prioritization based on total TEQs or just the three main toxic congeners is very similar. This is not surprising because dioxin sources typically emit mixtures of all congeners. Therefore, unless a particular source has a very peculiar signature (e.g., dioxin-like toxicity of PCP-treated wood is made up almost entirely of OCDD and OCDF), relatively small differences in congener patterns are not expected to significantly vary the ranking order in comparison to sheer quantity.

Factoring in the likelihood of reaching the Harbor does not alter the ranking significantly (change of more than 3 units) with respect to TEQ quantity but it does modify it somewhat with respect to the three toxic congeners:

- The relevance of open burning of residential waste and sewage sludge incineration is decreased.

**Table B.3. Comparative ranking of dioxin sources to the Watershed**

| | Dioxin emissions | | | | | |
|---|---|---|---|---|---|---|
| | 17 Dioxin-like congeners | | 3 Toxic congeners | | Likelihood to reach Harbor | |
| **Source** | **g TEQ/yr** | **Ranking** | **g TEQ/yr** | **Ranking** | **Value** | **Ranking** |
| | **Releases from ongoing sources** | | | | | |
| PCB spills | 0.2–28 | 1 | 0.1–23 | 1 | M | 2 |
| Structural fires | 0.01–50 | 2 | 0.002–9 | 3 | H | 1 |
| Open burning of residential waste | 1–37 | 3 | 0.5–19 | 2 | L | 6 |
| Waste management fires | 0.01–15 | 4 | 0.003–5 | 4 | M | 3 |
| MedWI | 1.8–3.9 | 5 | 0.7–1 | 8 | H | 4 |
| Fe/steel recycling | 1.5–3.6 | 6 | 1–3 | 6 | H | 5 |
| LFG combustion + flaring | 0.09–5 | 7 | 0.02–4 | 5 | M | 8 |
| Wood burning (commercial, industrial, power generating) | 0.01–5 | 8 | 0.01–3 | 7 | M | 9 |
| On-road fuel | 2 | 9 | 0.8 | 9 | M | 12 |
| Crematoria | 0.01–3 | 10 | 0.004–1 | 12 | H | 7 |
| Fossil fuel combustion (commercial/industrial) | 1 | 11 | 0.8 | 10 | M-H | 11 |
| Off-road fuel | 0.3–1.7 | 12 | 0.1–0.7 | 16 | H | 10 |
| MSWI | 0.9 | 13 | 0.4 | 14 | M | 14 |
| SSI | 0.1–1.5 | 14 | 0.1–1 | 11 | M | 15 |
| Power plants | 0.4–1.0 | 15 | 0.2–0.6 | 15 | H | 13 |
| HWI | 0.7 | 16 | 0.4 | 13 | M | 16 |
| | **Releases from reservoirs** | | | | | |
| Diamond Alkali (river sediments) | ~14 (12)§ | 1 | 13 | 1 | H | 1 |
| Contaminated land sites | > 3–12 | 2 | > 4–7 | 2 | M | 2 |

§ in parenthesis, 2,3,7,8 TCDD only.

- The impact of MedWI, off-road fossil fuel combustion, and crematoria is increased.
- There is little modification to the relevance of other sources.

Under any criteria, the impact of the Diamond Alkali site on the Harbor remains significant. This source will be addressed in section C.3 (historical sources), but the focus of the current report is on curbing new inputs to the Harbor, for which the top priorities are (in *approximate* order of priority):

- Structural fires
- PCB spills
- Fires at waste management facilities
- Medical waste incinerators (MedWIs)
- Contaminated land sites
- Iron and steel recycling
- Open burning of residential waste
- Crematoria
- Landfill gas (LFG) flaring and combustion
- Wood burning at power generating, industrial, and commercial facilities
- Off-road fuel combustion

## C. DIOXIN SOURCES TO THE NY/NJ HARBOR

This section describes local sources of dioxins to the NY/NJ Harbor and attempts to estimate dioxin releases from such sources. Atmospheric sources taken into account include those within the NY/NJ Harbor Watershed as well as the entire areas of NY and NJ (see section B.3, *Determining the airshed area for the NY/NJ Harbor*). In general, estimates have been developed by multiplying the activity level (e.g., metric tons [T] of solid waste burned in barrels) by an appropriate emission factor (grams of dioxins released per T of waste burned). The emissions are given in TEQs (see section B.2. Toxicity), but the actual mass is substantially higher.[97] Emissions are typically on the order of a few grams (in TEQs) per year. Such small levels are of concern because dioxins are extremely toxic.

For industrial sectors, we present facility-specific measurements whenever available, as well as releases reported to the Toxics Release Inventory (TRI) in 2004 (the most recent year for which data were available).[98] TRI releases cannot, in general, be directly compared to our estimated releases using emission factors because facilities are required to report in grams of total dioxins, not in TEQs. Nevertheless, some facilities also report congener profiles, and we used this information to calculate emissions in TEQs.[99] For more details on TRI reporting see Box 1.

The major sources considered in this report include:

- C.1. Combustion sources;
- C.2. Industrial processes and products;
- C.3. Historical sources: contaminated sites and sediments.

### C.1. Combustion sources

Combustion of carbon-containing substances in the presence of some chlorine source has the potential for generating and releasing dioxins. Examples include combustion of wastes at incinerators and combustion

### BOX 1. TRI REPORTING

Facilities must report releases of dioxin and dioxin-like compounds[1] to TRI if they meet all three of the following criteria: they (1) are included in certain Standard Industrial Classification (SIC/NAICS) Codes;[2] (2) have 10 full-time employees; and (3) manufacture,[3] import, process or otherwise use more than 0.1 g of dioxins per year [308].

Reported releases can be estimated by using actual monitoring data, facility-specific emission factors, or industry-specific EPA default emission factors (EFs).[4]

Currently, facilities must report total dioxin emissions in grams and, when available, indicate how that total is distributed among individual congeners [338]. Recently, EPA has proposed revisions to the reporting requirements [338]. The three possible options are:

1. Report total dioxin grams and TEQ data;
2. Report total dioxin grams, individual compound grams, and TEQ data;
3. Report total dioxin grams and individual compound grams.

Options 2 and 3 are preferred because they provide information on individual congeners.

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[1] Dioxin and furan congeners that have dioxin-like activity (those that have chlorine in positions 2,3,7, and 8 and have been assigned a TEF) are reportable.

[2] Codes include manufacturing codes 20 through 39, electric utilities combusting coal and/or oil for distribution in commerce of electricity, and commercial hazardous waste treatment facilities regulated under RCRA.

[3] The definition of manufacture includes inadvertent production.

[4] These three approaches are ordered by accuracy. If a facility is required by law to monitor dioxins, then this data should be used, and information on individual congeners must be reported as well. Otherwise, if the facility has access to EFs for similar facilities, then it should use them; if not, it can use EPA default EFs. These EFs have been developed from three sources [308]: (1) a database of DLCs in the US [309]; (2) the Inventory of Sources of Dioxin in the US for 1987 and 1995 [293]; and (3) a document estimating exposure to these compounds in the US [310].

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[97] Dioxin emissions expressed in mass for most sources are available at *http://www.nyas.org/programs/harbor.asp*.

[98] Data were obtained by querying the TRI Explorer *(http://www.epa.gov/triexplorer/)* for 2004 "Facility" reports for each state, selecting dioxins and dioxin-like compounds for all industries.

[99] Only one congener distribution is reported per facility, and we applied it to releases to all the media (air, land, water).

of fossil fuels for energy generation. Uncontrolled combustion processes such as open burning of household trash or forest fires do not allow for emissions control and are becoming the major remaining source of dioxin emissions, as industries take measures to minimize their releases.

In general, commercial incinerators consist of a combustion chamber where conditions can be managed, and a gas stack to vent the combustion gases. Modern incinerators typically include one or more types of air pollution control devices (APCDs), designed to curb the amount of dioxins and other pollutants released.

Dioxin emissions were estimated for three main combustion categories:

a) Combustion of waste material at regulated incinerators;

b) Uncontrolled combustion; and

c) Other combustion sources.

For controlled combustion, most of the data used to estimate dioxin emissions is based on routine tests conducted under normal operations and does not include "upset emissions" (during start-up, shut-down, or malfunctions and accidents). Under these conditions, products of incomplete combustion are formed in larger amounts, as indicated by several tests at incinerators [32]. For instance, in medical waste incinerators, during malfunctions, dioxin emissions can rise up to 50 times over those in normal operating conditions [75]. Available dioxin emissions estimates for industrial sources come either from stack tests at specific facilities or from emission factors that are averages of several tests at multiple facilities. These discrete stack tests do not reflect the variation expected during day-to-day operations and often deviate from typical conditions [32].[100]

According to some estimates, incinerator tests may reflect as little as 2% of actual emissions [44] (as cited in [264]). For instance, measurements at municipal solid waste incinerators (MSWIs) found that dioxins in crude flue gas[101] and fly ash (ESP ash) increased one order of magnitude after start-up, when waste feed was resumed [166].[102] A similar situation applies to other industrial activities. Upset releases for some pollutants at several facilities in the US have been compiled by the Environmental Integrity Project [75] and showed that upset emissions make up a significant portion of total releases or may be greater than releases during normal operations [75].[103] New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAPS) exempt emissions resulting from nonroutine operations. Fewer than half of the states collect information on these releases. The state of New Jersey does not allow upset emissions to exceed limits affecting normal operations. This is not the case in NY. Many states have emergency provisions that do permit exceeding these limits. In summary, currently available dioxin emission factors and reported tests for industrial sources (including incinerators, power plants, and metal refineries) are likely underestimated. This is an important gap in our understanding of dioxin emissions that could be addressed by requiring continuous or repeated testing—during longer periods and spanning a variety of situations—at incinerators and other industrial facilities

### Local Combustion Sources

Table C. 1 summarizes air emissions from combustion sources in NY and NJ as well as dioxins associated with various residues and products. Although dioxin amounts in residues tend to be much larger than air emissions, few of these dioxins are expected to be released to the environment.

## C.1.a. Combustion of Waste at Regulated Incinerators

Many factors can contribute to the generation of dioxins, including:

- *Feedstock:* The presence of chlorine—either organic or inorganic[104]—in the combusted material is necessary to generate dioxins [369]. Sources of chlorine in incinerators include food and certain plastics such as PVC, while some

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100. Note that many tests—intended to prove compliance with regulations—are run under worst-case scenario conditions (e.g., minimum combustion temperatures, maximum feed rates of halogens) and could overestimate normal emissions [32]. However, these tests are typically better controlled and more closely supervised than routine operations, reducing the chances of upset conditions [32].

101. Taken after the ESP but before a wet scrubber.

102. According to the authors, modern pollution control devices should be able to manage these peaks and avoid exceeding regulatory limits [166].

103. Data are from Texas and Louisiana, which are the only states that have centralized excess emission reporting systems; thus the report focused on petroleum refineries, gas plants, and a carbon black plant. Emissions compiled in the report include carbon monoxide (CO), volatile organic compounds (VOCs), sulfur dioxide ($SO_2$), and nitrogen oxides (NOx). The combined upset emissions of the 37 facilities considered in the report released more than 3½ times the total pollution from all facilities in Dallas County, Texas [75].

104. Examples of organic chlorine include certain plastics and pesticides. Table salt (sodium chloride) and other chlorides contain chlorine in inorganic form.

## Table C.1. Combustion Sources to the NY/NJ Harbor

| | **Total air emissions (g TEQ/yr)** | | **Dioxins in ash (g TEQ/yr)** |
|---|---|---|---|
| **Sources** | **Watershed** | **NY & NJ*** | **Watershed** |
| **a. Combustion of Waste at Regulated Incinerators** | | | |
| Municipal Solid Waste Incinerators (MSWI) | 0.9 | 3 | 30–130 |
| Medical Waste Incinerators (MedWI) | 2–4 | 2–4 | 2 |
| Hazardous Waste Incinerators (HWI) | 0.7 | 1 | 2–54 |
| Sewage Sludge Incinerators | 0.1–2 | 0.3–3 | 0.02–0.6 |
| **Total regulated incinerators** | **4–7** | **6–11** | **34–187** |
| **b. Uncontrolled Combustion** | | | |
| Open burning of residential waste (NY only) | 1–37 | 4–96 | 30–173 |
| Agricultural burning (NY only) | 0.1 | 0.5 | 0.6 |
| Structural fires | 0.01–50 | 0.01–60 | 0.04–24 |
| Waste management fires | 0.01–15 | 0.02–20 | ? |
| Vehicle fires | 0.5–1 | 0.7–2 | 0.2 |
| Wild fires and prescribed fires | 0.4 | 1.9 | 0.09 |
| Tire fires | 0.6 | 0.9 | ? |
| **Total uncontrolled combustion** | **3–104** | **8–181** | **> 31–198** |
| **c. Other Combustion Sources** | | | |
| Power plants burning fossil fuels | 0.4–1 | 1–3 | 0.2–0.7 |
| Wood combustion (Industrial/commercial/electrical) | 0.01–5 | 0.03–12 | ? |
| Fossil fuel combustion (Industrial/commercial) | 1 | 3 | ? |
| Residential wood burning | 0.5 | 1 | 0.6 |
| Residential fossil fuel combustion | 0.6 | 1 | — |
| Outdoor wood boilers | 0.05–1 | 0.1–3 | ? |
| On-road fuel combustion | 2 | 4 | — |
| Off-road fuel combustion | 0.3–1.7 | 0.4–4 | — |
| Landfill gas flaring and combustion | 0.09–5 | 0.2–9 | ? |
| Crematoria | 0.01–3 | 0.03–6 | 0.1 |
| **Total other combustion** | **5–21** | **11–46** | **> 1** |
| **Total all combustion sources** | **11–133** | **25–238** | **66–386** |

* Whole states, including the Watershed. If numbers are the same, it means that all activity takes place within the Watershed.

metals (e.g., copper and iron) are catalysts of dioxin formation [158].[105] Most laboratory-scale research shows that there is a clear relationship between chlorine in feed and dioxins.[106] However, tests at incinerators suggest that when they are operating under optimal conditions and fitted with adequate air pollution control devices (APCDs), a reduction in the chlorine content does not result in lower dioxin emissions (as summarized in [334]).[107] It is important to note that chlorine in its many forms is ubiquitous, and therefore, under the right conditions, burning almost any material can produce dioxins.

- *Combustion conditions* (temperature, amount of oxygen, residence time): Conditions in the combustion chamber of modern incinerators can be optimized to destroy any dioxins already present in the feedstock itself and to achieve complete combustion of the waste.[108]

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[105] If sodium chloride, which is normally not an efficient chlorine source, is present together with these metals, it can effectively produce CDD/Fs [369].

[106] As reviewed in [268,293].

[107] It is likely that part of the reason is that incinerators are complex systems in which a myriad of variables can confound the effects of chlorine level.

[108] Temperatures of ~800 °C are needed in most incinerators [32].

- *Postcombustion conditions*: Dioxins can be formed after exiting the combustion chamber[109] under certain conditions, (even if they were not originally present or were totally destroyed during combustion). Products of incomplete combustion (PICs),[110] chlorine, and metals adsorb to fly ash. When fly ash gets to the postcombustion area (which is cooler), dioxins can be generated through complex processes either in particulates or gas–solid reactions [152].[111] Temperatures between ~ 300 and 500°C favor dioxin formation.

Waste that remains unburned is termed *bottom ash*, while the fine particles that are collected in air pollution control devices (APCDs) is *fly ash* [32].[112]

In an incinerator,[113] dioxins may be released in stack gases, solid residues (ash), and possibly in water effluents (if wet scrubbers are used as APCDs) [350].[114] Emissions to air from waste incinerators in the area are regarded as highly likely to reach the Harbor because most of them are located close to this water body and/or in the path of prevailing winds (see Section B.3 and Map 4 in Section C.2). Dioxin emissions associated with the major controlled combustion sources in the Harbor Watershed are developed in the following four sections and include:

- Municipal solid waste incinerators (MSWIs)
- Medical waste incinerators (MedWIs)
- Hazardous waste incinerators (HWIs)
- Sewage sludge incinerators (SSIs).

## Municipal Solid Waste Incinerators (MSWIs)

Most incinerators burning municipal waste are waste-to-energy (WTE) facilities that recover the heat to generate energy [122]. In the US, there are 105 municipal waste incinerators, 98 of which are WTE facilities.[115] There are three main kinds of combustors or furnaces designed to recover heat for energy generation: mass burn, modular, and refuse-derived fuel. Most incinerators in NY and NJ are mass burn, where waste is burned as is, except for the removal of pieces that are too large to enter the furnace.[116]

Dioxins generated in incinerators are found both in stack emissions and combustion residues (fly and bottom ash). To minimize air emissions, in addition to controlling combustion conditions, combustors can be fitted with APCDs, as summarized in Box 2. With more advanced air emission technologies, most dioxins are now associated with solid residues (fly or bottom ash) rather than direct air emissions. This does not necessarily mean that ashes will contain higher levels of these contaminants than in the past. Old MSWIs were net generators of dioxins. In contrast, modern, well-operated incinerators are net dioxin destroyers [152].

Municipal solid waste incineration (MSWI) generates ~25–30% of the burned mass as ash [157]. In the US, WTE facilities process 28.7 million T of waste/yr [122], which translates into 7.2–8.6 million T ash/yr. Dioxin levels in ash (fly and bottom) are, on average, 258 ng TEQ/kg [297]. It is estimated that ~10% of this ash (~0.8 million T/yr) is *beneficially*[117] used, with the remainder being landfilled [157].[118] Nationally, most of this beneficially used ash (87%) is applied as daily landfill cover, and the remainder is used for construction as road fill or subbase for parking lots [122]. Ash from MSWIs is periodically tested using the Toxicity Characteristic Leaching Procedure (TCLP) for metals [205] prior to management.[119] Dioxin tests are not required for ash from nonhazardous waste combustors.[120]

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[109] In the stack or within air pollution control devices.

[110] PICs are small organic compounds.

[111] Two main processes have been identified: (1) Precursor reactions, where PICs act as building blocks for dioxins, and metals (mainly Cu), if present, act as catalysts; (2) *De novo* synthesis, where a solid carbon source (e.g., fly ash or soot particles) reacts with oxygen and chlorine in the gas phase [365].

[112] Bottom ash includes unburned organic materials, metal, glass, and ceramics. Some metals that are volatilized in the combustion chamber, acids, and organic compounds later condense into particle surfaces [32].

[113] Incinerators typically consist of a combustion chamber or furnace, which may be adapted to recover heat for energy generation. Combustion gases leave the furnace and are vented through a stack. One or more APCDs can be included to intercept flue gases before they exit the stack to capture particulate matter or remove certain components such as mercury, nitrogen oxides, and acids.

[114] Scrubber water is a slurry containing salts, lime, and scrubbed contaminants [32].

[115] The remaining MSW incinerators are refuse-derived fuel (RDF) processing plants that do not generate power on site [122].

[116] Typically, waste is placed on a grate that moves through the furnace. Steel tubes carrying water run along the combustor. As the water is heated, it produces the steam that is used to generate electricity. Modular furnaces also burn unprocessed waste, and consist of two furnaces in series: a primary and a secondary combustion chamber [334].

[117] This means that it is used for some purpose rather than being landfilled (e.g., mine reclamation).

[118] Ash can be disposed of in monofills, monocells (designated divisions of landfills), or in mixed landfills [157].

[119] If hazardous, it has to be disposed of as hazardous waste.

[120] Ted Williams, Bureau of Solid Waste, Reduction and Recycling, Division of Solid and Hazardous Materials, NYS DEC. Personal communication, March 1, 2005.

## BOX 2. THE MOST COMMON CONTROL TECHNOLOGIES FOR MSWI INCLUDE:

- Electrostatic precipitators (ESPs): Particles in the combustion gases are charged by applying a strong electric field. The particles are then attracted to, and collected in, plates that receive an opposite charge. ESPs are classified as hot or cold based on the temperature of operation (above or below 230°C, respectively).
- Fabric filters (FFs): These are a series of filter bags made of fiberglass that can retain particles up to less than 1 μm in diameter. A fan forces the combustion gases into the filter. Acids damage the filters, so these filters are usually combined with a dry scrubber.
- Dry scrubbers (DS) or spray dryer absorbers (SDA): Lime and water as a slurry is sprayed into the gases exiting the combustion chamber to neutralize acids. The heat evaporates the water, and the combustion gases cool down as a result. A DS before an ESP makes it a cold ESP.
- Dry sorbent injection (DSI): Dry hydrated lime or soda ash is injected into the combustor or the postcombustion area to neutralize acid gases. DSI probably has little effect on dioxin emissions.
- Wet scrubber (WS): These are devices for acid gas removal but also should reduce emissions of dioxin in both vapor and particle forms. As gases exit the combustor, water is sprayed to remove the HCl. Subsequently, caustic or hydrated lime is sprayed to remove sulfur dioxide from the combustion gases.
- Activated carbon injection (CI): Activated carbon is injected into the gas stream exiting the combustor, agglomerating and absorbing mercury and dioxins. These particles are retained in existing particulate control equipment.[1]

APCDs typically providing the best control are (in decreasing order): SD/FF, DSI/FF, SD/ESP, and DSI/ESP [120]. Dioxin removal efficiencies have been reported for SD/ESP (62%) [20] and SD/FF (>99.7%) [120].[2]

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[1] Higher levels of carbon and mercury in fly ash might be an issue for beneficial applications, forcing its disposal at a higher cost [361].

[2] The efficiency of APCDs to remove pollutants from flue gases is defined as: (concentration before APCD – concentration after APCD)/concentration before APCD.

Municipal solid waste in the US contains ~0.6% PVC [324], with this material contributing ~20–50% of the chlorine. MSW likely to be burned in incinerators (after removing noncombustible and/or recyclable materials), has a PVC content of ~0.9% [324] and ~0.5–0.9% of chlorine by weight [50] (as cited in [293]). Research suggests that there is a chlorine concentration threshold of ~1% below which dioxin formation in modern incinerators is insensitive to chlorine levels in feed [357,362] (as cited in [334]). This is observed, particularly, in modern incinerators following good combustion practices and equipped with APCDs.[121] However, the amount of PVC (and thus chlorine) entering the waste stream could increase in the future if PVC use increases. In addition, the bulk of PVC was introduced in the market in the 1970s and many durable PVC applications are now reaching the end of life [26]. PVC in MSW could increase even more as hospitals try to decrease the amount of regulated medical waste sent to medical waste incinerators (MedWIs).[122] PVC makes up as much as 18% of noninfectious hospital waste [109], which is typically disposed of as municipal solid waste. In addition, treated medical waste from alternative technologies to MedWI (e.g., autoclaving) is subsequently disposed of as MSW, also potentially increasing chlorine levels in this waste stream.

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[121] However, this might not necessarily be the case for all incinerators [39] (as cited in [334]).

[122] Stricter regulations on MedWIs in the last 10 years forced many out of operation, leading to a sharp decrease in the number of operating facilities. As a result, hospitals are trying to minimize waste in need of incineration by doing a better job at sorting their waste. Janet Brown, Partner Coordinator, Hospitals for a Healthy Environment. Personal communication, February 15, 2005.

## Local Air Emissions from MSWIs

There are five waste-to-energy (WTE) facilities in New Jersey and 10 in New York, including five within the Harbor Watershed area (Table C. 2) [122]. In addition, there is an incinerator in Suffolk County that does not recover energy. In NY and NJ, ~17 and 9% of trash, respectively, is sent to WTE facilities [118].

Air emissions from MSWIs in the region were estimated (1) using stack test data when available (for all WTE facilities)[123] and (2) applying the emission factor (EF) suggested by the United Nations Environmental Programme (UNEP)[124] for the one incinerator where stack test data were not available.[125] Table C.2 shows the characteristics of MSWIs in the Watershed (technologies and controls) and estimated dioxin emissions. Although variations may occur during normal operations, it is expected that stack tests more accurately reflect actual emissions from incinerators.[126]

**Table C.2. Dioxin emissions to air from MSW incinerators in NY and NJ by facility**

| | | | | | EPA† | UNEP | |
|---|---|---|---|---|---|---|---|
| **State** | **County** | **Inciner. technol.** | **Air pollution control devices (APCD)§** | **Waste burned (T/yr)‡** | **Emission (g TEQ/ yr)** | **EF# (µg TEQ/ T)** | **Emission (g TEQ/ yr)** |
| NJ | Essex | MBWW | SDA/ESP/CI/SNCR/WESPHIX | 759,939 | 0.1 | 0.5 | 0.4 |
| NJ | Union | MBWW | SDA/FF/SNCR/CI | 405,301 | 0.03 | 0.5 | 0.2 |
| NY | Dutchess | RWW | SDA/FF | 136,548 | 0.01* | 0.5 | 0.07 |
| NY | Washington | MBWW | SDA/ESP/CI | 140,025 | 0.6 | 0.5 | 0.1 |
| NY | Westchester | MBWW | SDA/FF/SNCR/CI | 588,077 | 0.07 | 0.5 | 0.3 |
| **Total Watershed** | | | | **2,029,890** | **0.9** | | **1** |
| NJ | Camden | MBWW | SDA/ESP/CI | 295,532 | 0.09 | 0.5 | 0.1 |
| NJ | Gloucester | MBWW | SDA/FF/SNCR/CI | 161,839 | 0.02 | 0.5 | 0.08 |
| NJ | Warren | MBWW | SDA/FF/NOX/CI | 126,094 | 0.03* | 0.5 | 0.06 |
| NY | Nassau | MBWW | SDA/FF/SNCR | 846,766 | 0.4 | 0.5 | 0.4 |
| NY | Niagara | MBWW | SDA/FF/SNCR/CI | 727,496 | 0.4 | 0.5 | 0.4 |
| NY | Onondaga | MBWW | SDA/FF/SNCR/CI | 322,608 | 0.01 | 0.5 | 0.2 |
| NY | Oswego | MCU | SDA/FF/CI | 58,589 | 0.02* | 0.5 | 0.03 |
| NY | Suffolk | MBWW | SDA/FF/SNCR/CI | 194,515 | 0.01 | 0.5 | 0.1 |
| NY | Suffolk | MBWW | SDA/FF/SNCR/CI | 288,236 | 0.02 | 0.5 | 0.1 |
| NY | Suffolk | RWW | SDA/FF/CI | 130,161 | 0.03* | 0.5 | 0.07 |
| NY | Suffolk | MBR | WS | 3,378¶ | 1** | 350 | 1 |
| **Total outside Watershed** | | | | **3,155,215** | **2.2** | | **2.8** |
| **Total NY and NJ** | | | | **5,185,105** | **3.1** | | **3.8** |

† Sources: Large WTE: EPA 2002 stack tests [315]; small WTE, marked with (*): Walt Stevenson, EPA Headquarters, personal communications, June–July, 2006; Very small incinerators, marked with (**) based on UNEP EF.

‡ For incinerators in NY, data from NYS DEC for 2004 [214]. For NJ incinerators, it was assumed to be 85% of design capacity as reported in [122].

¶ Source: The Incorporated Village of Saltaire, NY (1999) [53 ].

* Most incinerators reported total dioxins. TEQs estimated assuming total:TEQ ratio = 51:1 (average for 167 tested incinerators).

** For this very small incinerator, emissions were estimated based on waste burned and applying UNEP emission factors.

§ MBWW: mass burn, water wall furnace; RWW: rotary, water wall combustor; MCU: modular combustion unit; SDA: spray dryer absorber (same as dry scrubber, DS); ESP: electrostatic precipitator; CI: activated carbon injection; SNCR: selective noncatalytic reduction for nitrogen oxides control; FF: fabric filter; DSI: dry sorbent injection; NOX: nitrogen oxides control device; WESPHIX: fly ash stabilization. WS: wet scrubber.

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[123] Air emissions for all large incineration plants (capacity to burn >225 T of MSW/day) in the US were addressed by 1995 MACT regulations. All emission controls were retrofitted by year 2000. MACT standards for small incinerators (capacity to burn 35 to 225 T/day) were adopted in 2000 with compliance achieved in 2005. Walt Stevenson, EPA Headquarters. Personal communication, January 11, 2006.

[124] The UNEP established four categories of EFs: The lowest EF (0.5 µg TEQ/T) is suggested for "state-of-the-art" facilities (those having at least one device to control particulates and other technologies such as an activated carbon adsorber or a selective catalytic reduction [SCR] device to control air emissions); we assumed this EF would apply to incinerators in compliance with MACT standards. A higher EF (30 µg TEQ/T) is assigned to incinerators having good combustion and APCDs efficiency but not meeting the requirements for state-of-the-art facilities. We applied the EF for minimally controlled incinerators (350 µg TEQ/T) to the very small incinerator in Suffolk County.

[125] Standards for very small incinerators (less than 35 T/day capacity) were recently adopted; compliance for these units is scheduled for December 16, 2010 [85].

[126] EFs are typically calculated from averages of several emissions measurements in different facilities. Applying EFs can over- or underestimate emissions from any particular facility. Differences in waste composition, incinerator design, operating conditions, malfunctions in equipment, etc., can result in a wide range of dioxin emissions.

### Local Estimates of Dioxins in Residues

In New York, most of the ash generated by WTE incinerators is sent to ash monofills or MSW landfills, while a small part is used as landfill alternative daily cover.[127] None is used for road or other types of construction.[128] Approximately 0.9 million T of ash were generated in 2003 by NY WTE facilities.[129]

Currently in NJ, ash from large WTE incinerators is commonly sent to municipal solid waste landfills.[130] Some ash is blended with dredge spoils and cement kiln dust and sent to Pennsylvania for mine reclamation or alternative daily cover for landfills. Ash is tested under TCLP for metals, except when there are dioxin tests of stack gases; then, ash has to be analyzed for dioxins as well.[131] In NJ, ~0.5 million T of ash were generated by WTE facilities in 2004.[132] Virtually all of this ash was landfilled[133] mostly in nonhazardous waste landfills,[134] with ~0.03 million T of ash landfilled within the Watershed.[135]

The amounts of dioxins associated with ash generated by MSWIs in the region were calculated using two approaches and are summarized in Table C.3. Estimates using EPA assumptions are about four times higher than those applying UNEP EFs. It is argued that the risk of dioxin release from ash is low due to their strong adsorption to solids. However, other routes may contribute to dioxin remobilization such as runoff and wind transport—for example, during storage and transport of the ash.[136] The U.S. EPA analyzed leachate samples from 5 MSWIs ash disposal facilities and detected dioxins in one of the sites at 3 ng/L (ppt) [297].

MSW itself contains dioxins ranging from 20 to 70 μg TEQ/T [353]. Table C. 4 suggests that dioxins are approximately conserved during waste incineration: although emissions to air are approximately two orders of magnitude lower than those in the original waste, the vast majority of dioxins ends up in ash.

Local information is lacking on volumes of liquid waste streams (e.g., wet scrubber effluents) and dioxin concentrations. Only one of the MSW incinerators in the region is equipped with a wet scrubber, and estimates from similar facilities have found very low levels in MSWI wet scrubber effluent. Therefore, this is likely a negligible source for our region.

**Table C. 3. Dioxins in ash generated by MSW incinerators**

| | Waste incinerated (T/yr) | Ash generated (T/yr)† | Dioxins in fly + bottom ash (g TEQ/yr) | |
|---|---|---|---|---|
| | | | EPA‡ | UNEP* |
| NY | 864,651 | 216,163 | 56 | 14 |
| NJ | 1,165,239 | 291,310 | 75 | 19 |
| **Total Watershed** | **2,029,890** | **507,472** | **131** | **33** |
| NY | 2,571,751 | 642,938 | 166 | 44 |
| NJ | 583,464 | 145,866 | 38 | 10 |
| Outside Watershed | 3,155,215 | 788,804 | 204 | 54 |
| **Total NY + NJ** | **5,185,105** | **1,296,276** | **334** | **87** |

† 25% of incinerated waste;
‡ 258 μg TEQ/T ash [297];
* Dioxins in ash were calculated for each facility and then added. EFs (in μg TEQ/T waste burned): 15 and 1.5 for fly and bottom ash, respectively, except for the very small incinerator in Suffolk County (500 and 15 μg TEQ/T for fly and bottom ash).

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[127] There are four ash monofills in NY: three in Suffolk County and one in Westchester [205].

[128] Ted Williams, Bureau of Solid Waste, Reduction and Recycling, Division of Solid and Hazardous Materials, NYS DEC. Personal communication, March 1, 2005.

[129] Excel table for update of the New York State Solid Waste Management Plan report [205]. Provided by Ted Williams, Bureau of Solid Waste, Reduction and Recycling, Division of Solid and Hazardous Materials, NYS DEC. Personal communication, March 7, 2005.

[130] One facility that collects fly ash (which has higher dioxin concentrations) separately sends it to the hazardous waste landfill in Model City, NY. Timothy Bartle, Supervisor, Compost and Incineration, Bureau of Resource Recovery & Technical Programs Division of Solid and Hazardous Waste, NJ DEP. Personal communication, March 2, 2005.

[131] Ibid.

[132] Timothy Bartle, Supervisor, Compost and Incineration, Bureau of Resource Recovery & Technical Programs Division of Solid and Hazardous Waste, NJ DEP. Personal communication, April 14, 2005.

[134] Ibid.

[135] Mixture of fly and bottom ash. Ibid.

[136] A few modern facilities handle ash in totally enclosed systems up to the point of transport for management [32].

## Table C. 4. Amounts of MSW incinerated annually and associated dioxins

| | Amount of waste (T/y) | Dioxins (g TEQ/y) In waste | Air emissions | Incinerator ash |
|---|---|---|---|---|
| Watershed | 2,029,890 | 41–142 | 0.9 | 33–131 |
| NY + NJ | 5,185,105 | 104–363 | 3.2 | 87–334 |

### Medical Waste Incinerators (MedWI)

Medical waste is any solid waste generated during the treatment, diagnosis, or immunization of humans or animals, or during research involving biological materials [82]. It is sometimes termed "hospital/medical/infectious waste." Historically, incineration of medical waste has been the treatment of choice because it reduces its volume and sterilizes infected materials. Medical waste typically contains ~55% paper, 10% water, and 30% plastics (mostly PVC) [168]. Medical waste contains much higher levels of PVC (5–15% by weight) and chlorine than other waste streams [26]. Therefore, chlorine reductions in this sector could possibly decrease dioxin emissions during incineration. PVC-free alternatives are available for many hospital products. For instance, soft products such as tubing, bags, and containers made of polyethylene or polyolefin plastics are available and contain no chlorine. Hard PVC applications can be replaced by metal, polypropylene, or polycarbonate plastics [168]. Several hospital suppliers offer chlorine-free products as well as other environmentally friendly products at competitive prices.[137] Two hospital organizations, Health Care without Harm (HCWH) and Hospitals for a Healthy Environment (H2E), have been actively working to eliminate incineration and to replace PVC in hospitals with nonchlorinated alternatives.[138]

Medical waste is divided into *red bag* waste and *clear bag* waste. Red bag waste, also known as *regulated* medical waste (RMW), includes biological and potentially pathological materials and should not be confused with hazardous waste.[139] RMW has to be sterilized or burned in medical waste incinerators.[140] The amount of RMW can be minimized by sorting. Clear bag waste—also termed *black bag* waste, *nonregulated* medical waste, or *municipal* waste—includes nonpathological materials and contains high amounts of PVC plastics, a source of chlorine. This waste is often incinerated, typically in municipal solid waste incinerators.[141]

The medical waste incineration sector had been poorly characterized until the early 1990s, when state regulatory agencies began setting emission limits. At that time, most facilities lacked APCDs. Later on, because of regulations, dioxin emissions from MedWIs sharply declined: incinerators had to implement measures to reduce emissions, including the installation of APCDs. Compliance costs forced many facilities to cease operations and provided an incentive to reduce the amount of RMW by better sorting at medical institutions.

### Local emissions

In New York, there are approximately 18,000 facilities generating ~200,000 tons of RMW/year and at least 30 commercial storage, treatment, and destruction facilities; more facilities are being added [206]. Currently, there are no operating RMW incinerators in NY.[142] The last one, operating in Suffolk County, shut down recently [326]. Medical waste generated in NY is either autoclaved in state or sent out of state, where it may be treated or incinerated.[143]

In New Jersey, 89,000 T of medical waste are generated each year. More than 30 facilities produce and treat their own regulated medical waste (RMW) by different methods (including incineration, autoclaving, chemical treatment, and other alternatives) and

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[137] Janet Brown, Partner Coordinator, Hospitals for a Healthy Environment. Personal communication, March 7, 2005.

[138] HCWH is an international coalition of hospitals and health care systems, medical professionals, and community groups that works towards ensuring that the medical profession does not pose harm to health or the environment. H2E is a joint project of the American Health Association (AHA), the U.S. EPA, HCWH, and the American Nurses Association to educate health professionals about pollution prevention options. A wealth of information and resources is available at http://www.h2e-online.org/ and *http://www.noharm.org/*.

[139] Hazardous wastes are those that pose a chemical, not a biological, hazard.

[140] Most medical waste incinerators in the US are modular furnaces using controlled air [305]. This type of incinerator consists of two combustion chambers in series. The primary combustion chamber operates at low oxygen concentrations (starved air) and relatively low temperatures. Destruction is completed in the secondary chamber, where temperatures are kept at ~1,000°C by burning additional fuel and there is excess oxygen.

[141] Note that clear bag waste has a greater proportion of PVC. NY sends clear bag waste to NJ. Janet Brown, Partner Coordinator, Hospitals for a Healthy Environment (H2E). Personal communication, February 15, 2005.

[142] Thomas Gentile, Chief, Air Toxics Section, Division of Air Resources, NYS DEC. Personal communication, May 24, 2005.

[143] Alan Woodard, Regulated Medical Waste Program, NYS DEC. Personal communication, July 20, 2006.

accept small amounts of waste from other NJ generators. This accounts for a portion of the total RMW generated in NJ. Facilities that generate RMW but do not have treatment capabilities typically send it out of state [189].

All of the five incinerators authorized to burn regulated medical waste in NJ are located within the Harbor Watershed [187].[144] These facilities have a combined capacity of ~3,000 T/yr (Table C. 5).[145] However, three of the incinerators burn other types of waste as well. Air emissions from these incinerators were estimated using EFs based on stack measurements at typical US medical waste incinerators (as summarized in [334]) and EFs developed by UNEP [350], which tend to be larger.[146] At the time of publication, stack tests for local MedWIs were not available.[147] Table C. 5 provides a summary of the estimated air emissions and dioxins contained in fly and bottom ash combined. It is possible that emissions for some of the facilities are overestimated because EFs are for facilities burning medical waste only. Fly ash is sent to hazardous wastes landfills (mostly to Model City, NY), while bottom ash goes to regular landfills, mostly outside of the Watershed.[148]

Three of the medical waste incinerators in the region have wet scrubbers. However, dioxin levels in these effluents from medical waste incinerators were not available. The relevance of this source should be investigated because these wastes will be discharged into on-site or publicly owned water treatment plants [32] and eventually into water bodies.

### Hazardous Waste Incinerators (HWIs)

Hazardous wastes are defined as wastes that contain significant amounts of hazardous substances, including pesticides, halogenated organic compounds, and pharmaceuticals; solvents, paints, and dyes; batteries; fuels, oils, and lubricants; and heavy metals.[149]

Some incinerators are dedicated to combusting hazardous wastes, often located at chemical plants producing the wastes. Industrial boilers and furnaces that burn coal or oil to generate electricity are allowed

## Table C. 5. Medical waste incinerators in NJ and dioxin emissions in TEQs by facility

| | | | | EPA - Air | | UNEP - Air | | Residues‡ | |
|---|---|---|---|---|---|---|---|---|---|
| **State** | **County** | **APCD†** | **Capacity (T/yr)** | **EF (µg/T)** | **Emission (g/yr)** | **EF (µg/T)** | **Emission (g/yr)** | **EF (µg/T)** | **Emission (g/yr)** |
| NJ | Mercer | FF/WS | 708 | 72.2 | 0.05 | 525 | 0.4 | 920 | 0.65 |
| NJ | Passaic | SNCR/WS/ESP | 725 | 72.2 | 0.05 | 525 | 0.4 | 920 | 0.67 |
| NJ | Somerset | None* | 454 | 1,770 | 0.80 | 3,000 | 1.4 | 20 | 0.01 |
| NJ | Union | DS/dust collector# | 454 | 1,770 | 0.80 | 3,000 | 1.4 | 20 | 0.01 |
| NJ | Union | WS/FF | 725 | 72.2 | 0.05 | 525 | 0.4 | 920 | 0.67 |
| **Total** | | | **3,065** | | **1.8** | | **3.9** | | **2.00** |

Sources: Capacity, NJ DEP [187]. EFs: EPA [334] and UNEP toolkit [350].Type of APCDs provided by David Olson, Air Quality Permitting Program, NJ DEP. Personal communication, April 28, 2005

* Confirmed by Shah Subash, Air Quality Regulation Program, NJ DEP. Personal communication, August 18, 2005.

# Information provided by Paul Romano, Permit Writer, NJ DEP. Personal communication, August 16, 2005.

† For acronyms, please see captions for Table C. 2.

‡ Fly and bottom ash. For incinerators with no APCDs, this refers only to bottom ash (fly ash is captured by APCDs).

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144. This reference listed six MedWIs. However, one of them, located in Middlesex County, is no longer in operation. David Olson, Air Quality Permitting Program, NJ DEP. Personal communication, April 28, 2005.
145. This represents ~3% of the RMW generated in the state.
146. The following EFs for air emissions are suggested: 3,000 µg TEQ/T of medical waste incinerated when no or minimal APCDs are present; 525 µg TEQ/T for incinerators that have good APCDs such as ESP or baghouses; and 1 µg TEQ/T for "state of the art" facilities, described as highly sophisticated plants where emission limits of 0.1 ng TEQ/Nm$^3$ are strictly enforced. UNEP states that this type of facility can be found in Europe and occasionally in North America. NJ incinerators fall in either of the first two categories.
147. Only the two incinerators in Union County are required to test for dioxin emissions. The rest are not required to either because of size or because medical waste constitutes a small fraction of the waste burned at the facilities. Personal communication with NJ DEP staff, August 2005 and John Jenks, Bureau Chief, NJ DEP Bureau of Technical Services.
148. In 2004, NJ MedWIs produced ~160 T of ash. Only ~4 T (~0.05 g TEQ, assuming a uniform distribution of dioxins in ashes) were landfilled in NJ, within the Watershed, while the rest was sent out of state. Data provided by Tim Bartle, Supervisor, Compost and Incineration, Bureau of Resource Recovery & Technical Programs Division of Solid and Hazardous Waste, NJ DEP. Personal communication, April 14, 2005.
149. Any material contaminated with hazardous substances must also be considered a hazardous waste. As noted above, medical waste is classified separately and is subject to different regulations.

to use no more than 5% of hazardous wastes as a supplemental fuel.[150] Some cement kilns or light-weight aggregate kilns also use hazardous wastes as supplemental fuel.[151]

Some of the most common APCDs for hazardous waste incinerators include:

- Wet scrubbers, which trap acids and particulates. Because they operate at lower temperatures than dry systems, they may reduce the amount of postcombustion dioxin and furan formation. On the other hand, wet scrubbers are less efficient than dry systems at trapping fine particulates, although they are better at controlling acids.
- Fabric filters (FFs).
- Electrostatic precipitators (ESPs).
- FF and ESP can be used in combination with a dry or wet scrubber to control acids.

### Local Emissions

There are at 10 incinerators burning hazardous waste in New York and New Jersey, five of which are located within the Watershed (Table C. 6) [313].[152] No data were available regarding the volume of hazardous waste burned at each individual facility in NY, but aggregate data indicate that approximately 106,000 T of nonaqueous hazardous waste were incinerated in 2001 [318].[153] In NJ, ~10,200 T were incinerated in 2001, including ~200 in the facility within the Watershed.[154]

Emissions to air from HWIs were calculated in two ways: (1) applying emission factors (EFs) to the amounts of hazardous waste incinerated in each NJ facility and the aggregate amount for NY State; (2) from stack test measurements, assuming that average stack flows during the tests are representative of normal operations and that incinerators operate 24/7. Stack tests and releases reported to TRI for each facility are presented in Table C. 6. All emission estimates, as well as amounts of dioxins in ash, are summarized in Table C. 7. Details on ash management are not available for all incinerators. Some of the ash is landfilled as hazardous waste, some is processed for metal recovery, and a portion is "beneficially" used as raw material for cement manufacturing, thermal insulation, sound adsorption, or fire-resistant products.[155]

UNEP emission factors (EFs) span a wide range of technologies and controls; hence the wide range shown in Table C. 7.[156] U.S. EPA's EFs are averaged across different incinerator technologies [334]. Stack test data are available for all the facilities from compliance tests performed between 1990 and 2001. Conditions during test may not reflect everyday operation (see section on accidental industrial emissions). However, all EFs are ultimately derived from actual measurements. Therefore, facility-specific stack tests should be more representative of actual conditions. These emissions are higher than estimates using EPA's EFs and lie within the wide range given by UNEP EFs. Four of the facilities have reported TRI releases to air in 2004 that are much lower than those measured during emission tests (Table C. 6).[157]

Most of the local hazardous waste incinerators (HWIs) are expected to generate liquid effluents that may be treated onsite or at municipal water treatment plants and are highly likely to reach the Harbor. Although there is very little information on aqueous effluents, most dioxins from HWIs are expected to be released to air or associated with ash [350].

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[150] Federal Register (1991c) F.R. (February 21) 56:7134.

[151] Four types of incinerators are used for hazardous wastes, all of which *can have* APCDs: (1) The rotary kiln is the most common incinerator used by commercial operations, since it can handle liquid, semisolid, and solid wastes. Following the kiln, an afterburner achieves complete destruction of the waste. (2) Liquid injection incinerators have a combustion chamber with one or two burners. (3) Fixed hearth incinerators burn the wastes under starved-air conditions. Combustion is completed in a secondary chamber, where oxygen is injected and which is kept at high temperature by burning additional fuel. (4) Fluidized bed incinerators are similar to those used for MSW. In the combustion chamber, the wastes are suspended, together with sand (the "bed") because of turbulent mixing by hot gases.

[152] We obtained additional information on the status of the facilities through personal communications with Michael Gerchman (NJ DEP, Div of Solid & Hazardous Waste) and Sev Chetty (NYS DEC, Division of Solid & Hazardous Waste Materials). Several of the incinerators in NY are no longer operating.

[153] Approximately 840,000 T of nonaqueous hazardous wastes were generated in NY in 2000. Some of the waste was exported, but NY is a net importer, with ~940,000 tons of hazardous wastes managed in state in 2000. Most of it (56%) was landfilled, 17% was recycled, 13% was treated, 10% was incinerated, and 3% was stored [211].

[154] Data provided by Michael Gerchman, Supervisor, Hazardous Waste Facilities, Bureau of Hazardous Wastes and Transfer Facilities, Division of Solid & Hazardous Waste, NJ DEP. Personal communication, June 9, 2005.

[155] Data provided by Sev Chetty, NYS DEC, Div. of Solid & Hazardous Waste Materials. Personal communication, September 14, 2005.

[156] UNEP divides HWIs into four categories depending on the APCDs, with air EFs ranging from 0.75 µg TEQ/T for state-of-the-art incinerators to 35,000 µg TEQ/T for incinerators with no APCDs [350]. Yet, the categories are not well defined, and we cannot assign specific EFs to incinerators in NY and NJ based on their APCDs.

[157] The TEQ amounts were calculated using the congener distribution provided by the facility.

## Table C. 6. Facility-specific dioxin emissions for hazardous waste incinerators in NY and NJ

| State | County | Combustor type | APCDs† | Air emissions (g TEQ/yr) |  |
|---|---|---|---|---|---|
|  |  |  |  | Stack tests§ | TRI (2004)¶ |
| NY | Albany | Lightweight aggregate kiln | HE/MC/FF/VS/ME | 0.34 | 0.0001 |
| NY | Albany | Lightweight aggregate kiln | MC/HE/FF/VS/DM | 0.34 |  |
| NY | Saratoga | Incinerator | QC/PCS/IWS | <0.01 |  |
| NY | Saratoga | Incinerator | QC/PTWS/IWS | 0.01 | 0.002 |
| NJ | Hudson | Incinerator | WS/QT | <0.01 |  |
| **Total Watershed** |  |  |  | **0.7** |  |
| NY | Monroe | Multiple hearth | Q/PBS/VS/WESP | 0.01 | 0.2 |
| NY | Monroe | Kiln | Q/VS | 0.34 |  |
| NY | Niagara | Incinerator | QC/ABS/IWS | <0.01 | 0.00002 |
| NJ | Gloucester | Incinerator | QT/VS/PT/DM | <0.01 |  |
| NJ | Gloucester | Incinerator | None‡ | <0.01 |  |
| **Total NY & NJ** |  |  |  | **1** |  |

Sources: U.S. EPA [313], Michael Gerchman, Supervisor, Hazardous Waste Facilities, Bureau of Hazardous Wastes and Transfer Facilities, Division of Solid & Hazardous Waste, NJ DEP, personal communications in February and July, 2005. Thomas Gentile, NYS DEC. Personal communication, May 24, 2005.

† QC: quench chamber; PCS: packed column scrubber; IWS: two-stage ionizing wet scrubber; HE: heat exchanger; MC: multiclone; FF: fabric filter; VS: venturi scrubber; ME: mist eliminator; Q: quench; PBS: packed bed scrubber/absorber; WESP: wet electrostatic precipitator; ABS: absorber/condenser, quench; PT: packed tower; DM: demister.

‡ This incinerator burns aqueous hazardous waste (containing amines) and meets emission requirement without an APCD. There is no specific requirement for hazardous waste incinerators to install APCDs as long as they meet emission limits. Michael Gerchman, Supervisor, Hazardous Waste Facilities, Bureau of Hazardous Wastes and Transfer Facilities, Division of Solid & Hazardous Waste,NJ DEP. Personal communication, July 11, 2005.

§ Data from stack tests reported to EPA [318]. For NJ: stack tests provided by Michael Gerchman.

¶ TRI releases in TEQs were calculated using the congener distribution provided by each facility.

## Table C. 7. Dioxin emissions from hazardous waste incinerators

|  | Hazardous waste incinerated in 2001 (T/yr) | Air emissions (g TEQ/yr) |  |  | Dioxins in ash (g TEQ/yr) |
|---|---|---|---|---|---|
|  |  | EPA† | UNEP† | Stack tests¶ | UNEP‡ |
| NY | 105,532 | 0.22 | 0.08–37 | 1 | 3–95 |
| NJ | 10,241 | 0.02 | 0.01–4 | <0.01 | 0.3–9 |
| **Total** | **115,773** | **0.25** | **0.1–41** | **1** | **3–104** |
| **Watershed*** | **60,492** | **0.13** | **0.05–21** | **0.7** | **2–54** |

Sources: NY: [313]; NJ: Michael Gerchman, Supervisor, Hazardous Waste Facilities, Bureau of Hazardous Wastes and Transfer Facilities, Division of Solid & Hazardous Waste,NJ DEP. Personal communication, July 11, 2005.

† EFs: 2.13 and 30–900 µg TEQ/T of hazardous waste burned for EPA and UNEP, respectively.

¶ Data from stack tests reported to EPA [318] and provided by Michael Gerchman (for NJ).

‡ EF: 0.75–350 µg TEQ/T of hazardous waste burned [350].

* NJ: 188 T incinerated within the watershed; NY: assumed activity level and emissions are proportional to the number of incinerators in the Watershed.

### Sewage Sludge Incinerators (SSIs)

As of 1995, there were about 170 SSIs in the US. Most municipal SSIs burn sludge exclusively. Different combustion technologies are available: about 80% of incinerators are multiple hearth, 15% are fluidized bed, and 3% electric infrared. The remaining 2% are cofired with municipal solid waste.[158]

Currently, there are 15 facilities in NY and 9 in NJ permitted to incinerate sewage sludge, with 14 located within the Watershed. Table C. 8 shows only those incinerators currently in operation. A total of ~48,000 dry T of sewage sludge are incinerated per year in the Watershed.

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[158] U.S. EPA, Solid Waste Disposal, January 1995.

Sewage sludge incinerators in the US are not required to monitor for dioxins.[159] Dioxin emissions to air from these incinerators vary widely, depending on the kind of APCDs in place, with EFs (developed by UNEP) ranging from 0.4 $\mu$g TEQ/T sludge burned for state-of the art incinerators to 50 $\mu$g TEQ/T for old incinerators with no pollution control. Limited information was available on the APCDs in place in local facilities,[160] but similar types of incinerators would be expected to have similar devices.[161] For incinerators equipped with some sort of wet scrubber (e.g., a venturi scrubber), with or without an electrostatic precipitator (ESP), we applied an EF of 4 $\mu$g TEQ/T, which corresponds to "updated incinerators with some pollution control" [350]. For all other incinerators, the range of UNEP EFs was applied. Estimates are presented in Table C. 8. Note that even under the worst-case scenario, emissions to air are relatively low.

There is limited information about dioxins in ash from SSIs. According to EFs suggested by UNEP, ash from sewage sludge incinerators contains a rather low amount of dioxins. Waste water from sewage sludge

## Table C. 8. Dioxin emissions by faciity from sewage sludge incinerators in NY and NJ

| State | County | Incinerator | APCDs | Sludge burned (Dry T/yr) | Emissions (g TEQ/yr) | |
|---|---|---|---|---|---|---|
| | | | | | **Air** | **Residues** |
| NY | Albany | MH | ND (no data) | 5,523 | 0.002–0.28 | 0.003–0.13 |
| NY | Albany | MH | ND | 2,995 | 0.001–0.15 | 0.001–0.07 |
| NY | Dutchess | FB | VS/IP | 658 | 0.0026 | 0.0003 |
| NY | Warren | FB | ND | 2,286 | 0.001–0.11 | 0.001–0.05 |
| NY | Herkimer | FB | ND | 694 | <0.001–0.03 | <0.001–0.02 |
| NY | Oneida | FB | VS/IT | 6,227 | 0.0249 | 0.0031 |
| NY | Saratoga | FB | ND | 3,543 | 0.001–0.18 | 0.002–0.08 |
| NJ | Monmouth | FB | TS/VS/WESP | 1,897 | 0.0076 | 0.0009 |
| NJ | Bergen | FB | VS/IT | 2,358 | 0.0094 | 0.0012 |
| NJ | Morris | MH | ND | 4,780 | 0.002–0.24 | 0.002–0.11 |
| NJ | Somerset | FB | VS/TS/WESP | 4,320 | 0.0173 | 0.0022 |
| NJ | Mercer | MH | ND | 7,634 | 0.003–0.38 | 0.004–0.18 |
| NJ | Morris | FB | VS/TC/WESP | 3,869 | 0.0155 | 0.0019 |
| NJ | Passaic | MH | VS/cooler/WESP | 1,314 | 0.0053 | 0.0007 |
| **Total Watershed** | | | | **48,097** | **0.09–1.5** | **0.02–0.6** |
| NY | Cayuga | MH | ND | 2,986 | 0.001–0.15 | 0.001–0.07 |
| NY | Erie | MH | ND | 13,546 | 0.005–0.68 | 0.007–0.31 |
| NY | Erie | FB | ND | 3,086 | 0.001–0.15 | 0.002–0.07 |
| NY | Nassau | FB | VS/ITS | 600 | 0.0024 | 0.0003 |
| NY | Monroe | MH | WS | 21,769 | 0.0871 | 0.0109 |
| NY | Suffolk | MH | ND | 1,998 | 0.001–0.10 | 0.001–0.05 |
| NY | Erie | MH | VS | 2,134 | 0.0085 | 0.0011 |
| NY | Jefferson | FB | VIS/TI | 1,457 | 0.0058 | 0.0007 |
| NJ | Atlantic | MH | AB/VTV/TS | 12,746 | 0.0510 | 0.0064 |
| NJ | Gloucester | FB | VS/TS | 13,291 | 0.0532 | 0.0066 |
| **Total outside Watershed** | | | | **73,613** | **0.2–1.3** | **0.04–0.5** |
| **Total NY + NJ** | | | | **121,710** | **0.3–2.7** | **0.06–1.2** |

List of active SSI, APCDs and activity level provided by Alia Roufaeal, Division of Enforcement and Compliance Assistance, EPA Region 2. Personal communication, August 18, 2004.

MH: multiple hearth; FB: fluidized bed; ND: no data; VS: Venturi scrubber; TS: tray scrubber; WESP: wet electrostatic precipitator.

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[159] As established under Part 503, Federal Sewage Sludge Regulations.

[160] Information was obtained from comprehensive reports submitted to U.S. EPA Region 2, Division of Enforcement and Compliance Assistance, Air Compliance Branch. Four of these reports measured dioxins in stack gases. However, we did not use this data because they were not reported in a useful format (e.g., only one congener was measured, or only total emissions were provided). In any case, these data would not have made an appreciable difference in air emissions. Access to these reports was facilitated by Dan Ciobanu, Air Compliance, U.S. EPA Region 2.

[161] Dan Ciobanu, Air Compliance, U.S. EPA Region 2. Personal communication, April 6, 2005.

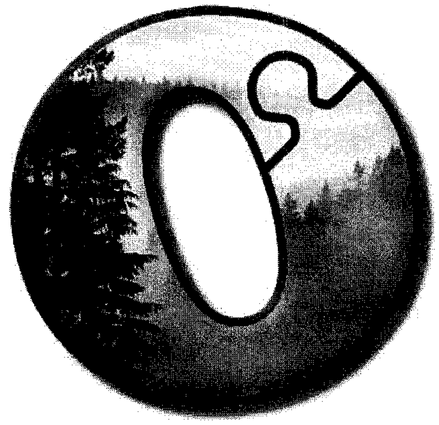
incineration is often reintroduced to the system, so no releases are expected [350].

### Measures to Prevent or Reduce Dioxin Emissions from Incinerators

Dioxin emissions from any type of incinerator can be minimized in a number of ways:

1. From a pollution prevention perspective, the best option to curb dioxin (and other) emissions is to **reduce the volume of waste**. Decreasing the feedstock volume at incinerators can reduce associated emissions. Many organizations are working towards the goal of reducing the MSW stream, and some (e.g., the New York City Zero-Waste Coalition)[162] have proposed the zero waste approach as a philosophy and a design principle for the 21st century. Several communities and countries have adopted zero waste goals, including New Zealand (the only country so far) and the state of California.[163] This "whole system" approach examines the flow of resources and waste through society in order to identify opportunities for waste elimination. Zero waste maximizes recycling, minimizes waste, reduces consumption, and ensures that products are made to be reused, repaired, or recycled back into nature or the marketplace. In this way, a zero waste approach preserves resources, saves energy and water and reduces pollution, including greenhouse gases. The main recommendations leading to waste stream reductions [168] as well as zero waste are:

**Zero Waste Symbol**



   a. Design for the environment (DfE).[164] Using this approach, an industry may evaluate the use of resources at the preproduction stage, considering disposal options and their life-cycle costs and impacts. Thus it may design products that can be disassembled and their component parts reused.
   b. Emphasize pollution prevention and source reduction efforts. Support and create programs accordingly. For instance:
      i. Educate the public about purchasing options and waste management practices that reduce waste generation from production to disposal as well as about programs that offer alternatives to disposal (e.g., product exchange networks).
      ii. Outreach to institutions, companies, and organizations to promote purchasing policies and waste management practices that reduce waste at all stages of the product life cycle.
   c. Reduce, reuse, recycle, including mandatory recycling programs, take back programs, pay-as-you-throw (PAYT); encourage composting and other programs that divert recyclables items from the waste stream.
2. **Optimize combustion conditions** (adequate temperature, amount of oxygen, and residence time) to ensure complete destruction of any dioxins already present in the incinerator feed. This can be achieved by maintaining very high temperatures, prescribed residence times, and an adequate amount of oxygen [152].[165] However, conditions have to be optimized to maximize combustion and minimize metal volatilization [32].[166]

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[162] This coalition has published a plan to attain the goal of zero waste by 2024: "Reaching for Zero: The Citizens Plan for Zero Waste in New York City" [49].

[163] Barbara Warren, Consumers Union. Personal communication, January 8, 2006.

[164] DfE "is the systematic integration of environmental considerations into product and process design" (Environment Canada. http://dfe-sce.nrc-cnrc.gc.ca/home_e.html Accessed on June 1, 2006). This approach takes into account the environmental effects of products (throughout their life cycle) and processes, evaluates alternative materials or technologies, and promotes those that minimize negative environmental impacts.

[165] For example, >1 second at 1,000 °C, or >2 seconds at 850 °C, with 3–6% excess oxygen (by volume).

[166] Most of the mercury in waste will vaporize, and adequate pollution control is needed to reduce emissions (ideally, mercury should not be disposed as MSW). Volatilization of other metals such as lead and cadmium is more dependent on the chemical form and the temperature. These metals will end up in fly ash as they recondense and adsorb to fine particles in the cooler postcombustion area [32]. APCDs can be used to minimize fly ash emissions.

3. **Operator training:** Operators play a key role in ensuring proper incinerator functioning, monitoring, and maintenance and should be properly trained. Certification procedures should be considered [32].
4. **Rapidly cool down combustion gases:** The cooldown process should be controlled to prevent dioxin generation during postcombustion. Temperatures between 300 and 500°C, with a peak at ~400°C, are optimal for the generation of dioxins. These temperatures are common in the postcombustion area and in air pollution control devices (APCDs). Rapidly cooling gases exiting the combustion chamber and minimizing the time spent between 300 and 500°C reduces dioxin emissions.
5. **Install air pollution control devices:** Some amount of dioxin formation is unavoidable, but releases can be minimized by fitting the incinerators with proper APCDs to trap all the particles where dioxins are adsorbed.[167]
6. **Minimize starts and stops**: "Upset emissions" are those emissions released during start-up, shut-down and malfunctions. These emissions can be substantially higher than those measured during normal testing (see section on Accidental Emissions). To minimize dioxin levels, the following recommendations can be adopted:
   a. Minimize starts and stops.
   b. Have all pollution control devices running during start-up and shut down.
   c. Optimize general operating conditions, including using auxiliary burners to maintain adequate temperatures [32].
   d. Collect and properly treat ashes from APCDs during the start-up period (e.g., by re-introducing them into the combustion chamber) [166].
7. **Continuous Monitoring:** Tests should be conducted over long periods of operation to capture variations during the typical cycles of incinerator operations, in order to:
   a. Characterize dioxin emissions during shutdown, start-up, and other upsets. Consider variations in waste composition (e.g., varying heating values) and winter and summer conditions [32].
   b. Encourage the development and adoption of continuous emission monitoring technologies [32].[168]
8. Assure that federal requirements for dioxin emissions controls are fully implemented and enforced.
9. Support efforts aimed at keeping chlorine out of the waste stream, including environmentally preferred purchases (EPP).

**Specific measures to prevent or reduce dioxins emission from Municipal Solid Waste Incinerators:**

- Evaluate the pros and cons of MSW incineration vs. landfilling (see Box 3).

**Specific measures to prevent or reduce dioxins emission from Medical Waste Incinerators:**

1. Source reduction of chlorine-containing products and materials that enter the medical waste stream by promoting the use of PVC alternatives
2. Waste separation, to ensure that only "red bag" or regulated medical waste (RMW) is incinerated, while materials from "clear bag waste," such as paper products, glass, metals, and plastics are recycled. Waste segregation results in cost savings because disposal of regulated waste is more expensive.
3. Consider alternatives to incineration for infected material to minimize dioxin production. Medical waste can be sterilized, shredded, and disposed of as municipal solid waste.[169] Alternative treatments include microwave shredders, chemical shredders (sterilization by chemical agents), and autoclaving and shredding.[170] All of these technologies are approved by NJ DEP. In NY, several treatment options can be used after approval by NYS DOH. Autoclaving followed by landfilling is less expensive than implementing stricter APCDs in

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[167] The EPA concluded that a spray drier and fabric filter (SD/FF) combined with good combustion practices and carbon injection is the best option to reduce dioxin (and mercury) emissions and was the basis for the MACT regulation [81].

[168] There are systems that allow for repeated sampling and dioxin analysis over periods of up to a month.

[169] NJ DEP Medical waste hotline. February 23, 2005.

[170] NJ DEP Medical waste hotline. February 23, 2005.

## BOX 3. ADVANTAGES AND DISADVANTAGES OF MUNICIPAL SOLID WASTE INCINERATORS (MSWI)*

**Positive aspects include:**

- Large MSWIs (i.e., WTE) use the fuel value in the incinerated waste to generate electricity
- Incineration reduces the volume of material that must be landfilled by about two thirds
- Required emissions controls in large, modern incinerators substantially reduce the amount of air pollution that is generated during the waste combustion process

**Negative aspects of these facilities include:**

- MSWIs generate multiple air pollutants that are emitted and spread over a large geographic area. Pollution is transferred to downwind communities that may or may not derive a benefit from the facility generating the pollution.
- Although incineration substantially reduces the volume, the weight of material that must be disposed of is typically reduced by less than 65%, and landfills are still necessary to dispose of the ash and associated toxic contaminants. As a result, two solid waste facilities (MSWI and landfill) require siting, operating and monitoring, rather than just one.
- Other means of electricity generation could be more efficient and environmentally friendly, and could perhaps reduce the economic viability for power producers such as MSWIs.

* Summarized from [168]

incinerators [36]. Other alternative sterilization methods are available (plasma arc, gamma radiation) but can be more expensive [36,168]. However, every alternative has its downside. For instance, autoclaving may release steam with toxic chemicals that are present in the material being sterilized, such as formaldehyde.

### Specific measures to prevent or reduce dioxins emission from HWI:

Although HWI may not be a significant atmospheric source within the Watershed, some recommendations are put forward.

1. Reduce the volume of hazardous waste generated, including:
    - DfE, with a focus on minimizing the use and generation of hazardous materials
        - Require that industrial sources complete a pollution prevention analysis to determine whether any hazardous waste streams can be reduced or eliminated or whether less toxic materials can be used in their processes.[171]
    - Promote purchasing policies that favor environmentally preferred products. Such products (e.g., cleaning agents, office supplies) are ranked according to their whole life cycle impacts (during their production, use, and disposal).[172]

### Specific measures to prevent or reduce dioxins emissions from SSI:

These are available at different stages throughout its life cycle: from primary sources discharging to water pollu-

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[171] RCRA (40 CFR 262.27) requires HW generators to attest that either they are conducting or already have a waste minimization plan in place (http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=85503a1ce5a5af56d214cd0dbf81f40a&rgn=div6&view=text&node=40:25.0.1.1.3.2&idno=40). Storage/ treatment/disposal facilities must certify that they have a waste minimization plan to reduce the amount and toxicity of waste they generate (40 CFR 264.73).

[172] The Commission for Environmental Cooperation (CEC), through its North American Green Purchasing Initiative, has developed an online Ecological Self-Assessment Tool, "Eco-SAT" *(http://www.cec.org/eco-sat)*. The website provides a best-practices guide that serves as an educational tool, and a questionnaire to score and compare the green purchasing initiatives of a company or organization. This questionnaire is designed to help professional buyers evaluate and improve their organization's purchasing initiatives. The City of San Francisco has signed legislation to phase out the use of toxic products by the city government [276]. The measure includes cleaning products, pesticides, and treated wood, and promotes environmentally friendly alternatives. The governor of New Jersey recently signed an executive order requiring state agencies to use only nonhazardous cleaning products [253].

tion control facilities (WPCFs) to sludge management and disposal. Options to reduce releases to water from WPCFs, where sewage sludge is produced, are discussed in Section C.2 (Industrial Processes and Products). In this section we discuss measures to reduce emissions during disposal management, specifically at incinerators. When sewage sludge is managed through incineration, the application of APCD controls at the incinerating facilities will minimize releases of pollutants. However, sewage sludge incinerators are not required to monitor for dioxins under Part 503, Federal Sewage Sludge Regulations [84]. Some states (e.g., New Hampshire) have chosen to periodically monitor dioxin air emissions from sewage sludge incinerators. One possible recommendation at the regional level may be considered:

- Current monitoring programs could be expanded to include dioxins.

## C.1.b. Uncontrolled Burning

Uncontrolled burning refers to accidental or intentional fires initiated by humans or due to natural events where materials are burned without controls—in the open such as in agricultural fields, in barrels, or in other uncontrolled combustion devices—as opposed to burning in incinerators specially designed to optimize combustion and minimize emissions. Some examples include wildfires (which could be set by lightning or human activity), prescribed fires, garbage burning, and structural fires. Uncontrolled burning is of concern because low combustion temperatures, poor turbulence (i.e., mixing of combusted waste with air), and lack of air pollution control devices result in incomplete combustion and contaminant generation. As a result, many toxics are released to air and remain in ashes and residues, including dioxins, PAHs, PCBs, particulate matter, sulfur dioxide, and metals.

In the following sections, dioxin emissions are estimated for major uncontrolled combustion sources in the Harbor Watershed:

- Open burning of waste in rural communities;
- Structural and vehicle fires;
- Waste management–related fires.

The following minor uncontrolled combustion sources are developed in Appendix C:

- Wild fires and prescribed fires;
- Tire fires.

### Open Burning of Waste in Rural Communities

#### 1. Open burning of residential waste

Open burning of residential waste is the practice of disposing of household garbage by burning it, commonly in a barrel; thus this activity is also termed "barrel burning" or "backyard burning."

This practice is prevalent in rural areas where:

- Waste collection services are not readily available;
- People have to contract waste haulers themselves;
- There are few transfer stations, making it inconvenient for people who wish to take their own garbage and avoid hauling fees.

Nationwide, industrial sources of dioxins have declined within the past 20 years because of emission controls. On the other hand, emissions from open burning have remained approximately the same and thus have become proportionally the largest source of dioxins to air among those sectors quantified in the draft dioxin inventory for the US [334]. Figure C.1 shows estimated emissions to air from selected sources in the US and projected emissions for 2004 [334].

Combustion of household waste can release large quantities of dioxins, PAHs, polybrominated diphenyl ethers (PBDEs),[173] and several other pollutants[174] directly to air; and they also remain in residual ash that can be remobilized. Furthermore, there are no guarantees that people engaging in household waste burning will not also combust household hazardous waste, which can release even larger amounts of toxics. It is estimated that a single barrel burning household waste emits ~2,000 to 75,000 times as much dioxins to air as a modern municipal waste incinerator, per amount of waste burned [129]. The residual ashes are typically disposed of either by spreading or burying them in gardens and yards, dumping in creeks, or simply leaving them exposed to the elements, dispersed by the wind. Ashes in gardens can contaminate nearby surface waters.

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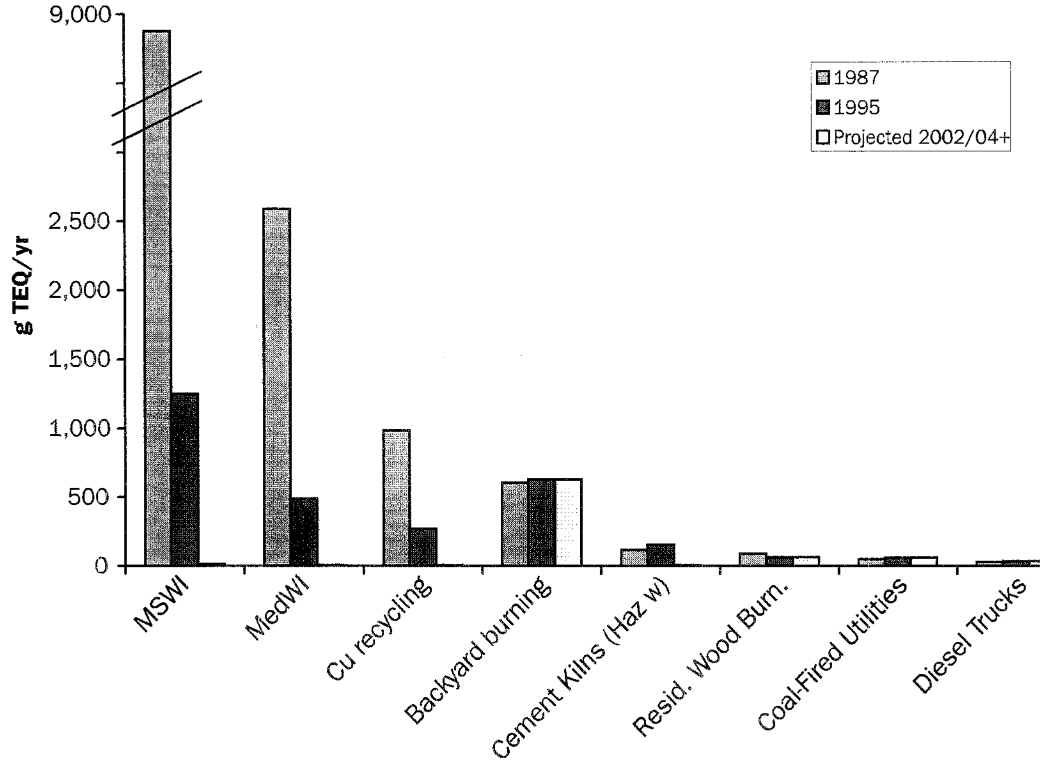
[173] For example, when combusting household items that contain foam materials such as sofas, mattresses, etc.

[174] Such as PCBs, particulate matter, sulfur dioxide, and metals.

## Figure C.1. Dioxin emissions to air in the US from selected sources



Source: Great Lakes Binational Toxics Strategy (GLBTS), 2002 [340].

Open burning can also result in accidental fires that release additional dioxins[175] and may be a significant source of dioxins to the food supply[176] because this activity is more prevalent in areas of animal and food production.[177] Agricultural production in NY State accounts for ~2% of national activity [283,284].

Waste likely to be burned in barrels and incinerators (after noncombustibles are separated) contains ~0.9% of PVC. During uncontrolled combustion of various wastes, a correlation between the amount of chlorine in the fuel (waste) and dioxin emissions is clear only when it contains more than 1% of chlorine [112,116]. However, a recent experiment found a statistically significant correlation between dioxin emissions and the amount of chlorine in the waste, even at fairly low levels, when all other variables were kept equal [105].[178] This study also identified other factors that significantly affect dioxin emissions, such as the presence of copper, moisture content, degree of compaction, and waste spatial orientation [105] (note that waste burned in this experiment contained ~1% copper by weight). Based on EFs measured by Gullet et al. [105], uncontrolled combustion of waste with no PVC would be expected to emit, on average 93% less dioxins than typical waste containing ~1% of PVC. Although perhaps not a common scenario, in certain occasions, waste containing >1% PVC might plausibly be burned (e.g., if people engaging in backyard burning discard large amounts of PVC such as toys or leftover building/home improvement materials). In addition, as discussed in the MSW incineration section, PVC in waste is likely to increase. Note that reducing PVC in waste would not render it safe to burn (chlorine is ubiquitous and dioxin generation would always occur) but could be another tool (together with efforts to eliminate open burning) to reduce dioxin emissions from this source.

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[175] In Minnesota, open burning is the leading cause of wildfires, accounting for ~38% of the fires. Arson causes 31% of wildfires, 30% are caused by other human activities, and only 1% are due to lightning. Dave Schuller, Firewise Communities Specialist, MN Department of Natural Resources. Open Burning and Firewise. Presentation at Open Garbage Burning: Preventable Pollution. A Workshop for Local Fire Officials. March 4, 2005. Duluth, MN.

[176] Reservoirs are likely another significant source.

[177] Dioxin Emissions and Trash Burning, presentation by Mark Mahony, Senior Policy Expert and Lead Region Coordinator for Enforcement—EPA New England. Forum on Open Burning. Public Health and Environmental Dangers Associated with Trash Burning. Held on Monday May 17, 2004. Old Dorm Lounge, Vermont Technical College. Organized by the Department of Environmental Conservation, and cosponsored by The American Lung Association of Vermont & The Vermont League of Cities and Towns. *http://www.anr.state.vt.us/air/htm/OpenBurnForumPresentations.htm. Accessed February 7,2005.*

[178] Waste containing none (0%), 0.2%, 1%, and 7% PVC by weight emitted, on average, 14, 79, 201, and 4,916 ng TEQ/kg, respectively. Waste with 7% calcium chloride released 734 ng TEQ/kg.

### Local Estimates

It is estimated that open burning of residential waste is the largest ongoing source of dioxins to air in our region, while even larger amounts remain associated with ashes (Table C. 9).[179] We have not included New Jersey in our estimates because we have not been able to confirm that open burning of household waste takes place in this state (see next subsection). For New York, the percentage of waste burned in rural areas is based on national and regional surveys.

### Current Regulatory Structure to Prevent Open Burning

In 1956, the State of New Jersey issued general control and prohibition rules for open burning, with certain exemptions and allowances.[181] For example, one- and two-family dwellings are exempted from the statewide ban[182] (~70% of homes in NJ are 1–2 family dwellings).[183] However, local and/or county regulations may apply to these households. It is estimated that only a few rural towns lack any type of rule regarding open burning.[184] The longstanding statewide ban and the number of local ordinances suggest that open burning activities in New Jersey may already have been minimized. However, since there is no available data, it is suggested here that the gap in the regulation should be closed.

Currently, New York State legislation[185] prohibits the burning of garbage in incorporated villages and cities; however, burning of municipal solid wastes generated on premises is currently permitted by State law in towns with total populations of less than 20,000.[186] There are ~1.3 million people within and 3.4 million people outside the Watershed living in towns with <20,000 habitants (not including towns known to prohibit open burning). This represents 4.7 million out of a total population of 18.7 million.[187] Nevertheless, and just as in New Jersey, rural towns and villages can impose their own restrictions.[188]

**Table C. 9. Dioxin emissions from open burning of residential waste in NY**

| | Rural population (million)* | Waste generated (million T/yr)** | Amount burned† | Emissions to Air‡ (g TEQ/yr) | Dioxins in Ash§ (g TEQ/yr) |
|---|---|---|---|---|---|
| NY-Watershed | 0.8 - 1.3 | 0.6 - 1.0 | 8 – 30% | 1-37 | 30-173 |
| NY-Total | 2.1 - 3.4 | 1.5 - 2.5 | 8 – 30% | 4-96 | 74-449 |

* Range given between rural population provided in US census 2000 and people in towns with <20,000 habitants. In both cases, populations of areas where open burning is not allowed (see footnote 188) were subtracted. For Putnam and Orange Counties, towns where we confirmed that garbage collection is provided by the town were also excluded.

** In 2000, on average, each person in the US generated 4.41 lb of waste per day. Excluding noncombustible items (metals and glass) and yard waste (mostly grass clippings and leaves, which are typically burned separately) results in ~3.28 lb/person/day (543 kg/person/yr). It was assumed that no recycling of plastics and paper takes place in households that practice open burning [324].

† Based on several US surveys summarized by the U.S. EPA [334].[180]

‡ EF: 79 µg TEQ/T ± standard deviation (Gullet et al., 2001 [105]), results in a range of 30–128 µg TEQ/T.

§ EF: 600 µg TEQ/T of waste burned (UNEP Toolkit [350]).

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[179] ~55% of the waste weight remains as ashes [304].

[180] Illinois: 40% of people burn 63% of waste (i.e. 25% of all waste); other polls indicated the % of people that admitted burning, but not the % of waste that they burned: Minnesota: 28%, Ontario: 24%, North East: 12%, California: 18%, St Lawrence Ct, NY: 48%, as summarized by U.S. EPA [334]. If in all cases 63% of the waste is burned, we obtain a range of roughly 8 to 30 %.

[181] NJAC 7-27-2 [179]. Prescribed burning (e.g., woody material or plant tissue) is allowed by permit when other options are not available or may cause harm to the environment. Burning of trash is never permitted. Garbage dumping is also illegal and each municipality has to contract a solid waste hauler to send municipal solid waste to approved licensed landfills. Heavy fines (~ $10,000) for open burning of residential waste have discouraged this activity. Other states banning open burning in the NE are CT, VT, MA, NH, and ME. Under certain restrictions, open burning is allowed in NY, as well as in PA and RI.

[182] NJ Air Pollution Control Act of 1954 *(http://www.state.nj.us/dep/rules/rules/njsa26_2c.html)*.

[183] Data from US Census 2000.

[184] We contacted several municipalities in NJ and they were all unaware of the exemptions in the state law. This is likely because the exemption is in the NJ Air Pollution Control Act of 1954, not under the regulation against open burning (NJAC 7-27-2). Our limited survey suggests that municipalities assume that no individual, including farmers, can burn waste under any condition, and would act consequently if were found to do so.

[185] 6 NYCRR Part 215 [210].

[186] Commercial operations are not allowed to burn. Farmers, however, are exempted from the prohibition. The following open burning activities are allowed with a permit: land clearing, burning of yard wastes in designated areas. Burning of toxic, explosive, or dangerous materials may be permitted if it is determined that there is no other safe or economical method of disposal [210].

[187] Data from US Census 2000.

[188] Currently, the following towns and counties have generally prohibited open burning of garbage (other burning activities such as plant tissue, or recreational fires may be allowed): Oneida and Herkimer Counties; town of Charlton, Saratoga [273]; Colonie, Albany [274]; Owasco, Cayuga[275]; Kortright, Delaware; and three towns in St. Lawrence County. Of 4 towns in Suffolk Ct with <20,000 people, two have bans and the other two require permits to burn (we assumed no burning). However, there is not a comprehensive inventory of towns and municipalities prohibiting open burning in NY. Debbie Jackson, NYS DEC,

Reducing or eliminating backyard burning was ranked as the top priority by the NYS DEC Comparative Risk Project [212], a study that evaluates the risks of toxic emissions in New York State. For over 10 years, efforts to move toward a statewide ban of open burning in NY [201] have consistently passed the State Assembly, but remain to be approved by the Senate, in part due to reluctance to place an additional burden on farmers. The NY Farm Bureau opposes the bill, mainly because of the additional cost that it would represent to farmers, as they will need to seek alternatives to waste disposal in a region with limited options.[189] In 2005, it was decided to exempt farmers from the proposed statewide ban, at least until better options are available to dispose of agricultural waste; however, the initiative still failed to obtain the State Senate approval.

### Key elements and constraints of open burning reduction efforts in rural areas

Surveys of residents in rural communities identify a few key reasons why they engage in open burning activities:

1. Waste collection service is unavailable or inconvenient in the area.
2. To avoid the costs of waste collection services and/or tipping fees.[190]
3. They have always done it.
4. To keep garbage out of the landfill.

Available research [290] and our own consultative process[191] have revealed that successful waste management plans are those that address the three pillars of open burning reduction efforts: regulatory/enforcement, education, and infrastructure. Several states or communities that have engaged in plans to reduce or eliminate open burning have used public education, developed alternatives for waste disposal (including recycling centers, collection systems, and transfer stations), and enforced current ordinances and/or have instituted new laws. Typically, all these elements have to be in place in order to eliminate open burning.

A case study of 23 rural communities describing their process to introduce waste management plans to curb open burning indicated that only one community continued to rely on a voluntary approach after a number of years [290] (a case study is provided at *http://www.nyas.org/programs/harbor.asp*). Nevertheless, some counties' experience suggests that sequencing is important and that regulations are not instituted overnight. A stepwise approach could be considered in rural communities where there is strong opposition to an open burning ban. From a regulatory perspective, the enforcement of current statewide laws that require recycling and proper hazardous waste disposal[192] coupled with an educational campaign may be first steps to disseminate information about the dangers of open burning of trash. Participants to our sector consultation process suggested that public officials and various local agencies (fire and sanitation departments, police force, park rangers, health officers) should be engaged and well informed about the need to prevent open burning of trash. Coordination at the local and state level was recommended. The federal government could also play a role— for example, by providing technical assistance. An example of this coordination is given by a recent joint resolution signed by New York and New Jersey as well as other Northeast states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont). These states have agreed to work together to reduce open burning of waste.[193]

The role of public education is significant in motivating rural residents to stop open burning of trash. Participants to our consultation process recommended that public outreach should always inform residents about the dangers of open burning (to their own health and/or safety due to accidental fires). Outreach materials should inform the public that the composition of

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Bureau of Solid Waste, Reduction & Recycling. Personal communication, March 22, 2006. The sanitary codes for Westchester and Rockland Counties prohibit open burning (Westchester County Sanitary Code, Article XIII, Air Quality, *http://www.westchestergov.com/health/Sanitary%20code.htm; Rockland County Sanitary Code, Article XII, Air Pollution Control, http://www.co.rockland.ny.us/health/code/sancode.htm).*

[189] Jeff Williams, Associate Director of Public Policy, Legislative Coordinator, NY Farm Bureau. Personal communication, October 12, 2005.

[190] Also waste hauling fee, it is the fee charged for unloading solid waste at a landfill, transfer station, or incinerator.

[191] The Harbor Project has organized a consultative "sector" process, including a meeting on October 26, 2005, which included various representatives of federal, state and local agencies, other parties working on reducing open burning, as well as those that oppose a ban on open burning activities.

[192] Households in rural communities (except farms) are not exempt from statewide recycling regulations and hazardous materials disposal. It is estimated that a good proportion of the open burning activities take place in rural households and that recyclable materials are not separated but rather are combusted with other household solid waste. Debbie Jackson, NYS DEC, Bureau of Solid Waste, Reduction & Recycling.

[193] This resolution originated in the shared concern about dioxins and other pollutants being released during open burning and it is aimed at facilitating collaboration among the states. The general goals are to estimate the magnitude of the problem, educate the public, support and strengthen open burning bans and their enforcement, and provide waste management options. The states are currently working on the development of public service announcements (PSAs) to educate about open burning. Vermont had developed PSAs for radio and television, which can be modified to be more state-specific.

waste has changed over the years and that it is more dangerous to burn trash today than it was decades ago. It can also include information on what materials should never be burned[194] and how to minimize the generation of household garbage by purchasing products with less packaging, reusing items, composting, recycling, and source separation. Finally, the public should be informed about available services, such as collection days for household hazardous waste or location of recycling facilities.

While the role of education is widely recognized (various examples of educational campaigns are provided at *http://www.nyas.org/programs/harbor.asp*), the importance of addressing infrastructure issues cannot be overlooked. When trash pickup services are available to rural communities, open burning becomes less of a problem.

One of the main problems is how to pay for the infrastructure and collection services that facilitate the proper management of solid waste. Municipalities throughout New York State have structured their collection services in different ways. These services and associated annual costs are described below:

- Through taxes:
  - $155/household (Dickinson, Broome County: population of 5,300, density 1,000 per sq mile, average household: 2.2 people).
- Private haulers:
  - $200 to $420/household (Herkimer County; includes towns with populations ranging from 700 to 13,000 and average household population of 2.2. The higher cost corresponds to towns with very low population density).
  - Recyclables included or can be dropped off without cost at a transfer station.
- Individual transportation:
  - $100–$300/household for tipping fees plus cost of transport to transfer station.

Funded mandates can go a long way in supporting the development of required infrastructure to support alternatives to open burning of waste. One of the arguments for not funding these alternatives or for not setting a ban on open burning is that the benefits do not justify the costs. However, we have found no cost/benefit analysis of this kind for this or any other region. Calculating benefits would require estimating potential losses from products contaminated with dioxins (and other toxins) above certain safe thresholds as well as estimating the costs of associated health effects. Losses could be estimated in relation to health risk standards and measurements of toxin levels. To the best of our knowledge, these standards do not exist for dioxins either in the region or in the US.[195]

### Incentives

Certain incentives can be offered to people to dispose of their waste properly. The "Cleaning the Air" toolkit, developed by the Western Lake Superior Sanitary District [358], presents several examples, including:

- Develop markets for compost, leaf mulching, and recyclable materials (as well as for agricultural plastics), in order to minimize the amount of waste that needs to be managed by residents; this measure can reduce tipping fees at transfer stations as well as the frequency of waste collection.
- Trade-in programs offering rain barrels, composting bins, or shredders (to prevent people from burning paper for safety concerns) in exchange for burn barrels and a "no burning" pledge.
- A particularly successful case is the "Barrel Buy-Back Program" of Chisago County, Minnesota: With a grant from the Minnesota Office of Environmental Assistance, this program offered six months of half-priced waste collection services in exchange for burn barrels. Part of the cost was covered by haulers themselves, which benefited from having new customers. It was estimated that the program reduced open burning from 13% in 1996 to 3% in 2000. The program was advertised by an extensive educational campaign [358].

## 2. Open burning of agricultural plastics

Our estimates suggest that burning of agricultural plastics contributes only a small amount of dioxins to our region, although many uncertainties remain and actual

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[194] Materials include: plastics, foam cushions, furniture, rugs, floor coverings, appliances, rubber, tires, metals, glass, tree stumps, roots, asphalt shingles, roofing materials, drywall, insulation, and treated wood (including deck lumber, railroad ties, and telephone poles). The materials and additives in these items can generate and release large amounts of dioxins and other toxics upon burning. Additionally, the ashes from a burn barrel should never be used to fertilize a vegetable garden because they contain numerous hazardous materials that would be harmful if ingested [201].

[195] Belgium has set a standard for dioxins in food of 5 pg TEQ/g of fat (this may include but it is not limited to milk, other dairy products, eggs, and meat).

emissions could be higher. A detailed discussion of this sector is provided in Appendix C. However, open burning of agricultural and residential wastes are part of the same problem, and many recommendations can address both. Some suggested measures specific for agricultural burning are also included in the next section.

**Proposed recommendations to stop open burning of waste:**

- **Provide adequate infrastructure** to properly dispose of or recycle residential and agricultural wastes. Create alternatives to open burning by developing comprehensive waste management plans that include:
  - Collection systems (municipal, waste haulers, or individuals transferring to collection points).
  - Ensure that transfer stations receive residential waste directly from individual residents (tipping fees may apply).
  - Recycling centers for metal, paper and cardboard, plastic bottles, and glass.
  - Centers accepting compostable material and leaves.
  - Recycling programs for agricultural plastics.
  - Establish periodical collection of key waste (hazardous waste, PVC, and other chlorinated materials).[196]
  - Investigate options to increase markets for recyclable materials (both residential and agricultural waste).
  - Require producers to devise waste management options before a product is introduced in the market and to be involved in implementation. Support the development of extended producer responsibility programs (EPR).
  - Investigate the expansion of current packaging laws (designed to reduce toxic materials from packaging) to include dioxin and dioxin precursors such as chlorine and PVC plastics.
- **Education**:
  - Educate public and local officials about the need to prevent open burning.
  - Outreach and education to rural residents and farmers about the hazards of open burning and the available alternatives for waste disposal.
    - Educational materials should include information about the health and safety hazards associated with open burning, as well as available options for proper waste management and minimization. For agricultural plastics, advertise best management practices to properly handle, bale, store and transport plastics to ensure they can be recycled.
    - Special emphasis on educating families (with a focus on children) about the risks of open burning and the proper way of disposing of wastes. Include these subjects in mandatory curricula.
- **Offer incentives** to stop burning garbage (e.g., burn barrel swap, coupons/discounts with waste haulers, drop off sites taking recyclables without cost)
- **Regulation**
  - Institute a state-wide ban on open burning, which will provide more incentives for proper waste management.
  - Enforcement of the ban. Enforcers can also act as educators as they find violations.
  - Close the regulatory gap in NJ legislation.
  - Consider legislation to require labels for products containing chlorine or PVC plastics.

## Structural Fires

Today, most of the remaining sources of dioxins involve uncontrolled combustion of different materials. One of these sources is structural fires, which involve residential (homes, apartment buildings) and nonresidential facilities (industrial and commercial properties, institutions such as hospitals, nursing homes, and prisons, educational establishments, mobile properties, and storage properties) [344]. Nationwide, ~75% of structural fires take place in residences, mostly 1–2 family homes [344]. The trend in NY State (excluding NY City) is similar [217]. Roughly 60% and 70% of homes in NY and NJ, respectively, are 1–2 family dwellings.

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[196] Note, however, that the elimination of these materials does not render waste safe to burn. Even small amounts of chlorine are enough for dioxin generation and other factors (e.g., the presence of copper or other catalyzers as well as the moisture content and degree of compaction of the waste) may significantly increase dioxin generation.

## BOX 4. PVC CONSUMPTION TRENDS

PVC consumption in the US has significantly increased:[1]

- ~0.9 million T in 1966
- ~5.8 million T in 2000
- ~6.4 million T projected for 2005 (10% increase from 2000)

As of 2000, the US and Canada combined consumed ~ 5 million T of PVC in the construction sector alone (including pipes and construction materials), with an additional 0.1 million T in home furnishings [2].

US domestic consumption of PVC building applications (siding, doors, windows, floors, and pipes) has remained about the same from 1999 to 2003, with ~4.4 million T consumed in 2003, or ~ 71% of the 6.3 million T of total PVC used that year.[2]

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1. Based on the 2003 and 1993 editions of the Chemical Economics Handbook, as cited in [14].
2. Data from APC Plastics Industry Producers' Statistics Group, Annual Markets Report, as compiled by VERIS Consulting, LLC. Data was faxed by Todd Abel, Manager, Science, Chlorine Chemistry Council. October 4, 2005.

In the US, the main causes of residential fires are cooking, heating, and arson (26, 15, and 11%, respectively) [345].[197] In over half of all residential structure fires, alarms are absent or not operating.

Buildings contain many combustible materials (mainly wood and plastics) in the structure itself and in furniture, appliances, and other items. Chlorinated materials in buildings include polyvinyl chloride (PVC) or vinyl, textiles treated with chlorinated paraffins, paints, certain flame retardants,[198] as well as bleach and other cleaning agents. PVC is of particular concern because it is widely used in construction materials (including siding, pipes, floors, windows, blinds, and electrical wires), and its use has been steadily increasing [14] (see trends in Box 4). Items that may contain PVC include computers, furnishings, carpet backing, bath curtains, kitchen items, luggage, toys, shoes, and apparel.[199] [200] Certain metals in structures favor dioxin formation. Copper, in particular, is a very effective catalyst of dioxin synthesis and can be found in electrical wires, copper-containing chemicals (e.g., chromated copper arsenate, a wood preservative),[201] and pipes.[202] Treated or painted wood may also generate higher amounts of dioxins when burned. Some buildings (as was the case in the World Trade Center) have transformers, which may contain oil with different amounts of PCBs that are contaminated with furans (a by-product). In addition, once burned, PCB oil can easily generate more furans [76].[203]

Dioxins generated during fires are released to air, both in the gaseous phase or attached to soot particles. Soot will eventually settle at varying distances from the fire, depending on particle size and atmospheric

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[197] Other causes involve electrical distribution, appliances, and smoking.

[198] Most flame retardants are brominated organic compounds. Controlled combustion of brominated and chlorinated phenols increases chlorinated dioxin generation (in addition to brominated and combined chloro-bromo dioxins) compared to when only chlorinated phenols are combusted [77]. Although more research is needed to determine whether these results are applicable to other halogenated compounds and combustion conditions, this is a reason of concern because brominated flame retardants (BFR) are ubiquitous in computers, furniture, and other items.

[199] For a detailed list of common PVC applications, see appendix A of CHEJ report on PVC [26].

[200] These PVC applications can be found in many types of buildings. For instance, PVC carpet backing and wall protection are rarely found in homes but are used in commercial and institutional settings. PVC shower curtains can be found both in homes and hotels. Cameron Lory, INFORM, Inc. Personal communication, May 23, 2006.

[201] CCA has been mostly used for outdoor wood uses. Effective December 31, 2003, wood may not be treated with CCA for residential uses, with certain exceptions [296].

[202] Pipes are often installed beneath the floor or behind a wall and, therefore, off-limits of most fires, which are typically confined to the room where the fire started. However, fires in 'crawl spaces' or those engulfing whole structures can affect these pipes. Some scientists believe that even if all organic chlorine (e.g. PVC) were absent from buildings, other chlorine sources (e.g., inorganic chlorine is naturally occurring in wood) coupled with the presence of metals would be enough to generate equally high dioxin emissions. However, given the fast pace at which chlorinated materials are incorporated to new building materials and other household items, the effects of increasing amounts of chlorine in buildings should be thoroughly studied. In addition, the relative impact of copper and other metals in dioxin releases from structural fires with and without organic chlorine should be determined and, if necessary, substitutes be found.

[203] Runoff water samples (which contained ashes) taken near the site of the World Trade Center after the September 11th attack included CDD/Fs, PCBs and BDD/Fs (brominated dioxins) among other contaminants [135].

## BOX 5. WORLD TRADE CENTER FIRES

Dioxins were among many toxic substances[1] released during the fires at the World Trade Center (WTC) in September 2001. Most of the TEQ in dust and runoff from the site [135] was due 2,3,4,7,8 PeCDF, a congener that may be associated with incineration [135]. Total dioxins in settled dust (most of which originated in construction materials rather than combustion residues or soot) were found to be ~100 pg TEQ/g, which is on the order of background concentrations [133]. One study of settled dust found that chlorine[2] was only present in the finer particles, probably resulting from combustion of plastics at high temperatures (larger particles originated from the collapse of the buildings) [124]. This study attributed the generation of dioxins during the fires to the extensive use of PVC in the affected buildings [124].

Several studies found substantially higher dioxin concentrations in both air and organic films that deposit on exterior windows around lower Manhattan than at a background sites [229,317]. Congener patterns in air were similar to those measured at the WTC during the fires (rather than the typical urban signature) [138]. Available data suggests that dioxins in air dropped to background levels by December 2001 [317].

The congener patterns of dioxins in air around the WTC shortly after the fires were related to combustion and pyrolysis including incinerators, fuel combustion, and PVC combustion, while off-site samples were similar to typical air samples [138]. Dust samples impacted by the WTC fires had profiles somewhat similar to those of WTC air samples [139]. A comparison with other samples concluded that the dioxin profiles found at the WTC show trends common to building fires in general [139].

Analysis of blood and urine samples from firefighters that responded to the WTC fire showed elevated concentrations of Hp-CDD/Fs compared with firefighters that were assigned to office duties [55]. These congeners are typical of releases from burnt chlorinated plastics and had previously been found in elevated concentrations in incinerator workers (Hp- and OCDD/Fs are the most abundant congeners in the general US population) [55]. Dioxins measured in WTC firefighters may represent exposure during this incident, previous cumulative exposure, or a combination [55].

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[1] Runoff from the site, which carried ash, contained PBDEs, PCBs, and chlorinated biphenylenes (PCBPs) [135].

[2] And, therefore, any chlorinated organic compounds, including dioxins.

conditions. Combustion residues (ash and incombustible materials) may also contain dioxins.

### Emission Factors

While the number of structural fires is known with a reasonable degree of certainty, the amounts and types of materials burned are much less well known.[204] However, the largest uncertainty is associated with emission factors (amount of dioxins emitted per mass combusted or per fire). The extremely variable nature of fires (materials burned, combustion conditions, and duration) makes it difficult and costly to carry out measurements and develop meaningful EFs. Many studies have measured dioxins in soot from structural fires.[205]

Much of the information available to estimate dioxin emissions from fires comes from small-scale experiments where individual materials are combusted, generally PVC and wood. Even in simplified experiments, conditions and thus dioxin emissions vary widely. A significant challenge is to be able to capture the whole of dioxin emissions (in gas, particulates or soot, and ash). The vast majority of the experiments have focused on soot, assuming that this is the phase where most dioxins will be found. However, there are indications that most of the dioxins may be released in the gas phase (up to 90%).[206] Given all the uncertainties and limitations, currently available EFs for

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[204] This is particularly the case for structures other than 1-2 family homes.

[205] As summarized by U.S. EPA [334].

[206] An experiment burning PVC and a mixture of PVC and wood found that dioxin emissions were an order of magnitude higher in the gas phase compared to the soot [153].

structural fires differ widely and are assigned very low confidence. Worldwide, virtually all efforts to calculate emissions from this source have cautioned that currently available EFs are unreliable and have concluded either that information was not adequate to provide estimates, or that these were highly uncertain [19,47,108,174,350]. The need for further research to shed light on the chemistry of structural fires and the relative contribution of different materials has been widely acknowledged [19,47,174,350].

The following is a list of currently available dioxin EFs for structural fires. All of them are based on limited information and numerous assumptions.

On the low end of suggested EFs are the following:

- Thomas and Spiro (1995) [267], based on poorly controlled wood combustion: **~25 μg TEQ/fire** (not specified whether this includes dioxins in gas and/or soot).
- Carroll (1996) [23], based on published information on dioxins from PVC combustion and fires, applied to PVC only estimated to burn during fires at 1- and 2-family homes: **0.2–26 and 1.2–41 μg TEQ/ fire in soot and ash**, respectively.[207]
- Carroll (2001) [24] same approach, including wood combustion (emissions were assumed to be additive): **0.04–95 and 1.3–286 μg TEQ/fire for PVC and wood**, respectively (i.e., ~75–85% of the emissions are attributable to wood), in soot.
- German Environmental Agency [225], based on a previous paper that measured dioxins in deposited soot [142] (as cited in [225,226]): **50 and 210 μg TEQ/fire** for apartment fires for dioxins emitted to air (soot) and residues, respectively, and **2,500 μg TEQ/fire**, each, for industrial fires.

The U.S. EPA used an average of the first two EFs in the draft dioxin inventory. This inventory is still in draft form, and it has been emphasized that the quality of the available data is poor and allows only an order of magnitude preliminary estimation of emissions from accidental fires. The draft dioxin inventory acknowledges that these EFs may underestimate actual emissions.

Higher emission factors have been chosen by other countries or agencies performing inventories:

- New Zealand Ministry for the Environment (2000) [174], based on a review of emissions from fires and PVC combustion: **~52–670 μg TEQ/fire** (studies included soot or soot and gas).
- Denmark Ministry of the Environment (2003) [107]:
  - Extrapolating German emissions by population: **~1 and 1.7 μg TEQ/person/year** for emissions to air and residues, respectively.[208]
  - Based on EFs measured in the US [105] for open burning of waste: **~40–1,400 μg TEQ/fire** (this includes both soot and gas phases).
- UNEP [350], based on a review of dioxin emissions for PVC and wood combustion: **~210–680 μg TEQ/fire** for gas and soot and an equal amount for residues (420–1,360 μg TEQ/fire altogether).

Based on the above information, a few observations can be made:

- The lowest EFs for air emissions typically consider dioxins in soot only, not in the gaseous phase. However, one study of burning wood and PVC in a closed room found that more than 90% of all dioxins emitted were found in the gaseous phase [153]. If this is the case in most fires, then most of the EFs are underestimations.[209]
- There is still a notorious lack of information regarding other types of structures (e.g. industrial and commercial properties, institutions, educational establishments, mobile properties, and storage properties) that account for ~25% of fires in the US and could conceivably involve larger fires. Some of these buildings could possibly contain higher amounts of PVC than 1-2 family dwellings in areas that could be reached by a fire (e.g. vinyl flooring in institutional buildings, school items, office supplies includ-

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[207] If EFs were originally expressed per amount of material burned, they were converted to μg TEQ/fire by applying appropriate fuel loadings (see details in subsection on Local Emissions).

[208] Emissions were provided in g TEQ/yr for 2002. The Danish population that year was 5,368,354 [254].

[209] Another study burning different PVC products in a combustor simulating uncontrolled burning found higher dioxin levels than most previous studies [116]. Although this finding was not adequately explained, it seems this sample would include both particulate and gas phases.

ing computers, wall protection, PVC pipes in between stories that would be available to fire, as opposed to buried pipes in smaller homes, as well as other PVC applications such as wall covering).

It is estimated that combustible materials in structures contain ~1% of PVC [23,26], but this could increase significantly if the use of PVC building materials continues to grow as in the last 30 years [26]. Experiments burning waste found that when chlorine concentrations are >1%, dioxin emissions increase [105,112,116]. If these findings hold for structures, further increases in chlorinated materials in buildings could have a significant impact on dioxin emissions during fires.[210]

In summary, it is undisputed that fires generate dioxins. Nevertheless, in light of the existing discrepancies, recognized uncertainty in EFs, and potential benefits for emission reductions, it is necessary to advance research in this field and devise experiments that will shed light on the overall emissions from fires (including other pollutants such as PAHs and PCBs). These experiments are key to understanding the chemistry of dioxin formation during structural fires, including the role of the many variables at play including materials involved, temperature, smoldering vs. actual combustion. These efforts could answer the question of whether or not eliminating or restricting certain materials would have a significant impact in minimizing toxic emissions in the event of a fire. This type of research would be invaluable to ascertain current levels of exposure by firefighters, who represent a population segment that could benefit the most from any measures to reduce toxic emissions from fires. These studies should address different types of structures. Efforts to characterize building materials and contents, as well as the frequency and duration of fires associated with specific types of structures, would also be helpful. There are fire research facilities in the US that are adequately equipped to run such experiments.[211] In addition, natural disasters provide further opportunities for tests in actual structures. This could be a joint effort with other nations that are also concerned about dioxin emissions from structural fires. Firefighters should also be involved in these efforts, both during research (as they can provide useful information regarding fires) and in determining what actions should be taken in light of the results.

### Local Emissions

Over 40,000 structural fires take place annually in the states of NY and NJ, with the overwhelming majority (83%) occurring within the Watershed (Table C. 10). Moreover, most of the fires in the Watershed take place in New York City (27,788 fires in 2001, or ~77% of the fires in the Watershed).

**Table C. 10. Structural fires in NY and NJ**

| | Number of structural fires |
|---|---|
| **Watershed** | |
| NY | 32,334 |
| NJ | 3,741 |
| **Total, Watershed** | **36,075** |
| **Outside Watershed** | |
| NY | 4,264 |
| NJ | 3,094 |
| **Total, outside Watershed** | **7,358** |
| **Total, states of NY and NJ** | **43,433** |

NY fires (2001): NYS Department of State, Office of Fire Prevention and Control [217]. NJ fires (2004): data files, by county, provided by Heather Puskar, Supervisor, NJ Fire Incident Reporting System (NJFIRS), Dept of Community Affairs, Division of Fire Safety. Personal communication, April 25 2005.

Emission factors (EFs) for fires are typically expressed either per amount of material burned or per fire. The conversion factor between the two is the "fuel loading" factor (material burned per fire). Table C. 11 shows various fuel loading factors; they are generally similar, except for one that is much higher and whose origin is uncertain[212] and, thus, was not used in this report. In Table C. 11, we present all the available EFs expressed in $\mu$g TEQ/fire. If the original EF was given per amount of material burned, we converted it by applying the fuel loadings provided by each publication or (if not available, and in the case of Thomas & Spiro) the range of fuel loadings shown in the table (0.5 to 1.7 T/fire).

Table C. 11 also provides the estimated dioxin emissions to air and associated with residues. The numbers span ~3 orders of magnitude, although estimates based on EFs by UNEP, the Danish EPA, and New Zealand dioxin inventory are in line and are higher than estimates based on the other EFs.

As noted before, some of these EFs might underestimate emissions because they do not consider re-

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[210] This would also impact fires involving construction and demolition debris.

[211] For instance, the U.S. EPA has a small open burn facility where small-scale fires can be simulated.

[212] Thomas and Spiro estimate that 6.2 tons of material are burned per fire. This estimate was provided to the authors through a personal communication but it was not specified how the factor was determined.

**Table C. 11. Dioxin emissions from structural fires in the region**

| | Fuel loading | Emission factors | | Dioxin emissions (g TEQ/yr) | |
|---|---|---|---|---|---|
| | (T/fire) | µg TEQ/T | µg TEQ/fire | Watershed | Total, NY + NJ |
| | | **Emissions to air†** | | | |
| Thomas & Spiro [267] | 6.2 | 4 | (2–7) | 0.07–0.3 | 0.09–0.3 |
| Carroll, 1996 [23] | — | (0.1–15) | (0.2–26) | 0.01–0.9 | 0.01–1.1 |
| Carroll, 2001 [24] | 1.7 | (0.8–224) | (1.3–381) | 0.05–14 | 0.06–17 |
| Germany [225] | — | (30–100) | 50 | 1.8 | 2.2 |
| New Zealand [174] | 0.5–1.7 | 100–400 | (52–670) | 1.9–24 | 2.3–29 |
| Denmark [107] | 0.7–1.4 | 50–1,000 | (36–1,378) | 1.3–50 | 1.6–60 |
| UNEP [350] | — | 400 | (208–678) | 8–24 | 9–29 |
| Open Burning [105] | — | 79 | (41 - 134) | 1.5 - 4.8 | 1.8 - 5.8 |
| CARB | 1.0 | — | — | — | — |
| **Mean (range), in air** | **0.5–1.7** | **185 (0.1–1,000)** | **244 (0.2–1,378)** | **9 (0.01–50)** | **11 (0.01–60)** |
| | | **Dioxins in ash** | | | |
| Carroll, 1996 [23] | — | (0.7–24) | (1.2–41) | 0.04–1.5 | 0.05–1.8 |
| Germany [225] | — | (124–420) | 210 | 7.6 | 9.1 |
| UNEP [350] | — | 400 | (208–678) | 8–24 | 9–29 |
| **Mean (range), in ash** | **—** | **194 (0.7–420)** | **228 (1.2–678)** | **8 (0.04–24)** | **10 (0.05–29)** |

† EFs in parenthesis were converted to the appropriate units based on information presented in the original source, or applying the range of fuel loads (0.5–1.7 T/fire). Some of these EFs represent emissions in soot only, or soot and gas phase combined. For details, see discussion on EFs, above.

leases in the gas phase, which may amount to as much as 90% of emissions from fires [153]. Our preliminary estimates suggest that structural fires may be a significant source of dioxins to air and ash.

Combustion residues (ash and noncombustible materials) from structure fires are typically collected and disposed of as municipal solid waste.[213] Water used to extinguish the fires or rain water will mobilize and transport some deposited soot and ash [107]. These combustion residues, which likely contain dioxins, can enter the Harbor or other water bodies via wastewater treatment plants or, untreated, via CSOs and surface runoff.

### Vehicle Fires

Vehicle fires in the region and estimated dioxins in ash and released to air are presented in Table C. 12. Although estimates are uncertain and based on few studies, the numbers suggest that this is not a major source locally.[214] However, the EFs are based on a single study. Thus, emission estimates are highly uncertain and do not reflect the large variability known to exist during accidental fires.

### Measures to reduce emissions from structure and vehicle fires:

Dioxin and PAH concentrations in air during simulated fires are elevated and considered to pose a danger to firefighters and others in the vicinity of the fire, while concentrations in soot are of concern to reconstruction workers [240].[215]

Recommendations to better characterize and/or prevent emissions from accidental fires may include:

- Fire prevention practices, including:
  - Educate individuals about fire risks and fire prevention practices. Specific actions include:
    - Install fire alarms throughout the home, check batteries periodically, and replace when needed.[216]
    - Check appliances for fraying wires.
    - Turn off electrical equipment when not in use.

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[213] As stated by Thomas Belton, Research Scientist, NJ DEP during a meeting of the dioxins workgroup. March 24, 2005.

[214] Both U.S. EPA and UNEP EFs are based on the same study, but while EPA applies EFs measured for cars only, UNEP assumes about 1% of reported fires involve large vehicles and have higher emissions that can be estimated by EFs measured from a subway car fire. This may represent a more realistic situation.

[215] Respirators and protective clothing are needed to protect firemen, and protective equipment should also be used once the fire is extinguished [240].

[216] Some fire departments or other municipal services provide smoke alarms free of charge [345].

## Table C. 12. Dioxin emissions from vehicle fires in NY and NJ

| | | | Emissions (g TEQ/yr)† | | |
|---|---|---|---|---|---|
| | | **Number of vehicle fires** | **Air (EPA)** | **Air (UNEP)** | **Residues (UNEP)** |
| Watershed | NY | 10,227 | 0.4 | 1.0 | 0.2 |
| | NJ | 2,206 | 0.1 | 0.2 | 0.04 |
| **Total Watershed** | | **12,433** | **0.5** | **1.2** | **0.2** |
| Outside Watershed | NY | 2,344 | 0.1 | 0.2 | 0.04 |
| | NJ | 1,347 | 0.1 | 0.1 | 0.02 |
| **Total NY+NJ** | | **16,124** | **0.7** | **1.5** | **0.3** |

Sources: NY fires: NYS Department of State, Office of Fire Prevention and Control [217]. NJ fires: data files, by county, provided by Heather Puskar, Supervisor, NJ Fire Incident Reporting System (NJFIRS), Dept. of Community Affairs, Division of Fire Safety. Personal communication, April 25, 2005.
† EFs: 94 and 18 µg TEQ/fire to air and residues, respectively (UNEP) [350]; 0.044 mg TEQ/fire (EPA [334]).

  - Check heating systems and fireplaces and maintain them in good condition.
  - Keep a fire extinguisher in the kitchen.
  - Consider installing sprinklers.
  - Avoid storing flammable materials such as wood piles around the house.[217]
  - Avoid open and recreational burning, as well as fireplaces without spark arrestors.[218]

- Given that there is a fundamental lack of understanding of the chemistry of dioxin formation in accidental fires; that the use of chlorinated materials in buildings and vehicles has been increasing over the years; and that emission factors have high uncertainty, we recommend further research and experiments to:
  - Develop better emission factors to properly characterize current levels of dioxin (and other pollutants such as PAHs and PCBs) releases from structural and vehicle fires, specific for each type of structure (e.g., different types of residences, industries, offices, and public buildings), and address the ranges of use of problematic materials.
  - Quantify the relative contribution of chlorinated materials (e.g., PVC) as well as copper and other metals (which catalyze dioxin formation) to dioxin emissions.
  - Upon experimental results, educate the public and develop guidelines for architects, engineers, and interior designers to minimize the use of materials likely to generate dioxins during combustion.

### Landfill and Waste Management–Related Fires

Fires may occur at various points during waste management activities—for example, dumpsters at commercial facilities or residences, transfer stations, and landfills. Although landfill fires are perhaps the least common of waste-related fires, when they occur, their effect can be severe because they are difficult to detect and extinguish.

Landfill fires may occur either near the surface or deep in the landfill. The first have more oxygen available—allowing for somewhat better combustion conditions—and can be more easily discovered and extinguished [262]. Deep fires are of greater concern because poor combustion results in larger releases of toxics (e.g., dioxins and PAHs) [262]. These fires tend to last longer because they are difficult to detect and fight [262]. It is estimated that ~5% of all landfill fires in the US are subterranean.[219]

In the US, there are approximately 8,300 landfill fires per year, which include waste as well as surrounding structures, vehicles, and vegetation [343].[220] For landfill fires where the cause has been reported

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[217] Dave Schuller, Minnesota DNR. Open Burning and Firewise. Presentation at Open Garbage Burning: Preventable Pollution. A Workshop for Local Officials. March 4, 2005. Duluth, MN.

[218] A spark arrestor is a device that prevents small pieces of ignited materials from escaping into other areas.

[219] David Cleverly, Environmental Scientist, National Center for Environmental Assessment, Office of Research and Development, U.S. EPA. Personal communication, October 24, 2005.

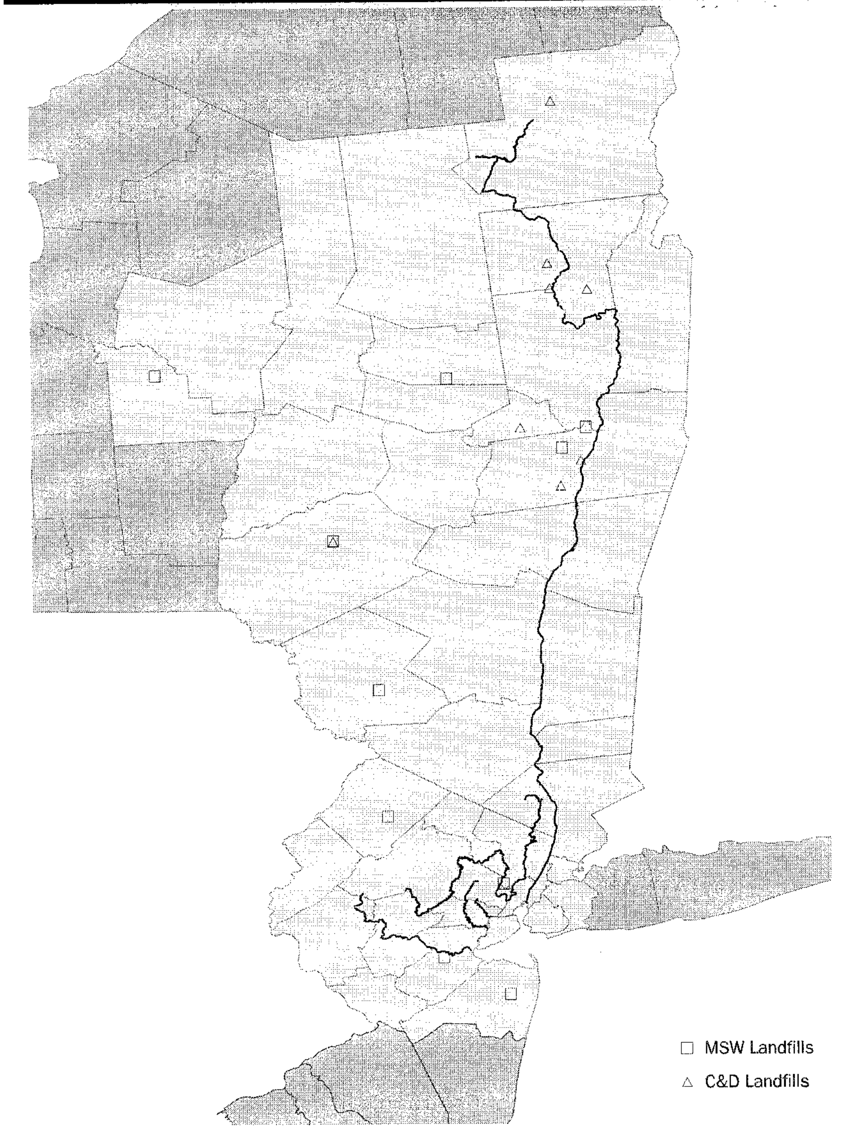
[220] Refuse is burned in ~77% of these fires; 12% of the fires involve trees, brush, or grass; 7% structures; and 4% vehicles [343].

(~50% of fires), a good proportion (~40%) are attributed to arson, and 20% are due to materials that are discarded while still smoldering (e.g., cigarettes and matches) [343]. Another 5% of the fires are due to the heat released by waste decomposition, which can cause spontaneous ignition of methane gas (also generated by microbial decomposition of the waste) [343]. This phenomenon is known as "spontaneous heating" or "hotspot." Landfill fires are more common when ambient temperatures are high because spontaneous combustion is more likely to occur under such conditions [343]. Construction and maintenance activity at landfills can also cause fires (e.g., due to vehicle sparks, welding, or heat generated by machinery) [343]. Other causes include problems at the landfill gas collection system, human error (e.g., smoking on site), and deliberate ignition of the landfill to reduce its contents [343].

Construction and demolition (C&D) waste comprises residues from roads and structures.[221] Fires at C&D debris–handling facilities and landfills have not been thoroughly studied, and, to the best of our knowledge, EFs for dioxins and other pollutants have not been developed. However, fires involving C&D waste are of concern because some of the combustible materials (e.g., treated wood and PVC) have potential for releasing dioxins, as described above in the section on structural fires. Assuming that similar materials compose combustible materials in buildings and C&D debris (i.e., ~1% PVC), a continued rise in the use of chlorinated construction materials could increase dioxins emissions from this source.[222] Anecdotal information suggests that C&D landfills are at higher risk of fires than other landfills, and there have been many instances of fires lasting weeks or going undetected for long periods of time [343].

Fires at facilities handling waste (other than landfills) may be initiated by causes similar to those noted above. The heat released by microbial decomposition can cause compost or mulch piles to ignite spontaneously. As long as the compost includes only yard waste or clean wood, the potential for dioxin release upon burning is lower than that of garbage. However, other compostable materials such as sewage sludge and organic waste could release larger amounts of dioxins when combusted.

**Map 1. Construction & demolition and municipal solid waste landfills in the Watershed**



Sources for addresses: [125,183].

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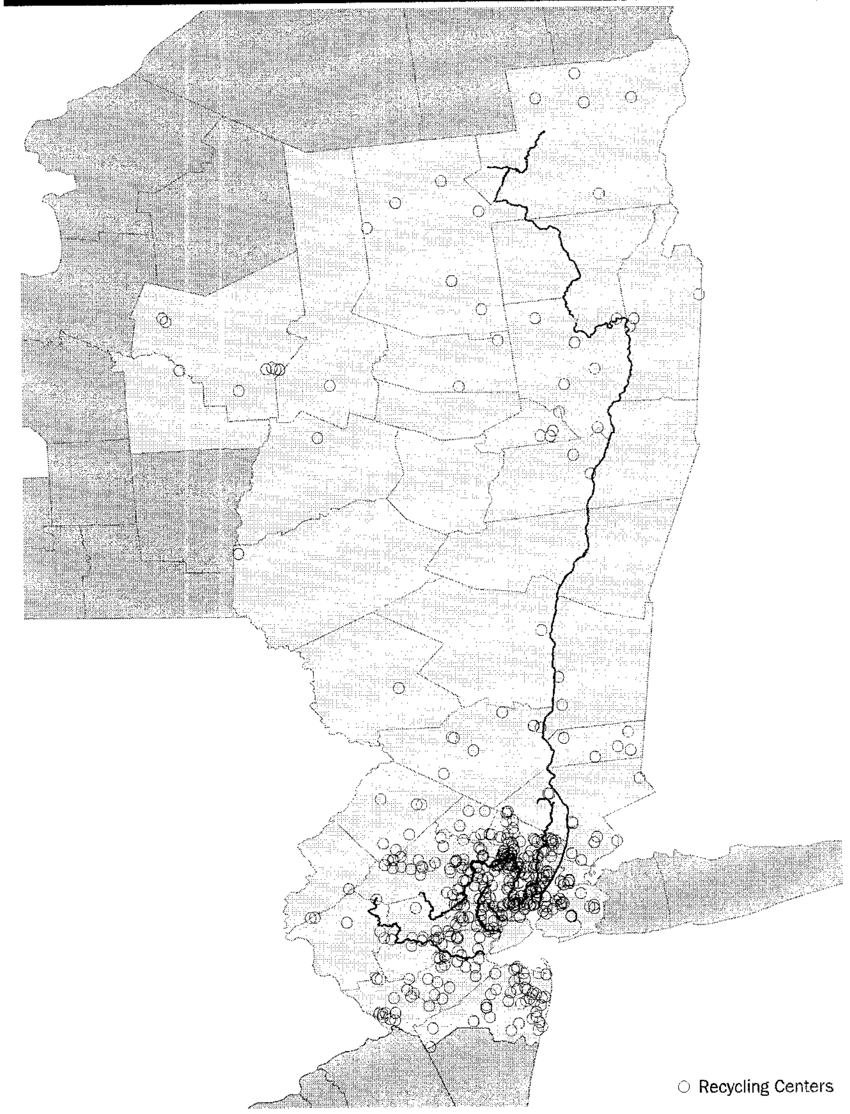
[221] Although each state has its own definition of C&D waste, it generally includes bricks, concrete and other masonry materials, soil, rock, wood, land clearing debris, wall coverings, plaster, drywall, plumbing fixtures, nonasbestos insulation, roofing shingles, and other roof coverings, asphaltic pavement, glass, plastics, and electrical wiring. The following are some of the wastes that are **not** classified as C&D debris: asbestos waste, garbage, fluorescent light ballasts or transformers, fluorescent lights, carpeting, furniture, and appliances [200].

[222] Copper (a dioxin catalyst) is removed from the C&D waste stream for its value as scrap material (to be recycled overseas). Additional copper could remain in wood treated with chromated copper arsenate (CCA). However, the U.S. EPA is taking steps to reduce or phase out the use of this wood preservative in homes [296]. Therefore, if copper were eliminated from this source, there would be even higher potential for dioxin reductions by chlorine elimination.

**Map 2. Recycling Centers in the Watershed**



Sources for addresses: [125,183].

At metal shredding facilities, the nonmetallic fraction (shredder residue or fluff) is separated from the metal and is typically stored in piles. This material is combustible and comes out of the shredder at high temperatures that may cause ignition. These fires are of particular concern because fluff may contain PVC and fire retardants, and is likely to be contaminated with PCBs, oils, and other materials that increase dioxin generation upon combustion. Fluff can also contain mercury, released upon breakage of switches found in cars and appliances [21]. This mercury will volatilize during fires. Fires at automobile salvage yards (also known as "junk yards") may be caused by sparks igniting vehicle fluids (e.g., when batteries are removed).

Only one study has attempted to estimate dioxin emissions from fires at MSW landfills, but, to our knowledge, no EFs are available for other fires related to waste management, such as transfer stations, recycling centers, shredder residue or fluff at metal shredders, or facilities and landfills handling C&D waste.

### Local Estimates

In NY, there are currently 26 active MSW landfills, and all of them, except for one, also accept C&D waste [204]. In addition, there are 108 registered land clearing debris landfills[223] and 18 permitted construction and demolition debris landfills that accept only C&D waste[224] [200]. As of November 2004, there were 158 regulated and 343 registered transfer stations operating in the state[225] [207] as well as 84 composting facilities[226] and numerous recycling centers.

In NJ, there are 13 operating landfills that accept MSW and C&D waste, as well as 59 transfer stations, 30 composting facilities,[227] and numerous recycling centers [182].

NY and NJ keep records of fires at MSW and C&D landfills, although there are no details available regarding the size and cause of the fires. However, landfill fires are reported in combined categories that include other types of fires involving MSW or C&D

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[223] These are three acres or less, requiring, at a minimum, a compacted soil liner.

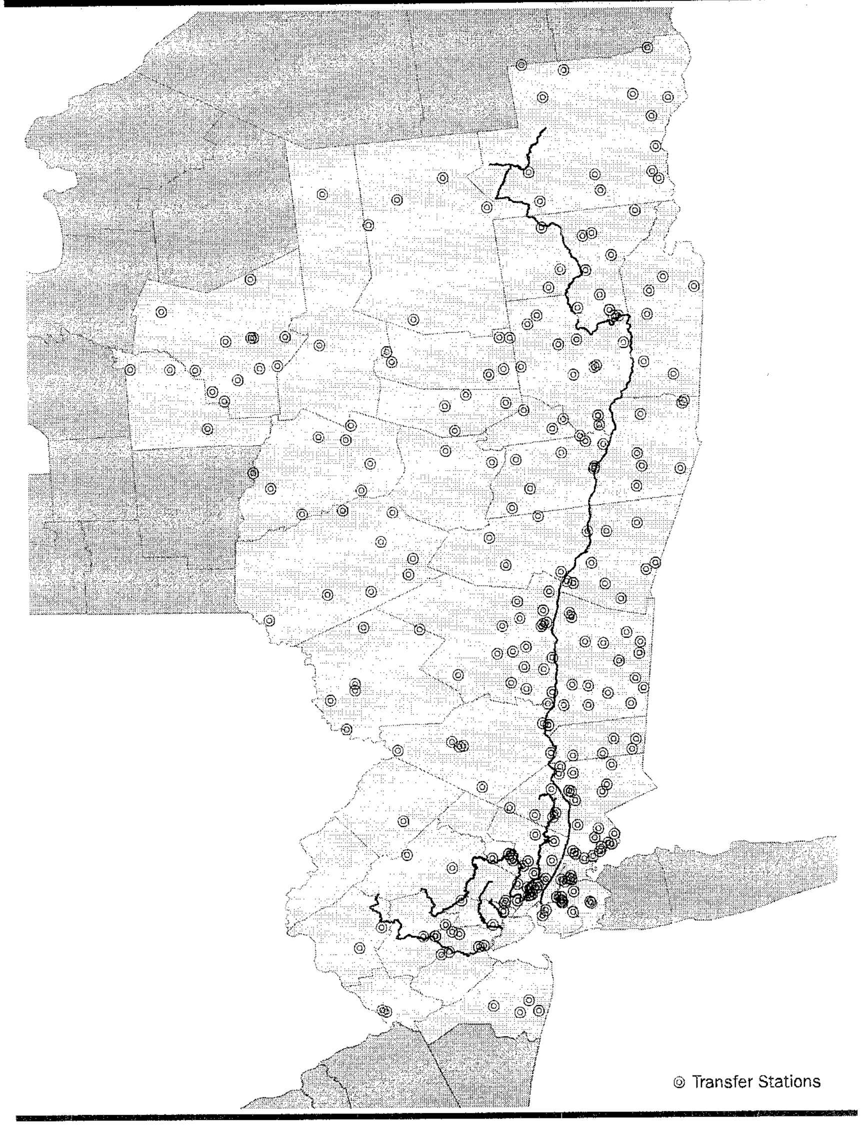
[224] These are greater than three acres, requiring, at a minimum, a single composite liner with a leachate collection and removal system. Note that the minimum liner requirements for MSW landfills are more stringent: a double composite liner with primary and secondary leachate collection and removal systems [204].

[225] Transfer stations that manage less than 50,000 cubic yards and are owned or operated by, or contracted by or on behalf of, a municipality are eligible for registration if other requirements are met. Those that do not meet these criteria have to be permitted (6 NYCRR 360-11.1(b), available at *http://www.dec.state.ny.us/website/regs/subpart360_11.html*).

[226] Most of these facilities compost biosolids or yard waste, although some compost food waste or wood.

[227] Materials composted may include leaves, grass, wood chips, brush, and source-separated organics.

**Map 3. Transfer stations in the Watershed**



Sources for addresses: [125,183].

waste. Only the individual fire stations responding to each fire incident may have more detailed information on the nature of the fires. Table C. 14 shows the annual number of fires reported in NY and NJ as either "*garbage dump or sanitary landfill fire*" or "*construction and demolition landfill fire*" (which may include transfer stations) between 2001 and 2004.

For NY, the fire reports included an address, which we compared with lists of active landfills, transfer stations, and recycling centers in the state.[228] Most fire incidents could not be matched with a facility in the list (e.g., some fires may be reported at a street location other than that listed for a given landfill).[229] Of ~440 fires reported between 2001 and 2004, 9 were confirmed to occur at a landfill location, 13 at transfer stations, 3 at recycling centers, and 9 at mixed facilities (e.g., transfer station and recycling). Over two-thirds of the fire incidents reported in this period involved C&D waste. As mentioned before, this type of waste may emit large amounts of dioxins when combusted (185–1,000 μg TEQ/T, Table C. 13).[230]

Reports for landfill fires in NJ did not include an address (only a township). Anecdotal information suggests that at least five of the ~190 fires reported between 2001 and 2004 took place in landfills and involved landfill contents. However, from the limited information we were able to gather by contacting several fire departments in NJ, it appears that the vast majority of the fires take place at other types of facilities handling waste such as recycling centers and transfer stations.

In order to calculate dioxin emissions from all fires involving waste, better information is needed on the type of fire, amount and type of waste burned, and appropriate emission factors for each scenario. These data are not readily available but we attempted to develop rough preliminary estimates for different fire scenarios. Based on the information gathered by contacting fire departments, the amount of waste burned per fire was estimated under different assumptions. Then the most closely related EFs that were available were applied. Table C. 13 summarizes these emissions *per fire* for each *assumed scenario.*

Note that the scenarios considered in this report are not necessarily representative of typical fires. In addition, all EFs are for uncontrolled combustion con-

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[228] Lists provided by David Lasher, Environmental Engineer Bureau of Solid Waste, Reduction and Recycling, Division of Solid & Hazardous Materials, NYS DEC.

[229] Reported addresses are often incomplete or ambiguous. In some instances, more than one road surrounds a facility and the reported location of the fire might differ from addresses in NYS DEC lists.

[230] Note that the upper end of this range is the EF for MSW landfill fires because EFs specific for C&D landfill fires have not been measured. Also note that the EF for C&D debris burning (assumed to be equal to mean EF for structural fires) are ~twice those for MSW uncontrolled burning, while EFs for MSW landfill fires are over one order of magnitude larger. In addition, the volumes of C&D waste assumed to be burned may be underestimated.

### Table C. 13. Dioxin emissions during uncontrolled combustion of waste

| Fire type | Waste burned (T)† | EF (µg TEQ/T)‡ | g TEQ/fire |
|---|---|---|---|
| MSW landfill (weighed average) | 117 | 1,000 | 0.1 |
| Dumpster | 3 | 79 | 0.0002 |
| Composting pile | 3,364 | 40 | 0.09 |
| Salvage yard | 5 cars + 1 building* | 94 µg TEQ/fire (car)<br>244 µg TEQ/fire (structure) | 0.001 |
| C&D waste | 3–117 | 185–1,000 | 0.0006–0.1 |

† Calculated based on volume burned and waste density—assumed to be that of MSW (0.7 T/$m^3$ [12]) except for salvage yard scenario. Volumes burned (in $m^3$): landfill fires, ~150 and 500 for surface and subsurface, respectively [12] (~5% of the landfill fires are subterranean:[231] 168 $m^3$ weighed average); composting piles, ~5; commercial dumpster, ~4; C&D waste, assumed a volume range from approximately the size of a small dumpster to the average landfill fire.

* Based on a personal communication with Capt. Lewis, Hopewell Junction Fire Prevention Bureau, February 6, 2006.

‡ Sources: Landfill fires, [12] (as reported in [263,350]); composting pile, [108] (EF for garden waste); vehicle fires, [350]; average for structural fires, Table C. 11.; C&D waste, assumed to range between structural fires and MSW landfill fires (within the range of EFs for burning C&D wood alone: 26 173 µg TEQ/T [126]).

ditions are highly uncertain. EFs for shredder residue were not developed. Only one study is available on fluff combustion, which found *total* dioxin emissions to be ~3 orders of magnitude greater than for residential waste [130]. Because individual dioxin congeners were not measured, emissions for the 17 dioxin-like congeners cannot be determined. Nevertheless, releases from shredder fluff fires are expected to be very high.[232]

EFs from Table C. 13 were used to make a preliminary estimate of the magnitude of dioxin emissions from fires during waste management in our region (Table C. 14). Most attempts to estimate emissions from MSW landfill fires only have been based on a Swedish study and extrapolated by population. For the US, this approach was deemed appropriate because the characteristics and proportion of waste diverted to landfills per capita are similar in both countries, although in the US ~50% more waste is generated per person.[233] However, this estimate was considered highly uncertain by the U.S. EPA. Local emissions for **MSW landfill fires only** based on this approach are also shown in Table C. 14.

It is possible that not all fires at waste management facilities are reported by some local fire departments. In addition, fire details are not reported; and suitable EFs are lacking. In spite of the large uncertainty, these preliminary estimates suggest that this sector might be among the largest ongoing sources of dioxins in the region and that it deserves more attention and research. Many of the facilities where these fires may occur are located close to the Harbor, increasing the likelihood for dioxin emissions to reach this water body. Maps 1 to 3 show the location of landfills, transfer stations, and recycling centers within the NY/NJ Harbor Watershed.[234]

## Measures to Prevent or Reduce Dioxins from Landfill Fires

At this point, there are large uncertainties in the number and characteristics of fires during waste management, as well as EFs for dioxins. Because preliminary estimates suggest that this might be an important local source of dioxins, measures to reduce the incidence of fires involving waste as well as recommendations for further research are put forth.

Recommendations for this sector focus on three main areas:

- **Waste minimization:** Options for pollution prevention at the source have already been discussed in the section about municipal solid waste incineration. The same recommendations would apply here to reduce the amount of waste generated and, thus, susceptible to combustion at various points. In addition, this measure could reduce the number of new landfills built and would help segregate combustible

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[231] David Cleverly, Environmental Scientist, National Center for Environmental Assessment, Office of Research and Development, U.S. EPA. Personal communication, October 24, 2005

[232] One of the fires in the Watershed involved a shredder residue pile estimated to be ~35 ft tall and 100 ft across, (Jeff Lenarski, Chief, Prospect Heights, NJ Fire Co; personal communication, December 15, 2005). Assuming the same density as MSW and applying an EF of 4 g ***total*** dioxins/T, such a fire would emit 44,000 g ***total*** dioxins [130]. For comparison, the EF for uncontrolled MSW combustion is ~0.006 g ***total*** dioxins/T [130].

[233] David Cleverly, Environmental Scientist, National Center for Environmental Assessment, Office of Research and Development, U.S. EPA. Personal communication, October 24, 2005.

[234] Data for NY facilities was provided by David Lasher, Environmental Engineer Bureau of Solid Waste, Reduction and Recycling, Division of Solid & Hazardous Materials, NYS DEC. For NJ, data was obtained from the Solid and Hazardous Waste website *(http://www.state.nj.us/dep/dshw/)*. Recycling facilities in the map include compost facilities and "Type A" recycling facilities, which accept metal, glass, paper, plastic containers, and cardboard.

material. Specifically for C&D waste, programs directed to deconstructing structures and salvaging rather than discarding all materials that can be reused is one way to divert waste from landfills and management facilities. There are several such initiatives.[235]

- **Reduce the incidence of fires during waste management operations:**
  - Landfill Management: The occurrence of landfill fires can be reduced by compacting the waste to prevent hot spots, checking the waste to ensure materials are properly extinguished, prohibiting smoking onsite, and generally maintaining good security [79].
  - Methane control and collection: Monitoring and control of methane emissions is another way to reduce landfill fires. Federal regulations require MSW landfill operators to monitor methane quarterly and to take actions if levels become explosive [79]. In addition, new MSW landfills are required to install a gas collection and control system.[236]
  - Flaring landfill gas (LFG) or capturing it for energy recovery, including onsite energy generation. Although LFG combustion can also release dioxins, the amounts seem to be lower (see section on landfill gas combustion).[237] Emissions could be reduced

## Table C. 14. Fires related to waste management in NY & NJ and estimated dioxin emissions to air

| | | Number of fires per year† | | Dioxin emissions (g TEQ/yr) | | | |
|---|---|---|---|---|---|---|---|
| | | **MSW** | **C&D** | **MSW‡** | **C&D#** | **Total** | **Based on popul.¶** |
| Watershed | NY | 5–27 | 12–80 | 0.001–3 | 0.007–8 | 0.008–11 | |
| | NJ | 9–29 | 5–17 | 0.002–3 | 0.003–2 | 0.005–5 | |
| **Total Watershed** | | **17–43*** | **17–97** | **0.004–5** | **0.009–10** | **0.01–15** | **0.7–110** |
| Outside Watershed | NY | 6–18 | 4–32 | 0.001–2 | 0.002–3 | 0.003–5 | |
| | NJ | 3–7 | 0–15 | 0.001–1 | 0–2 | 0.001–2 | |
| **Total Out. Watershed** | | **11–25** | **14–36** | **0.002–3** | **0.008–4** | **0.010–7** | |
| **Total NY + NJ** | | **28–61** | **31–129** | **0.006–7** | **0.02–13** | **0.02–20** | **1.3–207** |

† Range of fires between 2001 and 2004. Sources: NJ: Heather Puskar, Supervisor, NJ Fire Incident Reporting System (NJFIRS), Dept. of Community Affairs, Division of Fire Safety. Personal communication, July 25, 2005. NY: Data was provided by NYS DOS through a Freedom of Information Law (FOIL) request.

‡ Lower range given by lower number of fires assuming a garbage dumpster scenario; upper range given by highest number of fires assuming a landfill fire scenario (Table C. 13).

# EFs specific to C&D landfills have not been developed. EFs applied ranged from those for structural fires to MSW landfill fires (Table C. 13).

* Totals may not add up: lowest/highest number of reported fires in each state may take place in different years.

¶ Landfill fires only. EFs range from 0.5 to 4.7 µg TEQ/person/year. Watershed and states population: ~17 and 28 million, respectively (2004 estimate based on 2000 census).

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235. (1) **Green Worker Cooperatives:** This South Bronx organization is currently raising money to start a program to connect local residents with contractors to retrieve items that can be reused such as cabinets, flooring, sinks, and plumbing (no plastic materials). These items will be sold to self-sustain the program. Benefits include: local employment, resource conservation, waste diversion, reduced waste disposal cost to contractors. (Omar Freilla, Green Worker Cooperatives. Personal communication, February 27, 2006). (2) Over a year ago, the Community Environmental Center (CEC) opened the **Build It Green! (BIG)** warehouse in Astoria, Queens, to collect and sell salvaged (from NYC buildings that will be demolished), surplus (donated by building suppliers and contractors), and low-cost construction items. Thus, it provides affordable materials while decreasing the amount of C&D waste. Proceeds support the Stuyvesant Cove environmental education center programs on renewable energy and the East River estuary. (For more information, visit *http://www.bignyc.org/*.) (3) **NY Wa$teMatch**, in collaboration with the U.S. EPA, is promoting building deconstruction and material recovery in NY City. This organization has prepared guidelines for deconstruction as well as outreach materials to encourage this practice and educate different audiences about the benefits. (Further details and materials can be found at *http://www.wastematch.org/services/crandd.aspx#A*). **NJ DEP's** website (*http://www.state.nj.us/dep/dshw/recycle/builderinfo.htm*) shows that builder and demolition contractors can save money by recycling C&D materials (tipping fees for recycling are waived or less expensive than for landfills) and provides a list of recyclable materials and facilities accepting them. Another website promotes buying products made of recycled materials, some made from salvaged material (*http://www.state.nj.us/dep/dshw/recyclenj/*).
The **U.S. EPA** promotes source reduction of C&D waste by (more resources at *http://www.epa.gov/epaoswer/non-hw/debris-new/index.htm*): (1) reducing waste by designing for the environment at production and building planning stages: (a) standardizing lumber size to reduce cutoff waste; (b) replacing wood by steel (which is lighter, stronger, and can be recycled) in frames; (c) using salvaged building materials; (d) purchasing materials with recycled content; (e) providing advice and resources such as on how to set up a jobsite recycling program (Flyer available at *http://www.epa.gov/region09/waste/solid/cd3.pdf*).

236. This requirement applies to landfills opened after November 1987 with a capacity over 2.5 million m$^3$, which affects ~4% of landfills, because most are smaller. Certain states, such as California, have stricter requirements [79].

237. Combustion conditions can be controlled (e.g., by regulating the amount of air), while landfill fires—besides being inherently uncontrolled—typically smolder, releasing large amounts of smoke and toxics.

by installing pollution controls but these projects are more costly [79].
  - Promote best management practices in salvage yards to minimize the risks of igniting flammable materials during dismantling and other operations.
  - Best management practices at transfer, recycling, and composting centers to minimize the risk of spontaneous combustion of waste. In NY, special attention should be directed to the C&D waste stream.
- **Research** on emissions from fires at landfills, transfer stations, and recycling centers, including:
  - Characterize fires involving both municipal solid waste and construction and demolition debris (e.g., type of affected facilities as well as type and amounts of materials typically burned).
  - In order to reduce the uncertainty on EFs, conduct research to characterize dioxin (and other pollutants) emissions from fires involving a variety of waste at different types of facilities and under diverse scenarios. In particular, investigate the role of treated wood and PVC materials in toxic emissions from fires involving C&D waste. This is important because of the growing amounts of PVC used as a construction material.
  - Determine the proportions of different materials in landfills and their relative contribution to toxic emissions to air during fires. Substitute problem materials in commerce, accordingly.
  - Reduce disposal of combustible materials to landfills.[238]

## C.1.c. Other Combustion Sources

Many combustion processes in addition to control and uncontrolled combustion have the potential to release dioxins to the atmosphere. The larger sources under this category include:

- Landfill gas flaring and combustion;
- Wood burning by industrial, power generating, and commercial facilities;
- Off-road fuel combustion;
- On-road fuel combustion;
- Crematoria.

Minor sources for our region include:

- Fuel combustion by the commercial, industrial, and household sectors;
- Power generation;
- Wood combustion in outdoor boilers;
- Residential wood burning.

Only the larger sources within this category are discussed in this section, while the rest are developed in Appendix C.

### Landfill Gas Flaring and Combustion

Dioxins can be generated upon combustion of landfill gases. As municipal solid waste decomposes in landfills, it generates and releases off-gases or landfill gas (LFG) (typically ~50% methane, 45% carbon dioxide, and 5% nitrogen gas) [60,350]. The off-gases also contain trace contaminants, which were either in the waste or are generated during decomposition (e.g., chlorine and chlorine-containing compounds) [168].[239] An alternative to allowing LFG to escape into the air or flaring the gas is to capture it and combust it as an energy source, or clean the gas and upgrade it to pipeline-quality gas [335].[240] Energy recovery is promoted by the U.S. EPA through its Landfill Methane Outreach Program (LMOP) as a way of reducing emissions of greenhouse gas and other toxics, as well as odors [335].[241] Note that some industrial facilities may also flare some of their gaseous emissions (see Appendix C).

Data on dioxin emissions from LFG flaring are scarce: measurements were made at one flare in the US and another in the Netherlands (as summarized in [334]). Emission factors for LFG combustion in engines to recover energy were derived from a review of a few measurements in Europe, as reported by the

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[238] Sweden has banned landfill disposal of these materials [262].

[239] Trace components include oxygen gas, hydrogen sulfide, halides, and organic compounds [60].

[240] The vast majority of projects that recover energy use internal combustion (reciprocating) engines or turbines [335]. Note that even if a landfill is collecting LFG for energy recovery, it may still flare part of the gas. Rachel Goldstein, U.S. EPA LMOP. Personal communication, October 31, 2005. Landfill gas is extracted and collected using wells and a vacuum system [335].

[241] Methane is over 21 times more potent as a greenhouse gas than the carbon dioxide into which it is converted upon combustion. Most organic compounds are destroyed when combusted [335].

New Zealand Ministry for the Environment [174]. Therefore, it is important to bear in mind the limitations of these estimates.

### Local Emissions

Table C. 15 shows the estimated amounts of LFG flared and associated dioxin emissions in NY and NJ based on two approaches: (1) extrapolated from US data in 2000 and (2) from data available on local landfills, provided by the US Landfill Methane Outreach Program (LMOP). Most of the landfills that reported flaring landfill gas did not provide information as to the amount of LFG actually flared[242] and therefore estimates were based on the amount of waste in the landfill (waste in place).

Table C. 16 provides the number of active landfills in the region that collect and use their LFG. Most of these landfills generate energy by combusting the LFG in some type of engine, typically internal combustion (IC). This table also presents estimated releases of dioxins to air, assuming that all the gas was combusted in IC engines. According to the available EFs, this source releases more dioxins to air than does flaring, partly because a larger amount of gas is combusted. However, note that EFs span a wide range.

### Measures to Prevent or Reduce Dioxin Emissions from LFG Combustion and Flaring

Although LFG combustion and flaring generates and emits dioxins to air, these projects are encouraged because their benefits are considered to typically outweigh the disadvantages [294]:

- Reduced greenhouse gas emissions (see footnote 241);
- Destruction of toxic and/or malodorous organic compounds in LFG;
- Possibility of obtaining electricity or natural gas;
- Decreased risk of landfill fires.

In the US, certain landfills are required to collect and combust their LFG. Although installing equipment to recover energy involves further investment, selling the energy can offset the costs or even result in profits [302]. Depending on the final use, different degrees of purification may be needed. For instance, direct use for boilers or industrial processes requires only minimal processing and is often the most convenient option.

The U.S. EPA LMOP provides several tools to aid in LFG project development, including:[243]

- A handbook for landfill owners and operators, describing the steps involved in developing LFG projects, including simple criteria for conducting a preliminary economic analysis;
- Software to evaluate the economic feasibility of a project;[244]
- Software to calculate greenhouse gas reductions from LFG recovery projects;
- Case studies for several successful and cost-effective LFG projects throughout the country. Two interesting examples that illustrate the

**Table C. 15. Dioxin emissions to air from landfill gas flaring**

| | Extrapolated from US data (2001) | | Based on reported activity | |
|---|---|---|---|---|
| | LFG flared (billion $m^3$) | Dioxin emissions (g TEQ/yr)* | LFG flared (billion $m^3$)‡ | Dioxin emissions (g TEQ/yr)* |
| US | 16† | 6–38 | | |
| **Watershed** | **0.9§** | **0.4–2.2** | **0.2** | **0.07–0.4** |
| Outside watershed | 0.9§ | 0.3–2.0 | 0.3 | 0.1–0.6 |
| **NY + NJ** | **1.8§** | **0.7–4.2** | **0.4** | **0.2–1** |

† Estimated from the EPA 2001 Inventory of Greenhouse Gas Emissions (as reported in [334]).
§ Extrapolated by population, adjusted for economic activity (5.8%).
* EFs: 0.4 and 2.4 ng TEQ/$m^3$ measured in the Netherlands and the US, respectively, as reported in [334].
‡ From LMOP database, provided by Rachel Goldstein, U.S. EPA LMOP, November 3, 2005. LFG flared was either reported or calculated as LFG collected – LFG for recovery project. LFG collected was provided or estimated as 85% of LFG generated, based on amount of waste in place (WIP): LFG generated WIP (tons)/10^6 * 0.432.

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[242] The U.S. EPA LMOP has databases on landfill activities. Many landfill operators report whether landfill gas is flared, although this is not required. LMOP can often estimate the amount of gas flared. Rachel Goldstein, U.S. EPA LMOP. Personal communication, October 31, 2005.

[243] For further information, please visit the LMOP website: *http://www.epa.gov/lmop/.*

[244] Currently available to LMOP partners and endorsers only. Partners include industry (e.g., landfill owners and operators), the energy sector (providers and marketers as well as end users), state institutions (e.g., air and solid waste departments, universities, and NGOs), community partners (local and regional governments), and nonprofit organizations.

### Table C. 16. Dioxin emissions from landfill gas combusted for energy recovery

| | Number of operational landfill projects | LFG combusted (billion m³/yr)† | Dioxin emissions‡ |
|---|---|---|---|
| NY Watershed | 5 | 0.2 | 0.01–2.5 |
| NJ Watershed | 7 | 0.2 | 0.01–2.2 |
| **Total Watershed** | **12** | **0.4** | **0.02–5** |
| NY- outside Watershed | 12 | 0.2 | 0.01–2.5 |
| NJ- outside Watershed | 6 | 0.1 | 0.00–0.6 |
| **Total outside Watershed** | **18** | **0.3** | **0.02–3** |
| **Total NY+NJ** | **30** | **0.7** | **0.04–8** |

Source of landfill projects and gas combusted: U.S. EPA LMOP (2005 data) [339].

† For some projects, only the electricity produced, in megawatts (MW), was provided. It was assumed that 1 MW corresponds to 300–350 standard cubic feet per minute (Rachel Goldstein, LMOP, U.S. EPA Headquarters. Personal communication, October 21, 2005).

‡ Assuming that all the gas was combusted in IC engines. EFs: 0.06–12 ng TEQ/m³, as suggested by the New Zealand Ministry for the Environment [174].

kind of factors at play in the success of LFG projects are summarized in Box 6.

#### Recommendations

- Minimize waste (please refer to recommendations for incinerators) to reduce the number and load of landfills and, thus, the need to manage landfill gas.
- Promote collection and purification of LFG for use as natural gas substitute.
- Refine emission factors for dioxin (and other pollutants) associated with LFG flaring and combustion for energy recovery in different types of engines.
- Based on refined emission factors, determine whether installing pollution control devices in internal combustion and other engines should be mandated.
- Provide support and require landfill operators to review all options for LFG management. Allow LFG flaring only when no other alternatives are viable.

### Wood Combustion by Industrial, Power Generating, and Commercial Facilities

Many commercial and industrial facilities can burn wood for heat and electricity [58]. The industrial sector can use their combustible by-products along with wood chips for electricity generation and process steam. Power plants may use wood as co-firing or primary fuels to produce electricity.

The industrial sector, especially the paper and the lumber and wood products industries, is the largest consumer of wood in the US, accounting for 80% of wood combustion in 2000 [334]. Industrial furnaces burn mostly wood waste (chips, bark, sawdust, and

### BOX 6. LANDFILL GAS RECOVERY: CASE STUDIES

- An electric utility, American Municipal Power-Ohio, Inc. (AMP-Ohio), pooled LFG from several small landfills. The generated electric power was marketed at rates slightly higher than conventional power, but the price was fixed for 11 years, making it attractive for customers. By engaging small, independent power producers, the project qualified for accelerated depreciation and federal tax credits. Pooling the LFG from small landfills proved cost-effective, while generating electricity from each individual landfill was not.
- Lucent Technologies in Ohio, powers its boiler with LFG from a nearby landfill. The company saves ~$100,000 per year in fuel, and the LFG emissions reduction are equivalent to taking ~23,000 cars off the road in terms of greenhouse gas. In this case, the proximity and size of the landfill made it clearly profitable to start a large-scale landfill gas recovery project.

Additional case studies available at *http://www.epa.gov/lmop/res/index.htm*.

hog fuel)[245] in addition to wastes such as kraft black liquor[246] [334].

Dioxin emissions from wood combustion span several orders of magnitude depending on the type of wood and furnace or boiler [126]. Certain trends are clear: (1) Clean wood emits the lowest amounts of dioxins (0.026–5.1 ng I-TEQ/kg wood) when burned in a variety of combustors, with or without pollution control devices [126].[247] (2) Much higher emissions were measured when burning salt-laden wood (17.1 ng I-TEQ/kg) or salt-laden hog fuel (23–270 ng I-TEQ/kg) [126].[248] (3) Construction and demolition wood resulted in dioxin emissions of the same order of magnitude as salt-laden wood because of chemical treatments or paints containing chlorine and possibly some metals that may catalyze dioxin formation. Laboratory experiments burning PCP-treated wood found emissions contained within the clean wood range [126].

### Local Emissions

In NY and NJ only clean, unadulterated wood (i.e., wood that has not been painted or treated) is legally allowed to be burned. In NY, wood boilers with a capacity of >1,000,000 BTU/hour need to be permitted, except in New York City, where no wood can be burned. Table C. 17 shows the number of facilities permitted to burn wood in NY.[249] The three largest of these facilities are located outside the Watershed (in St. Lawrence, Franklin, and Erie Counties) and account for ~1/2 of all the wood burned by industrial/commercial/power plant facilities in NY State. Based on this and other estimates of wood consumption in the state, this sector could burn roughly 1 to 1.5 million T of wood/year in NY.[250]

In 2001, the Energy Information Administration (EIA) estimated a higher rate of wood consumption (Table C. 18). However, this estimate is based on sample surveys and allocated to states according to several indicators of activity.[251] Given the uncertainties surrounding these estimates, a range of wood consumption for the state is provided. In New Jersey, we have confirmed that at least two facilities have wood boilers that can burn up to ~2,400 T of wood/year,[252] much lower than the EIA estimate shown in Table C. 18. However, because this list is incomplete,[253] EIA data was used, bearing in mind that this likely represents an upper-end estimate. Data on the estimated amount of wood consumed by each sector and dioxin emissions are shown in Table C. 18.

**Table C. 17. Number of permitted wood boilers in NY**

| | Number of facilities | |
|---|---|---|
| **Type of Facility** | **Watershed** | **All of NY** |
| Industrial | 5 | 11 |
| Power generation | — | 6 |
| Commercial/residential | 2 | 10 |
| **Total** | **7** | **27** |

Source: Michael Jennings, Environmental Engineer, NYS DEC. Personal communication, February 17, 2006.

It is estimated that ~1.6% of the wood burned in the US is salt-laden [334]. This is a small percentage, but dioxins emissions from the burning of this wood are more than doubled. Although there are uncertainties about the nature of the wood being burned locally, it was assumed that all the wood burned in the region is clean.[254] Even under this assumption, upper range

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245. Hog fuel refers to fuel that has been processed by a hog machine. The wood is pulverized and pounded. Hog fuel will be as clean as the feed. It typically consists of a mixture of shredded bark and wood with sawdust, shavings, or sludge [22]. It is generally wet (which can lead to poor combustion), with a high ash content. It can also be produced from secondary materials such as pallets and construction and demolition wood [22]. This results in a drier material, but it may contain contaminants [22].
246. A residue of the kraft pulping process. For more details, see Appendix C.
247. These figures encompass the range of EFs suggested by the U.S. EPA (0.4–1.32 ng TEQ/kg, mean 0.52) [334].
248. Some lumber operations store the wood in salt water, resulting in very high levels of inorganic chlorine. The U.S. EPA suggested an EF of 13.2 ng TEQ/kg (range of 1.4–27.6 ng TEQ/kg) [334] for salt-laden wood.
249. The number of facilities is not necessarily proportional to the amount of wood burned. A few facilities account for most of the wood burned in the state.
250. Michael Jennings, Environmental Engineer, NYS DEC. Personal communication, May 10, 2006.
251. For instance, wood used by the commercial sector for combined heat and power is allocated according to manufacturing activity. Allocation for other uses is based on residential wood consumption (also from sample surveys). Full details are available in the Technical Notes [58].
252. Jim Marinucci, NJ DEP. Personal communication, May 8, 2006.
253. Electronic records for NJ, from which this information was obtained, may not include all facilities, or may not indicate the type of fuel burned.
254. In NJ, no logging facilities store wood in water, and no facilities burn salt-laden wood. All hogged fuel is also clean (Ed Lembicki, NJ Forestry Service; personal communication, March 6, 2006). In NY, it is believed that salt-laden wood is not burned around the Harbor, although some might be burned upstate (Michael Jennings, Environmental Engineer, NYS DEC. Personal communication, February 28, 2006). Some logging operations in Long Island may generate salt-laden wood waste, but this is landfilled (Ibid). Although this wood is not directly burned, it may contribute to dioxin emissions in the event of fires at landfills or during waste management activities. A handful of power plants and paper mill boilers in NY may burn hogged fuel. The majority of these boilers fire clean wood waste that they generate, including furniture and pallets. A few wood boilers fire "alternative fuels" like plywood, particle board, and creosote-treated wood that must not be coated with paints or lacquers. Burning of treated wood (including PCP- or CCA-treated wood and utility/telephone poles) is not permitted. (Michael Jennings, Environmental Engineer, NYS DEC. Personal communication, February 28, 2006).

## Table C. 18. Dioxin emissions from wood fuel combustion in NY and NJ

| Sector | Wood consumption (T/y)† |  | Dioxin emissions (g TEQ/y)‡ |
|---|---|---|---|
|  | NY | NJ |  |
| Commercial | 410,195 | 41,711 |  |
| Electric | 262,613 | — |  |
| Industrial | 1,344,376 | 217,277 |  |
| **Total** | **1,000,000–2,017,184** | **258,989** | **0.03–12** |
| **Watershed *** | **423,077– 853,424** | **139,854** | **0.01–5** |

† Data for NJ and upper end for NY for 2001 (most recent data) from EIA [62,63]. Lower end for NY estimated by Michael Jennings, Environmental Engineer, NYS DEC.

‡ Emission factors, assuming all wood is clean: 0.026–5.1 ng I-TEQ/kg wood [126].

* In NY: M. Jennings: ~1/2 of all wood was assumed burned equally among the 52 counties north of Orange and Westchester (i.e., ~19–39 thousand T burned per county); 22 counties are within the Watershed in this area. In NJ: adjusted for population of NJ living in the Watershed (54%).

estimates are considerably large. If facilities were in violation of the requirement of burning clean wood, emissions could be significantly higher. At least one facility in our region was reported for violations. Before it shut down in 1990, the Procter & Gamble facility in Staten Island was found to burn painted or treated wood in a boiler with no pollution controls.[255] This past example, as well as the fact that there still are no viable markets for the large amounts of treated or contaminated wood that are generated annually, points to the need for ongoing regulatory oversight.

### Recommendations

- Ensure that wood burning facilities combust only clean wood through periodic inspections and enforcement of regulations.
- Measure dioxin (and other pollutants) emissions at power plants and commercial and industrial facilities when wood is burned and develop more reliable emission factors for the types of wood burned, combustors, and pollution controls typically found in these three sectors.
- Require that facilities burning wood are equipped with proper pollution control devices.

## On-Road Fuel Combustion

The major source of dioxin emissions from on-road fuel combustion in the US today is associated with diesel, which is used in some passenger cars, sports utility vehicles (SUVs), pickup trucks, buses, and light- and heavy-duty trucks. Engines using diesel burn the fuel more efficiently but result in soot or particle emissions (also known as particulate matter or PM, which includes organic and elemental carbon).[256] Dioxins, PAHs, and other toxics have been measured in particulates [248]. Concentrations of dioxins in diesel exhaust particles range from 7 to 14 pg I-TEQ/g [159].[257] However, if diesel vehicles are equipped with particle filters, dioxin air emissions are negligible [350].[258] Heavy-duty diesel trucks release ~30 T of soot into the air every day in NJ alone, accounting for ~90% of the particulate emissions from all motor vehicles [193]. A recent study of bus emissions reports that, for older vehicles, larger amounts of pollutants were found inside the bus when the windows were closed and at the rear of the bus [149].[259] Dioxins generated during combustion processes in engines also accumulate in motor oil. This vector is discussed in Appendix C.

Leaded fuels, which contain chlorinated additives, emit more dioxins than unleaded fuels. In the US, the use of leaded gasoline has been banned for on-road vehicles since 1996. This, together with the use of catalytic converters, has virtually eliminated

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255. Barbara Warren, Consumers Union. Personal communication, January 8, 2006.
256. These emissions vary with the kind and year of the vehicle as well as with the mode of driving (e.g., start-up, warming, idle, creep, and cruise). In general, a vehicle driving in a heavily congested area (frequent speed change, stopping) will emit more particulate matter and carbon [246].
257. Some studies have found dioxins mostly in particulates, while others measured the majority in the gaseous phase [248]. A possible cause for the discrepancy is the variable exhaust temperature when samples are collected [248].
258. These filters will collect dioxins and many other toxic pollutants and should be disposed of properly.
259. Although dioxins in particular were not measured, the study followed an inert tracer that was added to the exhaust emissions. It is therefore reasonable to anticipate that these results are applicable to all exhaust components.

dioxin emissions to air from on-road gasoline combustion.[260] However, leaded fuel may still be sold for other uses,[261] including racing cars, on-farm equipment, aircraft, and recreational marine engines [301].[262] Currently, the main uses of leaded fuel are in aircraft (see section on off-road fuel combustion) and racing cars [311]. Given the decreasing availability of leaded fuels and their higher cost, it is unlikely that they are used significantly in any application that can use unleaded gas instead [311]. Therefore, it was assumed that on-road use of leaded fuel is not a concern for the region.[263]

### Local Emissions

Air emissions from motor vehicles can be estimated using emission factors developed by the U.S. EPA for road vehicles based on the distance traveled (Table C. 19). The EFs take into account dioxins in both the gaseous and particulate phases. However, these EFs are based on limited measurements, which points out their weakness.

## Measures to Prevent or Reduce Dioxin Emissions from On-Road Fuel Combustion

Most dioxin emissions from motor vehicles regionally are caused by diesel fuel combustion. Within this fuel category, most emissions are associated with heavy-duty trucks and buses (~70 to 95%), while diesel cars and SUVs account for another 5 to 20%. Cutting idling time is an economic and effective way to achieve toxic reductions, including dioxins. New York and NJ have anti-idling laws.[264] Further idling reductions could be achieved by electrifying truck stops so truck engines can be turned off while parking and still allow for cooling, heating, and other functions.

Proper engine maintenance and functioning is key to curbing emissions and would likely have a positive impact on dioxins. NJ has established a Roadside Diesel Smoke Emission Program and requires trucks over 18,000 lb gross vehicle weight to be tested annually for smoke emission opacity at licensed Diesel Emission Inspection Centers (DEICs).[265] NYSDEC law

**Table C. 19. Dioxin emissions from motor vehicles in NY and NJ**

| Fuel | Million vehicle miles traveled (2002)* NY | NJ | Total | EF# (g TEQ/mile) | Emissions (g TEQ/yr) |
|---|---|---|---|---|---|
| | | **Watershed** | | | |
| Diesel | 2,872 | 2,242 | 5,114 | 2.94E-10 | 1.5 |
| Gas | 58,679 | 49,617 | 108,295 | 2.77E-12 | 0.3 |
| **Total-Watershed** | **61,551** | **51,858** | **113,409** | | **1.8** |
| | | **Outside Watershed** | | | |
| Diesel | 3,878 | 1,139 | 5,017 | 2.94E-10 | 1.5 |
| Gas | 67,6167 | 19,612 | 87,229 | 2.77E-12 | 0.2 |
| **Total-Outside Watershed** | **71,495** | **20,751** | **92,246** | | **1.7** |
| **Total-NY&NJ** | **133,046** | **72,610** | **205,655** | | **3.5** |

* NY data provided by Mike Keenan, Chief, Bureau of Abatement Planning, Mobile Source Section NYS DEC. Personal communication, April 14, 2005. NJ data provided by John Gorgol, Research Scientist, NJ DEP, Bureau of Air Quality Planning. Personal communication, Friday, April 15, 2005.

# Emission factors derived from EPA's National Mobile Inventory Model (NMIM) [332]. Data provided by Harvey Michaels, U.S. EPA, Office of Transportation and Air Quality Assessment and Standards Division. Personal communication, April 26, 2005.

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[260] A catalytic converter is a device to treat exhaust gases by passing them through noble metals (platinum, rhodium, and/or palladium) to ensure complete combustion. Catalytic converters have recently been found to be responsible for elevated levels of these metals (as well as osmium, a possible impurity) in urban air [228].

[261] Leaded fuel use is no longer estimated for the US. Production or imports of leaded fuels are not reported either; therefore, no good accounts of its consumption are available. Anthony Kizlauskas, U.S. EPA Region 5. Personal communication, November 2, 2005.

[262] Confirmed by Jim Caldwell, US EPA Headquarters. Personal communication, March 1, 2005.

[263] Leaded fuel used by aircraft is available at airports. Anecdotal information suggests that individuals can and do purchase this type of fuel for use in tractors, lawn mowers, and even cars, but this is likely very minor.

[264] For instance, in NJ, idling time is limited to 5 and 3 minutes for heavy duty and diesel vehicles, respectively. In New York City and Rockland Ct, all vehicles are limited to 3 minutes of idling.

[265] Both in- and out-of-state heavy duty diesel vehicles, including trucks and commercial and school buses, may be randomly stopped and tested [193]. Fines are imposed upon vehicles that fail the test. (Presentation during a meeting of the Diesel Initiatives Workgroup of "Reducing Air Pollution Together": a series of workshops organized by NJ DEP. June 29, 2005. Available *http://www.nj.gov/dep/airworkgroups/docs/di/diesel_workgroup_handout_ppt.pdf*). There is a series of proposed rules to test diesel engine emissions from trains, boats and ships, and trucks and buses, but specific dioxins emissions tests are not likely to be mandated.

(6 NYCRR Subpart 217-5) requires Heavy Duty Diesel Vehicles (HDDVs) to have an annual emission inspection registered in the New York City Metropolitan Area and a roadside emission inspection program for HDDVs operating on state roadways [202].

A new law in NJ will create grants to install or improve pollution control devices (e.g., particle filters and oxidation catalysts) in diesel vehicles, including garbage trucks, transit buses, and publicly owned on-road and off-road diesel vehicles and equipment.[266] The U.S. EPA has a voluntary diesel retrofit program. Participants receive public recognition and ongoing technical assistance. This program also promotes anti-idling and the use of alternative fuels such as ultralow sulfur diesel and compressed natural gas.[267]

Another U.S. EPA program—SmartWay$^{SM}$ Transport—aims at reducing emissions from goods, products, and commodities transportation. Carriers, producers and retailers, all of which are involved in the transportation process, can become partners if they implement measures to reduce emissions. These include idling reduction, improved aerodynamics, improved logistics, and automatic tire inflation systems. Benefits to partners include fuel savings, long-term cost savings, appeal to environmentally conscious customers, and technical and infrastructure support from EPA.[268]

Most efforts to improve fuel efficiency, including the use of ultralight materials[269] and alternative fuels, including electric vehicles, have focused on passenger cars. However, the same principles can be applied to diesel vehicles, including heavy-duty trucks and buses, and could go a long way to reduce fuel consumption and associated emissions (including particulate matter, sulfur dioxide, carbon dioxide, dioxins, and PAHs).[270] Transit systems in cities such as Seattle, WA and San Francisco, CA include electric trolley buses and diesel–electric hybrid vehicles for their bus fleets. Many other cities and regions have purchased or are testing these types of vehicles.[271] The Port Authority of NY and NJ has recently authorized the purchase of 21 of these hybrid buses for use in NY and NJ airports [57]. In New York City, there is a City Clean Fuel Taxi Program to provide up to $6,000 financial reimbursement towards the purchase of new compressed natural gas (CNG) medallion taxicabs or the conversion of gasoline cabs.[272] Natural gas is available at a growing network of fueling sites around the City. NYC DEP has switched many of their vehicle fleet to hybrids and other more environmentally friendly models.[273]

Both New York and New Jersey have adopted the California Low Emission Vehicle (LEV) Program. NY regulations require new, cleaner LEV level II standards for all light and medium motor vehicles, starting with 2004 models, and for heavy-duty engines, starting with 2005 models [172,173]. Auto manufacturers were required to offer 10 percent of their sales fleet as zero emission vehicles (ZEVs) starting in 2003, typically electric vehicles. The State of New Jersey adopted LEV II in 2004, requiring that by 2009, automakers offer 40,000 gas–electric hybrid cars and 128,000 super clean gasoline cars for sale in New Jersey. The NJ DEP will provide credits for cars sold up to 2009. As an incentive, there is a federal tax credit that applies when purchasing hybrid cars (although this will eventually phase out).[274] Electric vehicles have not been widely adopted because this technology has faced various challenges, including limited battery range, high price of the vehicles, and subsidy requirements. In addition, recharging the batteries will likely increase electricity consumption, unless they are powered by solar panels.

Compact city design that encourages walking, biking, and use of public transportation can also reduce emissions. Compact cities make electrified modes of public transportation such as subways and electric buses more cost effective.

Some of the possible measures to reduce vehicle emissions from fuel combustion by motor vehicles include:

- Increase funding for anti-idling educational campaigns. Enforce current anti-idling regulations for trucks. Consider expanding regula-

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[266] For more information, visit the "Stop the Soot" website: *http://www.stopthesoot.org/index.htm.*

[267] More information on this initiative, please visit *http://www.epa.gov/otaq/retrofit/.*

[268] For more information, visit *www.epa.gov/smartway/transport.*

[269] Research is being conducted on designing such vehicles, including trucks, buses and planes. See "The Hypercar® Concept" *http://www.hypercar.com/.*

[270] Further information on the deployment of electric vehicles in the US is available from the Electric Drive Transportation Association (EDTA); *http://www.electricdrive.org/,* and the Advanced Transportation Technology Institute (ATTI); *http://www.atti-info.org/.*

[271] *http://www.electricdrive.org/index.php?tg=articles&idx=More&topics=64&article=793*

[272] The program is administered by the New York City Taxi and Limousine Commission and other city agencies and sponsored by NYSERDA. Ford dealerships are involved in conversion and selling new CNG vehicles. *http://www.nyc.gov/html/tlc/medallion/html/home/home.shtml.*

[273] Lily Lee, Acting Section Chief, Regulatory Planning Section, Bureau of Wastewater Treatment. Personal communication, January 13, 2006.

[274] Vehicles purchased in or after 2006 but before 2010 are eligible for a tax credit of up to $3,400. Whenever a given company sells >60,000 eligible vehicles, the tax credit begins to phase out (details available at *http://www.fueleconomy.gov/feg/tax_hybrid_new.shtml*). Up to 2005, tax deductions were offered.

tions to other vehicle types if voluntary programs do not succeed

- Educate consumers about the importance (and cost savings) of vehicle maintenance, including motor oil use, tire pressure, maintenance of air filters, oxygen sensors, and the use of overdrive gear and cruise control.[275]
- Require that diesel engines be fitted with pollution controls such as particle filters and oxidation catalysts.
- Optimize transport logistics and promote programs that encourage using fleets that are implementing emissions reduction measures.
- Promote alternative transportation and programs that reduce vehicle miles traveled (VMT), including improving access to public transportation, car pool commuting, biking lanes, and walking-friendly areas.
- Promote the use of low- or zero-emission technologies, such as electric vehicles, fuel cell–powered, hybrid cars, and ultralight vehicles.
- Fuel substitution. It is estimated that switching from leaded to unleaded gasoline has reduced dioxin generation from vehicles by ~80%. Alternative fuels that result in even lower dioxin generation during combustion include methane, methanol, ethanol, and compressed natural gas (CNG).
- Require automobile makers to attain higher gas mileage and educate drivers on driving strategies that improve mileage.

In addition, given the uncertainty in emission factors from this sector, the following actions are recommended:

- Quantify dioxin emissions under different driving conditions.
- Test the impacts on dioxin emissions from measures to reduce particulate and other types of vehicle pollution (e.g., particulate filters).
- Investigate the effect of chlorine and heavy metal concentrations in motor oil on dioxin emissions.

### Off-Road Fuel Combustion

Diesel fuel is used in off-road engines including construction and farm equipment, boats and ships, pumps, tanks (military tracked vehicles), and stationary power generators. Some vessels and tanks use heavy (residual) oil (see Table C. 20). Small engines used in lawn mowers, chain saws, boats, and jet skis powered by gasoline are 2-stroke engines, which are simpler than motor vehicle engines (typically 4-stroke engines), usually do not have catalytic converters, and therefore have the potential to emit larger amounts of dioxins. There is, however, limited data on dioxin emissions from off-road fuel combustion including concentrations in residues (motor oil) and air emissions, including soot.

Aircraft engines emit particulate matter and other toxics, and these emissions can affect ground-level pollution.[276] Although leaded fuel has a greater potential for dioxin formation because it contains halogenated scavengers,[277] fuel used for so-called "general aviation aircraft"[278] is the only aviation gas still in use that contains lead [195].[279] This represents only about 1% of total aircraft fuel consumption both nationwide and locally [61]. We are not aware of any studies measuring dioxins from aviation gas combustion. Most commercial aircraft use kerosene-based jet fuel, which contains no lead or halogenated additives [29]. Dioxins have not been detected from jet fuel combustion,[280] and emissions from this sector were not estimated.

In this section, only dioxin emissions to air are considered. However, as with motor vehicles, dioxins from fossil fuel combustion can accumulate in engine oil. This issue is discussed in Appendix C.

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[275] The Alliance to Save Energy provides a summary of measures leading to increased gas mileage. More tips and info at *http://www.ase.org/content/news/detail/3060.*

[276] Emissions that contribute to ground-level air pollution include those during idle time before take off and after landing, climbout and descent while below the mixing zone of the atmosphere, and landing. The mixing zone is the altitude above which air is not mixed; therefore, it is considered that pollution from this layer cannot reach ground level.

[277] Tetraethyl lead is used as an antiknock additive. Aviation gas has ethylene dibromide as a scavenger to protect the engine from lead fouling and could possibly generate brominated dioxins [29].

[278] This category refers to small planes, usually privately owned or belonging to corporations.

[279] Most aviation gas is designated "100LL" (100 octane and low lead) and contains 0.56 grams of lead per liter, conforming to American Society for Testing and Materials (ASTM) standards.

[280] Monitoring at the Frankfurt International Airport failed to detect any dioxins [350].

### Local Emissions

In order to calculate pollutant emissions from vessels, two approaches are possible. A top-down approach has been commonly applied by states to estimate emissions of certain pollutants. This approach is based on fuel sales for vessels in each state. Its main limitation is that not all fuel will be used in the place it was sold. Conversely, some vessels navigating the area would purchase their fuel elsewhere. The U.S. EPA has recently suggested that a better estimation is achieved by a bottom-up approach, based on an inventory of vessel activity in each port. Such an inventory for different types of vessels,[281] given in kilowatt-hours (kW-h, a unit of energy) for main and auxiliary engines, is available for the Port Authority of NY and NJ (PANYNJ) [7]. However, this inventory does not include private marinas. In addition, data is not provided regarding the relative use of diesel and residual oil fuels. Dioxin emissions were estimated using both approaches, acknowledging that the activity level will probably fall somewhere in between. Emission factors were obtained from a recent report that analyzed samples of main and auxiliary engines for both diesel and residual fuel combustion [38].[282] Emissions estimated using the top-down approach are much higher than those provided by the bottom-up approach (Table C. 20).

Dioxin emissions for other off-road sources were based on fuel sales in the region, applying available EFs for each kind of fuel. Fuel sales and associated emissions are summarized in Table C. 21 for diesel and Table C. 22 for gasoline. The U.S. EPA Office of Transportation and Air Quality Assessment and Standards Division has developed EFs for dioxins for fuel combustion for off-road vehicles based on EFs for on-road vehicles, applying lower fuel efficiency. The EPA EFs do not distinguish between 2- and 4-stroke engines (burning unleaded gasoline). Using UNEP's EF for 2-stroke engines with no catalytic converter burning unleaded gasoline results in dioxin emissions that are larger by two orders of magnitude (Table C. 22). Nevertheless, emissions to air seem to be dominated by residual oil combustion by vessels. Most of these dioxins would likely be directly deposited in the Harbor. However, note that the upper limit is controlled by the assumption that all locally purchased fuel was burned in the region, and this might be an overestimate.

### Measures to Prevent or Reduce Dioxin Emissions from Off-Road Engines

Federal regulations establish emission standards for new non-road diesel engines. Although dioxins are not addressed directly, emission standards are set for particulate matter, which has the potential to also reduce dioxin emissions.[283] New standards will begin to take effect in 2008, and EPA estimates that particulate matter emissions will decrease by 95%.

EPA has developed a model to estimate dioxin emission factors for several off-road sources. However, EFs for locomotives and engines burning residual oil are not covered by this model, and no difference is made between 2- and 4-stroke engines. Our preliminary es-

**Table C. 20. Regional dioxin emissions for vessels based on activity level and on fuel sales**

| | Vessel activity (kW-h)* | Fuel sales (thousand gallons)** | | Fuel sales (kW-h)† | |
|---|---|---|---|---|---|
| | | Dist fuel oil | Residual fuel oil | Dist fuel oil | Residual fuel oil |
| NY watershed | | 7,436 | 91,173 | 300,930,149 | 3,689,730,128 |
| NJ watershed | | 24,745 | 197,469 | 1,001,398,484 | 7,991,466,262 |
| **Watershed** | **927,486,004** | **32,180** | **288,642** | **1,302,328,633** | **11,681,196,390** |
| **Dioxin emissions, Watershed (g TEQ/yr)‡** | **0.09** | | | **0.04§** | **1.2§** |

* Data for PANYNJ in 2000 from [7].

** Data for 2002 from EIA (see Table C. 21).

† Conversion factors from [38]: 0.0376 TJ/m³ of fuel, 1 TJ = 277,778 kW-h, 1 gallon = 0.0038 m³.

‡ EFs: diesel fuel: 0.03 ng TEQ/kW-h; residual fuel: 0.1 ng TEQ/kW-h. For bottom-up approach, it was assumed that 10% of the fuel was diesel and 90% was residual, which is the proportion in locally sold vessel fuel. Under this assumption, dioxin emissions are 0.003 and 0.083 g TEQ/yr for diesel and residual fuels, respectively.

§ Fuel consumed in the Watershed was assumed to be proportional to vessel $PM_{10}$ emissions by county, as estimated by NYS DEC and NJ DEP.

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[281] Data is provided for ocean-going vessels (OGV), towboats, assistant tugs, dredging, ferries, and government vessels such as those of the U.S. Park Service, U.S. Coast Guard, and fireboats [7].

[282] This report concluded that emissions did not vary much for main vs. auxiliary engines and found that dioxin emissions from residual oil combustion were lower than previously thought.

[283] Information on regulations can be accessed online at *http://www.nyas.org/programs/harbor.asp.*

## Table C. 21. Off-road diesel and residual fuel sales and dioxin emissions in NY and NJ (2002)

| Category | Fuel type | Fuel sales (thousand gallons)§ |  | EF# (µg/thous gal) | Dioxin emissions (g TEQ/yr) |
|---|---|---|---|---|---|
|  |  | NY | NJ |  |  |
| **Off-highway diesel and residual fuel** |  |  |  |  |  |
| Railroad | Distillate fuel oil† | 19,011 | 29,782 | 0.3* | 0.02 |
| Vessel bunkering¶ | Distillate fuel oil | 8,959 | 79,821 | ** | 0.003–0.1 |
|  | Residual fuel oil‡ | 168,839 | 636,996 | ** | 0.08–3.3 |
| Farm | Distillate fuel oil | 41,813 | 9,505 | 2.06 | 0.11 |
|  | Kerosene | 670 | 2 | 2.06 | <0.01 |
| Construction | Distillate fuel oil | 29,372 | 44,663 | 2.06 | 0.15 |
| Military | Distillate fuel oil | 2,772 | 1,710 | 2.06 | 0.01 |
|  | Residual fuel oil | — | 223 | 15* | <0.01 |
| Other | Distillate fuel oil | 3,096 | 8,883 | 2.06 | 0.02 |
|  | Kerosene | 831 | 26 | 2.06 | <0.01 |
| **Total off-highway diesel** |  | **106,524** | **174,392** |  | **0.3–0.4** |
| **Total off-highway residual fuel** |  | **168,839** | **637,219** |  | **0.1–3.3** |
| **Total off-highway diesel & residual fuel** |  |  |  |  | **0.4–3.7** |
| **Watershed emissions diesel + residual@** |  |  |  |  | **0.3–1.4** |

§ Diesel and residual fuel sales in 2002, adjusted to match supplied volumes published in the Petroleum Supply Annual (PSA): EIA [68].

# EFs from EPA's National Mobile Inventory Model (NMIM) [332] except where otherwise indicated. Data provided by Harvey Michaels, U.S. EPA, Office of Transportation and Air Quality Assessment and Standards Division. Personal communication, April 26, 2005. EFs were not available for locomotives, commercial ships, and aircraft. For kerosene, EFs were assumed to be the same as for diesel.

¶ This category refers to fuel sold to ships, ocean-going vessels, barges, tug boats, marinas, and personal boats to be used for propulsion or boilers. Dan Walzer, fuel oil sales contact, Energy Information Administration (EIA). Personal communication, October 14, 2005.

* EFs suggested by UNEP [350], which assume similar emissions as for on-road fuel consumption. EFs in µg/T of fuel, were converted to µg/thousand gallons, assuming densities of 0.99 kg/L for residual fuel, 0.85 kg/L for diesel, and 0.74 kg/L for gasoline [350].

** For details on EFs for vessels, see Table C. 20.

† Distillate fuel oil includes diesel fuel and fuel oil.

‡ Residual fuel oil refers to heavy oils (Nos. 5 and 6 fuel oils).

@ Activity in the Watershed assumed to be proportional to $PM_{10}$ emissions by category, as estimated by NYS DEC and NJ DEP.

## Table C. 22. Off-road gasoline sales and dioxin emissions in NY and NJ (2001)

| Category | Fuel consumption (thousand gallons)* |  | Proportion of 2-stroke engines† | Dioxin emissions (g TEQ/yr) |  |  |
|---|---|---|---|---|---|---|
|  | NY | NJ |  | 2-stroke‡ | 4-stroke§ | Total |
| **Off-Highway Gasoline** |  |  |  |  |  |  |
| Agriculture | 19,677 | 4,216 | 1% | <0.001–0.002 | 0.001 | 0.001–0.003 |
| Aviation | 12,802 | 3,115 | NA | NA | NA | NA |
| Industrial & Commercial | 26,906 | 20,390 | 3% | <0.001–0.01 | 0.002 | 0.002–0.01 |
| Construction | 27,325 | 16,211 | 18% | <0.001–0.05 | 0.002 | 0.003–0.06 |
| Marine | 55,873 | 39,920 | 72% | 0.004–0.5 | 0.002 | 0.006–0.5 |
| Other | 3,991 | 709 | 25% | <0.001–0.01 | <0.001 | 0.000–0.008 |
| **Total off-highway gasoline** | **146,574** | **84,561** |  | **0.005–0.6** | **0.008** | **0.01–0.6** |
| **Watershed¶** | **54,776.3** | **28,450.1** |  | **0.001 - 0.1** | **0.003** | **0.004-0.1** |

NA: not applicable.

* Federal Highway Administration [287]. Gasoline was assumed to be unleaded.

† Based on 2000 activity nationwide, estimated by U.S. EPA Office of Air Quality Planning & Standards from NONROAD model runs prepared for the National Emissions Inventory, as presented in [334]. Two-stroke engines were assumed to lack catalytic converter.

‡ EFs for 2-stroke engines: 7 and 0.06 µg TEQ/ thousand gallons, from UNEP and NMIM, respectively.

§ EFs for 4- stroke engines: 0.06 µg TEQ/ thousand gallons, from NMIM.

¶ Activity in the Watershed assumed to be proportional to $PM_{10}$ emissions by category, as estimated by NYS DEC and NJ DEP.

timates indicate that combustion of residual fuel is the main source of dioxins from off-road sources. Testing emissions from these types of engines and developing emission factors is important to better characterize this sector.

For this sector, the following recommendations are put forth:

- Investigate the effect of cleaner fuels (e.g., ultralow sulfur diesel) on dioxin emissions.
- Better characterize dioxin emissions by testing different types of off-road engines and fuels under varying conditions.
- Develop education programs and outreach to implement the U.S. EPA's recommendations to reduce pollution from boats [331], including:
  - Limit engine operation at full throttle.
  - Eliminate unnecessary idling.
  - Follow the manufacturer's recommended maintenance schedule.
  - Phase out older, dirtier marine engines.

  For marine vessels:
  - Eliminate unnecessary idling and consider the use of "cold ironing" at the port (using electric power instead of relying on the ship engine to provide refrigeration and other functions while the vessel is docked).

### Crematoria

Table C. 23 shows the number of crematoria and cremations in the region, as well as the estimated range of emissions to air and dioxins in residues, based on EFs by UNEP. Dioxin emissions were measured at two crematoria in the US deemed to be representative of facilities nationwide by the Cremation Association of North America (CANA).[284] EFs derived from these tests (as summarized in the draft dioxin inventory [334]) were equal to the lowest one proposed by UNEP. However, all other measurements of dioxins from crematoria in several countries (as summarized in [334]), which include facilities similar to those in the US, were, on average, two orders of magnitude higher, with EFs falling between UNEP's estimates for moderate and no control (see Table C. 23 captions). The reason for this discrepancy is not clear and should be investigated. Therefore, the full range of emissions based on UNEP EFs is presented. Further research should be aimed at providing more representative EFs for cremations. Note that crematoria are subject to "start-up" conditions at the beginning of each cremation, which result in higher emissions (see section on Accidental Industrial Emissions) [299]. Ashes are commonly scattered or kept in a memorial [174], but they are estimated to contain very low amounts of dioxins.

### Measures to prevent dioxin emissions from Crematoria

A new funeral procedure has been developed in Sweden to address the shortage of burial spaces as well as emissions from cremation, including dioxins and mercury (from mercury dental amalgams). This process is known as *promession:* the body is first freeze-dried and pulverized, which reduces the volume (the body is ~70% water), then buried in a shallow grave, where the remains degrade within 6 to 12 months [37].[285] The town of Jonkoping in Sweden is in the process of converting its crematorium into a "promatorium" in order to avoid the cost of installing selenium filters to curb mercury emissions [143]. However, the freeze-drying process is energy intensive.

**Table C. 23. Estimated dioxin emissions from crematoria in the region**

| | Number of crematoria* | Number of cremations* | Emissions to air (g TEQ/yr)† Optimum control | Emissions to air (g TEQ/yr)† Moderate control | Emissions to air (g TEQ/yr)† No control | Dioxins in ash (g TEQ/yr)† |
|---|---|---|---|---|---|---|
| Watershed | 42 | 34,782 | 0.01 | 0.3 | 3 | 0.09 |
| NY + NJ | 80 | 66,086 | 0.03 | 0.7 | 6 | 0.17 |

* Crematoria and cremations in NY and NJ in 2003 from the Cremation Association of North America (CANA) [40]. Watershed numbers were extrapolated by population (54% and 49% of NY and NJ, respectively).

† Emission factors from UNEP Toolkit [350]: optimum, moderate, and no control: 0.4, 10, and 90 µg TEQ/cremation, respectively; dioxins in ash: 2.5 µg TEQ/cremation.

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[284] Tests included burning of a body plus plastic wrappings, clothes, and either a coffin or cardboard and wood [334]. One crematorium was located in California, the other in NY. All US crematoria consist of a primary and secondary combustion chamber. Only one or two use any APCD. The NY crematorium had a scrubber for air pollution control, but dioxin concentrations before the scrubber (which were lower than after) were used to develop the EF [334].

[285] The coffin and body are frozen to –18°C before lowering them into liquid nitrogen at –196°C, which leaves them extremely brittle. A vibrating pad is used to reduce the remains to a powder, and a magnetic field removes all traces of mercury and other metal residues from fillings or hip replacements. Then the powder is dried in a vacuum chamber. Finally, the remains are placed in a biodegradable coffin made from vegetable matter and buried.

**Recommendations**

- Further research to solve the wide discrepancy between emission factors measured in the US and other countries.
- Evaluate new alternatives to cremation, such as promession, to assess costs and possible environmental impacts.

## C.2. Industrial Processes and Products

Table C. 24 summarizes dioxin emissions from industrial production, as well as dioxins associated with product use or disposal. Those sectors that have relatively higher emissions within this category are developed in further detail; the remaining minor sectors are discussed in Appendix C.

The location of several of these industrial facilities in the Watershed, along with regulated waste incinerators is shown in Map 4.

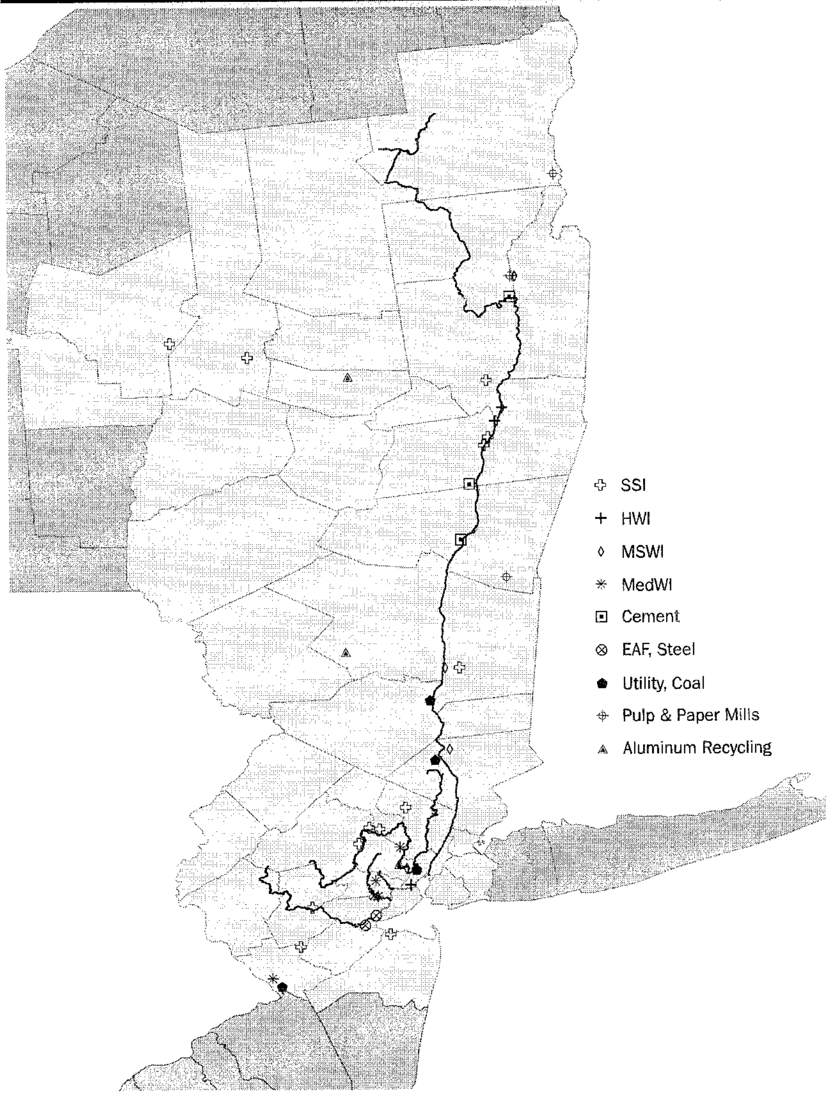
### C.2.a. Metal Production

Primary metal production refers to the processing of ores[286] to obtain metals. These processes vary, but usually involve chemical reduction (by high temperatures and addition of substances such as carbon) and purification processes. The presence of chlorine and carbon or certain metals during these steps favors dioxin formation.[287]

Secondary production refers to the recovery of metals from scrap. Metal recycling has the potential for higher levels of dioxin formation because the scrap metal usually contains paints, oils, coatings, plastics, and other impurities that may provide both chlorine and carbon. In this case, dioxins can be generated during scrap pretreatment to remove these impurities[288] or during metal refining in the furnaces (smelting) [350]. Dioxins may also originate from fuels combusted in the furnaces [175]. In addition, casting operations involve melting and pouring the hot metal into molds. These high-temperature processes can also result in dioxin emissions, depending on the mold material.[289]

Dioxin emissions from metal production are poorly characterized, in part because a large fraction of the emissions are fugitive, and thus they do not come out at a specific smoke stack where they can be measured [175]. Some local evidence of dioxin generation during secondary metal production comes from

**Map 4. Industrial facilities and waste incinerators in the Watershed**



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[286] Minerals that contain some form of the metal.

[287] Copper and, to a lesser degree, iron, lead, and zinc act as catalysts of dioxin synthesis [175].

[288] Thermal pretreatment may involve burning or partial pyrolysis, or drying to evaporate water, if present. Pyrolysis is burning without oxygen, which may suppress formation of dioxins. Drying generally has low potential for emissions, depending on the temperature [175].

[289] Dwain Winters, Dioxin Policy Project, EPA Headquarters. Personal communication, April 20, 2005.

samples collected from Mill Creek, a tidal creek in southwestern Staten Island, where a facility incinerated old electronics to recover metals. This facility is thought to have been directly discharging contaminants to the Creek, because higher dioxin concentrations were measured in the Creek compared to the surrounding Arthur Kill, and the dioxins had a different congener makeup.[290] Mass loadings were not

## Table C. 24. Industrial processes: dioxins in products and residues, and emissions to air, water, and land

| | Emissions to air (g TEQ/yr) | | Dioxins in other vectors (g TEQ/yr) | |
|---|---|---|---|---|
| **Activity or product** | **Watershed** | **NY & NJ** | **Watershed** | **Dioxins associated with:** |
| **a. Metal production** | | | | |
| Secondary iron/steel | 2–4 | 2–5 | 0.2 | residues/ash |
| Secondary Aluminum | 0.06 | 0.4 | — | residues/ash |
| Secondary Lead | 0.03–0.07 | 0.03–0.07 | ? | residues/ash |
| **Total metal recycling** | **2–4** | **3–6** | **0.2** | **residues/ash** |
| **b. Cement** | | | | |
| | **0.3–0.8** | **0.3–0.8** | **0.001–0.2** | **residues/ash** |
| **c. Chemicals** | | | | |
| PVC manufacture | — | 0.0002 | — | — |
| 2,4-D | — | — | 0.5 | land-applied product |
| PCP (during use) | 0.3 | 0.6 | 2 | emissions to land |
| PCP (stock in use) | — | — | 19,357 | poles currently in use |
| PCP (retired poles) § | 0.009–0.04 | 0.02–0.08 | 483 | poles retired annually |
| PCBs (spills/releases) | — | — | 0.2-28 | spills & releases to land † |
| PCBs (stock in use) | — | — | 45 – 4,500 | PCB products in use † |
| **Total chemicals** | **0.3** | **0.6 – 0.7** | **3 - 31** | **various wastes/releases‡** |
| **d. Paper/pulp** | | | | |
| Wood boilers | 0.4 | 0.6 | ? | ash |
| Water effluent | — | — | 0.001 | emissions to water |
| Pulp | — | — | 0.006 | associated with products eventually landfilled, incinerated, or recycled |
| Sludge | — | — | 0.2 | mostly sent to landfills/lagoons* |
| **Total paper/pulp** | **0.4** | **0.6** | **0.2** | **various wastes** |
| **e. Sewage sludge management other than incineration** | | | | |
| Sewage land-applied | — | — | 0.3 | land |
| Sewage landfilled | — | — | 0.9 | landfill |
| Sewage incinerated | — | — | 2 | sludge sent to incinerators¶ |
| Sewage exported | — | — | 9 | sludge sent out-of state |
| **Total sludge** | **—** | **—** | **13** | **sludge generated** |
| **Total industrial processes** | **3 - 6** | **4 - 8** | **16 - 43** | **various wastes/releases†** |

† PCBs in stock and those released annually also contain ~7,400–360,000 and 3–400 g TEQ of dioxin-like PCBs, respectively.

‡ Does not include dioxins in products in use or those associated with retired PCP poles.

§ Emissions to air, assuming that 1–5% of poles given to individuals are burned.

* Approximately 0.005 g TEQ/yr are estimated to be directly applied to land.

¶ For dioxins in air emissions and combustion residues, refer to section on incineration.

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[290] Simon Litten, Bureau of Watershed Assessment and Research, NYS DEC. Personal communication, April 14, 2005.

calculated but are believed to be small.[291] It has been reported that this facility may be no longer operating at this time.[292]

The following sectors are involved in metal processing in the NY/NJ Harbor Watershed: (1) secondary iron/steel, (2) secondary aluminum, (3) secondary lead, and (4) titanium production. The first is described in the next subsection, followed by recommendations. The remaining three represent minor releases. These, along with other metal production sectors associated with dioxin releases not found in the Watershed, are described in Appendix C.

### Secondary Iron and Steel Production

While iron sintering[293] and primary iron and steel manufacturing at foundries[294] have the potential to release dioxins, there are no such facilities in the Watershed region because these are typically located close to areas of mineral ore extraction.

Secondary steel production takes place at "minimills" and "specialty mills," which smelt low-cost raw materials—usually scrap [88]. The ferrous scrap,[295] ingot iron, and/or steel are melted in a furnace. This process combusts impurities in the iron and can result in dioxin emissions,[296] especially when scrap is contaminated with paints, plastics, lubricants, and other organics [350]. The most common type of furnace is the electric arc furnace (EAF).[297] There are 105 plants that use EAFs in the US [88]. In 2002 they produced 47.8 million metric tons (T) of steel [88]. According to the Steel Recycling Institute, the *percentage* of steel produced from recycled postconsumer scrap in the US has remained stable through 2004. However, because total steel production has grown, the *amount* of recycled scrap has increased by ~6.5 million T.[298]

Dioxin emissions from electric arc furnaces (EAFs) depend on the kind of scrap used, pollution controls, and other variables. No testing of dioxin emissions to air has been performed in the US. The average emission factor (EF) from tests in Canada and Germany is 1.21 $\mu$g TEQ/T steel, as presented in the latest U.S. EPA draft dioxin inventory [334]. UNEP suggests EFs of 3 $\mu$g TEQ/T steel for EAFs using clean scrap and some emission controls, and 10 $\mu$g TEQ/T for those using dirty scrap and limited controls.

Steel mills forge or roll the steel into specific shapes. These facilities produced 96.1 million T nationwide in 2003 [88]. Forging requires heating the steel to up to 1,300°C and could potentially result in dioxin emissions.[299]

### Local Emissions

There are two electric arc furnace facilities in New Jersey, within the Watershed, and another one in NY, outside the Watershed (Table C. 25) that process scrap metal.[300] Other facilities in the iron/steel sector do not recycle scrap.[301] Because all three local EAFs are equipped with fabric filters (baghouses),[302] which are considered by the U.S. EPA as the best available control technology, the lower EFs were applied to estimate dioxin releases from these facilities. Steel production, dioxin emissions to air, and dioxins in ash from the three local EAFs are presented in Table C. 25. Only one facility in NJ reported total dioxin air emissions to TRI in 2004, while both facilities had reported in 2003 (Table C. 25). It was not possible to calculate emissions in TEQs because congener distributions were not reported; however, stack tests were available for the EAF in Sayreville. Note that measured emissions are considerably higher than estimates based on EFs or reported to TRI.[303] This discrepancy may arise from the plant not operating nonstop, the fact that TRI emissions may

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[291] Ibid.

[292] Ibid.

[293] For a description of sintering, please see Appendix C.

[294] Blast furnaces are used to convert sinter into pig iron (crude iron), which is further refined into steel or ingot iron. This type of furnace cannot be fed scrap iron. In integrated steel plants, iron ore is smelted to liquid iron in blast furnaces and then refined in basic oxygen furnaces, sometimes together with some scrap, to produce liquid steel. In 2002, 9 companies with 17 integrated facilities produced 45.9 million T of steel in the US [88].

[295] From steelworks, steel product manufacturers (e.g., vehicles), and postconsumer scrap [350].

[296] PAHs and other pollutants may be released as well.

[297] EAFs consist of a cylindrical furnace where metals are fed and carbon electrodes are placed. The current circulating through the electrodes generates heat and melts the metal.

[298] Environmental protection magazine E-news brief of April 21, 2005 (Stevens Publishing Corporation).

[299] "Cold" forging processes are possible, where temperatures may range from room temperature to several hundred degrees [93].

[300] Robert MacDonald, American Iron and Steel Institute. Personal communication, March 4, 2005.

[301] A previous report identified 10 iron and steel production plants [266]. However, many of these are involved in shaping rather than refining the metal.

[302] Information about the plant in NY was obtained from its Title V Permit [203]. For the other two plants, information was provided by Patrick Hennessy, Environmental Manager, personal communication, June 30, 2005; and Paul Eisen, Air Quality Specialist, BE&K, personal communication, July 14, 2005.

[303] Expressed in total mass of the 17 dioxin-like congeners, stack test emissions would amount to ~12 g/yr (not shown in table), which is higher than the 7.95 g reported to TRI.

be estimated rather than actually measured, and/or because EFs are based on a few measurements that might not apply to a particular facility's characteristics.

There are also 3 steel mills and at least 22 iron and steel casting companies within the Watershed.[304] This activity may result in dioxin emissions. In addition, if some scrap—which contains impurities—is melted, it may increase dioxin emissions.

There is not enough information regarding the amount of iron and steel cast at these facilities to directly calculate dioxin emissions but some of the companies report a "monthly melt" value. According to this data, ~36,000 T of metal were cast in 2002 in the Watershed. Assuming that all of this metal is steel or iron is likely an overestimate because this amount probably includes other metals, although data was not available for four facilities. Assuming that ~3 ng TEQ/T are emitted during ferrous casting,[305] ~$10^{-4}$ g TEQ/yr would be emitted to air (0.1 *mg* TEQ/yr). Although emissions to air seem to be low, this estimate is highly uncertain because the activity level is not known, the EF comes from a single sample in New Zealand, and it does not include emissions during the melting of the metal.

### Measures to Reduce and Prevent Emissions from Secondary Iron and Steel Production

Recommendations center on two main areas: (1) avoiding conditions that favor dioxin releases during metal recycling and (2) research to better characterize dioxin emissions from this activity.

Current regulations for **iron and steel** foundries set limits for particulate matter (PM), which likely has the co-benefit of reducing dioxin emissions. This regulation also sets some requirements regarding scrap selection and inspection.[306]

Scrap refined by secondary iron and steel production comes mainly from construction and demolition debris, automobiles, other vehicles and machinery, and appliances.[307] This scrap metal is likely contaminated with chlorinated materials including PCBs (e.g., from small capacitors in old appliances), phenols, and chlorinated plastics such as PVC [364] (e.g., from cars), which remain in the shredder fluff. The 1998 Convention on Long-Range Transboundary Air Pollutants on POPs proposed the elimination of PVC from **copper recycling** as a primary measure to reduce dioxin emissions [349]. Replacing PVC with nonchlorinated materials could aid in the reduction of dioxin emissions from secondary metal smelting, given that this is one of the main sources of chlorine in scrap. Removal of small capacitors could reduce the amount of PCBs in scrap metal. Decreasing the amount of contaminants and impurities in scrap metal reduces dioxin concentrations during combustion, but this measure is often beyond the control of the scrap metal recyclers.

**Table C. 25. Dioxin emissions and steel production by facilty from EAFs**

| | | | Emissions to air | | | | Dioxins in ash (g TEQ/yr)‡ |
|---|---|---|---|---|---|---|---|
| | | Production | (g/year) | (g TEQ/yr)‡ | | | |
| State | County | (T/yr) | TRI EPA | EPA | UNEP | Stack test¶ | UNEP |
| NJ | Middlesex (Perth Amboy) | 647,000 | 19 (2004)§ | 0.8 | 1.9 | | 0.1 |
| NJ | Middlesex (Sayreville) | 556,000 | 8 (2003) | 0.7 | 1.7 | 3.4 | 0.1 |
| **Total, Watershed** | | **1,203,000*** | **27** | **1.5** | **3.6** | | **0.2** |
| NY | Cayuga | 500,000† | | 0.6 | 1.5 | | 0.1 |
| **Total, NY+NJ** | | **1,703,000** | | **2.1** | **5.1** | | **0.3** |

* Harley Scardoelli, Treasurer, Gerdau Ameristeel. Personal communication, June 23, 2005.
† From Nucor webpage: *http://www.nucorauburn.com/Aboutus.htm*. Accessed August 10, 2005.
‡ EFs are as follows: EPA, 1.21 µg TEQ/T; UNEP (air), 3 µg TEQ/T; UNEP (ash), 0.15 µg TEQ/T.
§ Reported emissions in 2003 were 0.18 g.
¶ Assuming the plant operates 24/7. Source: 2003 stack tests.

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[304] Several more casting facilities are located outside the Watershed in NY and NJ. Data from Engineered Casting Solutions, 2002, provided by Susie Harris, USGS. Personal communication, March 8, 2005.

[305] From one air sample taken close to the casting area of a smelting and casting company in New Zealand, an emission factor of ~2.9 ng I-TEQ/T of iron cast was derived [176]. The sample was taken at a small facility with an electric induction furnace for iron and steel and no air pollution control in place.

[306] A summary of applicable regulations is available at *http://www.nyas.org/programs/harbor.asp.*

[307] Smaller sources include food, aerosol and paint cans; drums; and oil filters, which have to be empty or drained. Chip Foley, Vice President, Government Relations, Vice President, Steel Recycling Institute. Presentation during workshop on "Opportunities for Priority Chemical Reduction in the Iron and Steel Sectors" at Villanova University, May 17, 2006. Webcast available at *http://www.engineering.villanova.edu/research/vce/news_and_events/iron_steel.htm.*

### Measures to Avoid Dioxin Releases during Iron and Steel Recycling:

- Pollution prevention practices to prevent the entry of contaminants into EAF such as changes in material specifications and types of raw materials accepted (such as avoidance of oily scrap), improved quality control programs, and programs to prevent the entry of contaminants. For instance, it could be required that metal shredders remove any small capacitors (that may contain PCBs) prior to shredding thereby preventing PCB releases as well as reducing dioxin emissions.
- Certain measures that improve operational and energy efficiency appear to also reduce dioxin emissions [364],[308] such as minimizing the time the roof[309] is open to receive the metal charge:
  - Reducing air infiltration into the EAF; avoiding operational delays; and using fabric filter baghouses for pollution control and ensuring their proper operation by installing bag leak detectors, monitoring off-gas entry temperature, preventive maintenance, and improvement of fabric filter design and material, as well as baghouse operation
- Require metal processing facilities to implement measures to reduce fugitive emissions, such as ensuring that emissions from all processes are captured, and monitoring to detect and repair leaks.
- Proper management of baghouse collected material to avoid the inadvertent release of dust containing dioxins/furans:
  - Transfer dust in enclosed containers.
  - Best environmental practices for the disposal of the collected dust.

### Further Research:

- Regular testing of dioxin emissions at metal recycling facilities, particularly of those that recycle dirty scrap, and installation of APCDs if warranted.
- Quantify and characterize fugitive emissions.
- Measure dioxin emissions at casting facilities.

## C.2.b. Chlorinated chemicals

### PCP-Treated Wood

Pentachlorophenol (PCP) is a wood preservative that is currently used almost exclusively in utility poles. Dioxins are a by-product of PCP manufacture and, thus, are associated with poles in use and those that are taken out of service throughout the Watershed (Table C. 26). However, these dioxins have a low potential to actually reach the Harbor (see discussion in Appendix C). Dioxins are also released to air if poles are combusted (this is a possibility because individuals receiving retired poles may be unaware of, or ignore, the instructions on proper disposal). However, our worst-case scenario estimates suggest that these quantities are very small (Table C. 26). A detailed discussion on PCP and dioxins is provided in Appendix C.

### Products containing PCBs

PCBs were widely used in transformers, capacitors, and other electrical equipment until their production was banned in 1977 [219]. Nevertheless, a significant amount of equipment in use today still contains, or is contaminated with, PCBs [219]. PCB fluids contain low levels of furans, which are a by-product of PCB production. Typical furan concentrations in PCB blends are on the order of 10 $\mu$g/g [265][310] but the TEQ of PCB fluids is mostly due to dioxin-like PCBs.[311] When PCBs are combusted, mostly furans are formed, but mixtures (e.g., Askarel) containing both PCBs and chlorobenzenes produce dioxins as well.[312] In addition to combustion, there is evidence of dioxin-like compounds formation during heating of PCBs, including malfunctioning of electrical equipment. During normal use, arcing[313] is fairly common in transformers; it produces furans.[314] Therefore, all used PCB fluids should be assumed to have dioxins and furans in excess of their original concentrations.

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[308] The reason for this is unclear, but it might be related to maintaining high temperatures during the process and minimizing its duration and associated emissions [364].

[309] This is the top of the furnace, which is opened when scrap is loaded.

[310] Another impurity of PCBs are chlorinated naphthalenes (typically ranging from 5 to 500 µg/g [52]). Naphthalene is an impurity of biphenyl, the raw material that was chlorinated to produce PCBs.

[311] Approximately 89% of the TEQ in a Clophen (a German PCB blend) sample was due to coplanar PCBs [52].

[312] After a fire in Binghamton, NY in 1981 in which Askarel fluid was burned, 2,3,7,8 TCDD was found in soot at levels ranging from 2.8 to 200 ppm, respectively [76].

[313] Arcing is the flow of electricity (as an electric arc) from one conductor to another (in this case, through the PCB fluid).

[314] Simon Litten, Bureau of Watershed Assessment and Research, NYS DEC. Personal communication, April 14, 2005.

**Table C. 26. Dioxin stock and releases associated with PCP-treated utility poles**

| Number of poles & PCP content | Total NY & NJ | Watershed§ | Units |
|---|---|---|---|
| Number of utility poles (all types) (2005) [86,220] | 5,065,220 | 2,599,714 | poles |
| Number of PCP utility poles in service (2005)* | 2,279,349 | 1,169,871 | poles |
| Tons of PCP in utility poles† | 12,217 | 6,271 | T |
| **Dioxins in poles in use†** | **37,715** | **19,357** | **g TEQ** |
| Dioxins released to air during use‡ | 0.6 | 0.3 | g TEQ/yr |
| Dioxins released to soil during use‡ | 3.0 | 1.5 | g TEQ/yr |
| Total dioxin release during use | 3.5 | 1.8 | g TEQ/yr |
| **Dioxins in poles taken out of service per year**** | **940** | **483** | **g TEQ/yr** |
| **Total dioxin release after disposal (burning)** | **<0.08¥** | **<0.04¥** | **g TEQ/yr** |

* In 1995, ~45% of utility poles in the US were treated with PCP, 42% with inorganic arsenicals, and 13% with creosote [86]. It was assumed that these data are representative of the local scenario. A phone survey of local utilities, conducted by the Harbor Project indicated that 57% of them are currently replacing their poles with creosote.[315]

† Pole volume: 0.67 $m^3$; wood contains 8 kg PCP/$m^3$ [72]. Dioxin content in PCP: 4.05 and 0.84 mg TEQ/kg PCP for PCP manufactured before and after 1987, respectively [71]. It was assumed that 30% of the poles contain post-1987 PCP formulation and the remaining 70% contains pre-1987 formulation [72].

‡ EFs to air: $7.8 \times 10^{-9}$ and $3.5 \times 10^{-7}$ g TEQ/pole/yr for post- and pre-1987 PCP formulation, respectively [71]. EFs to soil: $1.3 \times 10^{-6}$ g TEQ/pole/yr for both formulations [71].

§ Utilities servicing the Watershed possess ~51% of all the poles in NY and NJ [220].

** Approximately 1.9% of poles in use [72].

¥ Assuming that 50% of the poles retired yearly are given out to individuals for reuse and that between 1% and 5% are burned. Retired poles are trimmed and weigh ~0.5 T/pole. EF for C&D wood waste was applied: 173 µg TEQ/T wood [126] (worst-case scenario).

### Local estimates

Based on estimated PCB fluids still in use and released in the Harbor Watershed region [219], the amounts of associated dioxins were estimated (Table C. 27). Although the range spans two orders of magnitude and there are uncertainties regarding the amounts of PCBs, this estimate suggests that this is a significant source of dioxins and, even more, of dioxin-like PCBs (Table C. 27). Note that these estimates **do not** account for higher concentrations of dioxins in used PCB fluids.

The majority of estimated PCB releases are associated with small capacitors that are disposed of each year (Table C. 27). Small capacitors containing PCBs can be found in old lamp ballasts, home appliances, and commercial devices that are still in use today and are eventually disposed of [219]. Small capacitors can thus find their way to metal shredders, landfills, or incinerators. At each of these points there is potential not only for PCB oil (and associated dioxins) spills but also for combustion (intentional or accidental) that would release existing and newly formed dioxins, PCBs, and other pollutants. Combustion emissions would be accounted for in other sectors (see sections on metal recycling, waste management–related fires, and incinerators), although available EFs do not necessarily factor in the effect of PCBs.

Recommendations for products containing PCBs have been developed in a separate report: "Pollution Prevention and Management Strategies for Polychlorinated Biphenyls in the New York/New Jersey Harbor" [219]. Please refer to this report for specific recommendations. It should be noted that one product in particular, small PCB capacitors, are a significant dioxin source, and there are currently only minimal regulations on their proper disposal.

### Polyvinyl Chloride (PVC)

PVC or vinyl is a chlorinated polymer used for a wide variety of applications including building materials, pipes, medical supplies, packages, wire insulation, hoses, computer components, car interiors, toys, carpet backing, and furniture [2]. Of the ~6.5 million T of PVC consumed in the US and Canada in 2002, 45% was used in pipes, 30% in construction,[316] 8.5% in consumer goods, 6% in packaging, 5.5% in electrical

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[315] Consolidated Edison of New York (Con Ed), servicing New York City and Westchester, estimates that it has ~210,000 poles in service and a similar number of cross arms, but the proportion of PCP-treated wood is not available. Prior to 1975, only creosote-treated wood was purchased, but these poles would have been mostly replaced by now or are nearing the end of their life span. From 1975 until 1995, the company has used PCP. Since 1996, only wood treated with chromated copper arsenate (CCA) has been purchased for new service and replacements. David Roche, Senior Scientist, EH&S, Consolidated Edison of New York. Personal communication, September 27, 2005.

[316] Siding 15%, doors and windows 6%, profiles 4%, flooring 3%, and 2% other, for a total of 30% in construction applications.

## Table C. 27. Dioxins in PCBs in use and released in the Watershed

| | | | | Dioxins | | Coplanar PCBs | |
|---|---|---|---|---|---|---|---|
| **Application** | **Aroclor fluids** | **PCBs in use (T)** | **PCBs released (kg/yr)** | **in stock (g TEQ)** | **releases (g TEQ/yr)** | **in stock (g TEQ)** | **releases (g TEQ/yr)** |
| Askarel transformers | 1242,1254,1260 | 1,900 | 550 | 28-2,850 | 0.008-0.8 | 7K- 41K | 2-12 |
| Mineral oil transfrmrs.* | 1242,1254,1260 | 18 | 1.5-14 | 0.27-27 | <0.001-0.02 | 0.06K-0.4K | 0.005-0.3 |
| PCB large capacitors | 1016,1242,1254 | 1,000 | 4,200 | 15-1,500 | 0.06-6 | 0.09K -21K | 0.4-90 |
| PCB small capacitors | 1016, 1254 | 60-70 | 6-14 K | 0.9-109 | 0.1-21 | 0.5K-298K | 0.5-298 |
| Carbonless copy paper | 1242 | >12 | ? | 0.18 | ? | 7K-41K | 2-12 |
| **Total** | | **~3,000** | **~(11-19)K** | **45-4,500** | **0.2-28** | **7K- 361K** | **3-400** |

Source: PCB fluids in use and released: Panero et al. (2005) [219]. Mean dioxin concentrations in new Aroclors from UNEP toolkit [350]: Aroclors 1245, 1248, 1254, and 1260: 15, 70, 300, and 1500 mg TEQ/T, respectively. Mean coplanar PCBs in Aroclors from Rushneck et al. [241]: Aroclors 1016, 1242, 1254, and 1260: 0.09, 5.2, 21, and 3.5 g TEQ/T, respectively.
*PCB contaminated.

and electronics applications, and 5% in other applications [2].

PVC resin contains 57% of chlorine by weight and is the major contributor of chlorine to municipal solid waste incinerators, backyard burn barrels, and medical waste incinerators [26]. When PVC is burned, it releases dioxins, PAHs, hydrogen chloride gas (HCl)—which is an irritant, vinyl chloride monomer—a carcinogen, and other toxics [121]. Given the large amounts of PVC used in construction, it is suspected to play a significant role in the toxicity of fumes, particularly in regard to HCl [26].[317]

Dioxins can be generated at several points throughout the life cycle of PVC:

- During PVC production, reportedly low amounts of dioxins are released to the environment, while larger amounts are associated with residues that may end up in landfills or storage lagoons [25].
- Small amounts of dioxins are also associated with the final PVC products, although the rate of migration is believed to be negligible.
- PVC burning: It has been well established that pure PVC emits large amounts of dioxins when burned [23,24,116,146]. Although there is controversy regarding the role of PVC in dioxin emissions when mixed materials are burned, dioxin emissions increase dramatically when PVC is present in concentrations >1% (during uncontrolled combustion of waste) [105,112,116,129]. PVC may burn and contribute to dioxin emissions:
  - While in use, for instance, during structure and vehicle fires.
  - When products are disposed of at the end of their useful life, if burned in approved incinerators, backyard barrels or open fires.
  - In fires during waste management and at landfills.

There is a good deal of controversy regarding the significance of PVC production on dioxin releases to the environment. A study by the UK found that dioxin levels in PVC food packaging were unlikely to significantly affect levels of dioxins in food [348]. The Vinyl Institute, based on data collected from member facilities in the US and Canada, estimated that dioxins associated with PVC resins amounted to 1.6–3 g TEQ/yr in the entire US in 1996 [25]. Emissions from the incineration of wastes in manufacturing facilities were estimated in ~11–31 g TEQ/yr nationwide [25]. Throughout the county, dioxins in wastewater treatment plant solids were calculated in ~12–28 g TEQ/yr, while spent catalyst would amount to another ~7–26 g TEQ/yr [25]. These solids, together with incinerator ash and other residues from this industry, are typically disposed of in "secure" landfills, although at least one facility disposed of its waste water

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[317] Firefighters responding to a fire involving large amounts of PVC were more likely than controls to experience several severe symptoms—including respiratory—that were consistent with exposure to HCl [147,148]. Several firefighters' organizations have expressed concern about the multitude of toxics to which firefighters are exposed when PVC is burned and have requested replacing PVC with other materials. (Letters from various organizations, including the International Association of Firefighters, the Uniformed Fire Officers Association [NYC], the Fire Brigades Union [UK], and the San Francisco Fire Department, were provided by Mike Schade, PVC Campaign Coordinator, Center for Health, Environment and Justice [CHEJ]).

treatment solids by landfarming[318] [25]. About 0.3 g TEQ/yr were estimated to be released in waste water [25]. Greenpeace International estimated that 5 to 10 g TEQ/yr are released to the environment for every 100,000 T of vinyl chloride monomer (VCM) produced [103]. Combining this EF with the ~8 million T of VCM capacity in the US in 2000 [2] results in much higher emissions of almost 400 to 800 g TEQ/yr. Greenpeace based the EFs in values reported by the European industry (which were similar to those measured in North America) but tried to account for fugitive emissions during production [103].

In general, there is skepticism over the actual magnitude of dioxin emissions during PVC production because industries self-report their releases. There are variations among facilities and, in fact, a single facility in the US accounts for 82% of dioxin releases reported to TRI in 2003. About half of the 28 PVC manufacturing facilities in the US reported total releases to TRI of 27,356 g total dioxins in 2003. Of these, the vast majority (94%) corresponded to wastes landfilled or impounded onsite (69% in RCRA landfills). Only 3% were releases to air, and another 3% was otherwise released to land.

Although the focus of this report is on dioxins, other disadvantages or environmental problems are associated with PVC production, use and disposal. These are discussed in Appendix C.

**Local Emissions**

There are three facilities producing PVC resin in the region, all three in NJ, outside the Watershed (Table C. 28). These are nonintegrated facilities,[319] meaning that they produce only PVC and not its intermediaries ethylene dichloride (EDC) or vinyl chloride monomer (VCM).[320] Dioxins in products, wastes, and air emissions from these three facilities are very small (Table C. 29). These plants did not report dioxin releases to TRI, although they reported other releases, including VCM.[321]

The U.S. EPA estimated that 0.02–4.52 g TEQ were associated with PVC products manufactured in the US in 2000 [334].[322] Extrapolating to the Watershed[323] would give 0.001–0.26 g TEQ. The toxicological relevance of dioxins in PVC products is unclear but, unlike additives, these compounds are believed to remain attached to the plastic.

**Table C. 28. PVC manufacturing facilities in NJ**

| Company | City | County | Capacity (T) |
|---|---|---|---|
| Colorite | Burlington | Burlington | 54,432 |
| OxyVinyls | Pedricktown | Salem | 163,296 |
| PolyOne | Pedricktown | Salem | 58,968 |
| **Total** | | | **276,696** |

Source: Ackerman, 2003 [2].

**Table C. 29. Dioxins associated with PVC production in NJ**

| | Emission factor (µg/T PVC) | Dioxins (g TEQ/yr)* |
|---|---|---|
| Air emissions | 0.0008 | 0.0002 |
| Waste water | 0.03 | 0.008 |
| Residues | 0.02 | 0.006 |
| Products | 1 | 0.28 |

Emission factors: UNEP toolkit [350], based only on a study by the Vinyl Institute.
*These values were estimated assuming the three plants produce at capacity.

Dioxins associated with PVC production seem to be low. However, the main concern is PVC combustion during use or disposal. PVC consumption in the US has steadily increased since the mid-1990s (0.9 million T) to 2000 (5.8 million T) [14]. The amount projected for 2005 is 6.4 million T [14]. Extrapolating to the Watershed, almost 0.4 million T/yr would be used locally. Each year in the Watershed, thousands of tons of PVC are estimated to be burned, as materials consumed in structural fires, waste combusted at regulated incinerators, backyard barrel burning, or waste management fires (Table C. 30).

There is significant debate about the specific role of PVC in dioxin levels during combustion when it is mixed with other materials. There seems to be a general consensus that the source of chlorine (organic

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[318] Landfarming, land treatment, or land application, is a technique to degrade hazardous wastes by spreading contaminated materials on soils. The toxics are thus degraded by soil microorganisms. Biodegradation can be enhanced by aeration; addition of minerals, nutrients, and moisture; and/or inoculation of specialized microorganisms.

[319] Dan Ciobanu, Air Compliance, EPA Region 2. Personal communication, April 6, 2005.

[320] PVC production involves several steps: Chlorine gas ($Cl_2$) is produced at chloralkali facilities and is used to chlorinate ethylene (purified from petroleum or natural gas), resulting in EDC. EDC is later converted to VCM, which is then polymerized into raw PVC resin. Finally, the resin is combined with additives and shaped into the final products.

[321] The three PVC manufacturers in NJ released ~14 T of VCM to air in 2002, as reported to TRI.

[322] This does not account for imports.

[323] Watershed population, adjusted for economic activity, is 5.8% of the US total.

vs. inorganic) is far less important than the presence and level of chlorine in the material being combusted [105]. Nevertheless, some scientists argue that when PVC is burned, the levels of dioxins generated are much higher than when the only source is inorganic chlorine [268]. Several controlled laboratory experiments consistently support this hypothesis (as summarized in [268]). In addition, the experiments that fail to establish a link between PVC (or other organochlorines) and dioxin tend to suffer from different design flaws whereby large variations in conditions (usually in large-scale incinerators) are not taken into account and mask the differences between PVC and other chlorine sources [268].[324]

### Measures to Reduce Dioxin Emission from PVC Use and Disposal

Some companies have phased out PVC and replaced it with other plastics or materials in response to consumers' concerns and/or campaigns by environmental groups such as the Center for Health Environment and Justice (CHEJ). The health care sector and some organizations (e.g., Hospitals for a Healthy Environment, Health Care without Harm) have been working with hospitals to replace PVC-containing products with chlorine-free ones. Kaiser Permanente (health care) will phase out PVC wherever possible, and Sacred Heart Medical Center (Eugene, Oregon) is looking to use non-PVC devices in all units of the hospital [48]. Some of the companies that have phased out PVC or are taking steps in that direction include Nike, Microsoft, and The Body Shop. Firestone has replaced PVC roofing materials with thermoplastic polyolefin (TPO). Steelcase, Inc., a furniture maker, aims to eliminate PVC from its products by 2012 [155]. Several local resolutions have been passed in the US aimed at reducing purchases of PVC products because of concerns about dioxins and other toxics associated with its life cycle (e.g., in Marin County, CA; NYC; Oakland, CA; Olympia, WA; San Francisco, CA; and Seattle, WA). There is currently much debate on whether the U.S. Green Building Council should consider PVC as a "green" building material. The Australian Green Building Council and the cities of San Francisco and Boston have all ruled out PVC as a green material. In the state of New York, PVC cannot be counted towards "green building" tax credits, while the NYC building code does not allow PVC pipes in certain types of buildings.

In general, alternative materials (both natural and synthetic) to PVC are available and affordable (Table C. 31). In some cases, the up front cost may be higher than for PVC products, but the life cycle cost is lower. For instance, PVC flooring can be replaced with linoleum, which is initially more expensive but much more durable and cheaper to clean and maintain than PVC flooring. Notably, PVC cannot withstand foot traffic and, therefore, must be coated with protective layers[325] that are removed with chemicals and reapplied periodically. Many hospitals, schools, and public buildings have PVC floors because these institutions have traditionally had shiny floors. Linoleum flooring is not shiny, but the public can be reeducated to accept this fact and weigh it against the many disadvantages of PVC. In addition, increased demand for non-PVC (and chlorine-free) materials would increase their affordability.

Recommendations to prevent or reduce dioxin emissions:

- Replace PVC products with available alternatives.

**Table C. 30. PVC in the waste stream in the Watershed**

| | Waste amount (T/yr) | PVC content | Amount PVC discarded (T/yr) |
|---|---|---|---|
| Barrel burning | 51,331–1,127,907 | ~ 1% | 513–11,279 |
| Structural fires | 18,759–61,125 | ~ 1% | 188–611 |
| Waste management fires | 105–337,500 | ~ 1% | 1–3,375 |
| MSW incinerated | 2,029,890 | ~ 1% | 20,299 |
| RMW incinerated | 3,065 | 5–15% | 153–460 |
| **Total** | | | **21,154–36,024** |

References for amount of waste and PVC content for each sector are provided in the corresponding section.

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[324] Some of the factors that can confound the relationship between chlorine in feed and emissions in full-scale incinerators include: the effect of APCDs, combustion conditions, measurement imprecision, and localized flow stratification [234].

[325] These are associated with health problems in janitorial staff as well as people using the buildings, including hospitals, schools, and public buildings. "Toxins in Construction." Teleconference hosted by INFORM, Inc. February 16, 2005.

**Table C. 31. Alternatives to PVC materials**

| Product | Alternative* | Affordability |
|---|---|---|
| Car components | Polyolefins | Competitive for most uses |
| Blinds | Wood, aluminum | Variable |
| Bottles | HDPE, PP, PET | Slightly more expensive, expected to decrease with higher demand |
| Hard floors | Bamboo, ceramic or recycled glass tiles | Bamboo is comparable. Tiles are more expensive |
| Flooring | Cork, Stratica, Linoleum | Up front cost higher, but 30–50% savings over 20 years |
| Gloves | Nitrile | Competitive in large quantities |
| Medical bags and tubing | Polyurethane, silicon, polypropylene, polyethylene | Variable. Usually competitive in large quantities. Prices expected to decrease as demand increases. |
| Pipes | HDPE, copper, cast iron, vitrified clay, concrete | Higher, but lower labor installation cost |
| Roofing | TPO, EPDM | Comparable |
| Siding | Wood, fiber cement, aluminum | Variable. Durable and low maintenance materials can be less expensive over the lifetime |
| Wallpaper | Natural fiber | More expensive |
| Windows | Wood, aluminum | Variable |

* HDPE, high-density polyethylene; PP, polypropylene; PET, polyethylene terephthalate; TPO, thermoplastic polyolefin; EPDM, ethylene propylene diene monomer. Source: [26]. For a detailed analysis of PVC alternatives see [2].

- Promote environmentally preferred purchases (EPP) that favor nonchlorinated materials.
- Outreach to educate the public about the benefits of PVC product substitution.
- Investigate the impacts of increasing amounts of PVC entering the economy on dioxin emissions, especially in relation to structural, vehicle, and waste management–related fires, and open burning of residential waste. These sectors contain levels of PVC that, if increased, could result in dramatically higher dioxin emissions.

### C.2.c. Sewage Sludge (at Water Pollution Control Facilities)

Sewage sludges contain dioxins which may enter the facility from storm water runoff or wastewater inputs (industrial and residential), or be created at the water treatment plant by microbial activity or chlorination [334]. The major source will vary at different plants, but most dioxins likely represent the "recycling" of dioxins produced elsewhere or contained in products rather than generation at the plant [168]. Dioxin concentrations and congener patterns depend on the type of treatment the plant is using and the district type it serves [168]. Industrial activities are believed to be the largest contributor of dioxins in sludge, because they account for the greatest volume of wastewater and are more likely to have all of the precursors and activities that are known to generate dioxins.

In wastewater from residential areas, the biggest dioxin source may be laundering and bathing water [168]. Several studies have concluded that the presence of dioxin in this wastewater originates in certain dioxin-containing textile dyes and pigments, rather than in the fabrics, detergents, laundry bleach, or the washing process itself [113] (as cited in [334]). Researchers have found that homologue patterns measured in skin were similar to those found in the textiles and differed from those found in other human tissues.[326] Other studies suggest that sources of dioxins in sludge may include deposition from combustion and pentachlorophenol, which has been used as a biocide in the past [232].

We identified four national or regional datasets providing dioxin and coplanar PCB concentrations in sewage sludge (results are summarized in Table C. 32):

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[326] In addition, concentrations in skin decreased with depth. All this evidence strongly suggests direct dermal exposure rather than transport from inside the body.

- A 2001 U.S. EPA survey of 94 municipal wastewater treatment plants in the US analyzed sewage sludge samples as part of the effort to determine the need to regulate dioxin concentrations in sewage sludge applied to land.
- A survey of 180 publicly owned treatment works (POTWs) by the Association of Metropolitan Sewerage Agencies (AMSA) analyzed ~200 sewage sludge samples and found virtually identical mean concentrations, except that samples corresponding to POTWs in U.S. EPA Region 2 tended to have higher concentrations *when including dioxin-like PCBs* [8].[327] At least part of the reason for the higher TEQs is that Port Richmond POTW receives wastewater from a pigment manufacturer that inadvertently produced PCBs (it is no longer manufacturing this pigment), while another POTW receives Port Richmond sludge for dewatering.[328]
- NYS DEC analyzed sewage sludge samples from 12 NYC POTWs after September 11, 2001. Dioxin mean concentrations were similar to those found in the two studies mentioned above, although when dioxin-like PCBs were included, the mean concentrations were substantially higher.[329]
- NJ DEP analyzed sewage sludge samples from several NJ POTWs suspected to have elevated dioxin concentrations, among those whose sludge would eventually be land-applied.[330] Therefore, these samples are biased high and may not be representative of all NJ POTWs. In addition, the dataset was small, and the limit of detection was high, resulting in many nondetects for PCBs.[331] For these reasons, these data were **not** used to estimate dioxins in locally produced sludge.

The average of the U.S. EPA, AMSA, and NYS DEC datasets was used to estimate dioxins in local sludge, while NYS DEC data was used for coplanar PCBs. The NJ DEP dataset was excluded because it targeted specific POTWs and was not comparable to the rest of the data.

### Local Emissions

In 2004, ~320K dry T of sewage sludge were generated in NY state by 584 POTWs, with ~260 facilities in the Watershed generating ~180K T in the same year (57% of the state total) Table C. 33 [215].[332] Of the 350K T of sludge, ~49% was "beneficially used," 25% incinerated, 25% landfilled, and 1% otherwise managed [215]. Beneficial uses include heat drying to pelletize the sludge for use as a fertilizer, composting, direct land application, and chemical stabilization, representing 37, 24, 20, and 19 %, respectively, of the 170K T sludge/yr that is processed for use [215]. It is estimated that ~23% of this sludge (~40K T/yr) is actually used in NY State. Of the landfilled sludge, ~54% goes to NY landfills:

## Table C. 32. Dioxin-like compounds in sewage sludge

| Dataset | Geographical area | Dioxins and coplanar PCBs in sludge (pg TEQ/g)<br>CDD/Fs | Coplanar PCBs | CDD/Fs & PCBs |
|---|---|---|---|---|
| U.S. EPA | US | 33.8 | 9.8 | 43.6 |
| AMSA | US | 38.4 | 10.1 | 48.5 |
| NYS DEC | NYC | 34.5 | 32.1 | 66.6 |
| NJ DEP* | NJ | 44.3 | 19.2 | 63.5 |

Sources: U.S. EPA [316], AMSA Survey [8], Simon Litten, Bureau of Watershed Assessment and Research, NYS DEC. Personal communication, April 13, 2005. Anthony Pilawski, NJ DEP. Personal communication, February 28, 2006.
* Assuming nondetects are present at 1/2 the detection limit. This dataset is biased high and is not comparable to the other three (see discussion above).

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[327] Data for each specific POTW is not available to protect the anonymity of the facilities.

[328] Although the pigment manufacturer was inadvertently releasing mainly PCB 11 (which has no dioxin-like properties), two minor congeners (PCB 77 and 126) were significantly contributing to the TEQ by virtue of their toxicity (Simon Litten, Bureau of Watershed Assessment and Research, NYS DEC. Personal communication, January 24, 2006). TEFs for mammals for PCB 77 and 126 are 0.0001 and 0.1, respectively. For more details on inadvertent PCB production by pigment manufacturing, see the NYAS report on PCBs [219]. This particular pigment manufacturer has closed the production line that generated PCBs, after which effluents from the plant showed a decrease in PCBs. It is likely that PCBs in sludge at the Richmond POTW have also decreased (Lily Lee, Acting Section Chief, Regulatory Planning Section, Bureau of Wastewater Treatment. Personal communication, January 13, 2006).

[329] Data provided by Simon Litten, Bureau of Watershed Assessment and Research, NYS DEC. Personal communication, April 13, 2005.

[330] Anthony Pilawski, Bureau of Pretreatment and Residuals, NJ DEP. Personal communication, April 11, 2005.

[331] Thus, data is greatly affected depending on whether nondetects are regarded as zero, 1/2, or the full detection limit.

[332] This report covers POTWs only. Privately owned water treatment plants are not required to report to NSY DEC but are usually very small.

26 municipal solid waste landfills that accept biosolids and one monofill [215]. Six of these landfills, accepting ~6.2K T/yr, are located within the Watershed. Compared to the late 1980s and early 1990s, there has been a trend of increasing the proportion of sludge beneficially used and decreasing that landfilled, while incineration remained about the same. Most of the sludge generated in New York City is sent out of state. Outside New York City, any direct land application of sludge (typically generated by small POTWs) is mostly local because of high transportation costs.[333] These POTWs may give the sludge away to small farms or local residents. Very small amounts of sludge may be imported from other states.[334]

In NJ, ~230K dry T of sewage sludge were generated in 2003 by 343 waste water treatment plants (Table C. 33) [190]. A small portion of this sludge was generated by privately owned facilities that hold a NJ permit.[335] Approximately 27% of the sludge was incinerated, 16% processed for beneficial use in state, 43% was processed out of state, another 6% was disposed of out of state, and the remaining (~8%) was applied as landfill cover in NJ [190]. The ~100 waste water treatment plants within the Watershed generated ~170K T of sludge (or 73% of the state total) in 2003 [190].[336] A large amount of the sludge processed in NJ for use is locally applied.[337] As in NY, a small amount may be imported from other states, mainly from Philadelphia.[338]

The amounts of dioxins associated with sludge generated in the region, landfilled, and land-applied are summarized in (Table C. 33). Coplanar PCBs are estimated to contribute to toxicity in sludge in amounts similar to dioxins. The only two management modes that may result in releases to the Harbor are land application and landfilling/landfill cover. However, the amount of dioxins associated with this sludge are relatively low, and it was estimated that their potential to reach the Harbor is medium-low.

Dioxin concentrations in untreated soils range from 0.003 to 186 ng TEQ/kg (ppt), while those for soils treated with sewage sludge are 1.4–15 ng TEQ/kg [233]. Average sewage sludge concentrations measured by the U.S. EPA and AMSA are within the untreated soil range but higher than treated soils. A proposed standard limiting dioxins to 300 ppt TEQ in land-applied sludge was evaluated by the U.S. EPA[339] but the

**Table C. 33. Amounts and fate of sludge generated in NY and NJ and associated dioxins**

| | Amount of sludge (T/yr) | | | Dioxins in sludge | Coplanar PCBs in sludge |
|---|---|---|---|---|---|
| | NY (2004) | NJ (2003) | Total NY+NJ | (g TEQ/yr)¶ | |
| Land applied†* | 521 | 9,283 | 9,804 | 0.3 | 0.3 |
| Landfilled/landfill cover* | 8,351 | 18,009 | 26,361 | 0.9 | 0.8 |
| Incinerated‡ | 31,997 | 34,608 | 66,605 | 2 | 2 |
| Exported§ | 142,255 | 107,413 | 249,668 | 9 | 8 |
| **Total, Watershed** | **183,125** | **169,313** | **352,438** | **13** | **11** |
| **Total, outside Watershed** | **137,353** | **64,021** | **201,374** | **7** | **6** |
| **Total, Whole State** | **320,477** | **233,335** | **553,812** | **20** | **18** |

Sources: NYS DEC (2004) [215], NJ DEP (2003) [190].

* Only these vectors are considered to have some possibility (albeit low) to reach the Harbor.

† Assuming that all land-applied sludge generated within the Watershed was applied within the Watershed.

‡ Some might be sent out of state.

§ Landfilled, beneficially used, or otherwise managed.

¶ Mean concentration: 36 and 32.1 ng TEQ/kg sludge for CDD/Fs and coplanar PCBs, respectively.

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[333] Sally Rowland, Recycling & Biosolids Management Section, NYS DEC. Personal communication, April 11, 2005.

[334] Ibid.

[335] Facilities that do not hold a permit for land application typically take the sludge to one of the bigger treatment plants. Anthony Pilawski, Bureau of Pretreatment and Residuals, NJ DEP. Personal communication, April 11, 2005.

[336] This amount includes sludge generated by privately owned water treatment plants that are required to report to NJ DEP. However, these facilities represent ~2% of the total sludge.

[337] Class A beneficial use sludge includes composting and pelletizing. A large percentage of this sludge is used locally but can also be exported as far as Canada. Class B sludge is land-applied locally in southern NJ. Anthony Pilawski, Bureau of Pretreatment and Residuals, NJ DEP. Personal communication, April 11, 2005.

[338] Some companies commercialize composted sludge, which is sold in retail stores. Ibid.

[339] In 2001, it was established that no regulations were needed for sludge that was incinerated, landfilled, or placed in containment ponds because current regulations were enough to protect the general population [312].

agency decided a regulation was not necessary, based on apparent declining trends of dioxins in sludge and the increases in cancer incidence expected from land application of sludge, as calculated in the risk assessment[340] [319]. However, a 2004 review of studies that had measured dioxin concentrations before and after sludge application found that, on average, sludge increased soil dioxin levels ~7 times [233]. This review concluded that sewage sludge application to agricultural soils may have a slight impact on dioxin levels in most food and forage crops, but the impact on animal tissue levels is likely much greater [233]. They also identified gaps in available data and indicated the need for more controlled studies measuring the effects of sewage sludge application on dioxin levels in food [233].

### Measures to Reduce Dioxin Emissions Associated with Sewage Sludge

Air dioxin emissions related to the management of sewage sludge at incinerators have been discussed in the combustion section. The current section focuses on sewage sludge management other than combustion. Preventing dioxins at the primary source from discharging to waste water treatment plants has the following benefits:

- It reduces dioxin concentrations in sewage sludge and, consequently, loadings to soil. It could eliminate the concern about applying sewage sludge to agricultural fields.
- It decreases waste water and sludge[341] effluent concentrations, reducing loadings to nearby water bodies.

Specific recommendations include:

- Provide funding to undertake track-down projects (for a range of contaminants) to identify primary sources to POTWs:
  - Monitor influents and effluents to waste water treatment plants in regions where higher dioxin concentrations have been found in sludge.
  - Consider integrating industrial ecology principles to track-down efforts.
- Work with pertinent agencies to limit the allowable residual dioxin found in garments and fabrics with dioxin-containing dyes, pigments, and pesticides.
- Consider incentives for industry involved in pollution prevention and source reduction efforts leading to "zero emissions discharge" (ZED) for wastewater discharges, including dioxin and other persistent bioaccumulative toxics (PBTs).

## C.3. Historical sources

Ongoing sources of dioxins to air identified to date account for 10–25% of this contaminant's estimated global deposition from the atmosphere [260,334]. The remainder is believed to be associated with historical sources—dioxins that have been released in the past and are now being remobilized [28]. These historical sources include contaminated sites, sediments, and landfills. In addition, it is possible that some major sources have not yet been identified.

### C.3.a. Contaminated Sites in the Watershed

Previous NY/NJ Harbor studies on PCBs and cadmium indicate that historical contaminated sites in the Harbor watershed may continue to be sources of these contaminants to the present [16,21,219]. Dioxins are no exception to this pattern. Numerous Superfund, brownfield, and contaminated sites in the Watershed that are contaminated with dioxins are either known, or have the potential, to be sources of dioxins to the air, water, and sediments of the Harbor (see Map 5). The National Priorities List (NPL) identifies 18 dioxin-contaminated sites in the Watershed region (2 in NY and 16 in NJ).[342] Remedial measures (by removal or containment of the contaminated materials) have taken place in at least four of these sites. In addition, other sites contaminated with dioxins have been identified in NJ through the New Jersey Phase I and Phase II Dioxin Study conducted in 1983 and 1985, respectively.[343] Although many of these sites have been remediated, residual dioxin contamination may remain.[344]

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[340] An additional 0.003 cases/yr for the most exposed population (people using sludge as a fertilizer for crops and animal feed and consuming their own products). Incidence on the general population is expected to be lower [319].

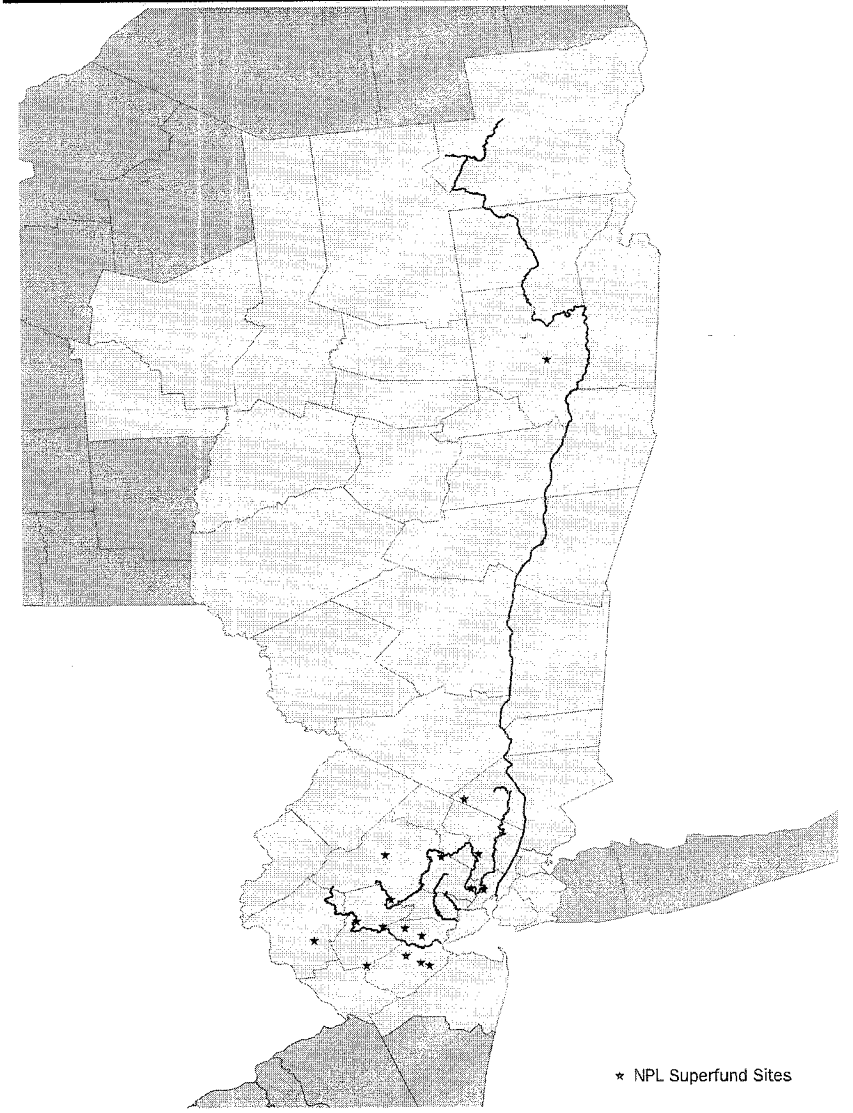
[341] During wet weather events, some sludge may be discharged in the effluent.

[342] One of these sites (W A Cleary) is not listed in the NPL list. Information was provided by Anne Hayton, NJ DEP.

[343] Anne Hayton, Technical Coordinator, Bureau of Environmental Evaluation and Risk Assessment, Site Remediation Program, NJ DEP. Personal communication, March 6, 2006.

[344] Jon Josephs, Hazardous Substances Technical Liaison, U.S. EPA Region 2. Comments submitted on Aug. 12, 2005.

## Map 5. Dioxin-contaminated Superfund sites in the Watershed



Addresses from NPL list.

Table C. 34 shows all the dioxin-contaminated sites we have been able to identify. Data has not been updated to confirm the current status (vis-à-vis remediation) of sites shaded in gray.[345]

Currently, there are no estimates of the importance of all these contaminated sites to the overall inputs of dioxins to the Harbor, although the individual contribution of certain sites (e.g., the Diamond Alkali Superfund site) has been better characterized and is described below.

It is very difficult to determine the amount of toxics that are re-mobilized from contaminated sites to the environment. Relevant pathways for land sites include soil runoff and transport by wind, leaching to groundwater, and volatilization.[346] For contaminated sediments, remobilization may involve desorption from sediments into the water column; resuspension of settled sediments; and dredging and disposal of contaminated sediments.

At least one initiative has modeled contributions from on-land contaminated sites to runoff. This model was developed by the Delaware River Basin Commission to estimate the amount of PCBs reaching the Delaware River from contaminated sites runoff using the Universal Soil Loss Equation (USLE) (see Box 7). Although there is great uncertainty in the estimated loads, this attempt can give an idea of the order of magnitude of the inputs. A similar approach was followed for the NY/NJ Harbor Watershed to estimate dioxin runoff.

Soil runoff for three sites in the Watershed was estimated using software that applies a revised version of USLE (RUSLE 2, see Box 7).[347]

Table C. 35 shows suspended solids delivery (i.e., the amount of soil detached and transported to the end of the slope) and dioxins mobilized by runoff. Estimated dioxin releases from these three sites are significant and put in perspective the potential impact that the tens of contaminated sites may have collectively. If the necessary data were available, applying RUSLE2 to all these sites could refine the overall picture. It should be noted that RUSLE2 calculates soil delivery at the end of a slope. The amount that actually reaches a given water body will depend

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345. Information posted online for Superfund sites was reviewed but was often found to be outdated. Several site managers were contacted, and a few were able to provide further data. Additional facts were obtained for a handful of sites by reviewing files requested through the Freedom of Information Act (FOIA) and Open Public Records Act (OPRA).

346. Given the low vapor pressures and water solubility of dioxins, volatilization and leaching are likely negligible pathways, although leaching can be enhanced under certain conditions such as presence of organic liquids (see section on Fate and Transport).

347. We received assistance from Tibor Horvath (Conservation Agronomist, USDA Natural Resources Conservation Service) to select the appropriate input parameters for the program.

## Table C. 34. Known dioxin-contaminated sites in the Watershed

| Name | City | State | County | Type of site | Notes |
|---|---|---|---|---|---|
| Niagara Mohawk Power Corp | Saratoga Springs | NY | Saratoga | NPL | |
| Ramapo Landfill | Ramapo | NY | Rockland | NPL | |
| American Cyanamid Co | Bound Brook | NJ | Somerset | NPL | |
| Asbestos Dump | Millington | NJ | Morris | NPL | |
| Brook Industrial Park[a] | Bound Brook | NJ | Somerset | NPL | Remediated. (Blue Spruce International is part of this site). Levels were ~100 ppb TCDD. |
| Caldwell Trucking Co. | Fairfield | NJ | Essex | NPL | |
| Chemical Insecticide Corp.[a] | Edison | NJ | Middlessex | NPL | Remediated |
| Chemsol, Inc. | Piscataway | NJ | Essex | NPL | |
| Curcio Scrap Metal, Inc. | Saddle Brook Twp | NJ | Bergen | NPL | |
| Diamond Alkali* (land site only)[a,b] | Newark | NJ | Essex | NPL | Enclosed in concrete (all sides and cap). Groundwater is pumped, treated, and discharged to Passaic. Levels were 50,000 ppb TCDD. |
| Dover Municipal Well | Dover Township | NJ | Morris | NPL | |
| Evor Phillips Leasing | Old Bridge Township | NJ | Middlesex | NPL | |
| Fried Industries | East Brunswick Township | NJ | Middlesex | NPL | |
| Global Sanitary Landfill | Old Bridge Township | NJ | Middlesex | NPL | |
| Higgins Farm | Franklin Twp | NJ | Somerset | NPL | |
| Myers Property[a] | Flemington | NJ | Hunterdon | NPL | Remediated to <1 ppb TCDD. |
| PJP Landfill | Jersey City | NJ | Hudson | NPL | |
| W A Cleary[a] | Edison | NJ | Middlessex | NPL | ~ 35 ppb TCDD |
| Atlantic Resources, Inc.[a] | Sayreville | NJ | Middlessex | NJ DEP | Dioxin levels <1 ppb, not considered dioxin site. No remedial action. |
| Bayonne Barrel and Drum[c] | Newark | NJ | Essex | NJ DEP | 20–900 ppb TEQ |
| Brady Iron and Metals[a] | Newark | NJ | Essex | NJ DEP | Remediated to <20 ppb at the most. Level not available but likely was 100–200 ppb TCDD. |
| Economics Laboratory[a] | Avenel | NJ | Middlessex | NJ DEP | 20 ppb remediated to <1 ppb. |
| Givaudan Chemical[a] | Clifton | NJ | Essex | NJ DEP | Remediated (excavated and placed in on-site "vault"). Levels used to be ~63ppb TCDD. |
| Pratt-Gabriel Company[a] | Paterson | NJ | Passaic | NJ DEP | Remediated. Was 39 ppb TCDD. Capped in place but NJ DEP needs to return and check. |
| Prentiss Drug & Chemical (a.k.a. Albert Steel Drum)[a] | Newark | NJ | Essex | NJ DEP | Remediated: Levels were ~248 ppb TCDD. Removed and capped, currently up to 20 ppb below cap. |
| Rockland Chemical[a] | West Caldwell | NJ | Essex | NJ DEP | 1.3 ppb remediated to < 1 ppb |
| Schnitzpahn Garden Center[a] | Greenbrook | NJ | Middlessex | NJ DEP | Remediated. Levels were <50 ppb. Dioxins contained in shed. |
| Sherwin Williams | Newark | NJ | Essex | NJ DEP | |
| Standard Chlorine[a] | Kearny | NJ | Hudson | NJ DEP | 60 ppb TCDD. Has open soil and lagoons w/ dioxins. |
| US Metals & Refining | Carteret | NJ | Middlessex | NJ DEP | Re-developed. No contaminated soils are exposed.[d] |

Sites were identified by querying the National Priorities List (NPL) for all sites in NY and NJ, and through personal communication with Jon Josephs, Hazardous Substances Technical Liaison, U.S. EPA Region 2. Sources of additional information: [a]Anne Hayton, Technical Coordinator, Bureau of Environmental Evaluation and Risk Assessment, Site Remediation Program, NJ DEP; [b]Alice Yeh, Project Manager, Emergency and Remedial Response Division, EPA Region 2; [c]Jim Kealy, Technical Coordinator, NJ DEP; [d]Paul Harvey, Case Manager, NJ DEP.

* This site also includes contaminated sediments in the Passaic River and Newark Bay.

## BOX 7: USING USLE TO CALCULATE DELIVERY OF CONTAMINANTS ATTACHED TO SOIL IN RUNOFF

The Universal Soil Loss Equation (USLE) is an empirical equation that allows predicting average annual soil loss by runoff based on a series of parameters that take into account soil and site characteristics:

$$Soil\ Loss = R \times K \times LS \times C \times P,$$

where R = rainfall erosivity factor (a measure of the extent to which rain will cause soil particles to detach and move that depends on rain intensity, quantity, and duration at a given location); K = soil erodibility factor (measure of the soil's susceptibility to erosion, varies with soil texture, organic matter, and other characteristics); LS = topographic factor (combines the effect of slope steepness and length); C = surface cover factor (takes into account whether the soil is protected by vegetation or other covers); P = management factor (accounts for practices that attenuate soil loss such as terraces or vegetated strips).

This equation was originally proposed in the 1970s; the factors were based on empirical observations. The equation and factors have since been refined, and software has been developed that handles the increasingly complex calculations. The latest version is RUSLE2 (Revised USLE). This tool is commonly used in conservation planning. For instance, the software allows calculating and comparing soil loss for a given location (usually agricultural land) under different scenarios to determine what set of management practices will be most effective in reducing erosion to acceptable limits. These management practices include different crop rotations, crop row orientation, and reduced tillage.

RUSLE2 software and databases for different geographical areas are available for download at the USDA-ARS National Soil Erosion Research Laboratory, Purdue University website (*http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm*) along with training materials. These databases contain the information that the program needs to calculate the different factors in the equation based on the geographical region and site attributes.

The amount of dioxins (or other contaminants) mobilized annually by soil runoff from a given site or area can be calculated as:

$$Dioxins\ in\ Runoff = Soil\ Loss \times Contaminated\ Area \times Dioxin\ Concentration\ in\ Soil$$

on the proximity, presence, and discharge location of catch basins; whether there are any barriers to contain runoff; and other site characteristics. The Bayonne site is located ~1,800 ft from the Passaic River. Several storm water catch basins (simple conduits for storm water and suspended particles) collect surface runoff. The exact discharge locations are unknown, but it is possible that they empty directly or indirectly into drainage ditches that are connected to the Passaic River.[348]

The Standard Chlorine site is located within the floodplain of the Hackensack River [54]. Surface runoff is collected in a ditch that runs along the site and discharges into the river [54]. The plant disposed of some of its wastes in two lagoons located in a small area next to the river, ~3 ft above its level. The sediments in the lagoons contain ~60 ppb of TCDD [54]. Soil around the lagoon had detectable levels of TCDD (0.52 ppb) [54].[349] Soil along the ditch collecting runoff from the lagoon area had TCDD at the ppt level and total TEQs of 1–2 ppb,[350] suggesting that either dioxin concentrations around the lagoon were actually higher or that some of the lagoon contamination was reaching the ditch. The runoff model was applied

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[348] A dye study will be conducted to determine the exact discharge location. Sediments and fish have reportedly been seen in these catch basins, indicating a potential connection to close-by drainage ditches that lead to wetlands and, eventually, the Passaic River. (Jim Kealy, Technical Coordinator, NJ DEP. Personal communication, January 30, 2006).

[349] Dioxins were below the detection limit in five out of six samples, but these were recognized to be biased low [54].

[350] Data was part of site files provided through an OPRA request.

only to soils around the lagoons (~25% of the whole site), assuming 0.52 ppb TCDD and extrapolating other congeners according to the ditch samples.[351] This estimate does not include dioxins that may be carried with lagoon sediments mobilized during heavy rain events or flooding. In addition, this site contains many other contaminants including PCBs, PAHs, and chromium (Cr).[352]

The Sherwin Williams site, located by the Passaic River, comprises two small areas with dioxin contamination. These areas are surrounded by vegetated sections that may intercept dioxins in runoff.

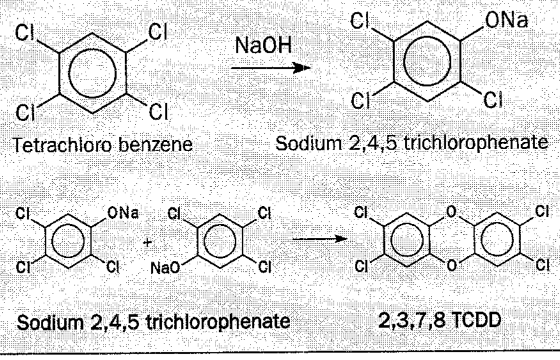
Because furans are always present in PCB fluids, PCB-contaminated sites are also expected to be sources of dioxins to the Harbor, and even larger sources of dioxin-like PCBs. Preliminary calculations presented in our previous report [219] suggest that PCB remobilization from contaminated land sites in the Watershed can potentially contribute large amounts of PCBs to the Harbor[353] and therefore also contribute dioxins.

### Diamond Alkali Superfund Site[354]

The Diamond Alkali Superfund site, one of the most heavily dioxin-contaminated sites in the country, is located within the NY/NJ Harbor. The manufacture of phenoxy herbicides at 80 Lister Avenue in Newark, NJ (next to the Passaic River) started before 1951, when Kolker Chemical owned and operated the site.[355] From 1951 to 1969, the Diamond Alkali Company (later known as Diamond Shamrock Chemicals Company) manufactured phenoxy herbicides and other chemicals: The facility produced DDT and sodium 2,4,5-trichlorophenate, which was then used to synthesize 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Dioxins, especially 2,3,7,8 TCDD, were generated as an unwanted by-product of this process, as shown in Box 8. Until 1969, an estimated 800 tons of 2,4,5-T were produced per year [17]. A mixture of 2,4,5-T with 2,4-D was widely used in the middle of the 20th century, especially as a defoliant during the Vietnam War and, to a lesser extent, the Korean Wars. The drums containing herbicides were marked with a

### BOX 8

These figures show how sodium 2,4,5-trichlorophenate (an intermediary in 2,4,5-T synthesis) is produced, and the side reaction that leads to 2,3,7,8 TCDD formation. At temperatures >150°C, dioxin formation greatly increases. Reaction temperatures at the plant fluctuated, but often reached 180°C [247].



### Table C. 35. Dioxins remobilized from selected contaminated land sites

| Site name | Area (acres) | Soil loss (kg/acre/yr)† | Dioxin concentration (μg TEQ/kg)‡ | Dioxins in runoff (g TEQ/yr)[356] |
|---|---|---|---|---|
| Bayonne Barrel & Drum | 16 | 1,996 | 20–900 | 1–9 |
| Standard Chlorine | 5.6 | 6,260 | 94 | 3 |
| Sherwin Williams | 0.4 | 5,080 | ~6–11§ | 0.006 |
| **Total for the 3 sites** | **22** | | | **3–12** |

† From RUSLE2.

‡ Bayonne site: 17,000 cubic yards of soil contain 20 ppb TEQ while ~6,000 cubic yards contain >80 ppb. The maximum concentration is 900 ppb. Based on this, it was assumed that 74% of the site has dioxin concentrations ranging from 20 to 80 ppb and 26% of the site has 80–900 ppb.

§ Mean at each of two areas with dioxin contamination.

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[351] Four samples taken from the ditch had virtually the same concentrations and congener profiles.

[352] The site is covered by 5–10 feet of fill containing Cr-laden slag, a residue of Cr purification at an adjacent facility [54].

[353] The mass balance for dioxins has determined that coplanar PCBs account for ~40% of the dioxin-like compounds (expressed in TEQs) entering the Harbor from the Hudson River (See Appendix A). This River accounts for ~20% of the coplanar PCBs entering the Harbor in a TEQ basis, while NJ Rivers, water treatment plants, CSOs, and runoff (which may include contributions from land-contaminated sites) explain another 70%.

[354] The information in this description is taken from: NJ DOH (1995 and 1996) [169,170] and EPA (1984) [292].

[355] Jon Josephs, Hazardous Substances Technical Liaison, U.S. EPA Region 2. Comments submitted on August 12, 2005.

[356] This total amount of dioxins in runoff includes 0.02 g/yr TCDD; 0.6–5 g/yr TCDF; and 1–4 g/yr of PeCDF for the two sites combined. These congeners are driving toxicity in biota in the NY/NJ Harbor.

color-coded stripe to identify the mixtures. The color code gave the defoliants their common names, Agent Orange, Agent Purple, etc.

The production processes typically resulted in herbicide containing 0.5 to 65.5 ppm of 2,3,7,8-TCDD [259].[357] Dioxins, including 2,3,7,8-TCDD, are significant contaminants in soils at and near the former Newark plant (which are now contained at 80 and 120 Lister Avenue), in the sediments of the Passaic River near the facility [17], and have spread to other areas of the River and the surrounding Harbor. A nearby facility, Brady Iron and Metals, used to recycle metals from materials received from Diamond Shamrock. This operation resulted in dioxin concentrations in soils of 100–200 ppb 2,3,7,8 TCDD. This contaminated site has since been remediated.

In 1960, the Diamond Alkali plant closed due to an explosion in the trichlorophenol reactor, which released 2,3,7,8 TCDD and other toxics.[358] The plant reopened in 1961 after new buildings and a reactor were added. In 1967, the plant was expanded to increase capacity, and a carbon column was added to remove dioxins from the trichlorophenol.[359] Air emissions at this plant were not controlled until 1963, when a caustic scrubber was installed for acid emissions [247]. Most water discharges were piped to the Passaic Valley Sewerage Commission, although several spills into the Passaic River were reported [247]. Production ceased in 1969. Small amounts of 2,4-D and other chemicals were produced until 1977 by Chemicaland, who was the next owner of the site and used the existing equipment.

The plant remained idle until 1981, when Marisol purchased the site. Diamond Shamrock Chemicals Company acquired the 80 and 120 Lister Avenue properties in 1986 and 1984, respectively. Subsequently, Occidental Chemical Corporation purchased the Diamond Shamrock Chemicals Company, but Diamond Shamrock Chemical Land Holdings, another subsidiary of Diamond Shamrock Corporation, retained ownership of the Lister Avenue sites. Tierra Solutions, Inc., an affiliate of the successor to the company from which Occidental purchased Diamond Shamrock Chemicals, is performing the environmental work pursuant to the company's indemnity obligation to Occidental.[360]

In the early 1980s, it was discovered that the surrounding soils were heavily contaminated with dioxins (ranging from 60 ppb to 51,000 ppb). Dioxins were also found in sediments of the Passaic River, and in September 1984, this site was added to the National Priority List (NPL). The following areas are currently included in the Diamond Alkali Superfund site:

- Properties at 80 Lister Avenue (3.4 acres) and 120 Lister Avenue (2.2 acres) in Newark, NJ
- The study areas of the Lower Passaic River Restoration Project (consisting of the 17-mile tidal portion of the Lower Passaic River from the Dundee Dam to the river mouth at Newark Bay and tributaries)
- The Newark Bay Project (consisting of all of Newark Bay and portions of the Hackensack River, Arthur Kill, and Kill van Kull) [292].

In 1987, EPA selected an interim remedy for the land site consisting of: (1) construction of a flood wall and slurry wall surrounding the properties; (2) installation of a cap over the properties to contain both the contaminated soils and the contaminated materials that were stored at 120 Lister Avenue; (3) pumping and treating of groundwater to reduce contaminant migration.

On-land remediation started in 1995. Construction began in April 2000 and was completed in December 2001. Sampling on- and off-site[361] was conducted by the U.S. EPA, and subsequent cleanup (e.g., soil removal, road vacuuming) of off-site land contamination resulted in approximately 79,000 cubic yards of contaminated material being stored in shipping containers at 120 Lister Ave. Dioxin, pesticides, volatile organic compounds, and other hazardous substances were found in the groundwater at this location. The 80 and 120 Lister Avenue sites are secured with a fence and 24-hour security.

The contaminated portion of the Passaic River has not yet been remediated. In 1994, Occidental Chemical Corporation signed a consent agreement to con-

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[357] According to other accounts, most 2,4,5-T formulations in the 1960s typically contained less than 0.2 ppm of 2,3,7,8 TCDD, while some formulations dating from 1966–1970 contained more than 10 ppm [232].

[358] Other accidents in which temperature and pressure in the reactor run out of control, causing safety devices to blow, occurred on a number of occasions previously. It was know that this reaction could cause explosions [247].

[359] Report on Lister Avenue Facility. Letter from J B Worthington (Director of Environmental Affairs, Diamond Shamrock) to Michael Catania, NJ DEP. June 10, 1983.

[360] Elizabeth Butler, Remedial Project Manager, U.S. EPA Region 2. Personal communication, July 2006.

[361] For example, transportation routes and streets, public areas, homes, air filtration systems in nearby buildings.

duct a Remedial Investigation/Feasibility Study (RI/FS) of the 6-mile stretch of the Passaic River to determine: (1) the distribution of a suite of contaminants in the sediments; (2) the receptors of the contaminated sediments (if and how contaminants move up the food chain); and (3) the transport of contamination within the site.

This and other studies showed that contamination exists along the entire 17-mile tidal stretch of the lower Passaic River. In 2003, the EPA expanded the study area to include the lower 17 miles of the Passaic River, from the Dundee Dam (Garfield City) to the mouth of the Passaic at Newark Bay.[362] The expanded study area addresses numerous contaminants (including dioxins) that have been released by many parties, contributing to pollution in the Passaic River.[363]

The Lower Passaic River Restoration Project was formed to undertake an in-depth study of the lower 17 miles of the Passaic River, which has been affected by heavy industrialization.[364] The project is a partnership of six major stakeholders—the U.S. EPA, the U.S. Army Corps of Engineers (ACE), the New Jersey Department of Transportation (NJ DOT), the NJ DEP, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Fish and Wildlife Service (FWS)—under the authorities of several laws, including the Superfund program, the Water Resources Development Act (WRDA), and the Clean Water Act. An agreement was signed with a group of 31 potentially responsible parties (PRPs) to fund the Superfund portion of this study. This agreement was subsequently amended to add another 12 PRPs. The WRDA portion of the study is being funded by Congressional appropriations as well as NJ DOT funds.

The goal of the Project is "to develop a plan to improve water quality, remediate the sediments, and restore the ecological health of the Lower Passaic River."[365] The project involves the development of a conceptual model to predict how sediments and contaminants move in the area. The project also includes human health and ecological risk assessments, computer modeling of fate and transport, and an assessment of remediation and ecological restoration alternatives.[366]

Currently, the Lower Passaic River Restoration Project is evaluating the feasibility of conducting interim remedial measures (IRMs) in the most heavily contaminated areas of the River. This would allow for an early intervention using currently available data, before the full RI/FS is completed.[367] A dredging and decontamination pilot project was conducted over a 5-day period in December 2005 to test different dredging variables and evaluate sediment resuspension.[368] Two innovative decontamination technologies will be applied to the dredged sediments: sediment wash and cement-lock,[369] as described in Box 9. Results of the pilot project, including a risk assessment, modeling of the suspended sediment plume, and restoration activities, will be presented in upcoming technical publications [9].

Although modeling efforts of the Passaic are still not completed, some estimations of the relevance of this area to the rest of the Harbor have been made. A recently published draft Geochemical Evaluation for the lower Passaic River, estimated that contaminated sediments spanning river miles 1 to 7 (~3 to 8 million cubic yards) contain **~20–30 kg of 2,3,7,8 TCDD** [145].[370] This study used several approaches to evaluate the areas and depths that would need to be dredged in order to leave sediment concentrations at < 0.03 ppt 2,3,7,8 TCDD.

Remobilization of sediment occurs primarily during high-discharge events. The Geochemical Evaluation estimated that Newark Bay receives **~14 g of 2,3,7,8**

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362. Alice Yeh, Project Manager, Emergency and Remedial Response Division, EPA Region 2; personal communication, March 2005.

363. Many of these parties agreed in March 2004 to pay approximately $10 million for a remedial investigation and, along with a larger group of potentially responsible parties, subsequently increased that amount to $10,750,000 [27].

364. For more information and the latest updates, visit *http://www.ourpassaic.org/*.

365. Lower Passaic River Restoration Project website *http://www.ourpassaic.org/*. Accessed on May 24, 2005.

366. The date for the final decision on remedy—called a Record of Decision, scheduled for the year 2014, is being revised. Elizabeth Butler, Remedial Project Manager, U.S. EPA Region 2., Personal communication, July 2006.

367. Alternatives being considered include dredging, capping, or a combination, as well as insitu remediation. A preliminary screening of technologies has been completed by Malcolm Pirnie, and a more detailed study will follow. The goal of the IRM will be to maximize the mass remediated (of dioxins and other contaminants), as opposed to minimizing risks (which will be addressed by the full RI/FS and requires modeling and more detailed data). Areas with higher contamination and more susceptible to remobilization will be prioritized. Any IRM would not preclude further cleanup as deemed necessary by the RI/FS. As discussed during the Lower Passaic River Restoration Project, Remedial Options Workgroup Meeting, February 1, 2006, Newark, NJ.

368. More details are given in a publication by Baron et al. [9].

369. Sediments were transported to the Bayshore Recycling Inc. facility on the Raritan River in Keasbey, NJ for temporary storage [9]. The sediment wash was demonstrated by Biogenesis Enterprises, Inc. in Keasbey, NJ, while the cement-lock thermal destruction will be performed by Endesco Clean Harbors at the International-Matex Tank Terminal in Bayonne, NJ [9].

370. In addition, these sediments contain ~6-11 T of DDT, 24-37 T of mercury, and ~6-8 T of PCBs.

## BOX 9. DECONTAMINATION TREATMENT TECHNOLOGIES FOR THE DREDGING AND DECONTAMINATION PILOT PROJECT:

**Sediment wash:** consists of removing the contaminants adsorbed to sediments in a process similar to that of a washing machine. The cleaned sediments can then be mixed with organic materials (e.g., manure) to dilute any remaining toxics, and composted to obtain manufactured soil.

**Cement-lock technology** consists of thermal treatment of the sediments in a cement kiln, in which the high temperatures volatilize and destroy organic matter and toxics. The resulting material is used to produce cement.

The end products of these two technologies can be commercialized, which is expected to offset some the cost of treatment.

Other options exist to treat contaminated sediments and soils. For instance, plasma vitrification can also destroy organic compounds, while some energy can be recovered. A summary of several of these technologies can be found at [341].

**TCDD/year**, 12 from the Passaic River, and the rest from Hackensack River and the Kills [145]. It is possible that a similar amount of dioxin may be released during a single large event.[371] By applying congener patterns from recent surface sediment samples in the area,[372] it was estimated that **~14 g TEQ/yr** are delivered from the Passaic into Newark Bay. It has also been estimated that ~4 to 8 kg of 2,3,7,8 TCDD alone have been transported in sediments from the Passaic River and deposited in Newark Bay over 40 years [17].[373]

Additional information about dioxins in Newark Bay sediments and remobilization of sediments contaminated with dioxins from the Diamond Alkali site shows that:

- Newark Bay is a depositional area that receives sediments from Arthur Kill and Kill van Kull (in addition to the Passaic).[374] Because sediments from the Kills are cleaner than those from the Passaic, concentrations of pollutants in Newark Bay sediments are lower than those in the lower Passaic River.
- The dioxin profile in dated sediment cores indicates that the largest amounts of dioxins were deposited in the early 1950s through mid-1960s and can be related to 2,4,5-T production at the Lister Avenue herbicide facility from the mid-1940s to 1969 [28].[375]
- A unique ratio of 2,3,7,8 TCDD/total tetra-CDD has been measured in river sediments adjacent to the plant as well as in sediments throughout the Passaic and Newark Bay [28]. This characteristic ratio (~0.7) is much higher than that of other dioxin sources, such as wastewater treatment effluents (0.04).[376] It would be highly unlikely that other sources would produce this same ratio at the same time in history, resulting in the observed dioxin concentration profiles in the area. This characteristic dioxin signature is observed throughout the sediment profile, suggesting that sediments are re-worked. The geochemical evaluation for

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[371] These events normally occur several times a year, and occasionally are big enough to even transport sediments out of Newark Bay and into the ocean. This was the case during an extreme event on April 5, 2005. The sediment transport can be seen in satellite pictures, as shown by Dr. Robert Chant, Assistant Professor, Institute of Marine and Coastal Sciences (IMCS), Rutgers University, during a short course on "Estuarine Dynamics and Particle Transport." SETAC Husdon-Delaware Chapter, 21st Annual Meeting. April 28, 2005, New Brunswick, NJ.

[372] Supplemental information on congener patterns can be obtained at *http://www.nyas.org/programs/harbor.asp.*

[373] This study was published in 1990. Until the 1970s, when the most heavily contaminated sediment was being deposited, navigational dredge spoils were being placed in upland sites adjacent to the bay, "generally as fill material which was subsequently used for development" [17].

[374] Presentation by Edward Garvey at the Lower Passaic River Restoration Project Delivery Team (PDT) Meeting. May 4, 2005, Newark, NJ.

[375] Analyses of dated sediment cores from Newark Bay and Arthur Kill have shown that dioxin concentrations increase with depth, peaking at a depth corresponding to the 1960s [28]. Although a good sediment core could not be obtained for the Kill van Kull, it is foreseeable that it may follow the same trend (Damon Chaky, Post-Doctoral Research Scientist, Lamont-Doherty Earth Observatory of Columbia University, personal communication, March 17, 2005). These cores are similar to those from the Passaic, adjacent to 80 Lister Avenue. Such core samples show that deeper sediments, corresponding to sediments deposited in the mid-1960s, have higher 2,3,7,8-TCDD concentrations than shallower sediments deposited in the mid-1980s [17]. This is consistent with the peak in 2,4,5-T production, which occurred around that time [17].

[376] Soil samples from 80 Lister Avenue and Passaic River sediments adjacent to the facility presented a high ratio as well (0.91–0.98) [28].

> the Lower Passaic suggests that this portion of the River experiences some years of net deposition and other of net erosion [145].

To provide a more refined picture of contaminant remobilization, ongoing efforts have focused on the exchange between the Passaic River and the rest of the Harbor. In February 2004, the U.S. EPA signed an agreement with Occidental to perform an investigation to establish the extent of the contamination in Newark Bay, portions of the Kill Van Kull, Arthur Kill and the Hackensack River. The Newark Bay study will include human health and ecological risk assessments, development of a computer model of fate and transport, and an assessment of remediation alternatives.[377] [378] Tierra Solutions, Inc. is performing this study with EPA oversight.

There has been controversy about, and litigation concerning, how to characterize the extent of the contamination and develop an RI/FS for this area—and how both these analyses relate to activities needed at once to protect the health of the Harbor and also foster Harbor development. Getting the relationship right between those two efforts remains a management and technical challenge.

**Recommendations to curb and better characterize dioxin remobilization from contaminated sites:**

- Support current efforts to characterize dioxin pollution, remobilization from natural processes, and dredging activities, and evaluate treatment technologies for dredged materials. Multi-stakeholder collaborative efforts such as the Lower Passaic River Restoration Project are particularly worthy.
- Support continued funding and timely cleanup efforts to address the legacy of dioxin contamination, including on-land sites as well as sites contaminated with PCBs that contain dioxin-like compounds, dioxins, and furans.
- In respect of the legacy of the Diamond Alkali Superfund site, we recommend:
  - Support immediate efforts to implement the most protective <u>interim</u> remedial actions at this site to stop the ongoing redistribution of dioxins in the Harbor. At the same time, support the development of <u>permanent</u> technical and managerial solutions (that assure protective remedial selection and also enable Harbor management work consistent with a developing Harbor).

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[377] Elizabeth Butler, Remedial Project Manager, U.S. EPA Region 2. Personal communication, July 2006.

[378] More details at *www.ournewarkbay.org*, and *http://www.csam.montclair.edu/earth/PRI/Passaic_R_Symp_oral.html*

# APPENDIX A.

## AN ASSESSMENT OF INPUTS AND OUTPUTS OF DIOXIN AND DIOXIN-LIKE COMPOUNDS FOR THE NEW YORK/NEW JERSEY HARBOR AND ITS WATERSHED.

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## I. INTRODUCTION

### Dioxin and Dioxin-like Compounds

There are 75 congeners of the chlorinated dibenzo-*p*-dioxins (CDDs) and 135 congeners of the chlorinated dibenzofurans (CDFs). The most toxic of these compounds is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) (62). 2,3,7,8-TCDD is often simply referred to as "dioxin." Compounds exhibiting toxicological and physiological effects similar to 2,3,7,8-TCDD are referred to as "dioxin-like" compounds (DLCs). DLCs include CDD and CDF congeners with chlorines in the laterally substituted positions—i.e., the 2, 3, 7 and 8 positions (see Figure B. 1 in the Technical Report). The dioxin-like PCBs are coplanar congeners with four laterally substituted chlorines—i.e., in positions 4, 4', 3, 3', 5, or 5'—and one or fewer *ortho* substituted chlorines (Figure B. 1). Brominated dibenzo-*p*-dioxins, dibenzofurans and biphenyls, certain polynuclear aromatic hydrocarbons, polychlorinated naphthalenes, and related compounds also exhibit dioxin-like properties (54). Although the toxicity of brominated or mixed chlorinated/brominated DLCs is recognized, information regarding the prevalence of these compounds in the environment is lacking (62). Assessment of DLCs in environmental media most often includes only the dioxin-like congeners of CDD/Fs and PCBs.

New York State has set several criteria for CDD/Fs. The water quality criterion for water sources for CDD/Fs is 7 x $10^{-7}$ $\mu$g as 2,3,7,8-TCDD/L; the ambient water quality standard for the protection of human health from fish consumption for CDD/Fs is 6 x $10^{-10}$ $\mu$g as 2,3,7,8-TCDD/L; and the ambient water quality wildlife-based standard for 2,3,7,8-TCDD is 3.1 x $10^{-9}$ $\mu$g/L (42). The New Jersey carcinogenic effect–based human health criteria for 2,3,7,8-TCDD for coastal and estuarine saline waters is 1.4 x $10^{-8}$ $\mu$g of 2,3,7,8-TCDD/L (41). The EPA maximum contaminant level for 2,3,7,8-TCDD in drinking water is 3 x $10^{-5}$ $\mu$g/L (58). The Food and Drug Administration recommends against eating fish and shellfish with levels of TCDD greater than 50 parts per trillion (57).

DLCs produce varying magnitudes of negative physiological/toxicological responses and differ in their effect on different types of organisms. This presents difficulty in assessing the risk associated with these chemicals. Toxic equivalency factors (TEFs) have been developed to allow comparison of the risk associated with the compounds at different concentrations and in mixtures.

An expert meeting was organized by the World Health Organization (WHO) in order to derive consensus TEFs for humans and wildlife. The TEFs published by WHO in 1998 indicate an order of magnitude estimate of the toxicity of a specific DLC relative to that of 2,3,7,8-TCDD (62). The WHO TEFs were established through comparison of physiological responses mediated by binding of DLCs to the aryl hydrocarbon (Ah) receptor and were tabulated for mammals, fish, and birds (62). A toxic equivalency (TEQ) expressed as equivalents of 2,3,7,8-TCDD can be computed for mixtures of DLCs using **Equation 1.** TEFs are intended to predict the relative toxicity of congeners that are in animal tissues or their diets. TEFs are also widely used to quantify TEQs for DLCs in abiotic environmental media. The process of summing converted TEQ concentrations of individual congeners to a single total

TEQ value is useful for comparing different environmental matrices (e.g., sediments) and prioritizing remedial efforts. However, because of the different physical-chemical properties of the congeners and because of their different magnitudes of bioaccumulation, it is impossible to accurately model the environmental fate of individual congeners in abiotic media using the total TEQ (62). A list of DLCs addressed in this report and their WHO TEFs are shown in Table B. 1 of the Technical Report. In the body of the text, 1998 WHO TEFs for mammals have been used. The major tables summarizing the various inputs and outputs for the Harbor, along with summary tables and figures, have also been assembled using the TEFs for fish (Appendix A.1) and birds (Appendix A.2).

**Equation 1**

$$TEQ = \Sigma_{I\text{-}n}\ TEF_I \times [Congener_I] + TEF_J \times [Congener_J] + \ldots TEF_n \times [Congener_n]$$

Where:

$TEQ$ = toxic equivalency concentration;
$[Congener_n]$ =concentration of a specific congener; and
$TEF_n$ = toxicity equivalency factor for a specific congener.

## Environmental Cycling

DLCs are lipophilic compounds that bioaccumulate in living organisms (54). Bioaccumulation in the food chain presents a risk to humans, with the primary route of exposure through the consumption of animal products (54). In the NY/NJ Harbor region, elevated levels of DLCs have been reported in fish (55) and crabs (8). Advisories recommending levels of local fish in the diet or forbidding consumption have been issued in New York and New Jersey as well as in other states (57).

Unlike PCBs, CDD/Fs were never produced intentionally for any application, except as specialty analytical standards. CDD/Fs are instead produced as undesirable by-products via a variety of processes and enter the environment in relatively small quantities. The most important of these processes, which results in their nearly ubiquitous presence in the environment, is combustion (12) including open garbage burning and incineration of municipal solid waste, medical waste, and sludges (49). Additional major sources include chemical manufacturing such as pulp and paper bleaching; production of halogenated compounds such as chlorophenols and polychlorinated biphenyls; metal processing; and textile manufacturing (49). Additional minor sources include production by aerobic action of organisms (23), soil processes (27), presence in natural clay deposits (25), and photolytic conversion of other chemicals (31). A significant deposit of CDD/Fs in the NY/NJ Harbor system is a former industrial site at 80 Lister Avenue in Newark, NJ on the Passaic River. This location was the site of a facility that produced a number of chemicals including sodium 2,4,5-trichlorophenate, which was then used to synthesize 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) (4). In mixture with 2,4-dichlorophenoxyacetic acid (2,4-D), 2,4,5-T was widely used in the middle of the 20th century as a defoliant. The most well-known use of this herbicide was by the US military for jungle and forest defoliation during the Vietnam War. The drums of herbicides were marked with a color-coded stripe to identify the mixtures (48); it was this color coding that gave these defoliants their common names—Agent Orange, Agent Purple, etc. From 1948 to 1969 an estimated 800 tons per year of 2,4,5-T were produced at 80 Lister Avenue (4). The process through which the herbicide was produced also resulted in the formation of 0.5 to 65.5 ppm of 2,3,7,8-TCDD in the finished herbicide mixture (48). CDD/Fs including 2,3,7,8-TCDD are significant contaminants in soils near the former Newark facility and also in the sediments of the Passaic River near the facility (4).

While CDD/Fs are hydrophobic, insoluble, and overwhelmingly associated with the organic fractions of soils and sediments, they are subject to a variety of transformation and transport processes in the environment (26). Among those are volatilization from the aqueous phase to the atmosphere; deposition from the atmosphere to the land or water; transport in the subsurface and in water bodies; photodegradation; OH radical reactions (26); anaerobic dechlorination of highly chlorinated congeners to less chlorinated congeners (24); and mineralization of lightly chlorinated congeners to carbon dioxide (64). Microbial reductive dechlorination of the more highly chlorinated congeners to congeners with 1 to 3 chlorines has been well documented in laboratory studies—including in sediments from the Passaic River (21,24) and the Arthur Kill (63). Pure cultures of bacteria have recently been shown to reductively dechlorinate some CDD/F congeners (7,17). Since lightly chlorinated congeners are more soluble than highly chlorinated congeners, they are more prone to movement from the sediment to the water column and to volatilization

(37). However, since the lightly chlorinated congeners (mono-, di-, and tri-chlorinated) are far less toxic than the more highly chlorinated congeners, with only a few exceptions (35,36), these compounds are not routinely analyzed for in environmental samples. It is unclear whether significant reductive dechlorination of CDD/Fs is occurring *in situ* in Harbor sediments. Analysis of samples from dated sediment cores using selective ion monitoring of the M/(M+2) ratio ($^{35}Cl/^{37}Cl$) were within normal EPA QA/QC guidelines (11). This suggested that no significant Cl isotopic fractionation had occurred, as might have been expected with biological transformation. On the contrary, Barabás et al. (2,3) performed a geostatistical analysis of Passaic River CDD/F contamination using a multivariate analysis model aimed at detecting a CDD/F reductive dechlorination fingerprint (end member). They concluded that reductive dechlorination and formation of 2,3,7,8-TCDD at the expense of 1,2,3,7,8-PeCDD is a significant component of CDD/F fate in Passaic River sediments (3).

## II. APPROACH

### Model

A mass balance assessment of DLCs including the 17 2,3,7,8-substituted CDD/Fs and the dioxin-like PCBs was performed for the NY/NJ Harbor and its Watershed. Mass balance models of the Watershed and Harbor were previously developed for mercury, cadmium, and PCBs (19,44,50,52). A similar model (**Figure 1**) was employed for this DLCs mass balance. The inputs include rivers, water pollution control facilities (WPCFs), combined sewer overflows (CSOs), storm water runoff (SWO), landfill leachate, and deposition and absorption from the atmosphere. Outputs include tidal exchange with the Atlantic Ocean and Long Island Sound, volatilization to the atmosphere, and removal of sediments from the Harbor through dredging. Accumulation of DLCs via sedimentation was also quantified. The boundary conditions for the estuary were defined previously as the zero salinity point of the Hudson River as the northern boundary and a line connecting Sandy Hook, NJ with the western tip of Long Island, NY as the southern boundary (19,44,50,52). The Harbor is also defined to include the lower tidal portions of the Passaic, Hackensack, Elizabeth, Rahway, and Raritan Rivers. The area of the Harbor water surface is 811 km$^2$, and the area of the associated watershed is 42,128 km$^2$ (56,59). The areas of the particular regions of the Harbor used for various calculations in this analysis are shown in **Table 1**.

**Table 1. Water surface areas in the NY/NJ Harbor (56,59)**

| Subbasin | Area km$^2$ | Percent of area |
|---|---|---|
| Battery to Newburgh Bridge | 310 | 38.2 |
| Upper Harbor | 104 | 12.8 |
| Lower Harbor | 318 | 39.2 |
| Jamaica Bay | 47 | 5.8 |
| Newark Bay | 32 | 3.9 |
| **Total water surface area** | **811** | **100.0** |

**Figure 1. Simplistic model of inputs and outputs of DLCs to the NY/NJ Harbor water column.**

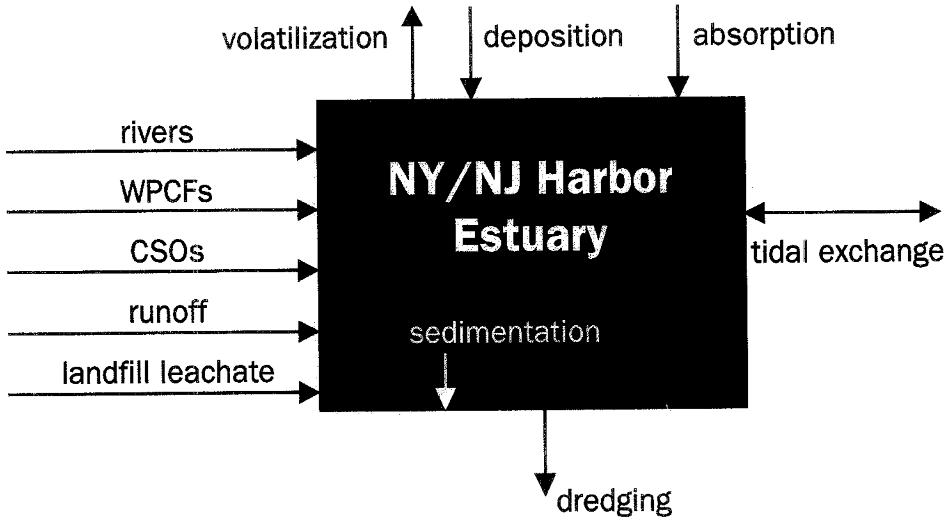


**Table 2. Sources and types of data available for the mass balance assessment**

| Component | Data available | Sources |
|---|---|---|
| NY Rivers and Harbor sub-areas (whole water concentrations) | All CDD, CDF, and PCB congeners and TEQ | (32)[†] |
| NY wastewater treatment facilities, CSOs*, (whole-water concentrations) | All CDD, CDF, and PCB congeners and TEQ | (32)[†] |
| NY SWOs[†] urban and suburban/rural samples (whole- water concentrations) | All CDD, CDF, and PCB congeners and TEQ | (32) |
| Landfills (filtered water concentrations) | All CDD, CDF, and PCB congeners and TEQ | (32) |
| NJ rivers and Harbor subareas (suspended sediment fraction concentrations) | Total CDD/F, total TEQ congener distribution | (43)[§] |
| NJ wastewater treatment Facilities, and CSOs*/SWOs[†] (whole-water concentrations) | Total CDD/F, total TEQ some congener distribution | (43)[§] |
| Atmosphere (gas phase and particle phase concentrations) | CDD/F congeners, TEQ | (35,36,51) |
| Harbor sediments (sediment concentrations) | CDD/F congeners, TEQ | (1,43,56,59) |

*Combined sewer overflows; † Storm water overflows; †Data that when provided to the author by NYSDEC had not yet been subjected to the internal or peer review process. The author applied half detection limit as the concentration for nondetected values and used the resulting data sets for averaging and calculation.
§Draft values provided by NJDEP.

## Expression of Mass Balance Data

The data available for estimating a mass balance for DLCs are shown in **Table 2**. The mass balance was based on total mass of DLCs (CDD/Fs plus coplanar PCBs) where possible; total mass of CDD/Fs alone; mass of individual congeners of CDD/Fs and PCBs, where available; and as toxic equivalent mass (TEQ) expressed as 2,3,7,8-TCDD based on the sum of the CDD/Fs plus PCBs or CDD/Fs alone, depending upon the data set. Data sets for dioxin-like PCB congeners are incomplete for many components of the mass balance. The ability to view the data in a variety of forms (i.e., mass versus TEQ) is useful since knowing which congeners are problematic is important and knowing the equivalent toxicity is useful for assessing the relative risk posed to humans and other biota. The 1998 World Health Organization (WHO) TEFs for humans/mammals (62) were used to calculate TEQs in the main text of this report (Table B. 1). **Appendix A.1** and **A.2** contain summary tables using TEFs for fish and birds, respectively. In some cases, when congeners with a high TEF are nondetect, the resulting TEQ is strongly affected by how the assignation of nondetect status is made (33). With three exceptions, the data sets used for this analysis used a value of half the detection limits for nondetect values. The data set of Lohmann et al. (35,36,51), the data provided by the New Jersey Department of Environmental Protection (NJDEP) (43) and US Environmental Protection Agency's (USEPA) Regional Environmental Monitoring and Assessment Program (REMAP) data (56,59) contain data points in which nondetects were assigned values of zero.

## Cautions on the Use of this Assessment

These analyses were carried out and are now reported using some data that, when provided, had not been subject to peer review or internal QA/QC protocols (see **Table 2**). Also, the standard deviation (SD) on the average values for concentrations tabulated throughout this report are ± *100 % or greater* in many cases. Standard error (SE, standard deviation of the mean) values are presented where possible to provide an indication of the variability to be expected for the mean values used in these analyses. Because the data sets for dioxin-like PCBs are not complete for some system compartments, statistical values are not always presented for these averages. *With the variability in concentration data, the different assignation of values to nondetect samples as described in the section Expression of Mass Balance Data, and the variability inherent in estimating water and mass flows from different compartments of the Harbor, the mass balance values reported herein should be understood to have high levels of uncertainty associated with them. As such, this document should be used only as a general guide to gain a sense of the relative sizes of the major sources and sinks of DLCs in the Harbor.*

# III. MASS BALANCE

## Inputs

### Riverine Inputs

Input of DLCs to the Harbor from the Hudson River above the head of tide was estimated using NYDEC data (32). Estimates of inputs from above the head of tide for the Passaic, Hackensack, Elizabeth, Raritan, and Rahway Rivers were provided by NJDEP (43).

### Hudson River

Whole-water concentrations of DLCs for sampling locations on the Hudson River are shown in **Table 3**. The concentrations between Kingston and Poughkeepsie, NY (32) were used to calculate the loading from the Hudson River to the NY/NJ Harbor. This location is somewhat remote from urban environments that would exert an influence on the ambient water concentrations and is closer to the upper defined boundary of the Harbor than the other available measurement points. An average annual flow of 650 $m^3/s$ (19,50) was used for the estimate. The average loadings (± standard error, SE) are shown in **Table 4**. The SE for the ambient water concentrations between Kingston and Poughkeepsie, NY was low, approximately 10%. When both CDD/Fs and PCBs were included, the loading was on a mass basis 6422 g/yr and on a TEQ basis 5.2 g as 2,3,7,8-TCDD/yr. The average loading when only CDD/Fs were included was on a mass basis 694 g/yr and on a TEQ basis 3.2 g as 2,3,7,8-TCDD/yr. In general, for all reaches of the Hudson River the most important congeners contributing to the loading to the Harbor on a mass basis were 3,3',4,4'-TeCB (PCB 77), 2,3,3',4,4'-PeCB (PCB 105), 2,3',4,4',5-PeCB (PCB 118), and OCDD; and on a TEQ basis were 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 2,3,4,7,8-PeCDF, and 3,3',4,4',5- PeCB (PCB 126).

### New Jersey Rivers

The Lower Passaic River harbors significant CDD/Fs in its sediments from past industrial activities, combined sewer overflows, and other sources (4,29). It therefore serves as a source of CDD/Fs to other parts of the Harbor (4,11,16). The Passaic River is tidally influenced for 17 miles upriver from the Harbor, and tidal pumping and mixing have the potential to resuspend and redistribute the CDD/Fs away from the contaminated areas. A few studies have examined the effect of the major contaminated site at 80 Lister Avenue on the Harbor at large. Bopp et al. (4) used dated cores from the Lower Passaic River and Newark Bay to determine that the high levels of 2,3,7,8-TCDD in sediments were associated with the time period corresponding to production of 2,4,5-T at this facility. Bopp et al. estimated that 4 to 8 kg of 2,3,7,8-TCDD were deposited in the form of contaminated sediments in Newark Bay in the 40 years preceding their study (4). Farley et al. (16) modeled 2,3,7,8-TCDD in sediments deposited in the Lower Passaic, Newark Bay, and Kill areas of the Harbor. They concluded that present-day inputs of 2,3,7,8-TCDD to the Lower Passaic River and Newark Bay from combined sewer overflows (CSOs) and water pollution control facilities (WPCFs), the other major sources of 2,3,7,8-TCDD accounted for in their model, did not account for the extent of present-day levels of 2,3,7,8-TCDD in Harbor sediments. This finding suggested that past discharges of 2,3,7,8-TCDD into the Lower Passaic River may have contributed to accumulation of 2,3,7,8-TCDD in the sediments of Newark Bay and New York Harbor. Chaky (11) used the ratio of 2,3,7,8-TCDD to total TCDD congeners in radionuclide-dated Harbor sediments as a tracer for determination of the influence of the 80 Lister Avenue site on 2,3,7,8-TCDD distri-

**Table 3. Concentrations of DLCs (CDD/Fs plus coplanar PCBs) observed in the Hudson River (obtained via analysis of data provided by (32))**

| Hudson River sampling location | DLCs range (pg/L) | TEQ range (pg as 2,3,7,8-TCDD/L) | DLCs average (pg/L) | TEQ average (pg as 2,3,7,8-TCDD/L) |
|---|---|---|---|---|
| Between Kingston and Poughkeepsie | 240–380 | 0.2–0.3 | 313 | 0.25 |
| At Poughkeepsie | 660–4,800 | 0.6–17 | 2,300 | 4 |
| At Haverstraw Bay | 330–920 | 0.3–0.8 | 660 | 0.6 |
| Between the Tappan Zee Bridge and the Harlem River | 520–2000 | 0.4–1.7 | 1,000 | 1 |
| South of the Harlem River | 340–1,300 | 0.4–4.7 | 660 | 2 |

bution throughout the Harbor. Chaky concluded that this site was a major contributor of 2,3,7,8-TCDD to the rest of the Harbor. Half of the 2,3,7,8-TCDD present in sediments up to the mainstem of the Hudson River at Hastings (26 miles upstream from the Battery) was estimated to have originated at 80 Lister Avenue. Thus the influence of the 80 Lister Avenue site appears to be significant and pervasive.

**Table 4. Average congener make-up of Hudson River loading of DLCs to the NY/NJ Harbor based on average ambient river concentrations measured between Kingston and Poughkeepsie (obtained via analysis of data provided by (32))**

| Congener | TEF | DLCs average Conc.* (pg/L) | DLCs average conc. (pg as 2,3,7,8-TCDD/L) | Loading DLCs (g/y) | Loading TEQ (g/y as 2,3,7,8-TCDD) | Congener % (mass basis)† | Congener % (TEQ basis)† |
|---|---|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 0.02 | 0.02 | 0.35 | 0.35 | 0.01 | 6.75 |
| 1,2,3,7,8-PeCDD | 1 | 0.02 | 0.02 | 0.4 | 0.40 | 0.01 | 7.65 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.04 | 0.004 | 0.85 | 0.09 | 0.01 | 1.6 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 0.12 | 0.01 | 2.5 | 0.25 | 0.04 | 4.79 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 0.08 | 0.01 | 1.6 | 0.16 | 0.02 | 3 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 3.18 | 0.03 | 65.3 | 0.65 | 1.02 | 12.5 |
| OCDD | 0.0001 | 28.10 | 0.003 | 576 | 0.06 | 8.97 | 1.1 |
| 2,3,7,8-TCDF | 0.1 | 0.15 | 0.02 | 3.1 | 0.31 | 0.05 | 5.96 |
| 1,2,3,7,8-PeCDF | 0.05 | 0.02 | 0.001 | 0.46 | 0.02 | 0.01 | 0.44 |
| 2,3,4,7,8-PeCDF | 0.5 | 0.06 | 0.03 | 1.14 | 0.57 | 0.02 | 10.9 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 0.04 | 0.004 | 0.77 | 0.08 | 0.01 | 1.48 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 0.03 | 0.003 | 0.67 | 0.07 | 0.01 | 1.28 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 0.03 | 0.003 | 0.52 | 0.05 | 0.01 | 1 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.02 | 0.002 | 0.32 | 0.03 | 0.005 | 0.61 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 0.54 | 0.01 | 11 | 0.11 | 0.17 | 2.1 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.06 | 0.001 | 1.2 | 0.01 | 0.02 | 0.23 |
| OCDF | 0.0001 | 1.38 | 0.0001 | 28.4 | 0.003 | 0.44 | 0.05 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 52.62 | 0.01 | 1079 | 0.11 | 16.80 | 2.1 |
| 3,4,4',5-TeCB (81) | 0.0001 | 0.84 | 0.0001 | 17.3 | 0.002 | 0.27 | 0.03 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 53.57 | 0.01 | 1098 | 0.11 | 17.10 | 2.1 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 3.78 | 0.002 | 77 | 0.04 | 1.21 | 0.74 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 146.79 | 0.01 | 3009 | 0.30 | 46.86 | 5.78 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 1.78 | 0.0002 | 36.5 | 0.004 | 0.57 | 0.07 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 0.62 | 0.06 | 12.7 | 1.27 | 0.20 | 24 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 13.36 | 0.01 | 274 | 0.14 | 4.26 | 2.6 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 0.94 | 0.0005 | 19 | 0.01 | 0.30 | 0.18 |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 4.24 | 0.00004 | 87 | 0.001 | 1.35 | 0.02 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 0.08 | 0.001 | 1.59 | 0.02 | 0.02 | 0.31 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 0.78 | 0.0001 | 16 | 0.002 | 0.25 | 0.03 |
| **Total CDD/Fs (±SE)§** | | **34 (±2.1)** | **0.16 (±0.017)** | **694 (±43)** | **3.2 (±0.34)** | | |
| **Total CDD/Fs plus PCBs (±SE)§** | | **313 (±30)** | **0.25 (±0.025)** | **6420 (±614)** | **5.2 (±0.49)** | | |

*Four samples were averaged for the analysis using half the sample detection limit for nondetections. 2,3,3',4,4',5-HxCB and 3,3',4,4',5,5'-HxCB were detected in 25%; 2,3,7,8-TCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,7,8,9-HxCDF, and 3,4,4',5-TeCB were detected in 50%; and the remaining congeners were detected in ≥75% of the samples, respectively.

†The congener percentages are based on total CDD/Fs plus coplanar PCBs contributions.

§SE, standard error computed for concentration average and extended to mass loading.

Concentrations of CDD/Fs in the tidal portions of the NJ rivers, including the Passaic River were provided by NJDEP (43) (**Table 5**). While the highest total CDD/F concentrations were detected in the Rahway, Elizabeth, and upper Raritan Rivers, the highest TEQ levels were observed in the Passaic, Hackensack, and Rahway Rivers. From NYSDEC data, average concentrations of DLCs (including both CDD/Fs and PCBs) at the midtidal point in the Passaic River were determined to be 1930 pg/L on a mass basis and 14.5 pg as 2,3,7,8-TCDD/L on a TEQ basis (32). The concentrations of CDD/Fs only at the midtidal point in the Passaic River was 315 pg/L on a mass basis and 13.8 pg as 2,3,7,8-TCDD/L on a TEQ basis (32). At the mouth of the Passaic River these values were 1800 pg/L on a mass basis and 11 pg as 2,3,7,8-TCDD/L on a TEQ basis at the surface, including both CDD/Fs and PCBs. The concentrations of CDD/Fs only was 275 pg/L on a mass basis and 10 pg as 2,3,7,8-TCDD/L on a TEQ basis (32). At the bottom of the mouth, these values were 1070 pg/L on a mass basis and 6 pg as 2,3,7,8-TCDD/L on a TEQ basis, including both CDD/Fs and PCBs. The concentrations of CDD/Fs only was 177 pg/L on a mass basis and 5.4 pg as 2,3,7,8-TCDD/L on a TEQ basis (32). Approximately 70 to 80% of the TEQ in the Passaic River samples consisted of 2,3,7,8-TCDD.

To maintain consistency with past NYAS mass balances (19,44,50,52), loadings of DLCs to the Harbor from the Passaic, Hackensack, Elizabeth, Rahway, and Raritan Rivers were calculated from above the head of tide. Concentrations of individual DLCs from above the head of tide for the New Jersey Rivers are not currently available. However, draft values for the total annual average load at the head of tide for all five major NJ Rivers tributary to the Harbor (i.e., Passaic, Hackensack, Elizabeth, Rahway, and Raritan) were provided by Joel Pecchioli of the NJDEP (43) and are as follows: total CDD = 1,311 g (TEQ = 1.06 g); total CDF = 29.8 g (TEQ = 0.6 g); and total coplanar PCBs = 1,188 g (TEQ = 0.8 g). Although the lower Passaic River is a significant source of 2,3,7,8-TCDD to the Harbor at large, CDD/Fs are distributed throughout the Harbor. Octachlorodibenzo-*p*-dioxin (OCDD) is the dominant congener in most of the environmental samples obtained from the Harbor, and similarly about 94% of the total CDD/F loadings at the heads of tide of the NJ Rivers is OCDD. As will be seen in the **SUMMARY**, loadings of total CDD/Fs from above the head of tide of the five NJ tributaries is a significant portion of total *mass* loadings to the Harbor. However, on a *TEQ* basis, the NJ River loadings from above the head of tide do not appear to constitute a significant portion of the overall Harbor input.

Comprehensive fate and transport models that properly address the tidal and sub-tidal flows, tidal mixing, and sediment transport are needed to address the true impact of the contaminated sediments of the Passaic River on the levels of DLCs in the Harbor at large. Modeling work being carried out by Hydroqual, Inc. under the New York/New Jersey Harbor Estuary Program's Contaminant Assessment and Reduction Project is intended to address this need. For the purposes of this report the contaminated site within the Lower Passaic River is considered a source within the Harbor. Therefore, if one considers a mass balance on the *total* Harbor, the CDD/Fs from the Lower Passaic River—contained mainly on resuspended sediments—would be available for sedimentation, subsequent removal by dredging, partitioning to the truly dissolved phase and subsequent volatilization, and advective transport both in the dissolved and particulate phase out of the Harbor to the Atlantic Ocean or Long Island Sound. All of these potential fates are accounted for in this assessment; and, as will be seen, the loss of 2,3,7,8-TCDD in excess to what may be accounted for coming into the Harbor may be indicative of the influence of this site on the Harbor.

**Table 5. Concentrations (± standard deviation) of CDD/Fs in the New Jersey Rivers below the head of tide (43)**

| Sampling location | Total CDD/Fs (pg/L) | Total TEQ (pg/L) |
|---|---|---|
| Passaic 1 (lower) | 245 + 213 | 8.0 ± 7.5 |
| Passaic 2 (mid) | 136 + 156 | 5.6 ± 7.5 |
| Passaic 3 (upper) | 155 + 196 | 4.1 ± 5.9 |
| Hackensack 1 (lower) | 109 + 85 | 2.6 ± 2.2 |
| Hackensack 2 (mid) | 114 + 124 | 2.1 ± 2.2 |
| Hackensack 3 (upper) | 201 + 136 | 2.3 ± 1.6 |
| Elizabeth | 362 + 417 | 1.8 ± 1.4 |
| Rahway | 665 ± 652 | 2.4 ± 2.0 |
| Raritan 2 (upper) | 253 + 43 | 0.4 ± 0.2 |
| Raritan 1-S (lower) | 103 + 78 | 0.4 ± 0.2 |

## Water Pollution Control Facilities (WPCF) Input

The NY/NJ Harbor receives approximately 2,160 MGD (million gallons per day) (2.98 x $10^9$ $m^3/y$) of effluent from 18 water pollution control facilities (WPCFs) in New York and 12 in New Jersey (15,43). Concentra-

**Table 6. Average discharge flow (30), total yearly flow, effluent concentrations of DLCs and TEQ (32), and resulting mass loadings of DLCs and TEQ to the NY/NJ Harbor from individual NY WPCF**

| Water pollution control facility | Average flow (MGD*) | Yearly input (m$^3$ x 10$^6$) | DLCs average (pg/L) | TEQ average (pg as 2,3,7,8-TCDD/L) | DLCs (g/y) | TEQ loading (g as 2,3,7,8-TCDD/y) |
|---|---|---|---|---|---|---|
| 26th Ward | 62 | 85.7 | 910 | 0.9 | 78 | 0.08 |
| Bowery Bay | 114 | 157.5 | 280 | 0.3 | 44 | 0.05 |
| Coney Island | 97 | 134.0 | 107 | 0.1 | 14 | 0.02 |
| Hunts Point | 120 | 165.8 | 690 | 0.9 | 114 | 0.2 |
| Jamaica | 81 | 111.9 | 520 | 0.6 | 58 | 0.07 |
| Newtown Creek | 246 | 339.9 | 940 | 3.6 | 319 | 1.2 |
| North River | 131 | 181.0 | 300 | 0.3 | 53.5 | 0.06 |
| Oakwood Beach | 28 | 38.7 | 140 | 0.3 | 5.5 | 0.01 |
| Owls Head | 107 | 147.8 | 160 | 0.2 | 23.8 | 0.03 |
| Port Richmond | 35 | 48.4 | 1,000 | 1.4 | 48.8 | 0.07 |
| Red Hook | 33 | 45.6 | 210 | 0.2 | 9.5 | 0.01 |
| Rockaway | 20 | 27.6 | 240 | 0.2 | 6.6 | 0.004 |
| Rockland County | 22.1 | 30.5 | 280 | 0.4 | 8.5 | 0.01 |
| Tallman Island | 56 | 77.4 | 220 | 0.2 | 17 | 0.02 |
| Wards Island | 194 | 268.0 | 130 | 0.1 | 34 | 0.03 |
| Yonkers | 81.3 | 112.3 | 570 | 1.4 | 64 | 0.2 |
| Poughkeepsie (C) | 7† | 9.7 | 1,090 | 1 | 10.5 | 0.01 |
| Rensselaer | 17.5 | 24.2 | 310 | 0.6 | 7.7 | 0.02 |
| **Total** | **1452** | **2006** | | | **918 (CDD/Fs plus PCBs)** | **2 (CDD/Fs plus PCBs)** |
| **Total** | | | | | **96 (CDD/Fs only)** | **0.7 (CDD/Fs only)** |

*MGD = million gallons per day.

†Personal communication by Ms. Jacqueline Rios, Point and Non-Point Source Control Section, Water Programs Branch, DEPP.

§Standard error

tions of DLCs were available for the 18 NY WPCFs that discharge directly into the Harbor (32). The NY WPCFs' names, their average discharge as reported by the Interstate Environmental Commission (30) for 2001, and the average concentration of DLCs in the effluent as provided by NYSDEC (32) are listed in **Table 6**. The concentration of DLCs (including CDD/Fs and PCBs) discharged by the 18 NY WPCFs ranged from 110 to 1,100 pg/L (average 440 pg/L), and the TEQ ranged from 0.1 to 3.5 pg as 2,3,7,8-TCDD/L (average 0.7 pg as 2,3,7,8-TCDD/L). The NYSDEC DLC concentration data were combined with the average 2001 flow of each of the WPCFs to estimate loadings to the estuary. The 18 plants sampled by NYSDEC that discharge to the estuary contribute about 918 g DLCs (including CDD/Fs and PCBs) per year on a mass basis and 2 g per year on a 2,3,7,8-TCDD basis (**Table 6**). For CDD/Fs alone, the 18 plants contribute about 96 g CDD/Fs per year on a mass basis and 0.7 g per year on a TEQ basis (**Table 6**).

WPCFs in New Jersey discharge about 520 MGD (0.72 x 10$^9$ m$^3$/y) of treated effluent to the estuary (30). The mean (± SD) effluent CDD/F concentration was 37 pg/L (± 40 pg/L) and the mean (± SD) TEQ was 0.28 ± 0.48 pg as 2,3,7,8-TCDD/L (43) (**Table 7**). OCDD made up 60% of the total mass of CDD/Fs. The NJ WPCFs therefore contribute an additional 27 g per year of CDD/Fs and 0.2 g as 2,3,7,8-TCDD per year to the Harbor. Thus the load of CDD/Fs to the estuary from all WPCFs for which there are data is about 123 g/yr and 0.9 g per year on a TEQ basis. The standard error (SE) for total CDD/F concentrations from different WPCFs varied from 3% to 90%, with a typical SE value of 40%. This value was used to provide an SE for the loading estimate. The average yearly discharge on a congener basis from each of the NY facilities was summed to give *total* congener discharge from NY WPCFs into the Harbor. To facilitate an estimate of a mass balance on each CDD/F congener, the discharge on a congener basis from the NJ facilities was *estimated* by apportioning the mass discharged (27 g CDD/F/y) to the average congener distribution of the NY WPCFs (**Table 7**). Note that both the WPCF flow (1,452 MGD) and CDD/F load (96 g, 0.7 g TEQ) from the NY facilities are about threefold that from the NJ facilities (520 MGD, 27 g CDD/F, 0.2 g TEQ). In general, for WPCF effluent, 3,3',4,4',5-PeCB (PCB 126), 1,2,3,7,8-PeCDD, 1,2,3,6,7,8-HxCDD, and 1,2,3,4,6,7,8-HpCDD made up the bulk of the *TEQ* loading, while 3,3',4,4'-TeCB (PCB 77), 2,3,3',4,4'-PeCB (PCB 105, 2,3',4,4',5-PeCB (PCB 118), and OCDD made up the bulk of the *mass* loading to the Harbor.

**Table 7. Estimated WPCF effluent loading to the NY/NJ Harbor on a congener basis based on available data (32, 43) and total estimated flows (30)**

| Congener | NY DLCs (g/y) | NY TEQ (g/y as 2,3,7,8-TCDD) | NJ DLCs (g/y) | NJ TEQ (g/y as 2,3,7,8-TCDD) |
|---|---|---|---|---|
| 2,3,7,8-TCDD | 0.09 | 0.09 | 0.02 | 0.02 |
| 1,2,3,7,8-PeCDD | 0.19 | 0.19 | 0.05 | 0.06 |
| 1,2,3,4,7,8-HxCDD | 0.13 | 0.01 | 0.04 | 0.004 |
| 1,2,3,6,7,8-HxCDD | 0.57 | 0.06 | 0.16 | 0.016 |
| 1,2,3,7,8,9-HxCDD | 0.38 | 0.04 | 0.11 | 0.011 |
| 1,2,3,4,6,7,8-HpCDD | 9.25 | 0.09 | 2.57 | 0.03 |
| OCDD | 70.7 | 0.01 | 19.6 | 0.0020 |
| 2,3,7,8-TCDF | 0.11 | 0.01 | 0.03 * | 0.003 * |
| 1,2,3,7,8-PeCDF | 0.07 | 0.004 | 0.02 | 0.0011 |
| 2,3,4,7,8-PeCDF | 0.12 | 0.06 | 0.03 | 0.017 |
| 1,2,3,4,7,8-HxCDF | 0.19 | 0.02 | 0.05 | 0.005 |
| 1,2,3,6,7,8-HxCDF | 0.13 | 0.01 | 0.04 | 0.004 |
| 2,3,4,6,7,8-HxCDF | 0.12 | 0.01 | 0.03 | 0.004 |
| 1,2,3,7,8,9-HxCDF | 0.46 | 0.05 | 0.13 | 0.013 |
| 1,2,3,4,6,7,8-HpCDF | 2.55 | 0.03 | 0.71 | 0.007 |
| 1,2,3,4,7,8,9-HpCDF | 2.68 | 0.03 | 0.74 | 0.008 |
| OCDF | 8.08 | 0.001 | 2.24 | 0.0002 |
| 3,3',4,4'-TeCB (77) | 52.2 | 0.01 | NA | NA |
| 3,4,4',5-TeCB (81) | 22.3 | 0.002 | NA | NA |
| 2,3,3',4,4'-PeCB (105) | 153 | 0.02 | NA | NA |
| 2,3,4,4',5- PeCB (114) | 57.6 | 0.03 | NA | NA |
| 2,3',4,4',5- PeCB (118) | 391 | 0.04 | NA | NA |
| 2',3,4,4',5- PeCB (123) | 29 | 0.003 | NA | NA |
| 3,3',4,4',5- PeCB (126) | 10.9 | 1.09 | NA | NA |
| 2,3,3',4,4',5-HxCB (156) | 68.3 | 0.03 | NA | NA |
| 2,3,3',4,4',5'-HxCB (157) | 6.9 | 0.003 | NA | NA |
| 2,3',4,4',5,5'-HxCB (167) | 21 | 0.0002 | NA | NA |
| 3,3',4,4',5,5'-HxCB (169) | 2.6 | 0.03 | NA | NA |
| 2,3,3',4,4',5,5'-HpCB (189) | 6.3 | 0.001 | NA | NA |
| **Total CDD/Fs (±SE)$^{\dagger}$** | **96 (±38)** | **0.7 (±0.3)** | **27$^{\S}$ (±11)** | **0.2$^{\S}$ (±0.08)** |
| **Total CDD/Fs + PCBs** | **918** | **2** | **NA** | **NA** |

NA = not available.
*NJ discharges apportioned to the average congener distribution of NY WPCFs (30).
§NJ WPCF mass discharge estimated by NJDEP (43).
†SE, standard error.

## Combined Sewer Overflows (CSOs)

There are an estimated 394 CSO outlets on the New York side of the NY/NJ Harbor, which release approximately 140 MGD (193.4 x $10^6$ m$^3$/y) of untreated wastewater (33). A value for total CSO flow into the Harbor used previously for the mercury mass balance is 313 x $10^6$ m$^3$/yr (50). CSOs were reported to significantly contribute to the levels of CDD/Fs in Harbor sediments (29). The NYSDEC (32,33,34) collected concentration data from 15 potential sewer overflow sources on the Harbor in order to characterize these releases (**Table 8**). The CSO samples obtained by NYSDEC were mainly WPCF influents during wet weather events (32). The DLCs in the samples ranged from 5,100 to 59,000 pg/L, and the TEQ concentrations ranged from 5 to 88 pg as 2,3,7,8-TCDD/L, if both CDD/Fs and PCBs are considered. The average concentrations for NJ and NY CSOs are shown in **Table 8**. Both the NJ (43) and NY values consisted of about 80% OCDD by mass (based on CDD/Fs only). The CSO congener apportionment for NY and NJ CSOs are shown in **Table 9**. Since the concentrations were similar for the NY and NJ flows, a Harbor loading was estimated using the untreated CSO flow into the Harbor (313 x $10^6$ m$^3$/yr) and the average NY concentrations (**Table 10**). The standard error (SE) on CSO total CDD/F concentrations from NY ranged from 17% to 30% (**Table 8**). An SE of 25% was applied to the total CSO loading to provide a range of variability. A mass loading of 7280 g/yr and a TEQ loading of 7.8 g as 2,3,7,8-TCDD/y are entering the Harbor from CSOs if both CDD/Fs and PCBs are considered. For CDD/F only, a mass loading of 890 g/yr and a TEQ loading of 3.3 g as 2,3,7,8-TCDD/yr are entering the Harbor. For CSO flows, 3,3',4,4',5- PeCB (PCB 126), 1,2,3,4,6,7,8-HpCDD, and 1,2,3,7,8-PeCDD made up the bulk of the *TEQ* loading, while 3,3',4,4'-TeCB (PCB 77), 2,3,3',4,4'-PeCB (105), 2,3',4,4',5- PeCB (PCB 118), 2,3,3',4,4',5-HxCB, and OCDD dominated the *mass* loading to the Harbor.

## Atmospheric Deposition and Absorption

There are few atmospheric measurements of CDD/Fs in the NY/NJ Harbor. Lohmann et al. (35,36,51) measured concentrations of CDD/Fs in the air at various locations in the Lower Hudson River Estuary (**Figure 2**) in 1998. The total concentration of *all* CDD/F congeners with 1 to 8 chlorines including both the gas and particle phases ranged from 6 to 17 pg CDD/F/m$^3$ and 2.1 to 21 fg as 2,3,7,8-TCDD/m$^3$ (36). Lohmann et al. (35,36) noted that the aerial CDD/F concentrations that they measured in the Lower Hud-

**Table 8. Average effluent concentrations of DLCs (CDD/Fs plus PCBs) and TEQ in combined sewer overflow discharges to the NY/NJ Harbor (32,43)**

| NY CSO location | CDD/Fs plus PCBs (pg/L) | CDD/Fs only (pg/L) | CDD/Fs plus PCBs TEQ (pg as 2,3,7,8-TCDD/L) | CDD/Fs only TEQ (pg as 2,3,7,8-TCDD/L) |
|---|---|---|---|---|
| 26th Ward CSO, Low Side | 21,900 | 1490 | 32.3 | 6.7 |
| 26th Ward CSO, High Side | 59,500 | 6440 | 88.4 | 19.5 |
| Bowery Bay High Side Interceptor | 24,000 | 5470 | 25.6 | 18 |
| Hunts Point Influent | 6,400 | 2827 | 10 | 7.9 |
| Jamaica Influent | 7,770 | 2685 | 12.1 | 9.7 |
| Manhattan Grit Chamber | 15,300 | 439 | 9.1 | 3 |
| Manhattan Pump Station | 16,960 | 800 | 13.6 | 3.8 |
| North River Influent | 38,200 | 2530 | 23.8 | 8.8 |
| Red Hook Influent | 48,700 | 4167 | 38.7 | 17 |
| Coney Island Influent | 6,470 | 1890 | 9.7 | 7.8 |
| Newton Creek Influent | 24,700 | 3450 | 27 | 15 |
| Owls Head Influent | 8,200 | 1720 | 10.3 | 6.9 |
| Port Richmond Influent | 23,500 | 2920 | 24 | 11 |
| **NY average CSO (±SE)†** | **23,200 (±6800)** | **2830 (±490)** | **25 (±7)** | **10 (±17)** |
| **NJ average CSO** | **NA** | **2630** | **NA** | **9.5** |

NA = not available. †SE, standard error.

**Table 9. Average congener makeup of combined sewer overflow entering the NY/NJ Harbor based on available data (32,33,43,50)**

| Congener | TEF | NY DLCs (pg/L) | NY TEQ (pg/L as 2,3,7,8-TCDD) | NJ DLCs (pg/L) | NJ TEQ (pg/L as 2,3,7,8-TCDD) |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 0.47 | 0.47 | 0.32 | 0.32 |
| 1,2,3,7,8-PeCDD | 1 | 2.0 | 2.03 | 1.14 | 1.14 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 2.9 | 0.29 | 2.42 | 0.24 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 10.1 | 1.01 | 7.12 | 0.71 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 7.8 | 0.78 | 6.11 | 0.61 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 270 | 2.70 | 209 | 2.09 |
| OCDD | 0.0001 | 2320 | 0.23 | 2184 | 0.22 |
| 2,3,7,8-TCDF | 0.1 | 1.7 | 0.17 | 1.56 | 0.16 |
| 1,2,3,7,8-PeCDF | 0.05 | 1.1 | 0.05 | 1.37 | 0.07 |
| 2,3,4,7,8-PeCDF | 0.5 | 1.8 | 0.92 | 1.71 | 0.85 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 4 | 0.40 | 6.88 | 0.69 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 3.8 | 0.38 | 4.59 | 0.46 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 3 | 0.30 | 3.0 | 0.30 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.13 | 0.01 | 0.32 | 0.03 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 60.5 | 0.61 | 61 | 0.61 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 4.3 | 0.04 | 3.81 | 0.04 |
| OCDF | 0.0001 | 140 | 0.01 | 138.23 | 0.01 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 1756 | 0.18 | NA | NA |
| 3,4,4',5-TeCB (81) | 0.0001 | 21 | 0.00 | NA | NA |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 3903 | 0.39 | NA | NA |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 208 | 0.10 | NA | NA |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 9483 | 0.95 | NA | NA |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 178 | 0.02 | NA | NA |
| 3,3',4,4',5- PeCB (126) | 0.1 | 110 | 11.05 | NA | NA |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 3042 | 1.52 | NA | NA |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 45 | 0.02 | NA | NA |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 1017 | 0.01 | NA | NA |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 26 | 0.26 | NA | NA |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 590 | 0.06 | NA | NA |
| **Total CDD/Fs only (±SE)†** | | **2830 (±490)** | **10 (±1.7)** | **2630** | **9.5** |
| **Total CDD/Fs plus PCBs (±SE)†** | | **23200 (±6800)** | **25 (±7)** | **NA** | **NA** |

NA = not available. †SE, standard error.

son River Estuary in 1998 were lower than those reported in other urban areas (37). They speculated that the urban levels in the NY/NJ Harbor area may be diluted by air movement off the Atlantic Ocean. Measurements of CDD/Fs in air from cities in upstate New York in the 1980s ranged from 3 to 22 pg CDD/F/m$^3$ (47).

**Deposition.** Atmospheric deposition of CDD/Fs to the water surface (811 km$^2$) of the NY/NJ Harbor was estimated using the gas concentration data of Lohmann et al. (35,36,51). Average particle-phase gas concentrations of 2,3,7,8-substituted CDD/Fs and an average depositional rate of 0.5 cm/sec were used to estimate dry deposition. The total deposition (wet plus dry) was assumed to be double the dry deposition. Total depositional flux values were estimated for the Liberty Science Center in Jersey City (13 measurements); for the combined Upper Bay (one measurement) and Raritan Bay (3 measurements); and for Sandy Hook (7 measurements) (**Table 11**). The estimated flux (43 to 240 ng/m$^2$/yr) were comparable to estimates of depositional flux of CDD/Fs to the upper Hudson River region estimated by Smith et al. (46), 194 ng/m$^2$/yr. They were also comparable to those reported by Brzuzy and Hites (5,6), who used soil concentrations

**Table 10. Average congener makeup of combined sewer overflow loading to the NY/NJ Harbor based on NY congener distribution and total estimated CSO flow (32,33,43,50)**

| Congener | TEF | DLCs (g/y) | TEQ (g/y as 2,3,7,8-TCDD) | Congener percentage (mass basis)* | Congener percentage (TEQ basis)* |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 0.15 | 0.15 | 0.002 | 2 |
| 1,2,3,7,8-PeCDD | 1 | 0.64 | 0.64 | 0.009 | 8 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.91 | 0.09 | 0.01 | 1 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 3.2 | 0.32 | 0.04 | 4 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 2.5 | 0.25 | 0.03 | 3 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 84.7 | 0.85 | 1.2 | 11 |
| OCDD | 0.0001 | 728 | 0.07 | 10.0 | 0.93 |
| 2,3,7,8-TCDF | 0.1 | 0.53 | 0.05 | 0.007 | 0.68 |
| 1,2,3,7,8-PeCDF | 0.05 | 0.33 | 0.02 | 0.005 | 0.21 |
| 2,3,4,7,8-PeCDF | 0.5 | 0.58 | 0.29 | 0.008 | 3.7 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 1.3 | 0.13 | 0.017 | 1.6 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 1.2 | 0.12 | 0.016 | 1.5 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 0.94 | 0.09 | 0.013 | 1.2 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.04 | 0.004 | 0.001 | 0.05 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 19 | 0.19 | 0.26 | 2.4 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 1.3 | 0.01 | 0.019 | 0.17 |
| OCDF | 0.0001 | 43.8 | 0.004 | 0.60 | 0.06 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 551 | 0.06 | 7.6 | 0.70 |
| 3,4,4',5-TeCB (81) | 0.0001 | 6.5 | 0.00 | 0.090 | 0.01 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 1224 | 0.12 | 16.8 | 1.56 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 65.2 | 0.03 | 0.90 | 0.42 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 2974 | 0.30 | 40.9 | 3.8 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 55.8 | 0.01 | 0.77 | 0.07 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 34.7 | 3.47 | 0.48 | 44 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 954 | 0.48 | 13.1 | 6.1 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 14.2 | 0.01 | 0.20 | 0.09 |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 319 | 0.003 | 4.4 | 0.04 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 8.3 | 0.08 | 0.11 | 1.06 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 185 | 0.02 | 2.5 | 0.24 |
| **Total CDD/Fs only (±SE)†** | | **890 (±220)** | **3.3 (±0.8)** | | |
| **Total CDD/Fs plus PCBs** | | **7280** | **7.8** | | |

*The congener percentages are based on total CDD/Fs plus coplanar PCBs contributions.
†SE, standard error.

from a variety of locations to estimate average deposition rates of CDD/Fs to temperate zones (in which the NY/NJ Harbor would fall) of the earth's surface to be 280 ng/m$^2$-y (averaged over a 60-year period). These estimates are far lower, however, than that of Chaky (11), who used a dated core from Central Park Lake to estimate a direct atmospheric deposition of CDD/Fs of 4000 to 5000 ng/m$^2$/yr. A review of depositional fluxes measured in other areas of the world ranged from 99 to 9,900 ng CDD/F (4 to 8 chlorines)/m$^2$/yr, depending upon time of year and whether the values were measured in an urban or a rural setting (37). Some urban settings in that review had flux measurements 10 to 100 times higher than those estimated for the NY/NJ Harbor region by Lohmann et al. (35,36).

The congener-specific deposition of CDD/Fs to the Harbor water surface was calculated by averaging depositional values from the three Harbor sampling locations. The resulting average yearly deposition to the Harbor on a congener-specific basis is shown in **Table 12**. The standard error on CDD/F gas concentrations measurements ranged from 20 to 110% (**Table 11**). An SE of 40% was used to provide an estimate of variability for deposition (**Table 12**). The CDD/F mass values

## Table 11. Estimates of total deposition of CDD/Fs in the NY/NJ Harbor region based on article phase gas concentrations (35,36,51)

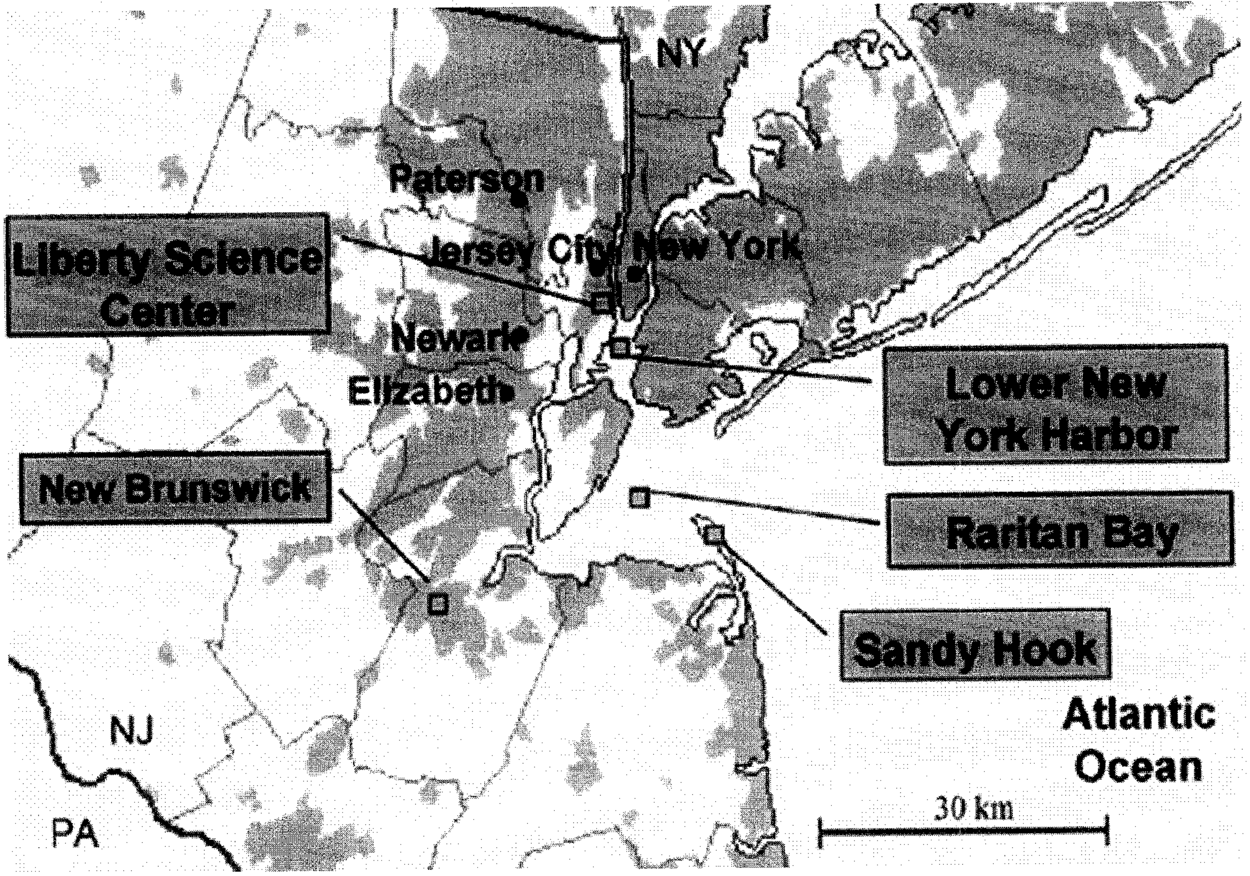
| Location | 2,3,7,8-Substituted dioxins/furans gas phase gas conc. (±SE)† (fg/m³) | 2,3,7,8-Substituted dioxins/furans particle phase gas conc. (±SE)† (fg/m³) | Total depositional flux mass basis (ng/m²/yr) | Total depositional flux TEQ basis (ng as 2,3,7,8-TCDD/m²/yr) |
|---|---|---|---|---|
| Jersey City | 26 (±5) | 340 (±70) | 108 | 1.8 |
| Upper Bay/Raritan Bay | 37 (±16) | 136 (±40) | 43 | 1.2 |
| Sandy Hook | 46 (±14) | 760 (±640) | 240 | 1.8 |

†SE, standard error.

deposited per year have a high degree of uncertainty associated with them primarily because of the variability associated with OCDD concentrations. OCDD is typically an important congener in atmospheric deposition because of its production in combustion and incineration processes.

Deposition of selected dioxin-like PCBs was estimated from data provided by Totten (51). Aerial concentrations of only a few of the dioxin-like PCBs were available, and some of those were concentrations for co-eluting congeners. The U.S. EPA database tabulating individual PCB congeners found in Aroclor mixtures as reported by Frame et al. (20,61) was employed to estimate contributions of dioxin-like PCB congeners to co-eluting PCB congener sets and assuming that Aroclors 1242, 1254, 1248 were the dominant sources

## Figure 2. Air sampling locations for dioxins and furans monitoring in the NY/NJ Harbor (drawing taken from Lohmann et al. (31,32)).



of PCB congeners. Atmospheric particle-phase fluxes for PCB 77, 81, 118, 123, and 156 were estimated. Depositional fluxes (wet plus dry) were calculated as discussed above for CDD/Fs, using averages of values from sampling locations at Jersey City, NJ and Sandy Hook, NJ. The deposition of coplanar PCBs is not completely accounted for in this analysis since data for only a limited number of congeners were available. PCB deposition to the Harbor has been shown to be an important process governing the fate of PCBs in this system (52,53).

An additional calculation was performed to estimate the total deposition of CDD/Fs to the entire Watershed land surface. If the total CDD/F flux to the land surface is assumed to range from 40 to 240 ng/m$^2$-yr (**Table 11**) and the land surface area of the Watershed is 42,128 km$^2$, then the resulting loading to the land by wet and dry deposition is 1,800 to 10,100 g/yr on a CDD/F mass basis (average 5,800 g/yr).

**Absorption.** The approach outlined by Totten et al. (52,53) was used to estimate the absorption of DLCs into the Harbor water surface from the atmosphere. The approach uses **Equation 2** to estimate this input. The average gas-phase CDD/F concentrations ($C_a$) reported by Lohmann et al. (35,36,51) and the total area for the Harbor water surface (**Table 1**) were used for these calculations. Further explanation regarding the acquisition of the $K_{OL}$ and $K_H$ parameters is given in the **Volatilization** section. Absorption accounts for only about 3 g CDD/Fs/yr on a mass basis and 0.5 g as 2,3,7,8-TCDD on a TEQ basis (**Table 12**).

Absorption of selected dioxin-like PCBs was estimated from data provided by Totten (51) manipulated as described above for deposition. Gas-phase concentrations

**Table 12. Estimates of wet plus dry deposition and absorption of CDD/Fs in the NY/NJ Harbor region based on average depositional values computed from Lohmann et al. (35,36,51) and for selected PCB congeners based upon average depositional values reported by Totten (51)**

| Congener | Dry plus wet deposition (g/y) | Dry plus wet deposition TEQ (g as 2,3,7,8-TCDD/yr) | Absorption (g/y) | Absorption TEQ (g as 2,3,7,8-TCDD/yr) |
|---|---|---|---|---|
| 2,3,7,8-TCDD | 0.04 | 0.04 | 0.03 | 0.03 |
| 1,2,3,7,8-PeCDD | 0.24 | 0.24 | 0.09 | 0.09 |
| 1,2,3,4,7,8-HxCDD | 0.41 | 0.04 | 0.04 | 0.004 |
| 1,2,3,6,7,8-HxCDD | 0.79 | 0.08 | 0.06 | 0.01 |
| 1,2,3,7,8,9-HxCDD | 0.78 | 0.08 | 0.03 | 0.003 |
| 1,2,3,4,6,7,8-HpCDD | 13.2 | 0.13 | 0.10 | 0.001 |
| OCDD | 75.4 | 0.01 | 0.83 | 0.0001 |
| 2,3,7,8-TCDF | 0.33 | 0.03 | 0.56 | 0.06 |
| 1,2,3,7,8-PeCDF | 0.55 | 0.03 | 0.37 | 0.02 |
| 2,3,4,7,8-PeCDF | 0.58 | 0.29 | 0.44 | 0.22 |
| 1,2,3,4,7,8-HxCDF | 1.11 | 0.11 | 0.12 | 0.01 |
| 1,2,3,6,7,8-HxCDF | 0.82 | 0.08 | 0.10 | 0.01 |
| 1,2,3,7,8,9-HxCDF | 1.07 | 0.11 | 0.043 | 0.0043 |
| 2,3,4,6,7,8-HxCDF | 0.06 | 0.01 | 0.0009 | 0.0001 |
| 1,2,3,4,6,7,8-HpCDF | 4.34 | 0.04 | 0.03 | 0.0003 |
| 1,2,3,4,7,8,9-HpCDF | 0.04 | 0.0004 | 0.0000 | 0.000000 |
| OCDF | 5.92 | 0.001 | 0.11 | 0.00001 |
| 3,3',4,4'-TeCB (77) | 48 | 0.0048 | 24 | 0.0024 |
| 3,4,4',5-TeCB (81) | 4.8 | 0.0005 | 204 | 0.02 |
| 2,3,3',4,4'-PeCB (105) | NA | NA | 90 | 0.009 |
| 2,3',4,4',5-PeCB (118) | 181 | 0.0046 | 161 | 0.016 |
| 2',3,4,4',5-PeCB (123) | 46 | 0.0046 | 169 | 0.017 |
| 2,3,3',4,4',5-HxCB (156) | NA | NA | 33.6 | 0.017 |
| **Total CDD/Fs only (±SE)†** | **106 (±42)** | **1.3 (±0.5)** | **3 (±1.2)** | **0.5 (±0.2)** |
| **Total CDD/Fs plus PCBs** | **386** | **1.33** | **560** | **0.56** |

†SE, standard error.

**Equation 2**

$$Absorption = K_{OL} \bullet \frac{C_a}{K_H} \bullet A \bullet 365$$

Where:

Absorption = absorption to water surface (pg/year);
$C_a$ = gas phase concentration (pg/L);
A = the total surface area ($m^2$);
$K_{OL}$ = the mass transfer coefficient for each dioxin and dioxin-like congener (m/d) (see **Volatilization** section);
$K_H$ = dimensionless Henry's Law Constant (14); and
365 = days in the year.

for PCB 77, 81, 105, 118, 123, and 156 were estimated. Absorption was calculated as discussed above for CDD/Fs using averages of air measurements from Jersey City, NJ and Sandy Hook, NJ. A standard error of 40% was applied to provide an estimate of variability.

## Storm Water Runoff

The loading of DLCs to the Harbor from storm water runoff was estimated based on urban and rural/suburban storm water analyses for DLCs provided by NYSDEC and from urban storm water analyses for CDD/Fs by NJDEP (43). The NYSDEC data provided by Dr. Simon Litten (32) consist of samples taken during storm events from small tributaries of the Hudson River as representative of runoff from more rural/suburban areas; and from urban/industrial areas of Albany, Staten Island, and Queens as representative of urban runoff. The NJ storm water data are also representative of urban areas. The average content of these samples is shown in **Table 13**.

These may be contrasted with a German study that reported that street runoff contained 1 to 11 pg TEQ/L while household wastewater contained up to 14 pg TEQ/L. Furthermore, washing machine effluent was a significant contributor to CDD/F loading from the household and had a different congener distribution from street runoff (28).

An estimate of total storm water runoff into the Harbor provided by Robin Miller of Hydroqual (39) was 717 cubic feet per second (cfs) or 640.3 x $10^6$ $m^3$/yr. This storm water flow estimate was apportioned into rural/suburban (15%) and urban (85%) components based on estimates of runoff flows from various compartments of the NY/NJ Harbor Watershed supplied by Robin Miller of Hydroqual(39). The urban runoff was assumed to contain an average of the NYSDEC (32) and NJDEP (43) urban CDD/F concentrations and an average of the dioxin-like PCBs reported for the NYSDEC samples. The rural/suburban runoff was assumed to contain the average of the NYSDEC stream flow storm water data. A congener-specific loading to the Harbor was estimated based on these assumptions (**Table 14**) and assuming a standard error of 50% as reflected in the standard error typical of the NY concentrations (**Table 13**). A mass loading of 2430 g/yr and a TEQ loading of 5.6 g as 2,3,7,8-TCDD/yr are entering the Harbor from runoff if both CDD/Fs and PCBs are considered. If only CDD/F contributions are accounted for, a mass loading of 780 g/yr and a TEQ loading of 4.4 g as 2,3,7,8-TCDD/y are entering the Harbor.

A simple check on the estimated value for the NY/NJ Harbor was carried out by estimating the DLCs

**Table 13. Average stormwater concentrations of DLCs (CDD/Fs plus PCBs) and CDD/Fs in discharges to the NY/NJ Harbor (32,43)**

| Location | DLCs average (pg/L) (±SE)[†] | TEQ average (pg as 2,3,7,8-TCDD/L) (±SE)[†] | CDD/Fs average (pg/L) (±SE)[†] | CDD/Fs average (pg as 2,3,7,8-TCDD/L) (±SE)[†] |
|---|---|---|---|---|
| Rural/suburban NY storm event streamwater | 580 (±230) | 0.53 (±0.2) | 420 (±170) | 0.46 (±0.18) |
| Urban NY average SWO, urban storm event streamwater | 4360 (±2170) | 10 (±5) | 1360 (±350) | 8 (±4) |
| Urban New Jersey average SWO | NA | NA | 2610 | 19 |

NA = not available. †SE, standard error.

deposited to the Watershed land surface from the atmosphere. This method was used to estimate mercury loadings to the Harbor via runoff by estimating the regional deposition of mercury to the land surface and assuming that a portion of this deposited material entered the runoff (19,50). A similar exercise may be carried out for DLCs. If the total CDD/F flux to the land surface is assumed to range from 40 to 240 ng/m²/yr (**Table 11**) and the land surface area of the Watershed is 42,128 km², then the resulting loading to the land by wet and dry deposition is 1800 to 10,100 g/yr on a CDD/F mass basis (average 5800 g/yr). If one arbitrarily assumes that 5% of this deposited material washes into the Harbor during the year, the resulting CDD/F loading would be 90 to 500 g/yr. The upper value is in the range of the value obtained from the storm water estimate (**Table 14**). If one assumes that this mass of CDD/F is suspended in the estimated 717 cubic feet per second (cfs) of runoff estimated to enter the Harbor, the concentration of CDD/Fs in the runoff would range from 100 to 570 pg/L. The upper value is in the range of CDD/Fs measured in runoff at the Jamaica location (32) and at Santa Monica Bay (30 to 12,000 pg total CDD/F/L) from developed and

**Table 14. Average congener makeup of storm water loading to the NY/NJ Harbor based on urban and suburban/rural apportionment (32,39,43)**

| Congener | TEF | DLCs (g/yr) | TEQ (g/yr as 2,3,7,8-TCDD) | Congener percentage (mass basis)* | Congener percentage (TEQ basis)* |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 0.47 | 0.47 | 0.02 | 8.40 |
| 1,2,3,7,8-PeCDD | 1 | 0.63 | 0.63 | 0.03 | 11.19 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 1.02 | 0.10 | 0.04 | 1.82 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 2.79 | 0.28 | 0.12 | 4.98 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 2.51 | 0.25 | 0.10 | 4.47 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 66 | 0.66 | 2.71 | 11.69 |
| OCDD | 0.0001 | 614 | 0.06 | 25.29 | 1.09 |
| 2,3,7,8-TCDF | 0.1 | 0.80 | 0.08 | 0.03 | 1.42 |
| 1,2,3,7,8-PeCDF | 0.05 | 1.44 | 0.07 | 0.06 | 1.28 |
| 2,3,4,7,8-PeCDF | 0.5 | 0.99 | 0.50 | 0.04 | 8.82 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 4.20 | 0.42 | 0.17 | 7.47 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 3.82 | 0.38 | 0.16 | 6.79 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 2.01 | 0.20 | 0.08 | 3.58 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.26 | 0.026 | 0.01 | 0.47 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 28 | 0.28 | 1.16 | 5.01 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 2.10 | 0.021 | 0.09 | 0.37 |
| OCDF | 0.0001 | 52 | 0.005 | 2.13 | 0.09 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 90 | 0.009 | 3.71 | 0.16 |
| 3,4,4',5-TeCB (81) | 0.0001 | 7.25 | 0.001 | 0.30 | 0.01 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 393 | 0.04 | 16.18 | 0.70 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 21.81 | 0.011 | 0.90 | 0.19 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 884 | 0.09 | 36.4 | 1.57 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 11.72 | 0.001 | 0.48 | 0.02 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 9.46 | 0.95 | 0.39 | 16.84 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 146 | 0.07 | 6.01 | 1.30 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 14 | 0.007 | 0.59 | 0.13 |
| 2,3',4,4',5,5'-HxCB (167) |  | 53 | 0.0005 | 2.18 | 0.01 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 0.56 | 0.006 | 0.02 | 0.10 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 14 | 0.001 | 0.56 | 0.02 |
| **Total CDD/Fs only (±SE)†** |  | **780 (±390)** | **4.4 (±2.2)** |  |  |
| **Total CDD/Fs and PCBs (±SE)†** |  | **2430 (±1215)** | **5.6 (±2.8)** |  |  |

*The congener percentages are based on total CDD/Fs and coplanar PCBs contributions.
†SE, standard error.

undeveloped land surfaces (18), and is similar to that of Bayreuth, Germany street runoff of up to 700 pg CDD/F/L (28).

### Landfill Leachate

DLC concentrations for landfill leachate from Freshkills landfill, Fresh Kills leachate treatment plant, and landfills within the Hackensack Meadowlands were made available by the NYSDEC (32). Concentrations of DLCs (including CDD/Fs and coplanar PCBs) from the sampling locations ranged from 300 to 30,000 pg/L on a mass basis and 0.3 to 14 pg as 2,3,7,8-TCDD/L on a TEQ basis. The average DLC concentration was 10,400 pg/L and 5 pg as 2,3,7,8-TCDD/L. The standard error on the concentration means were typically 35%. The flow of leachate entering the Harbor from landfills in New York and New Jersey was estimated to be about 4.2 MGD (5.8 x $10^6$ $m^3$/yr) (33). The total loading to the Harbor from the landfill leachate based on that flow and the average concentrations was estimated to be 40 g/yr on a mass basis or 0.02 g as 2,3,7,8-TCDD/yr on a TEQ basis. If only CDD/Fs are accounted for, the averages are 1.7 g/yr total mass and 0.01 g/yr as 2,3,7,8-TCDD. Thus, the loading contributed to the Harbor

**Table 15. Congener makeup of landfill leachate loading to the NY/NJ Harbor (32,33)**

| Congener | TEF | DLCs (g/yr) | TEQ (g/yr as 2,3,7,8-TCDD) | Congener percentage (mass basis)* | Congener percentage (TEQ basis)* |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 0.002 | 0.002 | 0.005 | 10.2 |
| 1,2,3,7,8-PeCDD | 1 | 0.001 | 0.001 | 0.004 | 8 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.003 | 0.00029 | 0.008 | 1.6 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 0.01 | 0.001 | 0.015 | 3.1 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 0.004 | 0.00040 | 0.01 | 2.2 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 0.21 | 0.002 | 0.56 | 11.7 |
| OCDD | 0.0001 | 1.38 | 0.00014 | 3.7 | 0.77 |
| 2,3,7,8-TCDF | 0.1 | 0.004 | 0.00039 | 0.010 | 2.2 |
| 1,2,3,7,8-PeCDF | 0.05 | 0.001 | 0.00006 | 0.003 | 0.3 |
| 2,3,4,7,8-PeCDF | 0.5 | 0.002 | 0.001 | 0.005 | 5.2 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 0.004 | 0.00035 | 0.009 | 2 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 0.002 | 0.00020 | 0.005 | 1.1 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 0.002 | 0.00025 | 0.007 | 1.4 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.001 | 0.00010 | 0.003 | 0.5 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 0.02 | 0.00024 | 0.065 | 1.3 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.002 | 0.00002 | 0.006 | 0.13 |
| OCDF | 0.0001 | 0.03 | 0.00000 | 0.08 | 0.017 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 2.48 | 0.00025 | 6.6 | 1.4 |
| 3,4,4',5-TeCB (81) | 0.0001 | 0.03 | 0.00000 | 0.08 | 0.02 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 7.13 | 0.001 | 19 | 3.9 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 0.48 | 0.00024 | 1.3 | 1.3 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 21.23 | 0.002 | 56.7 | 11.8 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 0.17 | 0.00002 | 0.47 | 0.097 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 0.04 | 0.004 | 0.1 | 20.7 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 2.68 | 0.001 | 7.2 | 7.4 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 0.28 | 0.00014 | 0.76 | 0.79 |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 0.97 | 0.00001 | 2.6 | 0.054 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 0.01 | 0.00007 | 0.018 | 0.38 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 0.26 | 0.00003 | 0.69 | 0.14 |
| **Total CDD/Fs only (±SE)†** | | **1.7 (± 0.6)** | **0.01 (± 0.004)** | | |
| **Total CDD/Fs and PCBs (±SE)†** | | **37 (± 13)** | **0.02 (± 0.01)** | | |

*The congener percentages are based on total CDD/Fs and coplanar PCBs contributions.
†SE, standard error.

**Table 16. Mean concentrations of CDD/Fs in sediments of the subbasins of the NY/NJ Harbor (1,56,59)**

| Harbor region | CDD/Fs (ng/kg) | 2,3,7,8-TCDD (ng/kg, dry wt.) | CDD/Fs TEQ (ng as 2,3,7,8-TCDD/kg) |
|---|---|---|---|
| **REMAP 1993/1994 (1,56,59)** | | | |
| Upper Harbor | 2,200 ± 1,850† | 5.5 ± 1.8* | 22.2 ± 5.7* |
| Lower Harbor | 2,150 ± 2,870† | 7.5 ± 3.4* | 17.0 ± 7.1* |
| Jamaica Bay | 1,020 ± 1,440† | 4.0 ± 2.6* | 16.4 ± 9.1* |
| Newark Bay | 6,960 ± 3,910† | 24.8 ± 16.1† | 60.7 ± 38.5† |
| **REMAP 1998 (59)** | | | |
| Upper Harbor | 2197 ± 2983† | 6.4 ± 8.7† | 23.3 ± 22.4† |
| Raritan Bay | 1,446 ± 2299† | 3 ± 5.4† | 9.7 ± 16.7† |
| Jamaica Bay | 1,130 ± 1,713† | 1.6 ± 2.9† | 6 ± 10.5† |
| Newark Bay | 3425 ± 3182† | 50 ± 76† | 76.2 ± 95.7† |

* Area normalized concentrations as reported in Adams et al. (2) (± 90% confidence limits)

† Average calculated from 1993/1994 or 1998 measurements provided by Adams (1) (± standard deviation).

by the landfill leachate component is insignificant compared to other sources. **Table 15** shows the estimated congener distribution for the leachate.

## Outputs

### Sediment Budget

The Regional Environmental Monitoring and Assessment Program (56,59), a long-term, interagency environmental monitoring and research program carried out by U.S. EPA-Region 2 and the NY-NJ Harbor Estuary Program (HEP) is assessing the environmental quality of the NY/NJ Harbor complex. As part of this program, chemical composition of sediments within the Harbor was measured in 1993/1994 and 1998 (1,56,59) (**Table 16**). Limited sediment concentration data for Newark Bay were available for 1993/1994 (56) and were provided separately for this analysis (1). The REMAP data include values for 2,3,7,8-substituted CDD/Fs and the 1993/1994 data set also includes values for a few dioxin-like coplanar PCBs (**Table 17**). The 1998 sediment CDD/F concentrations and the 1993/1994 sediment coplanar PCB concentrations were used to prepare estimates of storage of DLCs via sedimentation and removal from the system via dredging (**Figure 1**). A standard error on average sediment concentration values ranged from 20 to 40%. A standard error of 40% was used to provide an estimate of the variability of the average removals of CDD/Fs by dredging or average accumulation by sedimentation.

The REMAP data may be compared to those of Long et al. (38), who performed a study of Harbor sediment toxicity that includes data from samples collected in 1991 and 1993. They reported sediment concentrations for 2,3,7,8-substituted CDD/Fs and TEQs based on these congeners plus four of the coplanar PCBs. TEQ values of 13 ng/kg in Upper New York Harbor to 870 ng/kg in the lower Passaic River were reported. Sediments in Newark Bay typically contained an equivalent TEQ 2,3,7,8-TCDD concentration of 100 ng/kg, similar to the averages obtained from the REMAP data sets (**Table 16**). The NJDEP CARP analysis reported suspended sediment-normalized total CDD/F mean (± standard deviation) for the Passaic and Hackensack Rivers and Newark Bay of 7,670 ± 4,380 ng/kg sediment, with a mean TEQ of 177 ± 126 ng/kg sediment (43). Additional suspended-sediment normalized values from Newark Bay, Arthur Kill, and Kill van Kull have also been provided by NJDEP CARP (**Table 18**, (43)). These concentrations are somewhat higher than the REMAP bottom sediment data (see **Table 16**). Measurements of whole-water TEQ concentrations as 2,3,7,8-TCDD in the Lower Passaic River are higher (6 to 14 pg/L) relative to, for example, the average concentrations observed in the Hudson River (**Table 3**). This and the higher overall TEQ of the Newark Bay sediments indicates that movement of CDD/Fs—probably linked to heavily contaminated zones in the Passaic River—occurs and that at least some of this contamination is accumulating in Newark Bay sediments (see 4,8,11,16). Thus, dredging and sedimentation were quantified separately for the Newark Bay/Kills area using the higher concentrations.

## Dredging

The economic viability of the NY/NJ Harbor system is dependent upon the maintenance of adequate depth to allow passage of ships. The Harbor is naturally shallow and is dredged by the U.S. Army Corps of Engineers and the Port Authority of NY and NJ to maintain depths suitable for modern ship traffic. The resulting removal of sediments from the Harbor was estimated to be approximately 670,000 dry metric tons per year from 1987 to 1991 (16). A more current estimate of dredging volume is 1.5 to 2 MCY per year (13). Calculations were therefore based upon a total of 2 MCY per year and assuming that 20% of the dredged material originated from Newark Bay (lumped with the Kills), 21% from the Upper and Lower Harbor, 23% from the Raritan Bay, and the remainder, 36%, from elsewhere in the Harbor as reported by Farley et al. (16). The 2 MCY volume is equivalent to 547,700 dry metric tons per year dredged using the method of conversion from wet to dry sediments of Farley et al. (16). The removal DLCs from the Harbor via dredging were computed based upon the REMAP concentrations (1,56,59) available for each region as shown in **Table 17,** and the mass dredged. Sediments dredged from Newark Bay and the Kills (110,600 metric tons/yr) (13,16) were considered separately from those dredged from Upper/Lower Harbor (123,000 metric tons/yr) and those dredged from elsewhere in the Harbor (314,100 metric tons/yr) (13,16). The Newark Bay sediments were assumed to have concentrations listed for Newark Bay in **Table 17**. The average sediment concentrations for the remainder of the Harbor were assumed equal to the average of the Upper Harbor and Raritan Bay concentrations shown in **Table 17**. Limited data were available for dioxin-like PCBs in the 1993-1994 REMAP data (**Table 17**).

The loss from dredging (**Table 19**) from Newark Bay and the Kills on a mass basis is 460 g CDD/Fs/yr and on a TEQ basis 10 g as 2,3,7,8-TCDD/yr. The loss from dredging from the remainder of the Harbor is on a mass basis 720 g CDD/Fs/yr and on a TEQ basis 6 g as 2,3,7,8-TCDD/yr. The total loss from dredging on a mass basis is 1190 g CDD/Fs/yr and on a TEQ basis 16 g as 2,3,7,8-TCDD/yr. Using the available coplanar PCB data available from the 1993–1994 REMAP report (56), an order-of-magnitude calculation for PCBs loss through dredging was made. The loss

**Table 17. Average sediment concentrations in the NY/NJ Harbor for CDD/Fs 1998 (59) and coplanar PCBs 1993 (56)**

| Congener | TEF | Jamaica Bay (ng/kg dry wt) | Upper Harbor (ng/kg dry wt) | Raritan Bay (ng/kg dry wt) | Newark Bay (ng/kg dry wt) |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 1.6 | 6.4 | 3 | 49.9 |
| 1,2,3,7,8-PeCDD | 1 | 0.39 | 3.1 | 1 | 2.8 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.81 | 2.2 | 0.56 | 3.2 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 3.5 | 12.7 | 6.3 | 13.5 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 2.6 | 8.5 | 2.7 | 8.3 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 101 | 191 | 90.4 | 213 |
| OCDD | 0.0001 | 922 | 1750 | 1235 | 2370 |
| 2,3,7,8-TCDF | 0.1 | 10 | 15.8 | 9 | 15.6 |
| 1,2,3,7,8-PeCDF | 0.05 | 2.8 | 4.2 | 2.8 | 7.2 |
| 2,3,4,7,8-PeCDF | 0.5 | 0.33 | 9.6 | 2.7 | 14.4 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 2.4 | 8 | 3.8 | 41.7 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 1.8 | 5.4 | 2.4 | 14.2 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 1.5 | 5.9 | 2.9 | 11 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0 | 0.73 | 0.23 | 2.9 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 29.3 | 69. 9 | 32.9 | 232 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.74 | 3.1 | 1.4 | 10.2 |
| OCDF | 0.0001 | 47 | 98 | 48 | 419 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 848 | 4519 | 1184 | 11560 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 676 | 3594 | 1774 | 12516 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 2475 | 10634 | 3721 | 28147 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 698 | 5251 | 986 | 5040 |

**Table 18. Mean concentrations and standard deviations of CDD/Fs in suspended-sediments of three subbasins of the NY/NJ Harbor (NJDEP CARP (43))**

| Sampling location | CDD/Fs* (ng/kg sediment) | CDD/Fs TEQ* (ng as 2,3,7,8-TCDD/kg sediment) |
|---|---|---|
| Newark Bay | 6,140 ± 2,820 | 124 ± 74 |
| Arthur Kill | 17,830 ± 19,030 | 110 ± 102 |
| Kill van Kull | 3,970 ± 1,730 | 45 ± 19 |

* ±standard deviation.

from dredging from Newark Bay and the Kills on a mass basis is 7,750 g dioxin-like PCBs/yr and on a TEQ basis 69 g of equivalent 2,3,7,8-TCDD/yr. The loss from dredging from the remainder of the Harbor is on a mass basis 5,360 g dioxin-like PCBs/yr and on a TEQ basis 96 g as 2,3,7,8-TCDD/yr. The total loss from dredging on a mass basis is 13,104 g dioxin-like PCBs/yr and on a TEQ basis 165 g as 2,3,7,8-TCDD/yr. These estimates would be expected to vary substantially based upon the variability in the sediment concentrations and the amount actually dredged each year. Further refinement to the dredging values could be made since the NJDEP CARP (43) suspended sediment data indicate that Kill van Kull and Arthur Kill sediment concentrations are substantially different from the Newark Bay sediment concentrations (**Table 18**) and the CDD/F congener distribution patterns also differ (43) between these areas of the Harbor. Additionally, since sediment values do not include the contribution of all the coplanar PCBs, they underestimate the removal of DLCs that actually occurs. OCDD makes up 80 to 90% of the mass and 2,3,7,8-TCDD makes up 25 to 40% of the CDD/F TEQ removed in dredged material.

**Table 19. Average congener makeup of DLCs accounted for in sedimentation and dredging**

| Congener | TEF | Dredging (g/yr) | Sedimentation (g/yr) | Dredging (g as 2,3,7,8-TCDD/yr) | Sedimentation (g as 2,3,7,8-TCDD/yr) |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 8.5 | 19.6 | 8.48 | 19.6 |
| 1,2,3,7,8-PeCDD | 1 | 1.1 | 2.5 | 1.08 | 2.5 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.9 | 2.1 | 0.09 | 0.21 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 5.4 | 11.8 | 0.54 | 1.17 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 3 | 7 | 0.30 | 0.70 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 81 | 178 | 0.81 | 1.78 |
| OCDD | 0.0001 | 923 | 1,920 | 0.09 | 0.19 |
| 2,3,7,8-TCDF | 0.1 | 6.9 | 14.7 | 0.69 | 1.47 |
| 1,2,3,7,8-PeCDF | 0.05 | 2.4 | 5 | 0.12 | 0.25 |
| 2,3,4,7,8-PeCDF | 0.5 | 4 | 9.4 | 1.99 | 4.71 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 7.8 | 17.9 | 0.78 | 1.79 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 3.3 | 7.6 | 0.33 | 0.76 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 0.55 | 1.3 | 0.06 | 0.130 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 3.1 | 7 | 0.31 | 0.70 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 50 | 114 | 0.5 | 1.14 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 2.2 | 5 | 0.02 | 0.050 |
| OCDF | 0.0001 | 84 | 191 | 0.01 | 0.019 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 2,491 | 5,920 | 0.25 | 0.59 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 2,692 | 6096 | 0.27 | 0.6 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 6,284 | 14,598 | 0.63 | 1.5 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 1,637 | 4,042 | 164 | 400 |
| **Total CDD/Fs only (±SE)†** | | **1,190 (±475)** | **2,515 (±1,006)** | **16 (±6.4)** | **37 (±14.8)** |
| **Total CDD/Fs and PCBs** | | **1,4300** | **33,200** | **180** | **440** |

† SE, standard error.

## Sedimentation

Accumulations of DLCs in sediments that are deposited into the Harbor were estimated using sediment concentrations in **Table 17** and the sedimentation rates reported for various sub-regions of the Harbor. Farley et al. (16) used sedimentation rates of 2 cm/yr for dredged areas, 0.2 cm/yr for coves and broad shallow portions of the Harbor, and 0.02 cm/yr for subtidal banks. Mitra et al. (40) have recently estimated a sedimentation rate for Newark Bay of 2.6 cm/yr. Additionally, Woodruff et al. (65) reported that an annual sedimentation rate of 2--3 mm/yr over the entire Estuary is required in order to keep a constant river depth with respect to current sea-level rise. To estimate the storage of DLCs by burial in sediments a Harbor-wide sedimentation value of 2 mm per year was assumed for all areas of the Harbor except for Newark Bay. The Newark Bay/Kills sediments were accounted for separately to adjust for the higher expected concentration of 2,3,7,8-TCDD using a sedimentation rate of 2 cm/yr. Deposited sediments were assumed to have a concentration of 500 g dry solids/L (16).

Sediments deposited in Newark Bay/Kills (2 cm/yr, over an area of 32 km$^2$) were estimated to be 32 x 10$^7$ kg/yr and were assumed to have the concentrations shown in **Table 17** for Newark Bay. The remainder of sediment deposited in the Harbor (779 x 10$^7$ kg/yr) was assumed to have concentrations equal to the average of the Upper Harbor and Raritan Bay concentrations (**Table 17**). The total sedimentation (**Table 19**) of DLCs on a mass basis was 2,515 g CDD/Fs/yr and on a TEQ basis 37 g as 2,3,7,8-TCDD/yr. The total sedimentation of dioxin-like PCBs on a mass basis was 30,660 g PCBs/yr and on a TEQ basis 407 g as 2,3,7,8-TCDD/yr. The sedimentation in Newark Bay may to some extent represent the input from the Lower Passaic River. The sedimentation in Newark Bay alone was 1096 g CDD/Fs/yr on a mass basis and 24 g/yr on a 2,3,7,8-TCDD basis. Sixty-six percent of the TEQ was made up of 2,3,7,8-TCDD in Newark Bay sediments. The amount of CDD/Fs stored in sediment would be expected to vary greatly depending upon the sediment concentrations and yearly deposition rates. Further refinement of this estimate could be made using the individual sediment concentrations for Arthur Kill and Kill van Kull (43) and sedimentation rates specific for those areas. Furthermore, since the calculation does not include the contribution of all of the coplanar PCBs, this is an underestimate of the storage that actually occurs.

## Tidal Exchange

### Atlantic Ocean/New York Bight Via Verrazano Narrows

The loss of DLCs to the Atlantic Ocean was estimated based on freshwater outflow from the Harbor and tidal exchange between the New York Bight and the Harbor as described by Rosenthal and Perron-Cashman (44). **Equations 3** and **4** were used to calculate the net flux between the Harbor and the Atlantic Ocean. $Q_e$, the flow from the Estuary includes the ocean exchange, river flows, and wastewater flows and was estimated to be 1971 m$^3$/s (44). $Q_o$, an ocean exchange flow value, was determined to be 726 m$^3$/s through a salinity balance by Rosenthal and Perron-Cashman (44). Using the DLC concentrations for the Lower Harbor and the New York Bight, the net tidal exchange ($F_e$–$F_o$), which represents a net loss to the Harbor of DLCs, was determined. The Lower Bay had a total average concentration of DLCs of 114 pg/L, and the New York Bight had concentrations of 3 pg/L. Standard error on average values of ambient water concentrations ranged from 13 to 30%. A standard error of 20% was applied to provide an estimate of variability for the calculations. The mass of DLCs (CDD/Fs plus PCBs) leaving the Harbor were on a mass basis 7,070 g/yr and on a TEQ basis 10.7 g as 2,3,7,8-TCDD/yr (**Table 20**). If only CDD/Fs were accounted for, the mass loss from the Harbor is 930 g/yr and the TEQ loss was 7.5 g as 2,3,7,8-TCDD/yr.

**Equations 3 and 4**

$$F_e = Q_e \times [CDDFs]_e$$

$$F_o = Q_o \times [CDDFs]_o$$

Where:

$F_e$ = flux of CDD/Fs from Estuary to Ocean (g/yr);
$Q_e$ = flow from Estuary to Ocean (m$^3$/s);
$F_o$ = flux of CDD/Fs from Ocean to Estuary (g/yr);
$Q_o$ = flow from Ocean to Estuary (m$^3$/s);
$[CDDFs]_e$ = concentration of CDD/Fs in Estuary (Lower Harbor); and
$[CDDFs]_o$ = concentration of CDD/Fs in Ocean (NY Bight).

Table 20. Average congener makeup of net DLC output ($F_e$–$F_o$) from the NY/NJ Harbor to the New York Bight based on available data (32)

| Congener | TEF | DLCs (g/yr) | TEQ (g/yr as 2,3,7,8-TCDD) | Congener percentage (mass basis)* | Congener percentage (TEQ basis)* |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 1.7 | 1.7 | 0.02 | 16 |
| 1,2,3,7,8-PeCDD | 1 | 0.91 | 0.91 | 0.01 | 8.5 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 1.0 | 0.10 | 0.01 | 0.98 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 4.4 | 0.44 | 0.06 | 4.1 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 3.9 | 0.39 | 0.06 | 3.7 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 68 | 0.68 | 0.96 | 6.3 |
| OCDD | 0.0001 | 761 | 0.08 | 11 | 0.71 |
| 2,3,7,8-TCDF | 0.1 | 8.0 | 0.80 | 0.11 | 7.5 |
| 1,2,3,7,8-PeCDF | 0.05 | 2.4 | 0.12 | 0.03 | 1.1 |
| 2,3,4,7,8-PeCDF | 0.5 | 2.5 | 1.3 | 0.04 | 12 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 4.2 | 0.42 | 0.06 | 4.0 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 1.9 | 0.19 | 0.03 | 1.7 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 1.7 | 0.17 | 0.02 | 1.6 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.13 | 0.01 | 0.002 | 0.12 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 24 | 0.24 | 0.34 | 2.2 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.70 | 0.01 | 0.01 | 0.07 |
| OCDF | 0.0001 | 40 | 0.004 | 0.57 | 0.04 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 875 | 0.09 | 12 | 0.82 |
| 3,4,4',5-TeCB (81) | 0.0001 | 9.7 | 0.001 | 0.14 | 0.01 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 1,242 | 0.12 | 18 | 1.2 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 69 | 0.03 | 0.97 | 0.32 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 3,420 | 0.34 | 48 | 3.2 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 13 | 0.001 | 0.19 | 0.01 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 24 | 2.4 | 0.33 | 22 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 291 | 0.15 | 4.1 | 1.4 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 40 | 0.02 | 0.57 | 0.19 |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 129 | 0.001 | 1.8 | 0.01 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 3.4 | 0.03 | 0.05 | 0.32 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 25 | 0.003 | 0.35 | 0.02 |
| **Total CDD/Fs only (±SE)**† | | **930 (±280)** | **7.5 (±2.2)** | | |
| **Total CDD/Fs plus PCBs** | | **7,070 (±1,400)** | **10.7 (±2)** | | |

*The congener percentages are based on total CDD/Fs plus coplanar PCBs contributions.

†SE, standard error.

### Long Island Sound via East River

The East River is a tidal strait connecting Long Island Sound and the Upper Harbor. The net (out)flux of DLCs between the Upper Harbor and Long Island Sound ($F_{UH}$–$F_{LIS}$) was calculated from **Equations 5** and **6.** Caplow (9,10) provided an estimate of tidal transfer at the north end of the East River of 430 $m^3$/s and an estimated annual subtidal flow of 200 $m^3$/s for the East River. Concentrations of DLCs in the Long Island Sound at Port Jefferson and in the Upper Harbor (30) were used to estimate the net exchange of DLCs. The standard error on average concentration values ranged from 30 to 60%. A standard error of 50% was used to provide an estimate of the variability of the average outflux. The $Q_{LIS}$ was 630 $m^3$/s, the tidal exchange between the Upper Harbor and Long Island Sound plus the subtidal flow from the East River; and $Q_{UH}$ was 430 $m^3$/s, the tidal exchange between Upper Harbor and the Long Island Sound. The net flux out of the Harbor to Long Island

## Equations 5 and 6

$$F_{UH} = Q_{UH} \times [CDDFs]_{UH}$$

$$F_{LIS} = Q_{LIS} \times [CDDFs]_{LIS}$$

Where:

$F_{UH}$ = flux of CDD/Fs from Upper Harbor to Long Island Sound (g/yr);
$Q_{UH}$ = flow from Upper Harbor to Long Island Sound (m$^3$/s);
$F_{LIS}$ = flux of CDD/Fs from Long Island Sound to Upper Harbor (g/yr);
$Q_{LIS}$ = flow from Long Island Sound to Upper Harbor (m$^3$/s);
$[CDDFs]_{UH}$ = cc of CDD/Fs in Long Island Sound (Port Jefferson).

## Equations 7

$$Volatilization = C_{diss} \bullet A \bullet K_{OL} \bullet 365$$

Where:

Volatilization = volatilization loss (pg/year);
$C_{diss}$ = truly dissolved concentration of each congener (pg/L);
A = the surface area (m$^2$);
$K_{OL}$ = the mass transfer coefficient for each dioxin and dioxin-like congener (m/d); and
365 = days in the year.

## Equations 8

$$C_{diss} = \frac{C_T}{(1 + K_{DOC}\,[DOC] + K_{OC}\,[POC]}$$

Where:

$C_T$ = reported whole water (dissolved plus sorbed) concentration (pg/L);
$K_{DOC}$ = partitioning coefficient pertaining to dissolved organic carbon;
$K_{OC}$ = partitioning coefficient pertaining to organic carbon;
[DOC] = concentration of dissolved organic carbon; and
[POC] = concentration of particulate organic carbon.

Sound including CDD/Fs and PCBs was 5,135 g/yr or 11.9 g/yr as 2,3,7,8-TCDD and for CDD/Fs was 360 g/yr and 9.2 g/yr as 2,3,7,8-TCDD (**Table 21**).

### Volatilization

The approach outlined by Totten et al. (53) was used to estimate volatilization of CDD/Fs and coplanar PCBs from the Harbor. The approach uses **Equation 7** to estimate volatilization loss. $K_{OL}$ for each congener was calculated according to the method described by Totten et al. (53). $K_{OL}$ values are dependent upon the Henry's Law Constant (HLC), which were obtained at 25°C from Govers and Krop (22) for CDD/Fs and from Dunnivant et al. (14) for coplanar PCBs. The temperature was assumed to be 15°C, and the HLC were corrected for the temperature change as suggested by Shlu et al. (45). These values are summarized in **Table 22**.

**Equation 8** was used to estimate the truly dissolved fraction ($C_{diss}$) of each congener in each subbasin. The subregions of the Harbor as described by Farley et al. (16) differed in whole-water concentrations of DLCs (32) and in the relative amounts of dissolved organic carbon (DOC) and particulate organic carbon (POC) (16). Areas, DOC, and POC for each region were obtained from Farley et al. (16).

The standard error for the water CDD/F concentrations was approximately 40%. Totten (52) noted that the uncertainty on in KOL is also significant, 40%. The combined error of approximately 57% was used to provide an estimate of the volatilization component.

The results of this analysis are shown in **Table 23** and **Table 25**. The volatilization loss is heavily dominated by the loss of PCB congeners from the water, especially in the region of the Hudson River in the vicinity of the Tappan Zee Bridge. This finding is consistent with that reported by Totten (52). If one examines the volatilization loss based upon the CDD/Fs only, the loss is substantially less on a mass and TEQ basis, as expected given the far lower solubilities of the CDD/Fs relative to PCBs.

Lohmann et al. (35,36) summarized information on air-water exchange of *lesser* chlorinated CDD/Fs in the lower Hudson River Estuary. Their calculated volatilization losses are shown in **Table 24**. A quick

**Table 21. Average congener makeup of net DLC output from the NY/NJ Harbor to the Long Island Sound ($F_{UH}$–$F_{LIS}$) via the East River based on available data (32)**

| Congener | TEF | DLCs (g/y) | TEQ (g/yr as 2,3,7,8-TCDD) | Congener percentage (mass basis)* | Congener percentage (TEQ basis)* |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 1.89 | 1.89 | 0.04 | 15.8 |
| 1,2,3,7,8-PeCDD | 1 | 2.33 | 2.33 | 0.05 | 19.6 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 1.92 | 0.19 | 0.04 | 1.61 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 2.29 | 0.23 | 0.04 | 1.92 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 2.17 | 0.22 | 0.04 | 1.82 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 32.7 | 0.33 | 0.64 | 2.74 |
| OCDD | 0.0001 | 286 | 0.03 | 5.57 | 0.24 |
| 2,3,7,8-TCDF | 0.1 | 2.75 | 0.27 | 0.05 | 2.31 |
| 1,2,3,7,8-PeCDF | 0.05 | 1.16 | 0.06 | 0.02 | 0.49 |
| 2,3,4,7,8-PeCDF | 0.5 | 6.01 | 3.00 | 0.12 | 25.2 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 1.71 | 0.17 | 0.03 | 1.44 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 1.46 | 0.15 | 0.03 | 1.23 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 1.35 | 0.13 | 0.03 | 1.13 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 1.18 | 0.12 | 0.02 | 0.99 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 6.75 | 0.07 | 0.13 | 0.57 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 3.59 | 0.04 | 0.07 | 0.30 |
| OCDF | 0.0001 | 6.16 | 0.001 | 0.12 | 0.01 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 654 | 0.07 | 12.7 | 0.55 |
| 3,4,4',5-TeCB (81) | 0.0001 | 9.30 | 0.001 | 0.18 | 0.01 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 986.3 | 0.10 | 19.21 | 0.83 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 81.3 | 0.04 | 1.58 | 0.34 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 2,615 | 0.26 | 50.9 | 2.20 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 18.3 | 0.002 | 0.36 | 0.02 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 19.0 | 1.90 | 0.37 | 16.0 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 242 | 0.12 | 4.71 | 1.02 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 50.4 | 0.03 | 0.98 | 0.21 |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 45.3 | 0.0005 | 0.88 | 0.004 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 16.8 | 0.17 | 0.33 | 1.41 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 35.1 | 0.004 | 0.68 | 0.03 |
| **Total CDD/Fs only (±SE)†** | | **360 (±180)** | **9.2 (±4.6)** | | |
| **Total CDD/Fs plus PCBs (±SE)†** | | **5,140 (±180)** | **11.9 (±6)** | | |

*The congener percentages are based on total CDD/Fs plus coplanar PCBs contributions.
†SE, standard error.

check on the magnitude of the volatilization component estimated in **Table 23** can be made with the Lohmann data. If an area of 811 km² is used for the entire Harbor and a volatilization flux of 4.6 to 28 pg/m²/d is assumed (the range reported for the tetra- and pentachlorinated CDD/Fs), then the volatilization loss from the Harbor is in the range of 1.3 to 8.3 g/y—a similar order of magnitude loss as from the analysis above. This substantiates the order of magnitude of the volatilization loss calculation.

## III. Summary

Summaries of the CDD/F inputs to and outputs from the Harbor on a mass and TEQ basis are shown in **Figures 3** through **8** and in **Tables 26** and **27**. Sources and sinks of the three congeners with the highest mammalian TEFs (2,3,7,8-TCDD, 1,2,3,7,8-pentaCDD, and 2,3,4,7,8-pentaCDF) are shown in **Figures 9, 10,** and **11**. The major congener-specific sinks and sources of CDD/Fs in the Harbor on a mass basis are shown in **Tables 28** and **29** and on a TEQ basis are

**Table 22. Henry's Law constants (14,22) and $K_{OL}$ (53) computed for DLCs**

| Compound | Henry's Law constant at 25°C (kPa-m³/mol) | $K_{OL}$ (m/d) |
|---|---|---|
| 2,3,7,8-TCDD | 0.00162 | 0.184 |
| 1,2,3,7,8-PeCDD | 0.00148 | 0.164 |
| 1,2,3,4,7,8-HxCDD | 0.00144 | 0.156 |
| 1,2,3,6,7,8-HxCDD | 0.00144 | 0.156 |
| 1,2,3,7,8,9-HxCDD | 0.00144 | |
| 1,2,3,4,6,7,8-HpCDD | 0.000831 | 0.093 |
| OCDD | 0.000512 | 0.058 |
| 2,3,7,8-TCDF | 0.00269 | 0.273 |
| 1,2,3,7,8-PeCDF | 0.0019 | 0.201 |
| 2,3,4,7,8-PeCDF | 0.00257 | 0.595 |
| 1,2,3,4,7,8-HxCDF | 0.0019 | 0.195 |
| 1,2,3,6,7,8-HxCDF | 0.0019 | 0.195 |
| 2,3,4,6,7,8-HxCDF | 0.00178 | 0.184 |
| 1,2,3,7,8,9-HxCDF | 0.00095 | 0.108 |
| 1,2,3,4,6,7,8-HpCDF | 0.00141 | 0.148 |
| 1,2,3,4,7,8,9-HpCDF | 0.001 | 0.109 |
| OCDF | 0.000776 | 0.085 |
| 3,3',4,4'-TeCB (77) | 0.01039 | 0.541 |
| 2,3,3',4,4'-PeCB (105) | 0.010063 | 0.521 |
| 2,3,4,4',5-PeCB (114) | 0.01448 | 0.604 |
| 2,3',4,4',5-PeCB (118) | 0.0127 | 0.576 |
| 2',3,4,4',5-PeCB (123) | 0.0176 | 0.647 |
| 3,3',4,4',5-PeCB (126) | 0.00829 | 0.475 |
| 2,3,3',4,4',5-HxCB (156) | 0.00897 | 0.483 |
| 2,3,3',4,4',5'-HxCB (157) | 0.00856 | 0.769 |
| 2,3',4,4',5,5'-HxCB (167) | 0.0111 | 0.533 |
| 3,3',4,4',5,5'-HxCB (169) | 0.0066 | 0.412 |
| 2,2',3,3',4,4',5-HpCB (170) | 0.00884 | 0.471 |
| 2,2',3,4,4',5,5'-HpCB (180) | 0.01088 | 0.518 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.01039 | 0.409 |

shown in **Tables 30** and **31**. Finally, a side-by-side comparison of the total congener-specific inputs and outputs is shown in **Table 32**. Note that sedimentation is presented in these tables for comparison although it is not considered an output. Although the negligible landfill leachate input does not appear in the tables, it is included in the totals.

The following observations can be made:

- The mass balance for the 17 CDD/F congeners (**Figure 3** and **Tables 28** and **29**) suggests that CDD/Fs are being lost from the Harbor (2,490 ± 1,950 g/yr) at a *lower* rate than they can be accounted for entering the Harbor (3940 ± 750 g/yr). On a mass basis, OCDD is the major component of the CDD/F balance.
- The 2,3,7,8-TCDD equivalent (TEQ) balance for the 17 CDD/F congeners (**Figure 4** and **Tables 30** and **31**) suggests that TEQ is being lost from the Harbor (35 ± 30 g/yr) at a *higher* rate than it can be accounted for entering the Harbor (15.2 ± 4.4 g/yr).
- The Harbor is losing about 12.8 g/y of the 2,3,7,8-TCDD congener, while only 1.1 g/yr is accounted for entering (**Tables 28**, **29**, and **32**). Thus, while the losses from the Harbor are made up of about 37% 2,3,7,8-TCDD on a TEQ basis, the inputs are made of only 7% 2,3,7,8-TCDD on a TEQ basis. The imbalance in this congener may indicate that there are unidentified sources of 2,3,7,8-TCDD to the Harbor or that redistribution and subsequent export (primarily in dredged sediments) of his-

## Table 23. Volatilization losses from the NY/NJ Harbor subregions

| Harbor region | Volatilization<br>CDD/Fs plus coplanar PCBs (g/y) | CDD/Fs plus coplanar PCBs TEQ (g as 2,3,7,8-TCDD/yr) | CDD/Fs only (g/yr) | CDD/Fs only TEQ (g as 2,3,7,8-TCDD/yr) |
|---|---|---|---|---|
| Kingston to Poughkeepsie | 637 | 0.26 | 0.16 | 0.04 |
| Poughkeepsie to Tappan Zee Bridge | 3,680 | 1.04 | 1.81 | 0.31 |
| Tappan Zee Bridge to Harlem River | 8000 | 2.33 | 4.07 | 0.71 |
| South of Harlem River | 2,390 | 2.07 | 2.07 | 0.50 |
| Newark Bay/ Kills | 900 | 0.66 | 1.07 | 0.44 |
| Raritan Bay | 1,150 | 0.55 | 1.11 | 0.18 |
| Upper Bay/ Lower Bay | 1,400 | 0.68 | 1.14 | 0.30 |
| Jamaica Bay | 280 | 0.20 | 0.34 | 0.06 |
| **Total (±SE)†** | **18,450 (±10,500)** | **7.7 (±4.4)** | **12 (±6.8)** | **2.5 (±1.4)** |

† SE, standard error.

## Table 24. Volatilization losses from the lower NY/NJ Harbor (35,36)

| Homologue group | Volatilization (pg/m$^2$-d) | Absorption (pg/m$^2$-d) |
|---|---|---|
| Cl$_2$DDs | 4200 | 150 |
| Cl$_3$DDs | 52 | 3.6 |
| Cl$_4$DDs | 9.2 | 2.6 |
| Cl$_5$DDs | 4.6 | 1.3 |
| Cl$_1$DFs | 680 | 31 |
| Cl$_2$DFs | 180 | 57 |
| Cl$_3$DFs | 37 | 29 |
| Cl$_4$DFs | 28 | 13 |
| Cl$_5$DFs | 26 | 5.9 |

torical deposits of 2,3,7,8-TCDD contamination—e.g., the Lower Passaic River "hotspots"—within the Harbor are occurring, as reported previously by Bopp et al. (4) and Chaky (11). A comprehensive fate and transport model such as that being developed as part of the Harbor Estuary Program is needed to fully understand the impact of these highly contaminated sites on the rest of the Harbor.

- About 23.3 g/yr 2,3,7,8-TCDF are lost, while 5.5 g/yr 2,3,7,8-TCDF enter the Harbor (**Tables 28, 29,** and **32**). The 2,3,7,8-TCDF loss is roughly equally divided between volatilization, tidal exchange, and dredged sediments. This may indicate that inputs of 2,3,7,8-TCDF are underestimated or that outputs in one or more compartments are overestimated. Further examination of this toxic congener may be needed.
- If only CDD/Fs are taken into account, the primary input of 2,3,7,8-TCDD equivalents (TEQ) to the Harbor from external sources is about evenly divided between CSOs (21.4 %), runoff, (29.1 %) and the Hudson River (21 %), **Figure 6**. The TEQ from the Hudson River is made up largely of 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, and 2,3,4,7,8-PeCDF. Simon Litten (33) noted that there may be an unidentified source of 2,3,4,7,8-PeCDF in the lower Hudson River. On a TEQ basis 1,2,3,4,6,7,8-HpCDD, 1,2,3,4,6,7,8-HpCDD and 1,2,3,7,8-PeCDD are major components of CSO discharge. Interdiction and treatment of CSO and storm water flows has the potential to *significantly* reduce loadings of DLCs to the Harbor.
- While NJ rivers contribute a significant portion (34%) of the total mass loading of CDD/Fs to the Harbor (**Figure 5**), about 94% of this mass is OCDD (**Table 28**). On a TEQ basis the NJ Rivers contribute about 10.9% of the loading to the Harbor (**Figure 6**).

**Table 25. Estimate of total volatilization losses of DLCs from the NY/NJ Harbor**

| Congener | TEF | Volatilization of DLCs (g/yr) | Volatilization of DLCs (g as 2,3,7,8-TCDD/ yr) | Congener percentage (mass basis)* | Congener percentage (TEQ basis)* |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 1 | 0.72 | 0.72 | 0.004 | 9.36 |
| 1,2,3,7,8-PeCDD | 1 | 0.08 | 0.08 | 0.0005 | 1.08 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.04 | 0.00 | 0.0002 | 0.05 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 0.10 | 0.01 | 0.001 | 0.13 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 0.13 | 0.01 | 0.001 | 0.16 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 0.43 | 0.00 | 0.002 | 0.06 |
| OCDD | 0.0001 | 1.07 | 0.00 | 0.01 | 0.001 |
| 2,3,7,8-TCDF | 0.1 | 5.72 | 0.57 | 0.03 | 7.4 |
| 1,2,3,7,8-PeCDF | 0.05 | 0.46 | 0.02 | 0.003 | 0.30 |
| 2,3,4,7,8-PeCDF | 0.5 | 2.12 | 1.06 | 0.01 | 13.8 |
| 1,2,3,4,7,8-HxCDF | 0.1 | 0.27 | 0.03 | 0.001 | 0.35 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 0.12 | 0.01 | 0.001 | 0.16 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 0.13 | 0.01 | 0.001 | 0.16 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.02 | 0.00 | 0.0001 | 0.02 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 0.40 | 0.00 | 0.002 | 0.05 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.01 | 0.00 | 0.0001 | 0.002 |
| OCDF | 0.0001 | 0.11 | 0.00 | 0.001 | 0.0001 |
| 3,3',4,4'-TeCB (77) | 0.0001 | 4710 | 0.47 | 25.5 | 6.13 |
| 3,4,4',5-TeCB (81) | 0.0001 | 57 | 0.01 | 0.31 | 0.07 |
| 2,3,3',4,4'-PeCB (105) | 0.0001 | 3250 | 0.33 | 17.6 | 4.2 |
| 2,3,4,4',5- PeCB (114) | 0.0005 | 202 | 0.10 | 1.10 | 1.3 |
| 2,3',4,4',5- PeCB (118) | 0.0001 | 9426 | 0.94 | 51 | 12.3 |
| 2',3,4,4',5- PeCB (123) | 0.0001 | 88 | 0.01 | 0.48 | 0.11 |
| 3,3',4,4',5- PeCB (126) | 0.1 | 29 | 2.92 | 0.16 | 38 |
| 2,3,3',4,4',5-HxCB (156) | 0.0005 | 525 | 0.26 | 2.85 | 3.4 |
| 2,3,3',4,4',5'-HxCB (157) | 0.0005 | 24 | 0.01 | 0.13 | 0.15 |
| 2,3',4,4',5,5'-HxCB (167) | 0.00001 | 97 | 0.00 | 0.53 | 0.01 |
| 3,3',4,4',5,5'-HxCB (169) | 0.01 | 9.1 | 0.09 | 0.05 | 1.19 |
| 2,3,3',4,4',5,5'-HpCB (189) | 0.0001 | 18 | 0.00 | 0.10 | 0.02 |
| **Total CDD/Fs only (±SE)**[†] | | **12**<br>**(±6.8)** | **2.5**<br>**(±1.4)** | | |
| **Total CDD/Fs plus PCBs (±SE)**[†] | | **18,450**<br>**(±10,500)** | **7.7**<br>**(±4.4)** | | |

*The congener percentages are based on total CDD/Fs plus coplanar PCBs contributions.

†SE, standard error.

- CSOs contribute more CDD/Fs (21.4 % on a TEQ basis) to the Harbor than do the WPCFs (6 % on a TEQ basis) **Figure 6**, despite the fact that the WPCF flow is more than 10-fold that of the CSO flow. If wet weather influent flows (**Table 10**) are indicative of the CDD/F whole-water concentrations entering WPCFs, the WPCFs are doing a good job of preventing CDD/Fs from entering the Harbor. The primary congener of interest in WPCF effluent is 1,2,3,7,8-PeCDD. On a TEQ basis 1,2,3,4,6,7,8-HpCDD and 1,2,3,7,8-PeCDD are major components of CSO discharge (**Table 30**).
- The primary loss of the 2,3,7,8-TCDD congener (8.5 g/yr) and total CDD/Fs (1188 g/yr) from the Harbor was through dredging (**Table 29**). Indeed, dredging accounted for 46% of the total TEQ and 66% of the 2,3,7,8-TCDD leaving the Harbor. The importance of an accurate sediment budget for assessing the fate of this highly toxic congener is evident. Further

refinement of the sediment budget could be performed to more accurately capture the fate of 2,3,7,8-TCDD in sediments dredged from the Arthur Kill and Kill van Kull.

- The combined net outflux via tidal exchange to the Atlantic Ocean and Long Island Sound accounts for 47% of the CDD/Fs on a TEQ basis (**Figure 8**).
- The insoluble nature of the CDD/Fs (tetra-chlorinated and higher) precludes significant mass loss through volatilization; however, on a TEQ basis volatilization accounts for 7.2 % of the loss of DLCs from the Harbor (**Figure 8**).
- The data for dioxin-like PCBs is not complete and does not allow a complete PCB mass balance. However, from the data that are available, it appears that including coplanar PCBs in the mass balance would increase the *mass* of DLCs in this accounting by an order of magnitude and increase the *TEQ* of DLCs by several fold. Inclusion of other dioxin-like compounds, such as PAHs, would have a similar effect.

**Figure 3. Simplistic model of inputs and outputs of CDD/Fs g/yr to the NY/NJ Harbor.**

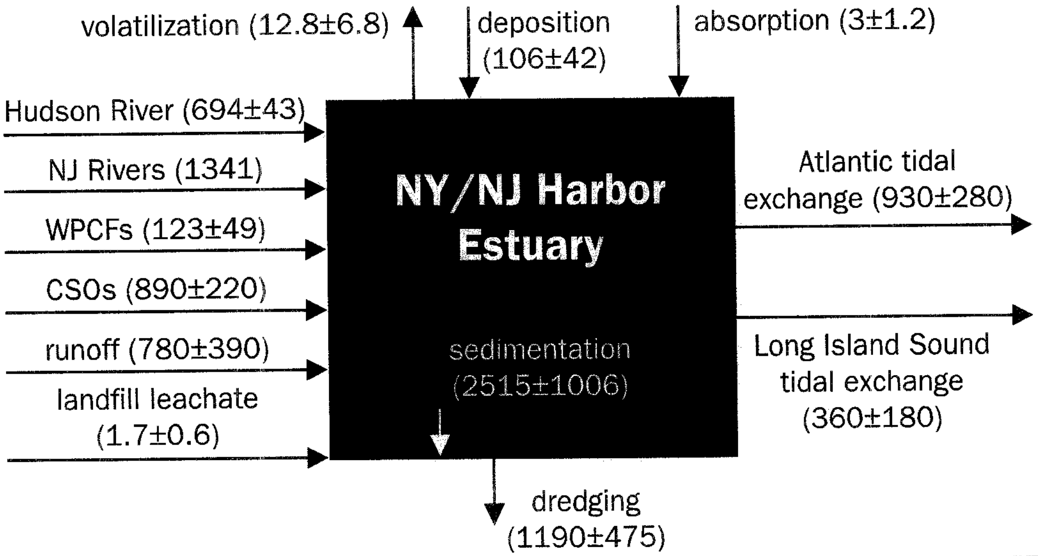


**Figure 4. Simplistic model of inputs and outputs of CDD/Fs as g/yr 2,3,7,8-TCDD to the NY/NJ Harbor.**

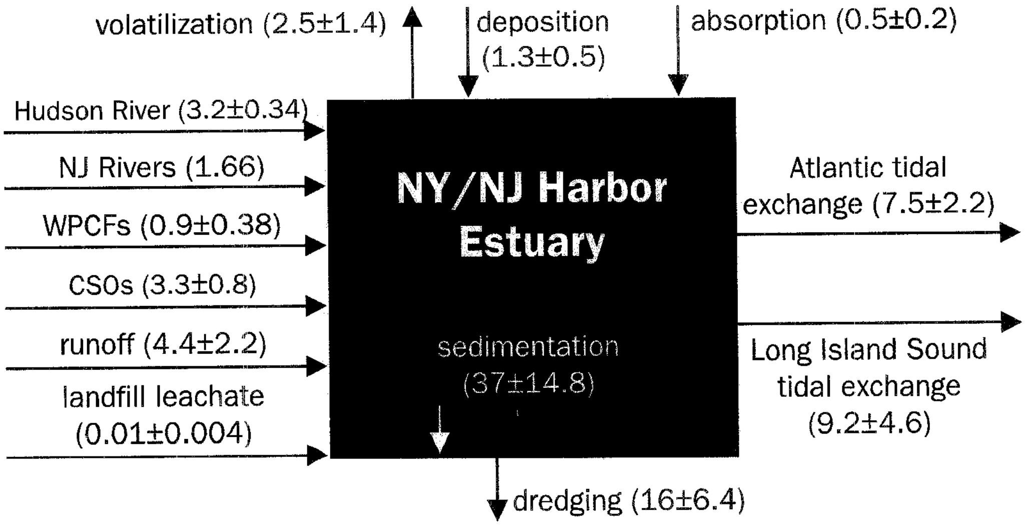


**Figure 5. NY/NJ Harbor inputs on a mass basis (g CDD/F/y)**

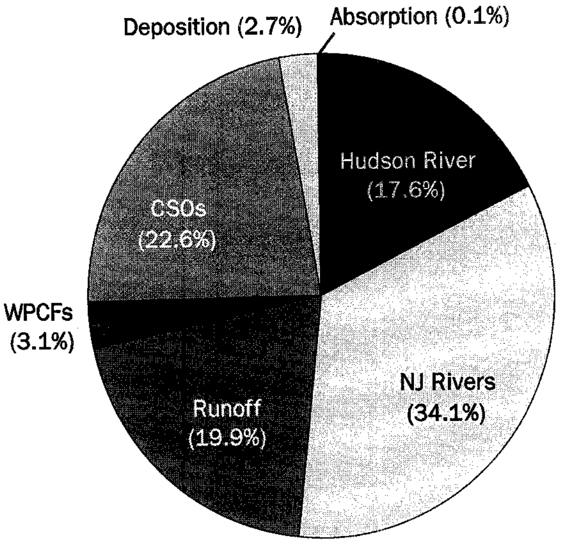


**Figure 7. NY/NJ Harbor outputs on a mass basis (g CDD/Fs/y)**

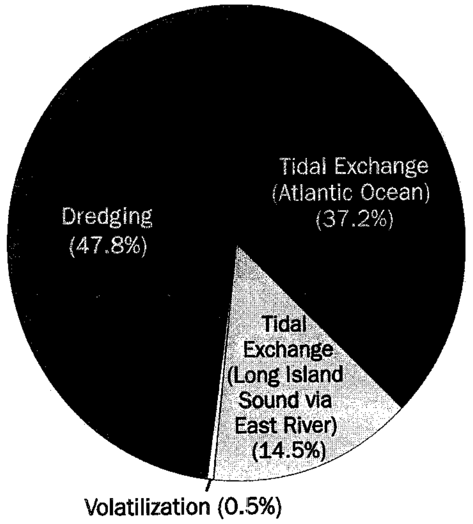


**Figure 6. NY/NJ Harbor inputs on a TEQ basis (g CDD/Fs as 2,3,7,8-TCDD/y)**

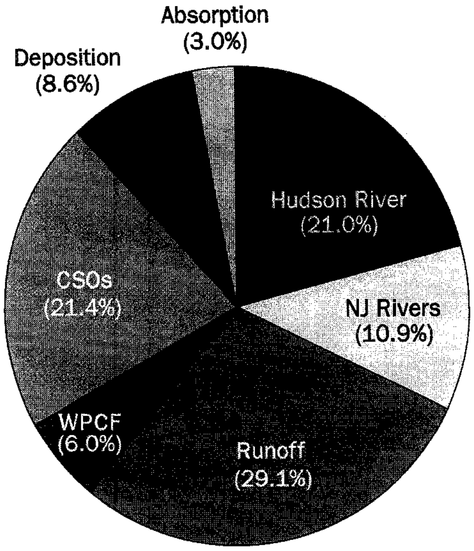


**Figure 8. NY/NJ Harbor outputs on a TEQ basis (g as 2,3,7,8-TCDD/y)**

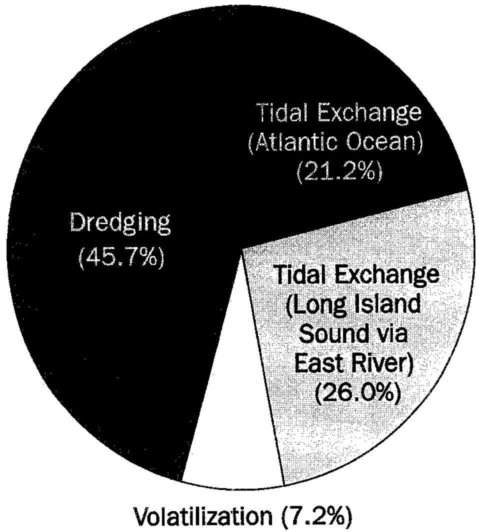


**Figure 9. Simplistic model of inputs and outputs of 2,3,7,8-TCDD in the NY/NJ Harbor.**

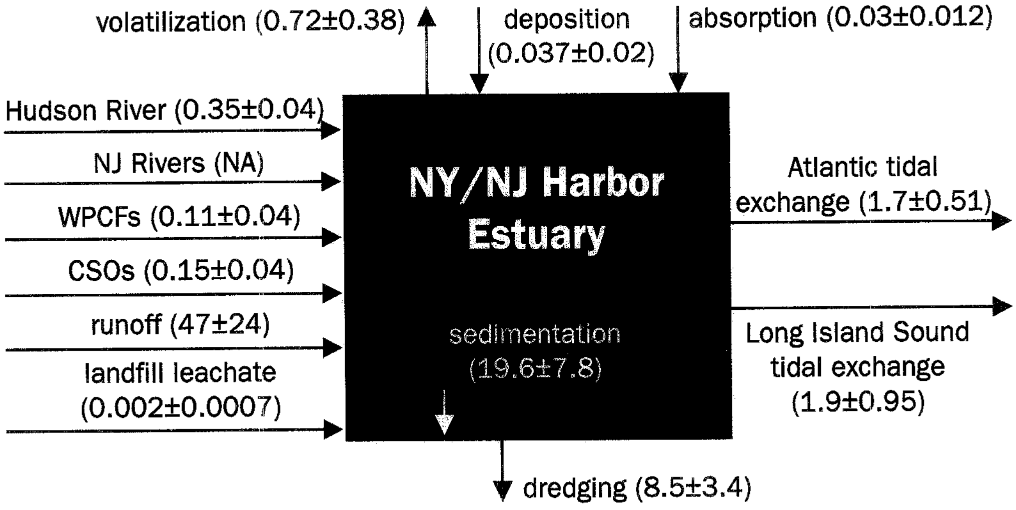


**Figure 10. Simplistic model of inputs and outputs of 1,2,3,7,8-pentaCDD in the NY/NJ Harbor.**

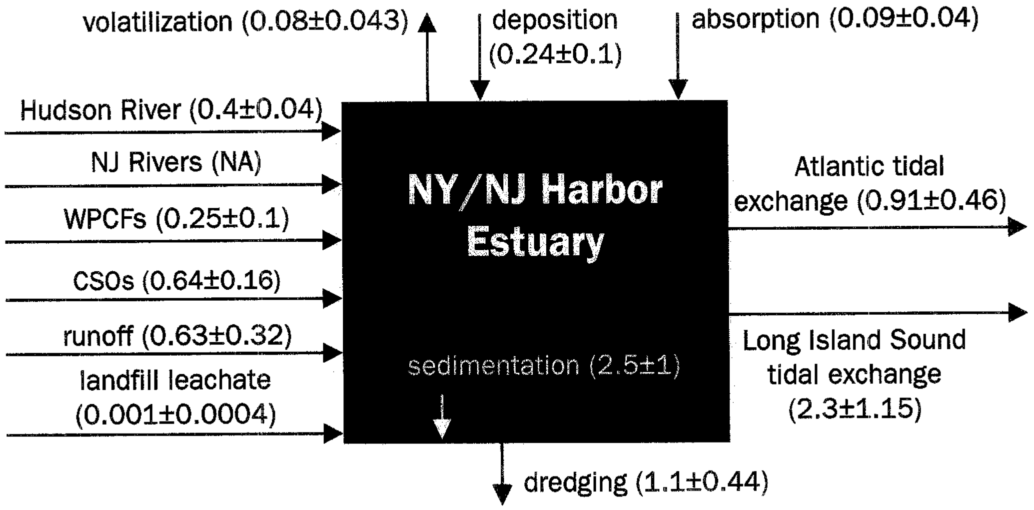
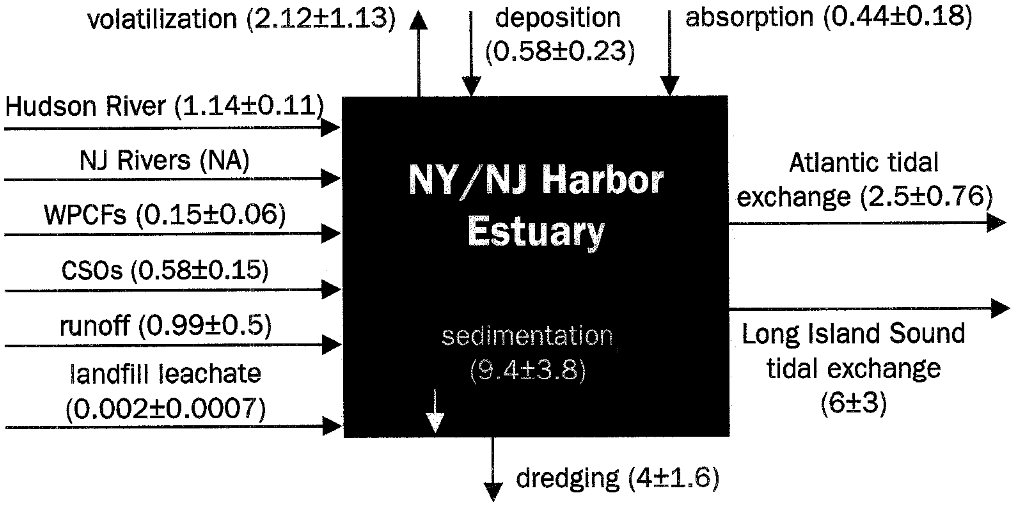


**Figure 11. Simplistic model of inputs and outputs of 2,3,4,7,8-pentaCDD in the NY/NJ Harbor.**



## Table 26. Summary of Harbor inputs of DLCs

| | CDD/Fs plus coplanar PCBs (g/yr) | CDD/Fs only (g/yr)† | CDD/Fs plus coplanar PCBs TEQ (g as 2,3,7,8-TCDD/yr) | CDD/Fs only TEQ (g as 2,3,7,8-TCDD/yr)† |
|---|---|---|---|---|
| Hudson River | 6,420 | 694 (±43) | 5.2 | 3.2 (±0.34) |
| NJ Rivers | 2,530 | 1,341 | 2.46 | 1.66 |
| WPCF | 944* | 123 (±49) | 2.2* | 0.9 (±0.38) |
| CSOs | 7,280 | 890 (±220) | 7.8 | 3.3 (±0.8) |
| Deposition | 386* | 106 (±42) | 1.3* | 1.3 (±0.5) |
| Absorption | 560* | 3 (±1.2) | 0.6* | 0. 5 (±0.2) |
| Runoff | 2,430 | 780 (±390) | 5.6 | 4.4 (±2.2) |
| Leachate | 37 | 1.7 (±0.6) | 0.02 | 0.01 (±0.004) |
| **Total inputs** | **20,552*** | **3,940 (±750)** | **25*** | **15.2 (±4.4)** |

NA = not available.
* Data set is incomplete.
† ± standard error.

## Table 27. Summary of Harbor outputs of DLCs

| | CDD/Fs plus coplanar PCBs (g/yr) | CDD/Fs only (g/yr)† | CDD/Fs plus coplanar PCBs TEQ (g as 2,3,7,8-TCDD/yr) | CDD/Fs only TEQ (g as 2,3,7,8-TCDD/yr)† |
|---|---|---|---|---|
| Tidal exchange (Atlantic) | 7,070 | 930 (±280) | 10.7 | 7.5 (±2.2) |
| Tidal exchange (Long Island Sound) | 5,140 | 360 (±180) | 11.9 | 9.2 (±4.6) |
| Volatilization | 18,450 | 12 (±6.8) | 7.7 | 2.5 (±1.4) |
| Dredging | 14,300* | 1,190 (±475) | 180* | 16 (±6.4) |
| Sedimentation | 33,200* | 2,515 (±1,006) | 440* | 37 (±14.8) |
| **Total outputs**§ | **78,150*** | **2,490 (±1,950)** | **210*** | **35(±30)** |

NA = not available.
* Data set is incomplete.
† ± standard error.
§ Assuming dredging, but not sedimentation, is considered a loss from the Harbor.

## Table 28. Average congener makeup of major inputs of CDD/Fs on a mass basis

| Congener | Hudson River | NJ rivers | WPCF | CSOs | Deposition | Storm water runoff | Absorption | Totals* |
|---|---|---|---|---|---|---|---|---|
| | (g/yr) | | | | | | | |
| 2,3,7,8-TCDD | 0.35 | NA | 0.11 | 0.15 | 0.037 | 0.47 | 0.03 | 1.1 |
| 1,2,3,7,8-PeCDD | 0.4 | NA | 0.25 | 0.64 | 0.24 | 0.63 | 0.09 | 2.2 |
| 1,2,3,4,7,8-HxCDD | 0.85 | NA | 0.17 | 0.91 | 0.41 | 1 | 0.04 | 3.4 |
| 1,2,3,6,7,8-HxCDD | 2.5 | NA | 0.72 | 3.17 | 0.79 | 2.8 | 0.06 | 10 |
| 1,2,3,7,8,9-HxCDD | 1.56 | NA | 0.49 | 2.45 | 0.78 | 2.5 | 0.03 | 7.8 |
| 1,2,3,4,6,7,8-HpCDD | 65.3 | NA | 11.8 | 84.7 | 13.2 | 65.7 | 0.10 | 241 |
| OCDD | 576 | 1260 | 90 | 727 | 75.4 | 614 | 0.83 | 3340 |
| 2,3,7,8-TCDF | 3.1 | NA | 0.14 | 0.53 | 0.33 | 0.80 | 0.56 | 5.5 |
| 1,2,3,7,8-PeCDF | 0.46 | NA | 0.09 | 0.33 | 0.55 | 1.44 | 0.37 | 3.2 |
| 2,3,4,7,8-PeCDF | 1.14 | NA | 0.15 | 0.58 | 0.58 | 0.99 | 0.44 | 3.9 |
| 1,2,3,4,7,8-HxCDF | 0.77 | NA | 0.24 | 1.26 | 1.1 | 4.2 | 0.12 | 7.7 |
| 1,2,3,6,7,8-HxCDF | 0.67 | NA | 0.17 | 1.19 | 0.8 | 3.8 | 0.10 | 6.7 |
| 2,3,4,6,7,8-HxCDF | 0.52 | NA | 0.16 | 0.94 | 0.06 | 2 | 0.043 | 4.7 |
| 1,2,3,7,8,9-HxCDF | 0.32 | NA | 0.58 | 0.04 | 1.1 | 0.26 | 0.0009 | 1.3 |
| 1,2,3,4,6,7,8-HpCDF | 11 | NA | 3.3 | 19 | 4.3 | 28 | 0.03 | 66 |
| 1,2,3,4,7,8,9-HpCDF | 1.2 | NA | 3.4 | 1.35 | 0.037 | 2.1 | 0.0000 | 8.1 |
| OCDF | 28.4 | NA | 10.3 | 43.8 | 5.9 | 52 | 0.11 | 140 |
| **Total CDD/Fs only (±SE)†** | **694 (±43)** | **1341** | **123 (±49)** | **890 (±220)** | **106 (±42)** | **780 (±390)** | **3 (±1.2)** | **3,940 (±750)** |

* Total does not include congener (except OCDD) contribution from NJ Rivers head of tide. † ± standard error.

## Table 29. Average congener makeup of major losses of CDD/Fs on a mass basis

| Congener | Tidal exchange (Atlantic Ocean) | Tidal exchange (Long Island Sound) | Volatilization | Dredging | Sedimentation | Total§ |
|---|---|---|---|---|---|---|
| | (g/yr) | | | | | |
| 2,3,7,8-TCDD | 1.7 | 1.89 | 0.72 | 8.5 | 19.6 | 12.8 |
| 1,2,3,7,8-PeCDD | 0.91 | 2.3 | 0.08 | 1.1 | 2.5 | 4.4 |
| 1,2,3,4,7,8-HxCDD | 1 | 1.9 | 0.04 | 0.9 | 2.1 | 3.9 |
| 1,2,3,6,7,8-HxCDD | 4.4 | 2.29 | 0.10 | 5.4 | 11.8 | 12 |
| 1,2,3,7,8,9-HxCDD | 3.9 | 2.17 | 0.13 | 3 | 7 | 9.2 |
| 1,2,3,4,6,7,8-HpCDD | 67.5 | 33 | 0.43 | 81 | 178 | 181 |
| OCDD | 761 | 286 | 1.07 | 923 | 1,920 | 1,970 |
| 2,3,7,8-TCDF | 7.99 | 2.75 | 5.72 | 6.9 | 14.7 | 23.3 |
| 1,2,3,7,8-PeCDF | 2.41 | 1.16 | 0.46 | 2.4 | 5 | 6.4 |
| 2,3,4,7,8-PeCDF | 2.52 | 6.01 | 2.12 | 4 | 9.4 | 14.6 |
| 1,2,3,4,7,8-HxCDF | 4.24 | 1.71 | 0.27 | 7.8 | 17.9 | 14 |
| 1,2,3,6,7,8-HxCDF | 1.86 | 1.46 | 0.12 | 3.3 | 7.6 | 6.8 |
| 2,3,4,6,7,8-HxCDF | 1.68 | 1.35 | 0.06 | 0.55 | 1.3 | 6.2 |
| 1,2,3,7,8,9-HxCDF | 0.13 | 1.2 | 0.03 | 3.1 | 7 | 1.9 |
| 1,2,3,4,6,7,8-HpCDF | 24 | 6.75 | 0.40 | 50 | 114 | 81 |
| 1,2,3,4,7,8,9-HpCDF | 0.7 | 3.59 | 0.01 | 2.2 | 5 | 6.5 |
| OCDF | 40 | 6.16 | 0.11 | 84 | 191 | 130 |
| **Total CDD/Fs only (±SE)†** | **930 (±280)** | **360 (±180)** | **12 (±6.8)** | **1,190 (±475)** | **2,515 (±1,006)** | **2,490 (±1,950)** |

§ Assuming dredging but not sedimentation is considered a loss from the Harbor. † ± standard error.

**Table 30. Congener makeup of major inputs of CDD/Fs to the NY/NJ Harbor, TEQ basis**

| | Hudson River | NJ rivers | WPCF | CSOs | Deposition | Storm water runoff | Absorption | Total* |
|---|---|---|---|---|---|---|---|---|
| **Congener** | **TEQ (g as 2,3,7,8-TCDD/yr)** | | | | | | | |
| 2,3,7,8-TCDD | 0.4 | NA | 0.11 | 0.15 | 0.04 | 0.22 | 0.03 | 1.1 |
| 1,2,3,7,8-PeCDD | 0.4 | NA | 0.25 | 0.64 | 0.24 | 0.72 | 0.09 | 2.2 |
| 1,2,3,4,7,8-HxCDD | 0.09 | NA | 0.02 | 0.09 | 0.04 | 0.09 | 0.004 | 0.3 |
| 1,2,3,6,7,8-HxCDD | 0.25 | NA | 0.07 | 0.32 | 0.08 | 0.26 | 0.01 | 1.0 |
| 1,2,3,7,8,9-HxCDD | 0.16 | NA | 0.05 | 0.25 | 0.08 | 0.17 | 0.003 | 0.8 |
| 1,2,3,4,6,7,8-HpCDD | 0.65 | NA | 0.12 | 0.85 | 0.13 | 0.56 | 0.0010 | 2.4 |
| OCDD | 0.06 | 0.13 | 0.01 | 0.07 | 0.01 | 0.05 | 0.0001 | 0.3 |
| 2,3,7,8-TCDF | 0.31 | NA | 0.01 | 0.05 | 0.03 | 0.11 | 0.06 | 0.5 |
| 1,2,3,7,8-PeCDF | 0.02 | NA | 0.005 | 0.02 | 0.03 | 0.02 | 0.02 | 0.2 |
| 2,3,4,7,8-PeCDF | 0.57 | NA | 0.08 | 0.29 | 0.29 | 0.27 | 0.22 | 1.9 |
| 1,2,3,4,7,8-HxCDF | 0.08 | NA | 0.02 | 0.13 | 0.11 | 0.08 | 0.01 | 0.8 |
| 1,2,3,6,7,8-HxCDF | 0.07 | NA | 0.02 | 0.12 | 0.08 | 0.10 | 0.01 | 0.7 |
| 2,3,4,6,7,8-HxCDF | 0.05 | NA | 0.02 | 0.09 | 0.01 | 0.10 | 0.0043 | 0.5 |
| 1,2,3,7,8,9-HxCDF | 0.03 | NA | 0.06 | 0.004 | 0.11 | 0.02 | 0.0001 | 0.1 |
| 1,2,3,4,6,7,8-HpCDF | 0.11 | NA | 0.03 | 0.19 | 0.04 | 0.18 | 0.0003 | 0.7 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | NA | 0.03 | 0.01 | 0.0004 | 0.008 | 0.000000 | 0.1 |
| OCDF | 0.003 | NA | 0.001 | 0.004 | 0.001 | 0.004 | 0.000011 | 0.0 |
| **Total CDD/Fs only (±SE)†** | **3.2 (±0.34)** | **1.66** | **0.9 (±0.38)** | **3.3 (±0.8)** | **1.3 (±0.5)** | **4.4 (±2.2)** | **0.5 (±0.2)** | **15.2 (±4.4)** |

* Congener totals do not include congener contribution from NJ Rivers head of tide, (except OCDD). † ± standard error.

## Table 31. Congener makeup of losses of CDD/Fs, TEQ basis

| Congener | Tidal exchange (Atlantic Ocean) | Tidal exchange (Long Island Sound) | Volatilization | Dredging | Sedimentation | Total§ |
|---|---|---|---|---|---|---|
| | TEQ (g as 2,3,7,8-TCDD/yr) | | | | | |
| 2,3,7,8-TCDD | 1.70 | 1.89 | 0.72 | 8.5 | 19.6 | 12.8 |
| 1,2,3,7,8-PeCDD | 0.91 | 2.33 | 0.08 | 1.08 | 2.5 | 4.4 |
| 1,2,3,4,7,8-HxCDD | 0.10 | 0.19 | 0.004 | 0.09 | 0.21 | 0.39 |
| 1,2,3,6,7,8-HxCDD | 0.44 | 0.23 | 0.01 | 0.54 | 1.17 | 1.2 |
| 1,2,3,7,8,9-HxCDD | 0.39 | 0.22 | 0.01 | 0.3 | 0.70 | 0.9 |
| 1,2,3,4,6,7,8-HpCDD | 0.68 | 0.33 | 0.004 | 0.31 | 1.78 | 1.8 |
| OCDD | 0.08 | 0.03 | 0.0001 | 0.09 | 0.19 | 0.2 |
| 2,3,7,8-TCDF | 0.80 | 0.27 | 0.57 | 0.69 | 1.47 | 2.33 |
| 1,2,3,7,8-PeCDF | 0.12 | 0.06 | 0.02 | 0.12 | 0.25 | 0.32 |
| 2,3,4,7,8-PeCDF | 1.26 | 3.00 | 1.06 | 2 | 4.71 | 7.3 |
| 1,2,3,4,7,8-HxCDF | 0.42 | 0.17 | 0.03 | 0.78 | 1.79 | 1.4 |
| 1,2,3,6,7,8-HxCDF | 0.19 | 0.15 | 0.01 | 0.33 | 0.76 | 0.68 |
| 2,3,4,6,7,8-HxCDF | 0.17 | 0.13 | 0.01 | 0.06 | 0.130 | 0.62 |
| 1,2,3,7,8,9-HxCDF | 0.01 | 0.12 | 0.003 | 0.31 | 0.70 | 0.19 |
| 1,2,3,4,6,7,8-HpCDF | 0.24 | 0.07 | 0.004 | 0.5 | 1.14 | 0.81 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.04 | 0.0001 | 0.02 | 0.050 | 0.07 |
| OCDF | 0.004 | 0.001 | 0.00001 | 0.01 | 0.019 | 0.01 |
| **Total CDD/Fs only (±SE)†** | **7.5 (±2.2)** | **9.2 (±4.6)** | **2.5 (±1.4)** | **16 (±6.4)** | **37 (±14.8)** | **35 (±30)** |

§ Assuming dredging but not sedimentation is considered a loss from the Harbor.
† ± standard error.

## Table 32. Average congener makeup of total inputs and outputs of CDD/Fs

| Congener | Input totals | Output totals | Input totals | Output total§ |
|---|---|---|---|---|
| | (g/yr) | | TEQ (g as 2,3,7,8-TCDD/yr) | |
| 2,3,7,8-TCDD | 1.1 | 12.8 | 1.1 | 12.8 |
| 1,2,3,7,8-PeCDD | 2.2 | 4.4 | 2.2 | 4.4 |
| 1,2,3,4,7,8-HxCDD | 3.4 | 3.9 | 0.34 | 0.39 |
| 1,2,3,6,7,8-HxCDD | 10 | 12 | 1.0 | 1.2 |
| 1,2,3,7,8,9-HxCDD | 7.8 | 9 | 0.78 | 0.92 |
| 1,2,3,4,6,7,8-HpCDD | 241 | 181 | 2.4 | 1.8 |
| OCDD | 3,340 | 1,970 | 0.33 | 0.20 |
| 2,3,7,8-TCDF | 5.5 | 23 | 0.55 | 2.33 |
| 1,2,3,7,8-PeCDF | 3.2 | 6.4 | 0.16 | 0.32 |
| 2,3,4,7,8-PeCDF | 3.9 | 14.6 | 1.9 | 7.3 |
| 1,2,3,4,7,8-HxCDF | 7.7 | 14 | 0.77 | 1.4 |
| 1,2,3,6,7,8-HxCDF | 6.7 | 6.8 | 0.68 | 0.68 |
| 2,3,4,6,7,8-HxCDF | 4.7 | 3.7 | 0.47 | 0.37 |
| 1,2,3,7,8,9-HxCDF | 1.3 | 4.5 | 0.13 | 0.45 |
| 1,2,3,4,6,7,8-HpCDF | 66 | 81 | 0.66 | 0.81 |
| 1,2,3,4,7,8,9-HpCDF | 8.1 | 6.5 | 0.08 | 0.07 |
| OCDF | 140 | 130 | 0.01 | 0.01 |
| **Total CDD/Fs only (±SE)†** | **3,940* (±750)** | **2,490 (±1,950)** | **15.2* (±4.4)** | **35 (±30)** |

§ Assuming dredging but not sedimentation is considered a loss from the Harbor.
*Includes total from NY Rivers head of tide loading—only OCDD is included in the separate congener listing.

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## MASS BALANCE - APPENDIX A.1. SUMMARY USING TEFS FOR FISH

## MASS BALANCE - APPENDIX A.2. SUMMARY USING TEFS FOR BIRDS

These two appendices to the mass balance are available online at *http://www.nyas.org/programs/harbor.asp.*

# APPENDIX B. CASES OF HUMAN EXPOSURE TO DIOXINS AND DIOXIN-LIKE COMPOUNDS

Some incidents and actions that resulted in human exposure to dioxins are described below.

- Health effects linked to 2,3,7,8 TCDD in herbicides used during the Vietnam War triggered extensive research on this particular congener. These herbicides typically consisted of mixtures of 2,4,5 trichlorophenoxyacetic acid (2,4,5-T) [259], which contained relatively high levels of 2,3,7,8 TCDD [259].[379] The different herbicide formulations were identified by the color-coding in the drum and were commonly called Agent Orange, Agent Green, etc. [259]. It has been estimated that over 76 million liters of these herbicides, containing at least 366 kg 2,3,7,8 TCDD, were sprayed in Vietnam between 1961 and 1971 [259].[380] Elevated 2,3,7,8 TCDD levels in fat were found in only three Vietnam veterans who were heavily exposed to Agent Orange [3].[381] On the other hand, the local population was highly affected because of long-tern exposure through multiple pathways [97].[382] Elevated 2,3,7,8 TCDD levels (up to 1,832 ppt) were measured in breast milk samples of southern Vietnamese women between 1970 and 1973, as well as in fish and shrimp from this area [244]. Levels of 2,3,7,8 TCDD have since been generally decreasing, as seen in breast milk samples collected from 1973 to 1995 [244]. However, in certain areas, exposure to 2,3,7,8 TCDD extends into the present, as showed by recent blood samples from residents of Bien Hoa, a southern Vietnam city located close to an air base that had been used for Agent Orange spraying missions [244].[383] Levels of 2,3,7,8 TCDD in soils and lake and river sediments in the area were also highly elevated. Researchers hypothesized that the main exposure route was through consumption of contaminated fish from a nearby lake and river [244], although direct contact with contaminated soils was potentially an important source [97].[384]
- In Yusho, Japan in 1968, more than 1,600 residents were exposed to PCBs and furans when they ingested contaminated rice oil. PCBs leaked into the oil from a heat exchanger in a processing plant [4,150]. The high temperatures associated with the heat exchanger increased the concentration of dibenzofurans, which are always present in PCBs. Dibenzofurans were also formed when people used the oil for cooking, increasing the dioxin concentration even more. Shortly afterwards, similar exposures took place in Yu-Cheng, Taiwan [115]. No fatalities were recorded, but many people exhibited severe skin rashes and lesions, irritation of the eyes, mouth, and throat, and gastrointestinal disorders.[385]
- In 1976, in Seveso, Italy, an explosion occurred in a chemical plant producing 2,4,5-TCP (trichlorophenol, used in the manufacture of chlorinated herbicides). A cloud of chemicals, including an unknown amount of 2,3,7,8 TCDD, was released into the air and eventually contaminated a mostly residential area of 15 km$^2$ with a population of 37,000 people [367]. Shortly after the accident, 2,3,7,8 TCDD levels in fat tissue were 828 to 56,000 ppt, among the highest ever measured in humans [3].[386]

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[379] 2,3,7,8 TCDD is a by-product of 2,4,5-T (see section on contaminated sites). Conservative estimates of average 2,3,7,8 TCDD levels in Agent Orange are ~3 ppm, although 13 ppm may be more realistic [259]. Levels of 2,3,7,8 TCDD in Agents Purple and Pink are much higher: ~33 and 66 ppm, respectively. Some of the herbicide formulations were mixtures of 2,4,5-T (and/or its esters) and 2,4-dichlorophenoxyacetic acid (2,4-D), which is also contaminated with 2,3,7,8 TCDD.

[380] Agent Orange was the most extensively used herbicide, and its level of 2,3,7,8 TCDD contamination could be four times the conservative level chosen for these estimates [259]. These estimates do not include residues remaining in emptied drums. In addition, surplus herbicide has been either incinerated aboard a ship or stored in several places, including Kelly Air Force Base in Texas, with unknown fate [259].

[381] No significant differences were found for most veterans when compared with levels in the average population.

[382] Millions of people were present during spraying over hamlets and were likely directly sprayed upon [259]. There are indications that in Vietnam at least 2.1 million and as many as 4.8 million people were present, not including those people in over a thousand hamlets for which data was not available.

[383] At least one spill from underground storage tanks in Vietnam occurred around 1970 at this location. Virtually all residents had elevated 2,3,7,8 TCDD levels in blood: up to 271 ppt, compared with 2–4 ppt measured in reference locations in Vietnam and in the general US population [244]. Although other congeners were also present, the high 2,3,7,8 TCDD levels suggest a major influence of Agent Orange contamination.

[384] One soil sample had 1 ppm 2,3,7,8 TCDD (1,000 times the US soil cleanup level standard).

[385] Furans were believed to be the major cause of the health effects, along with dioxin-like PCBs, although the relative contribution of dioxin-like PCBs and furans remains uncertain. Later studies have attributed some of the subtle effects to non-dioxin-like PCBs [106,250].

[386] Concentrations for the general US population were up to 38 ppt.

Several effects were observed in the exposed population, including chloracne, as well as neurological, endocrine, and reproductive diseases [3]. Various types of cancer were elevated among these individuals. The continued monitoring of this cohort has provided important evidence of the carcinogenicity or dioxins [255].

- In 1997, in the southern part of the US, chickens, eggs, and catfish were found to be contaminated with dioxins. The FDA, EPA, U.S. Department of Agriculture (USDA), and the Centers for Disease Control determined that the source was bentonite clay, or "ball clay," from a particular mine.[387] Ball clay is a mineral typically used as an anticaking agent in some feed ingredients, and thus it was ingested by the animals.
- In Germany (1997), increases in certain dioxin congeners in milk, butter, and meat were traced back to the use of dioxin-contaminated citrus pulp as animal feed. The lime that is normally used to neutralize the pulp was the source of contamination [281]. This lime was a by-product of a chemical production facility.
- In Belgium, in January 1999, PCB oil contaminated with high levels of dioxins was inadvertently mixed with recycled fat used to produce animal feed [13].[388] About a month later, signs of contamination were observed in poultry. This prompted an extensive sampling of food and feed and an embargo to all Belgian food products.[389] It was estimated that ~2% of the poultry supply chain was contaminated in this incident, but it was considered improbable that the general population would have been affected[390] [13].
- More recently, zinc oxide and copper oxide, distributed for use as a feed additive in 11 US states (including NY) and Canada, were found to be contaminated, requiring a recall from the market. These two minerals are reclamation products from the metal industry. Internationally, several incidents of food contamination have been reported.
- In 2004, high dioxin levels in dairy products were traced back to clay used to process potato by-products for use as a feed ingredient [92].
- In December 2005, a routine test by the Dutch food and product safety authorities found elevated levels of dioxins in a batch of pork fat used to produce animal feed [78]. The source of dioxins was an ingredient used to extract the fat [231]. The incident triggered quarantines in animal operations in the Netherlands, Belgium, and Germany while tests are conducted to assess dioxin levels in meat [231].

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[387] As there was no evidence that hazardous waste was buried at the mine, investigators have speculated that the source of dioxins may be prehistoric [367].

[388] The contamination took place in public containers where the oils and are fats collected. This practice was subsequently prohibited [13].

[389] The monitoring effort eventually led to the discovery of the source and extent of contamination in May 1999, although by this time the contaminated products had already been consumed or destroyed [13]. The incident also resulted in the adoption of tolerance levels for PCBs in food, based on dioxin concentrations of 5 pg TEQ/g fat.

[390] It was estimated that even the most exposed population (farmers consuming their own products) would have only increased their body burden to levels commonly seen in the 1980s.

# APPENDIX C. MINOR SOURCES OF DIOXINS

The following sectors have a low impact as dioxin sources to the region. Nevertheless, we provide them as a reference that might be of value in other geographical areas, or that might be important in the future as commercial and industrial practices change. This section also includes additional information and case studies for sections developed in the technical report.

## Combustion Sources

### Uncontrolled Combustion

### Open Burning of Agricultural Plastics

Nationally, the costs,[391] absence, and/or inconvenience of waste management options in rural agricultural areas result in a large fraction of the agricultural waste stream being burned [131], including plastics, crop residues, animal carcasses, and waste in general. Crop residues and animal carcasses are not commonly burned in this region. There is limited information about other wastes generated in agricultural operations in the Watershed area [74]. Therefore, the focus of our analysis is burning of plastics, keeping in mind that this might represent just part of the problem.

Plastic films are used as silos, soil cover to trap moisture, bale wraps, bags that serve as greenhouses, and weed control [131]. The main use of plastics in NY is in the dairy industry [196], such as silage bags and bale wraps. Because plastics offer many advantages, their use in agriculture has been steadily increasing. For instance, films used to cover soil around the crop prolong the growing season and control the emergence of weeds, reducing the need for herbicide applications.[392] Silo bags are cheaper than permanent structures (they do not require a large initial investment and are more economical for small or new producers) and can be set up anywhere, as needed. In addition, farmers can avoid the dangers of asphyxiation (caused by phosphine gas generation inside the silo) or of working high off the ground in a silo.[393]

In the early 1990s, about 30% of the plastics used in agriculture were films, and the rest were different kinds of containers (nursery pots, pesticide/agrochemical containers). Polyethylene is the plastic most commonly used for agricultural applications. Although polyethylene itself does not contain chlorine, plastics will most likely be burned together with other chlorine-containing wastes (e.g., brush and other refuse [74]), thus leading to dioxin emissions. Furthermore, most agrochemicals are packaged in plastic containers or bags, and it has been demonstrated that residues of chlorinated chemicals generate dioxins upon burning [130].[394]

**Local Emissions**

It is assumed that no open burning of plastics takes place in NJ because this practice is illegal and heavily fined and because NJ has now developed markets for these materials. In New York, there are not many incentives to recycle agricultural plastics [132]. There are indications that the amount of plastics properly disposed of (recycling or waste collection) is negligible given the lack of recycling programs and the cost of collection, compaction, and transportation, weighed against the possibility of burning or dumping in the farm [131] (both of which remain legal in NY).[395] Open burning regulations in the region have already been discussed in the technical report (section on uncontrolled combustion of household waste).

It has been estimated that of the **~12,830 T** of agricultural plastics used yearly in NY about one-half are burned.[396] The other half is dumped on-site [131], creating a mosquito habitat, a choking hazard for cattle and wildlife, the potential to clog water channels, and an unattractive view, which can affect tourism.[397] The Environmental Risk Analysis Program of Cornell University's Department of Communication is currently developing

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[391] The cost of properly disposing of farm wastes at a transfer station can be around $60/month.

[392] Lois Levitan, Ph.D., Cornell University Environmental Risk Analysis Program. Presentation at the Great Lakes Regional Pollution Prevention Roundtable. August 24-26, 2005, NYAS, New York, NY.

[393] Ibid.

[394] Pesticide plastic containers have labels approved by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which instructs not to reuse the container but to triple rinse, puncture, and dispose of it in sanitary landfills, by incineration, or (if allowed by state and local authorities) by open burning. This issue was discussed in a conference call of the GLBTS, dioxin/furan workgroup, burn barrel subgroup, May 10, 2005.

[395] The prohibition of open burning in towns with more than 20,000 habitants exempts agriculture. The apparent immediate convenience of dumping has to be weighed against the remediation cost of an on-site farm dump ($150,000 or more) [251]. The need for remediation may arise as many lending institutions require environmental assessments before financing farm loans or mortgages and may deny credit to farms that bury wastes on-site [251].

[396] This estimate assumes that the amount of plastic used is proportional to the level of agricultural activity (NY represents almost 2% of the US, based on total farm cash receipts). Therefore, ~2% of US plastic consumption (~761,000 T in the US in 2002) is attributed to NY [74].

[397] Lois Levitan, Ph.D., Cornell University Environmental Risk Analysis Program. Presentation at the Great Lakes Regional Pollution Prevention Roundtable. August 24–26, 2005, NY Academy of Sciences, New York, NY.

an extensive survey to more accurately determine the rate of agricultural plastic use and mode of disposal.[398]

There is virtually no data on dioxin emission factors (EFs) from burning of agricultural plastics. Assuming that EFs for household open burning can be applied,[399] dioxins released to air and associated with ashes were estimated (Table Ap.C.1).

**Table Ap.C. 1. Dioxin emissions from open burning of agricultural plastics**

| | NY | NY within Watershed† | Units |
|---|---|---|---|
| Agricultural plastics burned | 6,415 | 1,668 | T/yr |
| Emissions to air | 0.5 | 0.1 | g TEQ/yr |
| Dioxins in ash | 2.1 | 0.6 | g TEQ/yr |

Sources: Amount of plastic burned from [74]. EFs were assumed to be the same as for residential waste: 79 µg TEQ/T [105] and 600 µg TEQ/T [350] for air and ash, respectively.

† Assuming plastics burned proportionally to value of agricultural products sold in each county (26% of NY sales took place in counties within the Watershed [283,284]).

More research is needed to determine whether our assumptions are reasonable and to reduce the uncertainty of these estimates. The actual relevance of this source could be higher than what is suggested by our relatively low estimates because:

- These emissions occur in the same places where food is produced and, thus, the potential for human exposure is greatly increased.
- Actual emissions are likely underestimated because other types of agricultural wastes were not considered but are probably also burned in farms.[400]
- Emission factors for dioxins could be higher under conditions commonly found in farms:
    - pesticide residues are likely present in soils, plants, and materials burned, especially in pesticide containers;
    - soil may be moist, resulting in poorer combustion conditions.
- Toxics other than dioxins are also released when burning trash, such as heavy metals and PAHs.

Another reason to prevent agricultural burning relates to the increased demand for organic foods. Open burning is not allowed in certified organic farms.[401]

**Measures to prevent open burning of agricultural wastes**

Given the advantages provided by agricultural plastics, it is unlikely that their use could be reduced. However, burning could be eliminated by measures similar to those discussed for household waste (see technical report): providing infrastructure for proper waste management (including recycling), education, incentives, and regulations. The rest of this subsection provides a description of current practices and alternatives regarding agricultural waste disposal.

Nationally, it is believed that very little agricultural plastic is recycled. There are many difficulties associated with recycling films used in agriculture including high contamination,[402] dispersion of the source, and cost to the farmer to collect, compact, and transport the plastics [131].

The Ag (short for agriculture) Container Recycling Council (ACRC) has a recycling program for pesticide containers. ACRC is a national nonprofit member organization of plastic container producers. Member dues finance the recycling program, which is free to farmers.[403] All plastic containers (not just those produced by members) are accepted for recycling.[404] Factors hampering this program include: membership is not mandatory, pesticides imported

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398. This survey will also allow an estimate of the amount of plastic that could be collected for recycling. Another goal is to develop a model that could be applied to other regions to estimate agricultural plastic usage and disposal. Lois Levitan, Ph.D., Cornell University Environmental Risk Analysis Program. Personal communication, May 8, 2006.

399. This might be a plausible EF given that other wastes are likely burned together with plastics, but more research is needed to characterize the kinds and amounts of agricultural waste that are generated and burned, as well as emission factors for dioxins and other toxics.

400. Household wastes, however, are already contemplated in our estimate of open burning.

401. As part of the efforts to curb agricultural burning, the Minnesota Office of Environmental Assistance (MOEA) is seeking to educate the agricultural sector about the impacts of open burning in their business. Mark Rust, Pollution Prevention Specialist, MOEA. Presentation at "Open Garbage Burning: Preventable Pollution." A Workshop for Local Fire Officials. March 4, 2005. Duluth, MN.

402. They may contain up to 50% of soil and debris, pesticides, pathogens, and moisture.

403. Containers are typically collected at voluntary sites such as dealers who sell the product, or solid waste facilities. The containers are then reduced in volume, usually by granulating the plastic, and transported to US facilities, where it is recycled into other products (e.g., drainage pipes, fencing posts, and railroad ties). Rob Denny, Environmental Project Manager, Arrowchase. Personal communication, October 11, 2005.

404. Currently, the U.S. EPA is working on standards to ensure that pesticide containers are properly rinsed, transported and managed for recycling in order to facilitate the recycling process. Because recycling is not mandated, this initiative will likely have no immediate impact on the levels of plastic recycling or the situation of the ACRC program. Rob Denny, Environmental Project Manager, Arrowchase Consulting. Personal communication, October 11, 2005.

from foreign producers do not provide recycling options, and there are few collection centers (e.g., only two in NY State). Despite the relatively good response (~15–18% of containers are recycled), this program is likely to weaken.[405]

Similar programs in other countries have been much more successful (e.g., 70% of containers are recycled in Canada).[406] One remarkable example is that of Brazil, where 70–90% of pesticide containers are recycled because the national environmental agency requires industries to describe how the packaging will be disposed of before they can register any new pesticide.[407] This last example points to the importance of instituting extended producer responsibility (EPR) programs.

Nevertheless, recycling in our region is possible, and some programs have been successful. In the state of NJ, the Cumberland County Improvement Authority (CCIA), in partnership with the New Jersey Department of Agriculture (NJDA), has developed programs to recycle plastic containers[408] as well as greenhouse and nursery films. In April 2005, CCIA and NJDA initiated a pilot program to recycle other types of agricultural plastics.[409] [410] The newly launched recycling program in NJ would be able to handle plastics used by dairy farmers, including silage bags.[411]

At present, CCIA is the only place in NJ that collects a variety of plastics for recycling. Another collection center in Burlington, NJ also receives greenhouse film. CCIA collects and manages the plastic and arranges sales either to brokers or to the final recyclers, who are also responsible for transportation costs. The money collected from sales helps sustain the recycling program. Recyclers are located all over the world (e.g., Texas and China). The facility in Texas (Polyamerica) recycles nursery films into trash bags.[412]

Education and outreach also plays a role in ensuring the success of the agricultural plastic recycling programs, which are advertised to farmers through agricultural agents, waste haulers, the Rutgers Cooperative Research & Extension, trade organizations (e.g., the Vegetable Growers Association of NJ), brochures distributed to growers, and agricultural newspapers.[413] In addition, the information is communicated during "twilight meetings," when farmers get together. Farmers can send their plastics with the haulers or transport them directly.

Some of the elements that have made this program successful include:

1. Infrastructure:
    a. an existing recycling center (like CCIA) that can expand their programs to include agricultural plastics;
    b. actively looking for markets willing to take different plastics for recycling.
2. Distribution: The concentration of agricultural activity in southern NJ allowed a single center to handle all the recycling.
3. Education: Outreach to farmers to promote the programs using clear messages, showing pictures of the types of materials that are accepted, and demonstrating how materials should be handled, cleaned, bundled, stored, and transported.
4. Follow-up: Keeping in touch with farmers to learn what are the difficulties or obstacles to recycling, and incorporating their suggestions to solve those problems.
5. Incentives:
    a. engaging farmers, who take pride in being "good stewards of the land";
    b. credits towards pesticide application registration are awarded when certain amount of pesticide containers are taken for recycling;
    c. tipping fees that are favorable against other disposal options.

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[405] Ibid.

[406] Teleconference of the Burn Barrel subgroup (Great Lakes Bi-national Toxics Strategy). September 13, 2005..

[407] Rob Denny, Environmental Project Manager, Arrowchase. Personal communication, October 11, 2005.

[408] Pesticide containers and nursery pots.

[409] Funds were provided by a NJ DEP grant.

[410] Mulch film, drip irrigation tape, peat moss bags, silage bags, hay sleeves, bunker silo covers, silage wrap, low tunnel film, and floating crop cover. In addition, shrink-wrap and similar plastics may be suitable for recycling in this program [41]. Until a few years back, there were no markets for these types of plastics. Many farmers have expressed interest in this program even before it was officially announced. Karen Kritz, Agricultural Economic Development, NJDA. Personal communication, October 4, 2005.

[411] Dennis DeMatte, Recycling Coordinator, Cumberland County Improvement Authority. Personal Communication, October 3, 2005.

[412] Ibid.

[413] Ads in regular newspapers have not been effective in spreading the word. Karen Kritz, Agricultural Economic Development, NJDA. Personal communication, October 4, 2005.

6. Regulation: A statewide ban on open burning and illegal dumping.
   - A recent study focusing on films used in dairy farms in New York in an area around Otsego County [132] (mostly in the Watershed) analyzed the feasibility of recycling programs for this particular type of plastic. This report was able to identify only one plastic manufacturer that claimed to buy back or backhaul[414] certain kinds of films for recycling.

This report [132] recommends the following actions to start a recycling program:

- Start with a small recycling program.
- Involve leaders in the farm community.
- Create an educational program about best management practices (BMPs) to handle the films in a way that would increase their recycling value.
- Identify potential reprocessing markets and work with them to determine whether the average quality of the films collected are amenable for recycling.
- Select and advertise a collection time period.
- Train staff in sorting, handling, and bailing.

Currently, the Environmental Risk Analysis Program of Cornell University's Department of Communication is working on implementing these recommendations. The Program is organizing a demonstration tour of a mobile baler for agricultural films.[415]

## Wild Fires and Prescribed Fires

Wildfires are defined as uncontrolled burning of vegetative material, including forest and grassland fires. Prescribed burning refers to intentional fires aimed at managing forests, ranges, and wetlands by burning delimited areas when weather and biomass conditions are appropriate.[416] Reasons for prescribed fires include reducing the risk of future fires, improving wildlife habitat, controlling pests and disease, and perpetuating fire-dependent species [355]. Studies suggest that new formation of dioxins occurs during wildfires [334]. However, at least a fraction of these emissions is likely to be the result of remobilization of dioxins already present in the soil and plant material from previous fires, atmospheric deposition from other sources, or deposition of chlorinated dioxin precursors. Emission factors for fires are very uncertain because they are influenced by many variables, including the type and density of vegetation, the moisture content, wind, type of fire (crown vs. understory), etc. [334].

### Local Emissions

The acres burned in wild and prescribed fires in 2003 along with estimated dioxins in air emissions and residues are presented in Table Ap.C.2. It is very difficult to directly measure dioxin emissions from wildfires. One option is to assume the same EF of woodstoves (2 $\mu$g TEQ/T), although this is likely an underestimate because wildfires represent open burning (as opposed to an enclosed combustion chamber), and the biomass is usually "green" (as opposed to dry wood), leading to poor combustion conditions. In addition, leafy and brushy materials are burnt along with the wood, which is likely to affect the emission factor. The 2005 U.S. EPA draft dioxin inventory suggests an EF for wildfires of 20 $\mu$g TEQ/T (10 times higher than woodstoves), based on simulated forest fires, but noted that these EFs are considered only an order of magnitude of possible emissions [334]. UNEP suggested EFs of 5 and 4 $\mu$g/T for emissions to air and residues, respectively, based on open burning trials in Japan.[417] We applied the EF by EPA (20 $\mu$g TEQ/T). Using this EF, local emissions to air are relatively low. Dioxins in ash would remain on the land, and some could be dispersed by the wind or water; but these estimates are also very low.

### Measures to prevent or reduce dioxins from wild fires

The Food and Agriculture Organization (FAO) of the United Nations highlights that educating communities located close to forests in fire prevention issues

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[414] In this case, "backhaul" means the transport of plastics from their destination (e.g., local distributors) to the point of origin (the producer), taking advantage of the fact that the vehicles carrying goods or materials need to go back to their starting point.

[415] Demonstrations are scheduled for August, 2006 and will serve as learning curves for all parties involved. Lois Levitan, Ph.D., Cornell University Environmental Risk Analysis Program. Personal communication, May 8, 2006.

[416] It can also apply to the practice of burning plant residues in agricultural fields after harvest. This type of fire has not been included in our estimate, but it is believed to be very small in the region.

[417] UNEP also developed EF for agricultural burning of crop residues: a higher EF is suggested for lands that received pesticides or agrochemicals that can act as precursors of dioxins, and for lands that are high in moisture, leading to poor combustion conditions.

## Table Ap.C. 2. Dioxin releases from wild and prescribed fires in NY and NJ

| | **Acres burned†** | | **Emissions—NY & NJ (g TEQ/yr)‡** | | **Emissions—Watershed (g TEQ/yr)§** | |
|---|---|---|---|---|---|---|
| | **Wildfires** | **Prescribed fires** | **Air (EPA)** | **Ash (UNEP)** | **Air (EPA)** | **Ash (UNEP)** |
| NY | 1,617 | 152 | 0.3 | 0.1 | 0.2 | 0.04 |
| NJ | 2,790 | 13,636 | 1.5 | 0.3 | 0.2 | 0.05 |
| **Total** | **4,407** | **13,788** | **1.9** | **0.4** | **0.4** | **0.09** |

† NY wildfire data (average of 2000–2004): NYS DEC, Division of Forest Protection and Fire Management. Captain Dave Brooks. Personal communication, March 18, 2005. NY prescribed fires (2003): National Interagency Fire Center [163]. NJ data (average 2000–2004): NJ DEP, Division of Parks & Forestry, State Forestry Service. Bert Plante. Personal communication, July 13, 2005.

‡ Acres were converted to T of biomass burned assuming 10 T/acre for wildfires and 3.6 T/acre for prescribed burning (NJ DEP 2002 Periodic Emission Inventory: 2002 Area Source Calculation Methodology Sheets. VOC, NOx, CO, $SO_2$, $PM_{2.5}$, $PM_{10}$. Provided by Ray Papalski, Air Quality Planning, NJ DEP. Personal communication, June 30, 2005). EF to air: 20 ng TEQ/kg (U.S. EPA [334]). EF for ash: 4 µg TEQ/T (UNEP [350]).

§ In 2004, 61% of the total acres burned in wildfires took place in NYS DEC regions 3, 4, and 5. We assumed this is a good measure of the fires that typically occur within the Watershed. In NJ, from 2000 to 2004, on average 15% of the acres were burned within the Watershed.

results in fewer forest fires and thus reduces the cost of fire management [91].

Most wildfires are started by human-related activities, including waste burning, campfires, arson, smoking, and equipment use. In 2004, only 8 of 73 wildfires in NY were the result of natural causes (lightning), representing 1% of total acres burned.[418] Similarly, in NJ, lightning typically causes less than 0.5% of forest fires.[419] However, the majority of fires in this state are prescribed fires as opposed to wildfires (Table Ap.C.2).

Fire prevention practices that would minimize the risk of fires and their extension to woods include:

- Extinguish unattended camp fires.
- For households located within woodlands:
  - there should be no trees within 30 ft of the structure;
  - encourage the use of use nonflammable building materials, such as tile roofs and stucco sidings;
- Publicize programs such as the Firewise Communities/USA, a project of the National Wildland/Urban Interface Fire Program that provides educational resources and grants to communities to adopt fire safety measures. Communities that achieve certain standards can apply for recognition as a "Firewise community."[420]

### Tire Fires

Until recently, used tires were commonly disposed of in landfills or stockpiled.[421] These piles create habitats for rodents and mosquitoes, posing health hazards. In addition, although the tires themselves are not considered hazardous wastes, tire fires release hazardous compounds to air, including dioxins and PAHs, and produce an oily runoff that can contaminate the surrounding soil and even groundwater [181]. Tire fires are hard to ignite; but once they start, they are very difficult to extinguish—sometimes they continue to smolder for weeks or months—and leave a heavily contaminated area. Many superfund sites have resulted from tire fires [323]. The cost of responding to tire fires and remediating the resulting contamination are 10 to 15 times higher than the cost of removing the tires in the first place [342].

It has been estimated that there were 2–3 billion scrap tires in stockpiles in the US in 1992, although a 1994 estimate by the Scrap Tire Management Council gives the number at 800 million.[422] From 1990 to 2000, stockpiled tires were reduced to about 300 million as a result of abatement programs, better inventories, and tires consumed by fires [235].

In the US, in 2003, ~45% of the generated scrap tires were burned as fuel, 19% were used in civil engineering applications, 10% were used in ground rubber applications, 9% were landfilled, 3% were exported for retreading, 4% were directed to other uses, and 10% had unknown management [237]. Of

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418. Data provided by Capt. David Brooks, NYS Forest Rangers, NYS DEC. Personal communication, March 18, 2005.
419. Average of 2000–2004. Data provided by Bert Plante, NJ DEP, Division of Parks & Forestry, State Forestry Service. Personal communication, July 13, 2005.
420. More information can be found at *http://www.firewise.org/index.php.*
421. Stockpile owners charged a fee for accepting the tires [236].
422. Based on a survey of state scrap tire regulators.

the 130 million scrap tires used as fuel in 2003, 41% were burned by the cement industry, 20% by pulp and paper mills, 18% by electric utilities, 13% by industrial/institutional boilers, and 8% by dedicated tire-to-energy facilities [237]. According to the Rubber Manufacturers Association, as of 2003, there was only one dedicated tire-to-energy facility in the US (in Sterling, CT[423]), and no facility in NY or NJ used tires as supplemental fuel [237]. However, electric arc furnaces in NY are starting to use scrap tires as a source of carbon, steel, and energy [237]; two cement kilns in NY are permitted to supplement their fuel with tires (although they reportedly burn only coal), and a third one is seeking approval for the same; one paper mill in NY is also pursuing authorization to burn tires. More research is needed to determine whether local facilities do burn tires and the relative contribution of burning tires to air emissions compared with conventional fuels.

A study by Ikeguchi et al. measured emissions of 220 μg TEQ/T tire burned under poorly controlled conditions [116]. The UNEP suggests, as a first approximation, using the EF for open burning of trash or for structural fires (79 and 400 μg/T, respectively). The Ikeguchi et al. number was used to estimate emissions for tire fires.

### Local Estimates

About 20 million tires are discarded per year in New York State, and 8.4 million in the State of New Jersey [237].[424] Recently, more applications have been found for used tires, and fewer tires are stockpiled.[425] In New Jersey, the fate of ~7 million (or over 80%) of the scrap tires generated per year is known: ~34% are managed within the state, ~3% are estimated to be disposed of in illegal facilities in NJ and PA, and the remainder are exported to other states, including ~200,000 (or another 3%) going to facilities in New York.[426]

However, the biggest problem is the stockpiles already present in the states that have to be eventually cleaned up. There are currently ~95 tire piles in NY and 18 in NJ [188,208,322]. New York is one of the nine states where most tires are piled, accounting for ~15% of all US stockpiled tires. New Jersey has ~3% of all US stockpiles tires. According to the Rubber Manufacturers Association, 40 and 8 million tires are currently stockpiled in NY and NJ, respectively. Estimates by the states' environmental agencies are lower, at 29 and 3.5 million, respectively.[427] In both cases, a similar percentage is stockpiled within the Watershed: 36% and 46% in NY and NJ, respectively.

In New York ~3.7 million tires are estimated to have been burned in 21 **known** fires since 1989, with over 2 million tires burned within the Watershed [208], or an average of ~230,000 tires per year in NY, including ~130,000 within the Watershed. These numbers represent ~0.8 and 1.5% of the tires stockpiled in NY state and within the Watershed, respectively.

Given the random nature of fires, it is difficult to estimate the amount of tires that may be burned in any given year, especially when the number of stockpiled tires is relatively small, as is the case in NJ. Although records show that only one tire fire occurred in NJ within the last three years,[428] we provide the projected emissions assuming that the proportion of stockpiled tires burned per year is the same as in NY. We took this approach to give an upper-limit, rough estimation of the *potential* emissions that could be expected from NJ stockpiles.

Estimates of dioxin releases to air are shown in Table Ap.C.3. No measurements of dioxins in combustion residues were available. These numbers could reasonably be expected to decrease because both states are working in stockpile abatement.[429] In addition, these estimates are uncertain because the EF is based on a single experiment. Better characterization of dioxin emissions from tire fires is needed to obtain more reliable emission estimates.

### Measures to prevent or reduce dioxins from tire fires

Scrap and stockpiled tires can be recycled or reused into several products and applications, depending on their condition (in general, tires found in old piles are of lower quality and can be used only for certain applications) such as:

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[423] Near the Rhode Island state line.

[424] NJ estimate based on 1 tire per person per year [181].

[425] In the US, ~80% of the 290 million scrap tires generated in 2003 were used in some market [237].

[426] It is believed that a portion of scrap tires is not accounted for as a result of inaccurate reporting and illegal disposal [180].

[427] NY has inventoried all noncompliant piles and estimated the number of tires between 2003 and 2004 using aerial photography [213]. NJ has done a similar job by inspecting stockpiles throughout the state [188].

[428] ~100,000 tires were burned in this fire, releasing an estimated 0.3 g TEQ dioxins.

[429] See subsection on measures to reduce dioxins from tire fires.

### Table Ap.C. 3. Dioxin emissions from scrap tire fires

| | Stockpiled tires[*] | Tires burned (tires/yr)[†] | Air emissions (g TEQ/yr)[‡] | Residues[¶] |
|---|---|---|---|---|
| NY WS | 10,620,500 | 158,844 | 0.55 | ? |
| NJ WS | 570,000 | 8,525 | 0.03 | ? |
| **Watershed** | **11,190,500** | **167,369** | **0.6** | **?** |
| NY | 28,990,500 | 231,153 | 0.81 | ? |
| NJ | 2,497,500 | 19,914 | 0.07 | ? |
| **Total** | **31,488,000** | **251,067** | **0.9** | **?** |

[*] Noncompliant stockpiles. Sources: NY, NYS DEC, 2004 [213]; NJ, NJ DEP, 2002 [188].

[†] Source: NY, NYS DEC [208]. For NJ, it was assumed that the same percentage of tires as in NY burned within the Watershed (1.5%) and in the whole state (0.8%).

[‡] EF from Ikeguchi et al. (1999) [116] (220 µg TEQ/T tire burned). We assumed an average weight of 35 lb/tire (16 kg/tire): A passenger car tire weights ~20 lb, while a truck tire weights ~120 lb [237]. About 84% of tires generated are for passenger cars or light trucks, with 15% for heavy trucks, and 1% other types [237]. We assumed 85% tires weighed 20 lb, and 15% weighed 120 lb.

[¶] No EF available.

- Embankments for roads and highways, backfill for walls and bridge abutments, landfill collection systems and other applications,[430] septic systems construction,[431] playground structures, equestrian tracks, insulation and/or drainage systems around building foundations, erosion control/rainwater runoff barriers, wetlands/marsh establishment, race track crash barriers, boat bumpers at marinas, and artificial reefs.
- Ground rubber applications: rubberized asphalt, gravel substitute, carpet underlay, flooring material, patio decks, railroad crossing blocks, livestock mats, rubber tiles and bricks, movable speed bumps, new tire manufacturing, brake pads and brake shoes, automotive parts, agricultural and horticultural applications/soil amendments [322].
- Another option is to burn the tires for energy recovery in cement kilns, pulp and paper mills, electric utilities, boilers, and dedicated tire-to-energy facilities [336]. However, this option does not capture the full value of discarded tires and should be kept only for low-quality tires (e.g., those coming from old stockpiles being remediated) for which other options are not viable. In addition it is key that the combustors are equipped with proper air pollution controls.

The U.S. Department of Energy (DOE) is researching innovative uses for scrap tires, including highway noise barriers and railroad ties [327], which consist of a steel-beam core filled with concrete and encased in ground-up scrap tires and discarded plastic bottles.[432]

Recycling and reuse of scrap tires depends on the availability of viable and profitable markets. Demand for scrap tires comes from two different markets:[433]

- Low–value added markets (civil engineering, tires reused as fuel), which consume large quantities of the scrap tires but generate relatively low returns on investment.
- High–value added markets (ground rubber applications), which process a smaller quantity of scrap tires but have the greatest potential for return on investment.

For high-value added applications, rubber has to be finely ground (powder or crumb), which requires cooling the tires before grinding. A potential cooling source that would be much less costly than current practices is to couple tire recycling with liquefied natural gas (LNG) distribution terminals.[434]

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[430] Instead of purchasing other construction materials, scrap tires can be used for lightweight backfill in gas venting systems, in leachate collection systems, and in operational liners, as well as in landfill capping and closures, and as a material for daily cover.

[431] Alabama, Florida, Georgia, South Carolina, and Virginia allow tire shreds to be used in construction of drain fields for septic systems.

[432] There are many potential benefits from these ties over wood ties, including strength (over 200% stronger, which would allow the use of fewer ties per mile), durability (60 to 90 years versus 5 to 30 years for wood), and reduced use of toxic wood preservatives (pentachlorophenol, creosote, or arsenates).

[433] As summarized in The NYS Roundtable for Consensus on Tire Management: Parameters for Legislative Development; Final Draft, 2000. A copy of this report was obtained from Mann Jo Greene, Clearwater Inc.

[434] Some states (FL, AZ, CA, TX, RI) are currently providing incentives for use of rubberized asphalt for highway applications. It is also estimated that, as petroleum prices rise, the demand of ground tires as a replacement of raw materials in new tire manufacture will increase. Bob Shatten, President, SuperCool LLC. "Utilizing Valuable Cryogenic Refrigeration Energy Available at LNG Distribution Terminals." Poster presented at Industrial Ecology for a Sustainable Future, the 3rd International Conference of The International Society for Industrial Ecology, ISIE. Stockholm, Sweden, June 12–15, June 2005.

In general, markets for scrap tires in NY and NJ have not been developed, especially the high–value added applications. Scrap tire processing facilities face challenges securing markets for the tires they process. Tires processed in NJ are used to construct cover surfaces or civil engineering applications,[435] and alternative fuel.[436] NJ DEP is considering various market development initiatives for innovative applications. Nevertheless, most tires are exported to Maryland, Connecticut, or Pennsylvania [237] as well as Massachusetts, Delaware, and New York.

In 2000, the *NYS Roundtable for Consensus on Tire Management* developed recommendations for stockpiles abatement, research, and development for new scrap tire applications, and for developing higher–value added markets and increasing demand for tires at end-of-life, as well as for imposing a statewide tire registration fee. The revenue was to be placed in a dedicated tire management fund to support market development, and other recommended activities. However, most scrap tires generated in NY are still exported (sent either to Connecticut or Pennsylvania) or stockpiled. In central NY, some tires are used in landfill applications or incinerated in electric arc furnaces [237].

Both NY and NJ have developed plans to abate scrap tire stockpiles. The NY Waste Tire Management and Recycling Act of 2003 has been enacted to ensure their proper management.[437] Beginning in September 2003, and in effect until December 2010, a tax of $2.50/unit has been imposed on all new tires sold in New York State, including those on new vehicles [208]. Retail vendors or tire services facilities collect the fee, keep a fraction of the tax ($0.25) and remit the balance to the state.[438] The state has a comprehensive plan to abate noncompliant waste tire stockpiles by December 31, 2010, and the owners/operators are responsible for the remediation costs of the sites [209]. NYS DEC has inventoried all stockpiles and prioritized them for remediation based on the size and location of the piles and other considerations [213]. Several projects are being planned or evaluated to clean up piles throughout the state [213]. In addition, the Act mandates tire service providers to accept used tires from customers until December 31, 2010, and to recycle/reuse them. Landfilling is not allowed unless there is no beneficial use for the tires.

In New Jersey, 2004 legislation[439] imposed a fee of $1.50 per new tire sold statewide (except in new vehicles). Fee collection is conducted by retail vendors, who remit the revenue to the Tire Management and Cleanup Fund, established by the NJ DEP. Funding for abatement of abandoned tire stockpiles is awarded on a competitive basis to counties and municipalities. At least nine counties have received funds for these projects [181]. The number of stockpiled tires in NJ has been continuously decreasing within the last few years as a result of these projects.[440] In particular, all the piles within the Watershed are slated for remediation.[441]

A June 2006 U.S. EPA publication compiles strategies applied in states nationwide to address the problem of tire piles and provides links to resources for those working in this area [342].

Specific recommendations:

- Support the efforts to abate scrap tire stockpiles.
- Education and outreach to inform the public about benefits (e.g., tire stockpile abatement, prevention of fires) associated with the fees/tax charged on new tires sold.
- Support appropriate funding for the development of tire recycling markets—in particular, high–value added markets.
- Support studies on emission testing and conditions to maximize combustion/energy recovery without generating dioxins and dioxin-like compounds.

## Other Combustion Sources

### Power Generating Stations Combusting Fossil Fuels

In the US, ~70% of the electricity is produced in power plants burning fossil fuel (50% coal, 18% natural

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[435] NJ DEP, Scrap Tire Management in New Jersey; 2005; available at: *http://www.state.nj.us/dep/dshw/recycle/plan05.htm* and *http://www.state.nj.us/dep/dshw/recycle/Final Plan 05/E.pdf.*

[436] Some tires are exported to Mexico and Central America for reuse [181].

[437] A summary of the Waste Tire Management Plan, including the Act, is available from NYS DEC, Division of Solid and Hazardous Materials, Waste Reduction and Recycling Program at *http://www.dec.state.ny.us/website/dshm/redrecy/wstires.htm.*

[438] The balance is sent to the NYS Department of Taxation and Finance.

[439] NJ P.L. 2004, c.46.

[440] Michael Gage, NJDEP Bureau of Solid Waste Compliance, Tire Piles. Personal communication, July 19, 2005.

[441] Tires removed from piles are generally chipped on-site and either taken to the landfill, where they are treated as solid waste (landfills will not take whole tires because of the quantity of space they consume), or to a recycling facility. At the recycling facility tires are chipped and then dyed to use at playgrounds or ground (separating out the metal) and used on surfaces such as sports fields. Ibid.

gas, and 2% oil), 20% is generated in nuclear plants, 7% in hydroelectric plants, and the rest in other types of energy generation (e.g., wind) [156].[442] Some power plants also obtain energy by burning wood. This was addressed in the section on wood combustion by industrial, power generation, and commercial sectors (Section C.1.c).

When the fossil fuels are burned at these facilities in order to recover their energy and transform it into electricity, flue gases are generated, which may release pollutants, including dioxins. Light fuel oil and natural gas combustion tends to be cleaner, with little or no ash and dioxin production. However, some of these plants may co-combust wastes such as solvents and waste oil, which can increase dioxin generation [350]. In fact, at least in 2003, two power plants in the region burned over 100,000 barrels of waste oil (Table Ap.C. 4). Coal is typically combusted in either a "dry bottom" boiler, where most ashes deposit at the bottom (boiler ash) or a "wet bottom" boiler, which achieves higher temperatures, causing ashes to melt and collect as a liquid (boiler slag).[443]

There is very limited data on dioxin emissions to air from utilities burning fossil fuel or concentrations in ash. Dioxins were detected in air emissions from several oil- and coal-fired utilities in the US[444] equipped with a variety of pollution controls, as well as in ash from coal-burning utilities (as summarized in [334]). The UNEP reports EFs based on some measurements in Europe, but few details are given regarding the applicability of these factors [350].

Dioxins in ash have the potential to be released to the environment depending on residue management.[445] Coal-burning power plants in the US generate ~100 million T of residues per year: ~52% is fly ash, 25% sludge from wet-flue gas scrubbers, 16% boiler ash, and 7% boiler slag [285]. About one-third of the coal ash and just over one-fourth of the scrubber sludge is currently recycled in commercially beneficial uses.[446] The remainder (>70 million T/yr) is disposed of in impoundments and landfills [285]. The U.S. Department of Energy's Office of Fossil Energy has the goal of increasing the use of coal residues from the current 30% to 50% by 2010 [285]. Benefits of recycling coal ash include reduced $CO_2$ and other emissions from cement manufacturing, plus economic benefits of $0.5–1 billion [285]. However, the environmental impacts of dioxins and other pollutants associated with these residues should be carefully evaluated. A recent report by the U.S. National Research Council stresses that enforceable standards are needed to ensure that dumping coal fly ash in old mines does not pose environmental problems [33].[447]

### Local Emissions

There are 53 power plants burning fossil fuel in New York State (22 in the Watershed) and 32 in New Jersey (17 in the Watershed) [64,65] with a combined capacity of ~30,000 MW of power [156]. Of these, 19 burn coal—most as a primary fuel—including four plants within the Watershed. Based on the amount of fuel consumed by all the utilities, dioxin emissions are summarized in Table Ap.C. 4. Estimates based on EFs proposed by UNEP and U.S. EPA are in good agreement.

Thirty-two power plants (13 within the Watershed, including the four burning coal), reported dioxin releases to TRI in 2004, mostly to air.[448] Twenty of these plants provided congener distributions, allowing the calculation of their air emissions in TEQs. All information is summarized in Table Ap.C. 5. Although emissions in TEQs are a little lower than our estimates (Table Ap.C. 4), not all plants reported to TRI. Overall, emissions from this sector are relatively low.

Dioxins associated with ash from utilities burning coal were estimated in **0.2–0.7 g TEQ/yr** within the Watershed and **0.8–3.5 g TEQ/yr** in the whole of NY and NJ.[449] There is no information on the amount of ash produced by other types of power plants and their dioxin concentrations.

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[442] The share of natural gas has increased, but prices are now increasing, and there is interest in developing coal-fired power generation.

[443] This kind of combustor is often used for utilities cocombusting wastes, where high temperatures ensure total oxidation.

[444] No differences in dioxin emissions were found between facilities with hot-sided vs. cold-sided ESPs.

[445] Coal-burning power plants typically use jets of water to remove bottom ash, collecting this stream in basins or lagoons, where ashes settle [277]. Recently, a power plant burning coal experienced a leak after one such basin cracked, discharging millions of gallons of water-ash mixture into the Delaware River [178]. Fly ash (from APCDs) is also typically collected in storage lagoons or disposed of in landfills [277].

[446] The most common use for fly ash is as a Portland cement replacement in concrete and concrete products. Innovative uses include stabilization of reefs [285].

[447] This practice reduces the landfill space needed and may help neutralize acids from the mines, but there are indications that fly ash can contaminate nearby waterbodies.

[448] One coal-burning plant outside the Watershed reported disposing of 1 g dioxins off-site.

[449] Lower range derived assuming ash production rate is 10% of the coal combusted (UNEP, 2003 [350]) and a mean ash concentration of 0.7 ng TEQ/kg (EPA, 1999 [306]—most analyses were non-detects; therefore, this EF likely overestimates dioxins concentrations). Upper range derived using UNEP EF of 14 µg/TJ of coal combusted (TJ stands for Tera Joules, or $10^{12}$ Joules, a measure of energy).

## Table Ap.C. 4. Dioxin emissions to air from power plants burning fossil fuel in NY and NJ

| | | | | EFs | | Dioxin emissions to air (g TEQ/yr) | |
|---|---|---|---|---|---|---|---|
| Fuel type¶ | Fuel use (2003)† | Units | Fuel use (TJ)† | EPA* | UNEP (µg/TJ)‡ | Estimated | TRI§ |
| **Watershed** | | | | | | | |
| Bit coal | 2,272,797 | US tons | 48,870 | 0.079 | 10 | 0.2–0.5 | 0.02 |
| NG | 241,776,970 | thousand $ft^3$ | 9,551 | ? | 0.2 | <0.01 | 0.07 |
| RFO | 14,743,097 | barrels | 97,788 | 200 | 2.5 | <0.01 | |
| DFO | 345,981 | barrels | 2,126 | 200 | 0.2 | 0.2–0.5 | |
| Kerosene | 465,080 | barrels | 2,782 | 200 | 0.2 | <0.01 | |
| Waste oil | 100,000 | barrels | 663 | 4 | 35 | <0.01 | |
| F06 | 46,900 | barrels | 311 | 200 | 2.5 | <0.01 | |
| **Total—Watershed** | | | | | | **0.4 - 1.0** | **0.09** |
| **Outside Watershed** | | | | | | | |
| Bit coal | 8,185,748 | US tons | 176,010 | 0.079 | 10 | 0.6–2 | 0.17 |
| SBit coal | 1,038,464 | US tons | 22,329 | 0.079 | 10 | 0.1–0.2 | |
| NG | 132,613,684 | thousand $ft^3$ | 154,738 | ? | 0.2 | <0.01 | 0.10 |
| RFO | 1,124,764 | barrels | 7,460 | 200 | 2.5 | <0.01 | |
| DFO | 319,144 | barrels | 1,961 | 200 | 0.2 | <0.01 | |
| Kerosene | 284,036 | barrels | 1,699 | 200 | 0.2 | <0.01 | |
| Waste oil | 714 | barrels | 5 | 4 | 35 | <0.01 | |
| F06 | 9,021,000 | barrels | 59,834 | 200 | 2.5 | 0.1–0.3 | |
| Jet fuel | 3,747 | barrels | — | ? | 0 | <0.01 | |
| PC | 56,735 | barrels | 1,220 | ? | 10 | <0.01 | |
| WC | 6,597 | US tons | 142 | ? | 10 | <0.01 | |
| **Total—outside Watershed** | | | | | | **0.9–2** | **0.27** |
| **Total—NY & NJ** | | | | | | **1–3** | **0.36** |

¶ Bit: bituminous; Sbit: subbituminous; NG: natural gas; RFO: residual fuel oil; DFO: distillate fuel oil; F06: fuel oil No.6; PC: petroleum coke; WC: waste coal.

† Source: Energy Information Association (EIA) [64,65], 2003 data, except for a few NY regulated facilities where only 2002 data was available. Fuel consumption was converted to TJ (tera joules = $10^{12}$ J) using average heat value: coal, 20.381 Mill BTU/ short ton; kerosene, 5.67 Mill BTU/barrel; residual fuel oil, 6.287 Mill BTU/barrel; distillate fuel oil, 5.825 Mill BTU/barrel; natural gas, 1,106 BTU/$ft^3$ [69]. (1 BTU = 1,055 J)

‡ Source: UNEP, 2003 [350].

* Units are ng/kg for coal and waste oil, and pg/L for fuel oils and kerosene [334].

§ Only some facilities reported to TRI. For details see Table Ap.C. 5.

## Measures to prevent or reduce dioxin emissions from utilities burning fossil fuels

Demand-side management to reduce energy consumption and supply-side measures, such as switching to alternative fuels (wind and solar energy) are the two main recommendations to reduce dioxin emissions.[450] Cobenefits of these measures include significant emission reductions of other pollutants, including carbon dioxide ($CO_2$, a greenhouse gas), nitrogen oxides, and sulfur oxides (precursors of acid rain). In addition, conventional energy generation results in thermal pollution and waste issues such as ash generation and water treatment.

General recommendations to reduce emissions at power plants may include:

- Outreach and education targeted to individuals, industries, businesses, and institutions on energy conservation measures[451] including:
  - use of energy-efficient appliances;
  - good thermal insulation in buildings;
  - design buildings to take advantage of natural light;

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[450] Some of the negative impacts of wind turbines that need to be addressed include their noise and effect on birds and bats. Noise has been reduced by design improvements [111].

[451] More information on energy saving at the U.S. Dept. of Energy website: *http://www.eere.energy.gov/consumer/tips/.*

  - decrease reliance in electricity for water heating.[452]
- Encourage the use of cleaner fuels by power generators and alternative sources of energy by consumers, including solar, wind, and geothermal.

Initiatives to promote energy conservation include:

- The NY State Energy Research and Development Authority (NYSERDA) has programs to promote energy conservation, including grants for business and institutions to replace old or inefficient electrical equipment.[453]
- The NJ Clean Energy Program promotes the benefits of owning a "NJ Energy Star Home," which is part of the EPA Energy Star program. Homes that are built following energy-efficient systems and measures (including energy-efficient appliances) are certified by EPA to be at least 30% more energy efficient than a standard home. The NJ Clean Energy Program website offers links to participating builders. Benefits of owning an "Energy Star Home" include:
  - lower energy bills;
  - lower environmental impact;
  - higher resale value (boosted by energy savings).
- Some specific measures that individuals and companies can take to reduce energy consumption include (many more examples can be found in the websites referenced in the footnotes):
  - replace incandescent bulbs with compact fluorescent bulbs, and use ceiling fans to increase cooling efficiency during hot days;[454]
  - in offices and commercial and industrial buildings, program air conditioning systems to be turned off at night and restarted one hour before employee arrival.[455]

Some initiatives to promote alternative modes of power generation include:

- NYSERDA provides cash incentives to install small solar-powered systems.[456] Solar panels have been installed though this program in the Adirondack Museum as well as in schools, institutions, and businesses.[457]
- NYSERDA also offers incentives to install wind power systems.[458]
- A federal tax credit supports utility-scale wind turbines during the first 10 years of operation [111].
- The NJ Clean Energy Program, through their Clean Energy Financing and Assistance Programs, also offers financial incentives for homes and business installing an on-site solar electric, sustainable biomass, fuel cell,

**Table Ap.C. 5. Dioxins emissions to air reported to TRI in 2004 from power plants**

| | Dioxin emissions (g/yr)* | | | Dioxin emissions (g TEQ/yr)* | | |
|---|---|---|---|---|---|---|
| | Coal | Other | Total | Coal | Other | Total |
| Watershed | 1 (4) | 9 (9) | 9 | 0.02 (4) | 0.07 (4) | 0.09 |
| Outside Watershed | 8 (14) | 7 (5) | 15 | 0.17 (10) | 0.10 (2) | 0.27 |
| **Total NY & NJ** | **9** | **16** | **25** | **0.19** | **0.17** | **0.36** |

Source: TRI Explorer *http://www.epa.gov/triexplorer/* reports by facility (NY and NJ) queried for: year: "2004;" chemical of concern: "dioxin and dioxin-like compounds;" facilities: "all industries."
*Numbers in parenthesis are the number of facilities included in the amount.

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[452] If water is heated with electricity, measures such as insulating the heater, lowering the thermostat setting, and repairing leaking faucets would reduce demand for electrical power.

[453] Details about these programs and incentives, as well as other information can be found at NYSERDA's website: *http://www.nyserda.org/default.asp.*

[454] Energy-saving tips and an interactive tool showing measures that can be implemented in homes can be found at the Energy Star webpage: *http://www.energystar.gov/index.cfm?c=products.es_at_home.*

[455] Energy management guidelines for business and institutions as well as available programs are detailed at the Energy Star webpage: *http://www.energystar.gov/index.cfm?c=business.bus_index.*

[456] Further information available at NYSERDA's website: *http://www.nyserda.org/default.asp.*

[457] There are currently on the market solar panel tiles that can be interlocked with regular shingles and generate energy, adjusting the electricity meter backwards [243].

[458] More success stories and details can be found at *http://www.powernaturally.org/About/SuccessStories.asp.*

or wind energy generation system in New Jersey.[459]

- Several other programs are available nationwide to promote the use of renewable sources of energy—in particular, solar. Some of these are:
  - U.S. Department of Energy, Energy Efficiency and Renewable Energy *www.eere.energy.gov/RE/solar.html*
  - Sun Farm Network–New Jersey's Solar Power Company *www.sunfarmnetwork.com*
  - New Jersey Farm Bureau and Sun Farm Network Joint Project—Solar Energy Opportunities *www.njfb.org/SunFarm.pdf*

## Residential Wood Burning

When wood or other biomass is burned (for heating and cooking purposes) in households, many pollutants are emitted, including dioxins, PAHs, volatile organic compounds (VOCs), and particulate matter (PM). These emissions may affect both outdoor and indoor air quality, especially if the stove is not properly maintained. If painted or otherwise-treated wood[460] is burned (see section on PCP-treated wood), dioxin emissions may be much higher [350].

The majority of the households using wood as a primary source of heat are located in rural areas and mainly use woodstoves [334]. On the other hand, most or the wood consumed in urban residences is burned in fireplaces and, although rarely the main source of heat, may contribute to dioxin emissions [334].

### Local Emissions

In 2001, in NY and NJ, over 4.5 T of wood were consumed for residential wood burning [66,67,70].[461] The emission factors (EFs) for woodstoves were obtained from a report by Environment Canada [73]. This study found dioxin emissions to be higher in EPA-certified (noncatalytic)[462] than conventional stoves [73].[463] For fireplaces, we used an EF for wood burning measured in the UK under conditions deemed to represent those of a fireplace [128]. Estimated dioxin emissions are presented in Table Ap.C. 6, where we also projected emissions under the assumption that all stoves were replaced with EPA-certified noncatalytic stoves.[464] In this case, emissions would almost double but would still be relatively small. These estimates are uncertain because the study by Environment Canada tested only one stove of each kind (and only noncatalytic) and because other types of fuel may be burned in stoves and fireplaces for which there are no EFs available (e.g., wood pellets and manufactured fire logs). More tests are needed to confirm whether EPA-certified stoves truly emit more dioxins, and to determine EFs for catalytic woodstoves.

For dioxins in ash, we applied a preliminary EF for clean wood developed by the UNEP under the assumption that 3% of ash is generated. Dioxins in ash could potentially be released to the environment but are relatively low (Table Ap.C. 6).

### Measures to minimize dioxin emissions from residential wood burning

Measures to reduce emissions focus on the type of wood used as fuel (combustion feedstock) and on efficiency standards for woodstoves. Burning of painted or pressure-treated wood should be avoided—in particular, when they contain creosote or pentachlorophenol (PCP). In 1988, the U.S. EPA established emission standards for particulate matter that must be met by all new woodstoves sold in the US. These stoves can be catalytic or noncatalytic and are also more energy efficient. Both types of stoves achieve more complete combustion and result in much lower emissions of gaseous and particulate pollutants,[465] with similar results regarding performance [271].[466] However, as already mentioned, the only test that measured dioxins found

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[459] Details are available at their website: *http://www.njcleanenergy.com/html/Combined/cleanenergy_financing.html.*

[460] Especially wood treated with pentachlorophenol (PCP). Other wood treatments such as arsenicals and creosote will release pollutants other than dioxins when burned, which are also are of concern.

[461] This does include estimates of the wood that individuals may harvest on their own, based on surveys by the Energy Information Administration (EIA). Julia Hutchins, State-Level Consumption, Prices, Expenditures, Energy Information Administration. Personal communication, July 28, 2005.

[462] EPA-certified woodstoves can be either catalytic or noncatalytic. Catalytic stoves contain a ceramic combustor coated with platinum or palladium, while noncatalytic stoves have a secondary combustion chamber and the air supply is preheated.

[463] Only one stove of each type was tested, each with two types of wood: maple and spruce. This trend in emissions was observed in all test runs (three per wood type per stove). Maple wood produced higher dioxin emissions than spruce did in the certified stove. These EFs are the same that U.S. EPA used in the latest draft dioxin inventory, except that EPA averaged all EFs [334].

[464] We are not aware of measurements of dioxin emissions from catalytic stoves.

[465] Emission reductions of 94% for particulate matter, 80% for volatile organic compounds, and 85% for PAHs have been measured [73].

[466] Note that some maintenance/checking may be needed to ensure the stove is working properly. It is, therefore, critical that consumers are aware of these requirements [298].

**Table Ap.C. 6. Dioxin emissions from residential wood burning in NY and NJ**

| | Wood burned (T/yr)† | Dioxin emissions to air (g TEQ/yr)‡ | | | | | Dioxins in ash (g TEQ/yr)‡ |
|---|---|---|---|---|---|---|---|
| | | Conventional | Certified | Fireplaces | Total | All certified§ | |
| NY | 4,123,224 | 0.7 | 0.2 | 0.2 | 1.2 | 2.4 | 1.2 |
| NJ | 419,580 | 0.07 | 0.02 | 0.02 | 0.1 | 0.2 | 0.1 |
| **NY+NJ** | **4,542,804** | **0.8** | **0.3** | **0.3** | **1.3** | **2.7** | **1.4** |
| **Watershed*** | **1,818,861** | **0.3** | **0.1** | **0.1** | **0.5** | **1.1** | **0.5** |

†Source: EIA 2001 [66,67]. The EIA reports wood consumption estimates both in energy values (BTU), which are based on typical caloric value of the fuel, and in cords, which are equivalent to ~1.25 US tons.

‡ We assumed that ~28% of wood is burned in fireplaces and the remainder in woodstoves, ~11% of which are EPA-certified, with the remaining being older stoves [114]. EFs are as follows: conventional stoves, 0.26 µg TEQ/T; EPA-certified, noncatalytic woodstoves 0.74 µg TEQ/T [73]; fireplaces, 0.21 µg TEQ/T [128]; dioxins in ash, 0.3 µg TEQ/T [350]. UNEP reported EFs in µg TEQ/TJ of wood burned, and these were converted to µg TEQ/T by multiplying by the heat value they used for wood (15 MJ/T).

§ Projected emissions if all woodstoves were replaced by EPA-certified ones.

* Extrapolating by percentage of occupied housing units with wood heating in the Watershed (26 and 30% of NY and NJ, respectively). Data from U.S. Census Bureau (2000) [280].

higher emissions from certified than conventional stoves [73].[467] Although EPA-certified stoves could emit more dioxins to air, they are proven to dramatically decrease emission of other pollutants, including PAHs. Therefore, promoting these new woodstoves is probably justified.

There are on the market woodstoves designed to burn wood pellets. These are more efficient and generally less polluting than EPA-certified woodstoves. Wood pellets are made of compressed waste wood (from lumber operations) and sawdust and are regarded as a renewable fuel [167]. A certain amount of new wood is required in the pellets. It should be ensured that no materials are added during the manufacture of these pellets that could increase dioxin emissions. Research is needed to quantify dioxin emissions from this type of stoves and fuel.

Several local or regional programs to promote the replacement of old conventional stoves with certified ones have taken place since 1994.[468]

Specific recommendations include:

- Consider legislation to prohibit combustion of pressure-treated wood (for residential wood stoves as well as other combustion processes).
- Confirm whether noncatalytic, EPA-certified stoves truly emit more dioxins than older stoves.
- Test dioxin emissions from catalytic EPA-certified stoves and wood pellet stoves.
- Promote the use of natural gas as a lower-pollution option. Gas utilities could provide funding for rebates when switching to natural gas stoves
- Education campaigns to inform the public of the health and environmental consequences of wood burning (both indoor and outdoor). Brochures could be made available at stores, through real estate agents, and/or constructors.
- Establish EFs for fireplaces and evaluate the proportion of wood burned in fireplaces vs. stoves

### Outdoor Wood Boilers

Outdoor wood boilers are free-standing combustion units fueled by wood that are used to heat homes [218]. These boilers resemble sheds with short chimneys and are installed outside the home that will be heated [218]. These units consist of an oversized firebox[469] (combustion area) surrounded by a water reservoir [218]. Wood is combusted in the boiler and is used to heat the water, which is conveyed through insulated pipes to the home [218]. A thermostat in the home controls the rate of combustion by regulating

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467. This study found that most dioxins were emitted in the gas phase and were not associated with particulate matter (PM). This may explain in part why, even though PM emissions were much lower, there was not a corresponding decrease in dioxins. However, more testing is needed before these results can be generalized. A previous Danish study had also found that dioxin emissions were higher under "optimal burning conditions" [73].

468. Several programs have been carried out in the US to encourage the replacement of old stoves with EPA-certified or less-polluting (e.g., gas-fired) ones. Generally, areas that are particularly affected by pollution are targeted, and the incentives include rebates or discounts. The costs are covered by government agencies, gas utilities, and wood stove manufacturers, distributors, and retailers [330].

469. Logs up to 5 feet long can be accommodated, allowing big loads that can burn for hours without tending.

the amount of air that gets to the firebox [218]. This causes the wood to smolder, emitting large amounts of smoke. These units are becoming increasingly popular in rural areas as fuel prices increase, although the economic advantages are unclear [218]. Stacks are typically short, and smoke is released close to the ground [218]. One concern with these units is that individuals could easily burn any type of combustible material, from household garbage to treated wood.

**Local Emissions**

Locally, it is estimated that ~7,500 outdoor wood boilers are in use in NY [218] and another 75 in NJ,[470] although this is likely an underestimate.[471] It is difficult to determine the amount of wood used in these boilers because it depends on the model as well as the frequency and mode of use. However, it can be roughly estimated that between 8 and 12 cords of wood are used per boiler per year. We assumed that this wood was consumed in addition to wood burned in stoves.[472] No measurements have been performed to determine dioxin releases from these units, although emissions are likely higher than for wood stoves. Preliminary tests showed that PAHs are 3 to 4 times higher than for stoves, while PM emissions may be 7 to 12 times higher [218]. We estimated a possible range of emissions from outdoor wood boilers by applying the EF for residential wood burning in conventional stoves as the lower end and assuming emissions 12 times higher (as for PM) for the upper end. These numbers are summarized in Table Ap.C. 7. Note that this should be regarded as only a rough estimate of the possible relevance of this source locally. Better data is needed for the number of stoves in use, the amount of wood consumed, and EFs for dioxins. Nevertheless, these preliminary calculations suggest that this is probably not a primary concern for dioxins locally.

## Household, Commercial, and Industrial Fossil Fuel Combustion

This section includes estimates of dioxin emissions from combustion of coal as well as distillate and residual fuels by residential, commercial, and industrial activity other than power generation. This includes use for heating (residential and commercial) and other uses by the industrial sector. Emission factors for these activities have been developed by the U.S. EPA based on limited data from a few countries [334]. Fuel consumption and dioxin emissions to air from residential use of fossil fuel are presented in Table Ap.C. 8. Limitations notwithstanding, this sector seems to result in low emissions locally.

Emissions from industrial and commercial combustion of fossil fuels are similar for liquid fuels and higher for coal, but still relatively low (Table Ap.C. 9).

## Stationary Diesel Engines

Stationary internal combustion (IC) diesel engines have been used primarily for backup generation during energy outages or to reduce reliance on grid supply during periods of peak demand [194]. These units are of concern because air emissions of pollutants—including PM and nitrogen oxides (NOx)—are several times higher than those of conventional fossil fuel power plants per unit of electrical output [194]. The deregulation of electricity markets may increase the reliance on distributed generation during peak

**Table Ap.C. 7. Estimated emissions to air from outdoor wood boilers**

| | Number of boilers* | Wood consumed (T/yr)** | Dioxin emissions (g TEQ/yr)† | |
|---|---|---|---|---|
| | | | Lower end | Upper end |
| Total NY + NJ | 7,538 | 68,385–102,577 | 0.1–0.2 | 1.0–2.5 |
| **Watershed‡** | **3,018** | **27,381–41,072** | **0.05–0.08** | **0.4–1.0** |

* From [218] and NJ DEP meetings "Reducing Air Pollution Together," Homes and Restaurants workgroup.

** From 8 to 12 cords of wood per boiler per year. Lisa Rector, Senior Policy Analyst, NESCAUM. Personal communication, October 19, 2005.

† Lower end assuming EF for residential wood burning in conventional stoves (2 ng TEQ/kg) [334]. Upper end assuming emissions are 12 times higher than conventional stoves (as may be the case for PM) [218].

‡ Extrapolating by percentage of occupied housing units with wood heating in the Watershed (26 and 30% of NY and NJ, respectively). Data from U.S. Census Bureau (2000) [280].

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[470] As discussed during a series of meetings of the Homes and Restaurants Workgroup of the "Reducing Pollution Together," and initiative of NJ DEP to craft recommendations to reduce emissions of criteria pollutants. June to September 2005.

[471] Lisa Rector, Senior Policy Analyst, NESCAUM. Personal communication, October 19, 2005.

[472] Residential wood consumption is estimated by the EIA based on surveys, which includes wood harvested by individuals in addition to purchased wood. However, it is not clear whether the survey format is such that individuals would include wood used in outdoor wood boilers.

## Table Ap.C. 8. Dioxin emissions from residential fossil fuel combustion

| | Fuel consumption[*] | | Emissions to air (g TEQ/yr)[**] | |
|---|---|---|---|---|
| | **Distillate fuel (L)** | **Coal (T)** | **Fuel** | **Coal** |
| NY | 5,803,087,960 | 11,794 | 0.9 | 0.07 |
| NJ | 1,505,381,620 | — | 0.2 | — |
| **NY+NJ** | **7,308,469,580** | **11,794** | **1.1** | **0.07** |
| **Watershed[†]** | **3,871,304,492** | **6,369** | **0.6** | **0.04** |

[*] Data for 2001 from EIA [66,67].

[**] Emission factors are 150 pg/L for distillate fuel and 2.1 and 7.5 µg TEQ/T for anthracite (27.5% of coal used in residences in the US) and bituminous coal (72.5%), respectively [334].

[†] Extrapolated by population within the Watershed (54% of NY population and 49% of NJ population).

## Table Ap.C. 9. Dioxin emissions from industrial and commercial fossil fuel combustion

| | Fuel consumption (industrial + commercial)[*] | | | Emissions to air (g TEQ/yr)[**] | |
|---|---|---|---|---|---|
| | **Distillate fuel (L)** | **Residual fuel (L)** | **Coal (T)** | **Fuel** | **Coal** |
| NY | 3,155,117,080 | 1,389,008,260 | 2,508,408 | 0.9 | 1.5 |
| NJ | 926,535,440 | 156,595,300 | 9,072 | 0.2 | 0.0 |
| **NY+NJ** | **4,081,652,520** | **1,545,603,560** | **2,517,480** | **1.1** | **1.5** |
| **Watershed[†]** | **2,157,765,589** | **826,796,157** | **1,358,986** | **0.6** | **0.8** |

[*] Data for 2001 from EIA [66,67].

[**] Emission factors are 200 pg/L for both distillate and residual fuel and 0.6 µg TEQ/T for coal [334].

[†] Extrapolated by population within the Watershed (54% of NY population and 49% of NJ population).

## Table Ap.C. 10. Worst-case scenario estimate of emissions from stationary diesel engines

| | No. of stationary diesel engines[*] | Distillate fuel consumption (L)[†] | Emissions to air (g TEQ/yr)[‡] | |
|---|---|---|---|---|
| | | | **Low end** | **High end** |
| NY | 1,662–15,037 | 473,919,380 | 0.09 | 0.5 |
| NJ | 5,823–8,415 | 386,957,320 | 0.08 | 0.4 |
| **NY + NJ** | **7,485–23,452** | **860,876,700** | **0.17** | **0.9** |
| **Watershed** | **3,750–12,243** | **445,525,552** | **0.09** | **0.4** |

[*] Source: NESCAUM [194].

[†] Fuel consumption by the industrial sector from previous section.

[‡] Low end based on same EFs as for utilities burning diesel fuel (200 pg TEQ/L) [334]; high end assuming emissions from diesel engines are five times higher than for utilities.

demand, in which IC diesel engines would play a prominent role [194].

The Northeast States for Coordinated Air Use Management (NESCAUM) estimated the number of IC diesel engines in the Northeast based on permitted engines and on surveys and national sales data (Table Ap.C. 10). Emission factors for dioxins are not available, and data on the amount of fuel consumed by these units is lacking. It is likely that fuel combusted in stationary diesel engines is included in the amounts consumed by the industrial sector, which were considered in the previous section. The EFs used in that section for distillate fuel combustion are the same as EFs suggested for utilities and would not take into account the larger emissions expected from stationary engines. However, even if dioxin emissions were five times higher than for utilities and all the diesel fuel consumed by the industrial sector were combusted in these engines, emissions would be low, as summarized in Table Ap.C. 10.

### Used Motor Oil

We consider this sector as a combustion source because most dioxins in used motor oil are generated during fuel combustion in motor vehicles. Off-road combustion of fuel (including watercraft, construction, and farm equipment, stationary engines, aircraft, and trains) will also result in dioxin generation that accumulates in engine oil. However, data on the amounts of oil generated, mode of disposal, and associated dioxins are not currently available. More attention should be paid to this sector to determine whether this might represent a large source of dioxins and other pollutants to the environment.

Motor oil has been found to contain dioxins, with higher concentrations in used oil, [248]. Although the use of chlorinated additives in fuels and lubricants has declined (e.g., chlorinated scavengers used with leaded gas), organic chlorinated compounds may be either naturally occurring in petroleum or introduced to the fuel during refinement or shipment [248]. Similarly, motor oil can also have small amounts of chlorine [248]. Additional chlorine may be provided by the large masses of air consumed during engine combustion [248].[473]

Used motor oil can be recycled into fuel or oil, or it can be burned in boilers. Facilities that generate used motor oil are required to send it to collection points. It is assumed that oil generated by "do it for me's" (DIFM, people who have their oil changed at service stations) is disposed of properly. On the other hand, "do it yourselfers" (DIY, individuals who change motor oil themselves) are the main concern for improper disposal and constitute ~21% of the national population older than 18. Used motor oil should be dropped off at garages or specific collection points. However, a 2002 survey by the U.S. Department of Transportation (U.S. DOT) indicates that ~16% of the DIY population improperly dispose of oil by placing it in the garbage or pouring it down the drain, on the soil, or in the water [286].[474]

### Local Releases

Because no local data is available on the disposal of motor oil, national data was used to estimate regional activity.

Table Ap.C. 11 shows the amounts of oil generated and improperly disposed of in the Watershed along with associated dioxins. This estimate does not include spills that may occur during the use of motor oil. Oil generated by off-road engines is not included in this estimate because at this point there is no information available on quantities of oil generated by this sector or the amounts that may be improperly disposed of. Close attention should be payed to these sectors because it is possible that some of the oil could be dumped directly into the Harbor by boat owners.

## Measures to reduce dioxin releases associated with disposal of used motor oil

It has been estimated that used motor oil of many do-it-yourselfers (DIY), who change their own oil, may not be collected or recycled, but improperly discharged. The success of used motor oil collection programs depends on their wide public adoption. Service stations selling new oil and performing vehicle services are required to accept 5–10 gallons of used oil per person per day at no charge.[475] In addition,

**Table Ap.C. 11. Dioxins in used motor oil within the Watershed**

| State (Watershed only) | Registered vehicles* | DIY vehicles† | Used motor oil generated (gal/yr)‡ | | Used motor oil improperly disposed by DIY | |
|---|---|---|---|---|---|---|
| | | | Total | DIY | Amount (gal/yr)§ | Dioxins (g TEQ)¶ |
| NY | 4,231,351 | 1,496,792 | 11,404,481 | 5,388,451 | 862,152 | 0.04–0.2 |
| NJ | 2,562,063 | 906,300 | 6,905,358 | 3,262,681 | 522,029 | 0.02–0.1 |
| **Total** | **6,793,414** | **2,403,092** | **18,309,839** | **8,651,132** | **1,384,181** | **0.06–0.3** |

* NY: NYS Department of Motor Vehicles (DMV) (2004) [198]. NJ: extrapolated from state data (provided by Debra Massari, Executive Director, New Jersey Motor Vehicle Commission, personal communication, July 11, 2005) by Watershed population (49%).

†21% of the population over 18 years old (from Census 2000), adjusted by vehicle ownership rate (0.47, 0.56, and 0.59 cars/person in NY, NJ [Watershed only], and the US, respectively). Each DIY was assumed to have one car. DIFM vehicles were assumed to be the registered minus DIY vehicles.

‡DIFMs and DIYs were assumed to change their oil 2.2 and 3.6 times per year [286], generating ~1 gallons/change.

§16 % of used oil generated by DIYs.

¶ Dioxin concentration in used motor oil: 14-60 ng/kg [174]. Oil density: ~3.13 kg/gal [165].

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473. The atmosphere contains traces of hydrogen chloride, sodium chloride, and free chlorine (see section B of the technical report).

474. Approximately 5% of the oil is poured down indoor or in sewer drains, 24% goes to garbage or landfills, 5% is released to land, while the fate of 66% unknown but assumed to be improperly disposed of, including burning as fuel.

475. In New York, only those auto service stations selling at least 500 gallons per year of new oil are eligible for this rule. Sondra Flite, NJ DEP Bureau of Recycling and Planning. Personal communication, June 17, 2005 [199].

### BOX A. RECYCLING USED MOTOR OIL

- **Reprocessing:** This removes water and particles, producing oil suitable for use in asphalt or as fuel in industrial boilers.
- **Reconditioning:** Filtering process that results in oil of lower quality than virgin oil, but extends its useful life.
- **Refining:** The oil is cleaned of contaminants through vacuum distillation, then treated to remove remaining chemicals. This mixture is then combined with fresh additives to produce a finished lubricant. Used motor oil can be rerefined many times, and it is subject to the same performance standards as virgin oil [6].

different municipalities and counties throughout the Watershed accept used motor oils[476] during hazardous waste collection events.[477]

In New York and New Jersey, used motor oil must be either recycled or burned in boilers that meet certain specifications. Used motor oil is sometimes used as a dust suppressant; however, this is illegal in both New York and New Jersey.[478]

Measures to manage used motor oil emphasize proper disposal, reuse, and recycling, by either reprocessing it into fuel used for heating or rerefining it to return the used oil to its original virgin oil state (see Box A).[479]

Specific recommendations include:

- Encourage proper disposal of oil by DIY, by providing clear instructions on all motor oil sold and/or through coupons from distributors or stores on each bottle if oil is returned.
- Outreach and education to inform the public in general and "do-it-yourselfers" in particular about the environmental benefits and importance of recycling used motor, as well as information on how to recycle.
- Support statewide collection programs for used motor oil.
- Gather data on generation rates, management practices, and dioxin concentrations for off-road generation of motor oil.

### Industrial Flaring

Certain industrial facilities, including oil refineries and some chemical plants, may flare some of their gases as a way of reducing emissions of certain pollutants (e.g. volatile organic compounds or VOCs). These combustion processes may result in dioxin releases, especially if the gases flared contain large amounts of chlorine, which is possible at some chemical manufacturing facilities. At this time there is insufficient information on both the activity level and EFs. Therefore, no estimate of dioxin emissions is provided.

## Industrial Sources

### Metal Production Sectors

#### Secondary Aluminum Production

Dioxin emissions from the aluminum sector are almost exclusively associated with secondary production. Aluminum scrap and other aluminum-containing materials (which may contain oil, paint, plastics, and other organics) are melted in furnaces. Dioxins can be released during pretreatment (e.g. thermal cleaning), melting, or refining. Emissions to air, according to UNEP, may range from 0.5 to 150 $\mu$g TEQ/T aluminum, depending on the quality of the scrap and the kind of emissions control [350]. The U.S. EPA used, for its draft dioxin inventory, an EF of 22.4 $\mu$g TEQ/T based on measurements at six US facilities, including several where pollution controls are believed to be better than the average and may, therefore, underestimate releases when applied to poorly controlled facilities [334]. For this reason, we applied EFs suggested by UNEP. Residues from air pollution control devices (APCDs) can be highly contaminated

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[476] Used motor oil is not considered hazardous waste.

[477] A summary of collection programs in the State of New York, including motor oil and hazardous waste, is available at *http://www.dec.state.ny.us/website/dshm/redrecy/hhwsum.htm* (Accessed May 2005).

[478] 6 NYCRR Subpart 374-2.6. Standards for Disposal of Used Oil. (Available at: *http://www.dec.state.ny.us/website/regs/subpart374_2.html.* (Accessed June 17, 2005). NJAC 7:26A-1 et seq. Available at: *http://www.nj.gov/dep/dshw/resource/njac726a.pdf.* (Accessed June 17, 2005).

[479] Approximately 14% of the collected used motor oil in the U.S. is rerefined into virgin oil. This is an expensive process that could become cost effective if oil prices increase. Information from the API [6]. There are no rerefining facilities located in the Northeast, with the closest facility located in Illinois. There are several reprocessing facilities in New York and New Jersey. Reprocessing is endorsed by New Jersey (Sondra Flite, NJ DEP Bureau of Recycling and Planning. Personal Communication, August 9, 2005).

## Table Ap.C. 12. Secondary aluminum production in NY & NJ and dioxin emissions by facility

| | | | Emissions to air | | | |
|---|---|---|---|---|---|---|
| County | State | Capacity (T/yr) | UNEP‡ (g TEQ/yr) | Stack tests¶ (g total dioxin/yr) | Dioxins in ash* (g TEQ/yr) | Notes** |
| Montgomery† | NY | 40,000 | 0.02 | 0.01–0.001 | | CS. No APCD |
| Ulster | NY | 30,000 | 0.02 | NA | | CS. No APCD |
| Hudson† | NJ | 40,000 | 0.02 | NA | | CS. No APCD |
| **Total Watershed** | | **110,000** | **0.06** | | | |
| Niagara† | NY | 40,000 | 0.02 | NA | | CS. No data on APCD |
| Oswego | NY | 68,000 | 0.2 | 0.006–0.08 | 6–27 | C&PCS. FF* |
| St. Lawrence† | NY | 40,000 | 0.02 | NA | | CS. FF, CA |
| Camden | NJ | 136,000 | 0.07 | 0.008 | | CS, No APCD |
| **Total outside Watershed** | | **284,000** | **0.3** | | **6–27** | |
| **Total NY + NJ** | | **394,000** | **0.4** | | **6–27** | |

†Capacity for these plants was not provided, and it was assumed to be equal to the average consumption of scrap (both old and new) aluminum by US secondary smelters [221].

‡ We assumed an EF of 0.5 µg/T for plants processing clean scrap only and 35 µg/T for plants equipped with fabric filters [350].

¶ Information from NYS DEC through Freedom of Information Law (FOIL) request and NJ DEP through Open Public Records Act (OPRA) request. NA: not available.

* EFs, according to UNEP range from 100 to 400 µg TEQ/T scrap processed [350].

** CS: clean scrap; C&PCS: clean and postconsumer scrap; FF: Fabric filters; CA: catalytic afterburner. Source: NJ: OPRA request and NY: Title V permit [203].

(~5,000 ng/kg dust, or an EF of 100-400 µg/T aluminum [350]).

### Local Emissions for Secondary Aluminum Production

There are five secondary aluminum smelters in the state of New York and two in the state of New Jersey, with only three of these located in the Watershed.[480] Plant characteristics as well as emissions based on UNEP EFs are presented in Table Ap.C. 12. Only one of these facilities processes postconsumer scrap, and we present an estimate of dioxins in ash from this plant. The remaining facilities process only clean scrap, and estimated emissions are consequently low.

There are also at least 33 aluminum casting facilities in the Watershed, with several more in NY and NJ outside the Watershed region.[481] The relevance of emissions from casting facilities is currently unknown.

## Secondary Lead Production

Lead recycling accounts for ~80% of lead production in the US, and 92% of the recycled lead is recovered from lead–acid batteries [249].[482] There is one lead recycler in the Watershed, in Orange County, NY [278]. This is one of the 15 plants owned by 7 companies that recycled 99% of the lead in the US in 2003. Estimated emissions to air are negligible (Table Ap.C. 13). There are no EFs available to estimate dioxins associated with ash from this type of facility. Dioxins released to air reported to TRI air in 2004 were 0.18 g total dioxins. It was not possible to calculate emissions in TEQs because congener distributions were not available.

## Table Ap.C. 13. Dioxin air emissions from lead recycling

| | |
|---|---|
| Lead recycled nationwide (2003) [249] | 1,150,000 T |
| Lead recycled in NY (2003)* | 76,667–164,286 T |
| Emission factor [334]† | 0.42 µg/T |
| Dioxin emissions | 0.03–0.07 g TEQ/yr |

* Assuming 1/15 to 1/7 of US production is recycled in the NY facility.

† EF for reverberatory furnace without scrubber. Information on type of furnace and APCD for this facility obtained from NYS DEC issued Title V Permits [203]. However, EPA default emission factors for TRI reporting for secondary lead smelters with this kind of furnace are two orders of magnitude higher: 42.82 µg/T [308].

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[480] Pat Plunkert, Minerals Information Team, USGS. Personal communication, March 7, 2005. Original source: Light Metal Age magazine 8/03 V6 No 7,8 p. 8–9 *(http://www.lightmetalage.com)*.

[481] Most facilities also cast other metals, usually copper and copper alloys. Data from Engineered Casting Solutions, 2002, provided by Susie Harris, USGS. Personal communication, March 8, 2005.

[482] These are the batteries used to start cars, trucks, boats, and other types of engines.

### Copper Production

Copper can be recycled without loss of quality. Because copper is known to catalyze dioxin synthesis more effectively than other metals [158], its recycling has a much greater potential for dioxin formation than other metals. In the US and the Watershed, there is currently no secondary Cu production. All scrap Cu is exported, primarily to China, for recycling.[483] There are, however, several small plants in the Watershed that melt copper, copper alloy ingot, and or copper/copper alloy scrap[484] as well as 30 companies casting copper, brass, and bronze.[485] Better characterization of this sector as well as knowledge of the way in which these facilities operate (types of furnaces and APCDs) is needed in order to determine whether they might be emitting dioxins and in what amount. Note that the export of scrap generated in the US will result in dioxin emissions in other countries, where the copper will be recycled. The long-range transport of toxics may extend their influence beyond the point of generation.

### Primary Magnesium Production

Primary production of magnesium (i.e., extraction and purification from ore) can follow a thermal or an electrolytic process. Chlorine is used during the purification steps, resulting in dioxin generation [350].[486] Dioxins can be present in aqueous effluents (if a wet cleaning system is used) and in dust from APCD and air releases. EFs for air releases range from 50–250 $\mu$g TEQ/T of magnesium, water releases from 30–9,000 $\mu$g/T, and residues from 0 (for wet system) to 9,000 $\mu$g/ton [350]. The only Mg processing facility in the US is in Utah.

### Titanium Production

Titanium (Ti) production involves treatment of the ore with chlorine gas to form titanium tetrachloride, followed by electrolytic separation of the magnesium chloride ($MgCl_2$) impurities.

There is one Ti plant (Lawrence Aviation Industries, Inc.) in Port Jefferson, NY (Suffolk County). This plant has a capacity of 1,400 T of metallic titanium per year [95]. Higher dioxin generation is associated with the production of titanium oxide ($TiO_2$), a pigment whose manufacture produces a sludge that is contaminated with dioxins. However, there are no emission factors available for either process. There are no $TiO_2$ plants in NY or NJ.[487]

### Other Metals

Emissions from other nonferrous metal production are poorly characterized but are potential dioxin and furan sources. Many of these processes involve treatment with chlorine, including production of niobium, tantalum, tin, vanadium, nickel, and sodium. At least one of these processes (nickel refining by converting nickel chloride to nickel oxide) is believed to generate large amounts of dioxins, but no emission factor is available. In general, any thermal process should be considered a likely source of dioxins and furans.

### Iron Sintering

Sintering is a process that makes iron ore suitable for iron production. Finely powdered iron ore or residues are heated with coal or coke to produce a lumped material usable in blast furnaces to produce iron. The ore residues contain chlorinated organic compounds and generate dioxins in the sintering process, which accounts for most of the air emissions from the iron and steel sector [36,350]. Most of the dioxins associated with sintering are formed during the combustion step, and ~10% is the result of *de novo* synthesis in APCDs. One way to reduce dioxin formation is to ensure steady and consistent operation to minimize flame disruption leading to lower temperatures favoring dioxins. Air emission factors range from 0.3 to 20 $\mu$g TEQ/T sinter produced, depending on the kind of residues sintered and the emission control technology [350]. Any dioxin

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[483] Daniel Edelstein, Copper Commodity Specialist. US Geological Survey. Personal communication, March 9, 2005.

[484] Pat Foly, American Bureau of Metal Statistics. Personal communication, March 2, 2005.

[485] Data from Engineered Casting Solutions, 2002, provided by Susie Harris, USGS. Personal communication, March 8, 2005. Brass and bronze are copper alloys.

[486] Magnesium oxide (MgO) is purified by heating it to 700-800°C with coke and chlorine gas to produce magnesium chloride ($MgCl_2$), which is later electrolyzed using graphite electrodes to produce metallic magnesium.

[487] One facility in Edgemoor, Delaware generates ~0.1 million T/yr of dioxin-contaminated wastes [160]. These wastes also contain PCBs, lead, and other pollutants and have been disposed of at an on-site dump close to the Delaware River from 1997 to 2000. The accumulated material is estimated to contain 130–160 kg of dioxins [161]. Some of this waste has been used as road base, landfill cover, for treating drinking water and wastewater, and for other purposes [161] and is currently sent to a garbage dump in South Carolina [161], although these wastes are currently classified as hazardous. The $TiO_2$ facility has reported to TRI sending 41 kg of dioxins (98% OCDF) to an off-site nonhazardous waste landfill in 2003. Sludges from $TiO_2$ used to be disposed of in RCRA Subtitle D solid waste disposal facilities, which had the potential to leak some of the dioxins [334]. Currently, the sludge is classified a hazardous waste and, consequently, has to be disposed of in permitted facilities [334]. The facility (Dupont) is currently working on eliminating dioxin releases from the process (Joseph Malki, U.S. EPA Region 2, Waste Minimization. Personal communication, December 1, 2005).

in sinter will likely be destroyed during the next step (iron production). Up to 2 kg dust/T sinter can be generated in APCDs. Some of it can be recycled to the process or discarded as a waste [350]. UNEP estimates releases of 0.003 $\mu$g TEQ/T sinter in these residues.

## Cement Kilns[488]

The first step in cement production is calcination of the raw materials at high temperatures (~1,500°C) in rotary kilns to produce pre-cement or clinker.[489] The clinker is ground up with gypsum ($CaSO_4$) and other additives to produce cement.[490] When cement is mixed with sand, stone, water, and other materials, it produces concrete. Clinker production releases dioxins as well as other pollutants.[491] APCDs most commonly used to capture particulates in kilns are fabric filters and electrostatic precipitators (ESPs). As of 1995, most ESPs were hot type and, therefore, potentially associated with larger dioxin emissions than cold ESPs.[492]

Clinker production is the most energy-consuming and expensive step of cement manufacturing. It requires burning some kind of fuel, usually coal (~75% of US kilns use it) or coke, although other fuels can be used. Many cement kilns supplement their fuel with hazardous wastes such as oils, solvents, and industrial refuse, as well as other waste material including scrap tires, also referred to as tire-derived fuel (TDF). Clinker production can use either a dry or wet technology; the wet process is older and requires more energy.[493] While most US plants were operating wet kilns in the early 1980s, the opposite is true nowadays: in 2000 there were 32 wet and 77 dry kilns.

In general, wet kilns release more dioxins than dry kilns, most of which are formed within the APCDs. If raw materials contain high levels of organic matter, they may increase dioxin emissions. Approximately 2 to 20% of ash or cement kiln dust (CKD) is produced by mass and is mostly trapped by APCDs. This CKD contains metals and organic compounds including traces of dioxins, but it is not considered a hazardous waste.[494] CKD can be reintroduced to the kiln, disposed of in landfills, quarries, or piles, or used in *beneficial* applications (e.g., sludge, waste, or soil stabilization, land reclamation, acid neutralization, and agricultural and construction applications) [30]. According to the Portland Cement Association, of 18 CKD disposal facilities surveyed where 95% of the CKD is landfilled, 57% of the facilities monitored groundwater, 97% practiced dust control, 77% had water runoff controls, and 91% had road dust control.

Most cement production is concentrated in Texas, California, Pennsylvania, Michigan and Missouri, near lime deposits. There are 115 cement plants in US, but 75% of activity is accounted for by the 10 largest facilities.

There is limited research on the effect of tire burning on dioxin emissions at cement kilns. Some testing has shown that dioxin levels remain below the EU limit of 0.1 ng I-TEQ/Nm$^3$ and were not statistically different from measurements at other kilns, including those using only conventional fuel [1]. However, this study did not compare emissions with and without tires at the same kilns, used chipped (as opposed to whole) tires only, and the kilns were equipped with fabric filters or ESPs. Data recently reviewed by NYS DEC shows that TDF can cause typically minor increases or decreases in dioxin emissions [1]. Several studies indicate that high temperatures in the kiln's combustion zone ensure destruction of dioxins. Therefore, dioxins will be formed postcombustion, governed mostly by the temperature at the control device inlet [17]. The only way of assessing the impact of supplementing fuel with tires is to test each facility.

### Local Estimates

There are only three cement plants in New York State, all of them within the Watershed, and none in the state

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488. This section is summarized from UNEP, 2003, and CEC [30,350].

489. Kilns are ~50 m long and 5 m in diameter, slightly inclined, and rotating at 1–3 rpm. Raw materials are fed to the upper end (the cold end). The lower or hot end is where combustion occurs and off-gases pass countercurrently to the feed. Residence times are long (5–7 seconds), and temperatures are high (1,400°C at the hot end). Limestone is calcined to lime (calcium oxide, CaO), releasing carbon dioxide ($CO_2$). Lime combines with the other materials in physical and chemical reactions generating silicates, aluminates, and ferrites of calcium. The hot clinker is then cooled.

490. The main raw material for cement production is limestone (calcium carbonate or $CaCO_3$). Other ingredients include clay, aluminum oxide, iron, shale, and silica. These materials are finely ground and blended in varying proportions depending on the type of cement desired.

491. Emissions include large amounts of $CO_2$ (a greenhouse gas; this is partly offset because cement also absorbs $CO_2$), nitrogen oxides, carbon monoxide, volatile organic compounds that result in ozone formation at ground level, PBTs, mercury, and particulate matter.

492. When the flue gases enter the ESP directly, it is classified as "hot," which means that typical temperatures within the ESP are above 200°C. High temperatures (>230°C) favor dioxin formation in the ESP with higher emissions [334]. Temperatures can be reduced by rapidly cooling the gases before entering the ESP. This is usually achieved by adding a water quenching system (e.g., water spray) upstream of the ESP [334]. In this case, the ESP is classified as "cold."

493. The materials are ground in water to form a slurry that is pumped to the kiln. Dry kilns are usually smaller, and the materials are fed as dry powder.

494. However, there have been five known cases of groundwater contamination, 10 of surface water contamination, and 21 cases of damage to air quality as a result of CKD management operations [30]. Two CDK disposal units have resulted in Superfund sites due to groundwater contamination with metals [30].

of New Jersey.[495] Two of the NY facilities use wet technology, and the third uses the dry type. The main fuel used is coal, and the three plants are equipped with electrostatic precipitators (ESP) to control particulate emissions.[496] Dioxin emissions are higher if the kiln fuel is supplemented with hazardous wastes, but none of these facilities does this. However, the kilns in Warren and Greene Counties are permitted to supplement their fuel with whole and chipped tires, respectively [203], although they burn only coke and coal.[497] The third kiln has applied to modify its permit to allow for the use of TDF.[498] The kilns in NY are not fitted with scrubbers; therefore, we assume hot ESP conditions (>200°C).

The U.S. EPA measured dioxin emissions from several cement kilns [333]. Only one EF is provided for kilns that do not burn hazardous wastes, regardless of whether the electrostatic precipitator (ESP) is cold- or hot-sided or of the type of technology used (wet vs. dry) [333]. Conversely, EFs suggested by UNEP are based on the kind of technology and ESP operating temperature but make no distinction for kilns using hazardous wastes as supplemental fuel [350]. Table Ap.C. 14 presents plant capacity and estimated emissions to air from local cement kilns, as well as dioxins associated with cement kiln dust (CKD). The range of emissions to air using EFs is wide. Dioxins in stack gases measured between 2001 and 2003 suggest that air emissions tend to be in the lower end of this range.

The two kilns using wet technology reported to TRI dioxin releases to air of 0.14 g TEQ in 2004. This also agrees with the lower end of our estimates and suggests that this might not be a big concern for the region. We assume that stack tests are more representative of actual conditions in these facilities. Furthermore, these tests agree with TRI reports and estimates based on EPA EFs, which were developed based on US data. Therefore, emissions based on UNEP factors will not be taken into account in the range of dioxin emissions from cement kilns in the region.

Ashes would contribute a negligible amount. In addition, amounts released to the environment depend on ash management practices, including whether a large fraction of ashes is reintroduced to the kiln and whether best management practices are in place to minimize ash releases during transfer and storage operations.

## Measures to prevent and minimize releases from cement production

Different measures have been implemented nationwide to prevent or reduce dioxin emissions from

**Table Ap.C. 14. Emissions from clinker production in NY, by facility**

| | | | | **Emissions (g TEQ/yr)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Production (T)** | | **EPA‡** | | **UNEP§** | | **NYS DEC¶** | **TRI 2004#** |
| **County** | **Technol.** | **Clinker†** | **Ash*** | **Air** | **Ash** | **Air** | **Ash** | **Air** | **Air** |
| Warren | dry | 600,000 | 36,000 | 0.16 | <0.001 | 0.03 | <0.001 | 0.01 | Not reported |
| Albany | wet | 1,600,000 | 171,200 | 0.43 | 0.001 | 1–8 | 0.02–0.17 | 0.29 | 0.11 |
| Greene | wet | 591,026 | 63,240 | 0.16 | <0.001 | 0.4–3 | <0.01–0.06 | 0.01 | 0.03 |
| **Total** | | **2,791,026** | **270,440** | **0.75** | **0.001** | **1–11** | **0.02–0.23** | **0.32** | **0.14** |

† Sources: Warren County: Donna Malone, Quality Manager, Glens Falls Lehigh Cement. Personal communication, May 31, 2005. Albany County: Jeff Brenchley, Environmental Coordinator, Lafarge Ravena Plant. Personal communication, June 7, 2005. Greene County: Nicole Jarry, Director, Corporate Communications, St. Lawrence Cement Company. Personal communication, May 4, 2005.

*Ash production rates: 10.7 and 6% of clinker production for wet and dry technologies not burning hazardous wastes, respectively [30].

‡ EF for kilns not burning hazardous wastes: 0.27 ng/kg clinker for air releases and 0.003 ng/kg ash for ashes [300,334].

§ EFs are as follows: Dry technology, 0.05 ng/kg clinker (air) and 0.003 ng/kg ash (ash) [350]. Wet technology, air emissions, 0.6 and 5 ng/kg clinker for ESP operating at 200–300°C and >300°C, respectively [350]. Wet technology, ash concentrations: 0.1 and 1 ng/kg ash, regardless of ESP temperature [350].

¶ Measurements from stack tests performed in 2001, 2002, and 2003 for the plants in Warren, Greene, and Albany counties, respectively. Data provided by Thomas Gentile, Chief, Air Toxics Section, Division of Air Resources, NYS DEC. Personal communication, May 24, 2005.

# The TEQ amounts were calculated using the congener distribution provided by the facilities.

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[495] Data provided by the Portland Cement Association, U.S. Cement Plant Directory 2002, and by Hendrik G. van Oss, Cement Specialist, U.S. Geological Survey. Personal communication, March 3, 2005.

[496] Data from NYS DEC Title V Permits [203] and confirmed by the plants (Donna Malone, Quality Manager, Glens Falls Lehigh Cement, personal communication, May 31 2005; Jeff Brenchley, Lafarge Ravena Plant, Environmental Coordinator, personal communication, June 7, 2005).

[497] Nicole Jarry, Director, Corporate Communications, St. Lawrence Cement. Personal communication, February 24, 2006.

[498] There has been a period of public comment, and NYS DEC has recently published a "Responsiveness Summary" [216]. Based on studies and stack tests at other kilns and risk analysis, the agency considers that use of TDF by this facility will not have an adverse impact on emissions and the population. If the plant starts burning tires, it will have to demonstrate through testing that its dioxin (and other) emissions do not exceed regulatory limits [216].

cement kilns burning hazardous waste. They range from stopping the use of toxic waste as combustion fuel to installing air pollution control devices (APCDs) to control emissions. For example, three Texas cities have banned the use of cement made at waste-burning cement plants in their municipal projects [51].

Many cement kiln facilities are now applying APCDs to reduce emissions. In 2002, after settling a lawsuit challenging previous proposed standards, the U.S. EPA established maximum available control technology (MACT) emission standards for cement kilns, whether or not they burn hazardous wastes [30]. Additional information on these standards is available at *http://www.nyas.org/programs/harbor.asp.*

### Recommendation

Test the effect of fuel supplements, including tires (both chipped and whole), on dioxin and other toxic emissions before allowing their use by kilns.

## Paper and Pulp Production

Paper is typically produced from wood cellulose fibers. The lignin, which binds wood fibers together, has to be removed from the wood through pulping, which involves debarking, chipping, digesting, and bleaching. Nonintegrated mills perform pulping, while integrated mills also engage in paper-making operations. Pulping is usually done chemically (sulfite or Kraft processes), although it can also be achieved mechanically.[499] The fibrous mass (pulp) resulting from pulping is light to dark brown depending on the process and can subsequently be bleached for applications that require white material [350]. Paper brightness is often regarded as an indication of its quality, both by producers and consumers [117]. There are several possible bleaching agents. The main ones are [123]:

- Elemental chlorine (EC): Uses chlorine gas ($Cl_2$); known to form the largest amounts of dioxins and furans in wastewaters. The fibers used to produce the paper can be either virgin or recycled.
- Elemental chlorine free (ECF): Uses chlorine derivatives such as chlorine dioxide instead of $Cl_2$. Dioxin formation is reduced but not eliminated. Fibers can also be virgin or recycled.
- Total chlorine free (TCF): The delignification step uses oxygen ahead of the bleach plant, and bleaching is achieved with hydrogen peroxide or ozone. This designation is applied only to paper manufactured with virgin fibers because the bleaching process originally used for the recycled paper is typically unknown. This technology costs the same as the most advanced ECF, with better results [36].
- Processed chlorine free (PCF): This designation typically refers to processing of recycled fibers,[500] whereby bleaching is free of chlorine. If virgin fibers are used, these must come from a TCF process.

When using chlorine-based agents, bleaching results in a complex mixture of chlorinated organic compounds including dioxins, chlorinated phenols, chlorinated PAHs, and chlorinated lignin. The environmental and human impacts of many of these compounds remain unknown. When using elemental chlorine, ~4 kg of chlorinated organics are generated per T of pulp produced. Given the myriad of chlorinated compounds found in paper pulp effluents, a simple analysis is typically performed, which measures adsorbable organic halogens (AOX)[501] without distinguishing among different compounds [117]. During bleaching with chlorine and derived chemicals, lignin chlorination is the likely source of dioxins, which are found in the bleached pulp (and subsequently in the paper products), sludge, and wastewater effluents.

In the US, since 1988, the pulp and paper industry has been implementing changes in their processes. In 1998, the cluster rules were promulgated, which established limits and guidelines for releases to air and water from paper and pulp mills (details at *http://www.nyas.org/programs/harbor.asp*). It has been estimated that implementation of the cluster rules would result in 96% reduction in dioxins in wastewater discharges and 96% reduction in dioxins in sludge [303]. U.S. EPA is performing a detailed study to determine whether the existing effluent guidelines should be changed.[502]

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[499] The sulfite process involves an acidic cooking liquor process with aqueous sulfur dioxide ($SO_2$) and a base. This process requires high-quality fibers, while the products are of lower tensile strength. It is more frequently used for soft wood [350]. The Kraft or sulfate process is an alkaline cooking liquor process and is the dominating pulping process worldwide. It uses a sodium-based alkaline pulping solution (liquor) consisting of sodium sulfide ($Na_2S$) and sodium hydroxide (NaOH). It is applicable to all kinds of woods/fibers and produces cellulose of high tensile strength.

[500] The manufacturing process of recycled paper is unknown; therefore, it cannot be labeled as TCF.

[501] Chlorinated compounds are adsorbed onto activated carbon and quantified by combustion.

[502] As part of this study, EPA will check that releases are complying with regulations and will review the affordability of different technological alternatives. A preliminary report has been published in 2005 [337].

Based on available data,[503] the U.S. EPA concluded that:

- Most permits (except for at least seven)[504] were developed following cluster rules guidelines [337].
- Almost all of the mills for which data was available in the PCS database complied with cluster rules limits for 2,3,7,8 TCDD and 2,3,7,8 TCDF.
- Data for many mills were missing from the PCS database; bleach plant effluent data is not included in PCS per the U.S. EPA detailed study.
- Data reported to TRI is typically calculated based on average concentrations compiled by trade associations from several sources.[505]

Some of the actions that the U.S. EPA will pursue to complete the report include:

- Contact state staff to understand how permits that do not follow cluster rules guidelines were developed.
- Determine why data are missing for several mills.[506]

Emissions to air are expected from boilers that generate energy for the mills [350]. These boilers typically burn lignin, bark, wood chips, and black liquor (spent liquor from the Kraft process) and may also burn sludge [350]. Dioxins will also be associated with ashes resulting from fuel burning.

**Local Emissions**

There are 36 pulp and paper mills in the Watershed: 22 in NY and 14 in NJ. In combination, these mills produce ~5,500 T of products/yr and ~1,200 T/yr of recycled paper. Only two of these facilities are integrated mills that have bleaching plants. These two plus a third one are the only mills reporting dioxin emissions to TRI.

One facility in Essex County, NY (International Paper in Ticonderoga) uses Kraft pulping followed by a four-step bleaching sequence: Elemental Chlorine, caustic Extraction, caustic Extraction, chlorine Dioxide (CEED); while another in Warren County, NY (Finch Pruyn in Glens Falls) uses a sulfite ammonium-based pulping and chlorine Dioxide, caustic Extraction, chlorine Dioxide (DED) bleaching sequence.[507] Both mills are subject to 1998 cluster rules. Based on data reported in the draft dioxin inventory [334][508], a negligible amount of dioxins would be associated with pulp products, releases to water, and sludge (Table Ap.C. 15) from bleaching mills in the Watershed. The two bleaching mills in NY reported nondetectable 2,3,7,8 TCDD and 2,3,7,8 TCDF in bleach mill effluent to EPA's Permit Compliance System (PCS) in 2002.[509] In NJ, paper and pulp mills discharge to WPCFs,[510] which are in charge of writing the permits for the mills,[511] but there are no bleaching mills in this state. Releases to water, air and landfills reported to TRI by 4 paper mills in the Watershed in 2004 are shown in Table Ap.C. 15 and Table Ap.C. 16.[512]

There are also several small paper making mills that mainly buy pulp or recycled paper and make paper products and specialty papers. Although emissions from these operations were not calculated (as

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503. Data include: Permit Compliance System (PCS) database for 2005 (compiled by EPA to track status of facilities regulated under the CWA); 2002 TRI data (most recent set available at time of analysis); National Pollutant Discharge Elimination System (NPDS) permits; and information provided by trade associations for the sector (the American Forest and Paper Association [AF&PA] and National Council of the Paper Industry for Air and Stream Improvement, Inc. [NCASI] regarding the bases for releases reported to TRI.

504. EPA analyzed 73 permits (out of 78 phase I mills operating in 2004).

505. Of nine mills contacted, six calculated dioxin releases for TRI using a method developed in the *"NCASI Handbook of Chemical Specific Information for SARA (Superfund Amendments and Reauthorization Act) Section 313 Form R Reporting"* (SARA Handbook), which suggests a CDD/F concentration of 88.2 pg/L (nondetects = 0), and this is multiplied by the annual volume discharge. Two mills used monitoring data, while one combined monitoring with SARA Handbook factors [337].

506. States are responsible for entering discharge monitoring report data into PCS, while the U.S. EPA Office of Enforcement and Compliance Assurance (OECA) is responsible for maintaining PCS [337].

507. Lockwood-Posts Directory, Book 2, 2003.

508. Dioxin concentrations in effluents and residues as well as volumes generated are based on the SARA Handbook, produced by NCASI to help mills estimate their releases for reporting purposes. Emission factors in this publication are based on data compiled by NCASI from several sources, including tests by member companies [334].

509. Data provided by Betsy Bicknell, Senior Environmental Engineer, Project Manager, ERG; and Ahmar Siddiqui, U.S. EPA Headquarters. Personal communication, February 29, 2006.

510. The following POTWs receive discharges from paper and pulp mills: Passaic Valley Sewerage Commissioners, Rahway Valley Sewer Authority, Bergen County Utilities Authority, and Middlesex County Utilities Authority.

511. Joseph Mannick, Bureau of Point Source Permitting Region 2, NJ DEP. Personal communication, April 25, 2005.

512. Note that each of these facilities reports a single congener distribution and does not specify which media of release this distribution applies to. We applied the congener profile for each facility to all three media of release.

## Table Ap.C. 15. Dioxins associated with paper pulp and residues

|  | Emission factors | Activity level (2004)* | Dioxins in products and wastes (g TEQ/yr) Watershed | 2004 TRI releases (g TEQ)[‡] |
|---|---|---|---|---|
| Bleached pulp | 0.02 pg/g | 0.32 mill T/yr | 0.006 | NA |
| Water effluent | 0.49 pg/L | 2.1 MGD** | 0.001 | 0.007[§] |
| Sludge | 1.72 ng/kg | ? | 0.2[†] | 0.02[¶] |

Emission factors and US activity level from draft dioxin inventory [334].

* Provided by Betsy Bicknell, Senior Environmental Engineer, Project Manager, ERG; and Ahmar Siddiqui, U.S. EPA Headquarters. Personal communication, February 29, 2006. However, one of the mills has been operating at lower than normal production volumes.

** Million gallons per day

† Amount of sludge generated is not available. Emissions were extrapolated from US activity level (2.3 million dry T/yr) by Watershed population, adjusted by economic activity (5.8% of US).

‡ Reported by three mills in the Watershed. TEQ amounts calculated using the congener distribution provided by each of these three facilities.

§ Releases to water. ¶Dioxins landfilled.

information is not available), dioxin releases from deinking pulp mills[513] used in paper recycling, and paper-making operations are likely negligible.[514]

It is estimated that in the US, 51% of paper mill sludge is disposed of in landfills or surface impoundments, 4% is applied to land directly or after composting, and the rest is incinerated [334].

Releases to air from boilers in the Watershed were estimated from fuel consumption by the paper sector (Table Ap.C. 16). Air emissions reported to TRI (Table Ap.C. 16) were ~1 order of magnitude lower than our estimates. The amount of ash generated in these boilers is also unknown, but UNEP estimated that ashes can contain ~1 mg TEQ/kg [350].

International Paper in Ticonderoga, NY (Essex County) has submitted a plan to NYS DEC to perform a two-week trial burn to determine the feasibility of burning tires as a fuel supplement in its power boiler [272]. The boiler is currently equipped with multicyclones and a wet scrubber to control particulate matter and sulfur dioxide emissions.[515] These emission controls are not expected to be effective at controlling fine particulate matter (PM) emissions, and burning tires will likely increase these emissions.[516] If the plan is approved by NYS DEC, the mill will run the test to determine the effect of adding tire-derived fuel (TDF) on boiler operation, including stack emissions of both criteria contaminants and other pollutants (e.g., dioxins, PAHs, PCBs, and heavy metals) over baseline emissions.[517] [518]

### Measures to prevent and/or minimize emissions from pulp and paper mills

The paper and pulp sector can release dioxins to air, water, and residues throughout the production process.

Regarding emissions to air, standards for boilers in effect since November 2004[519] do not directly address dioxins, but carbon monoxide limits are intended to control dioxins and other hazardous organic pollutant (HAP) releases.[520] Energy efficiency measures at these facilities can reduce emissions to air.

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513. Paper recycling typically employs deinking to brighten the paper (although there are mechanical alternatives). There are three mills that recycle some amount of paper in the Watershed. Although some rebleaching might take place during recycling, the bleaching demand is much lower, because the paper has previously undergone bleaching. In addition, it is possible to separate nonwhite paper. As a result, most of the recycling industry has moved away from chlorine-based bleaching in favor of more innovative, nonchlorine methods, and those still using chlorine are using hypochlorite. Joseph T Swackhammer, U.S. EPA, Office of Water. Personal communication, January 9, 2006.

514. The largest amounts of dioxins are typically associated with the bleach plant effluent. The pulp itself is washed several times, and, as a result, dioxins and furans end up in the wastewater from the bleach plant. Joseph T Swackhammer, U.S. EPA, Office of Water. Personal communication, January 9, 2006.

515. James Coutant, Regional Air Pollution Control Engineer, NYS DEC Region 5. Personal communication, January 24, 2006.

516. Available literature shows that fine PM emissions are consistently increased when tires are burned. The effect of tires on other pollutants, including dioxins, is not consistent. The types of pollution control devices that work best to control fine PM are electrostatic precipitators or fabric filters. Douglas Elliott, VT Department of Environmental Conservation, Air Pollution Control Division. Personal communication, January 30, 2006.

517. James Coutant, Regional Air Pollution Control Engineer, NYS DEC Region 5. Personal communication, January 24, 2006.

518. Although the boiler is subject to NY regulations, dioxin emissions are not addressed. Following the trial burn, if it is approved, the NYS DEC will have to decide whether emissions of tested pollutants are acceptable in order to determine whether a subsequent permit will be issued to burn tires on an ongoing basis. Vermont DEC will also be involved in this review, but the permitting authority lies with the NYS DEC. Douglas Elliott, VT Department of Environmental Conservation, Air Pollution Control Division. Personal communication, January 30, 2006.

519. 40 CFR Part 63 (Available online at *http://www.epa.gov/ttn/atw/boiler/fr13se04.html.* Accessed March 29, 2005) addresses pulp and paper mills, several manufacturers, electric, gas and sanitary services, steel works and blast furnaces, and other boilers.

520. Carbon monoxide is taken as a surrogate of these emissions, since they all are the result of incomplete combustion. This assumption, however, has been objected to by some commentators. Carbon monoxide limits are set at 400 ppm, and particulate matter at 0.025–3 pounds per million British thermal units (lb/MMBtu) for new boilers and 0.07 to 0.21 lb/MMBtu for existing boilers.

## Table Ap.C. 16. Fuel consumption and air emissions from paper/pulp mill boilers

| | Fuel usage (T/yr) | | | Air emissions (g TEQ/yr)§ | | |
|---|---|---|---|---|---|---|
| **Fuel** | **US†** | **NY & NJ‡** | **Watershed‡** | **NY & NJ** | **Watershed** | **2004 TRI releases (g TEQ)¶** |
| Pulping/ black liquor | 67,627,636 | 6,424,625 | 3,922,403 | 0.4 | 0.3 | |
| Wood | 1,605,046 | 152,479 | 93,093 | 0.01 | 0.01 | |
| Wood residues/ by-products | 20,446,892 | 1,942,455 | 1,185,920 | 0.1 | 0.08 | |
| Wood/paper-related refuse | 348,923 | 33,148 | 20,238 | 0.002 | 0.001 | |
| Waste oil | NA | NA | NA | NA | NA | |
| **Total** | | **8,552,707** | **5,221,653** | **0.6** | **0.4** | **0.02** |

† Source: EIA tables on fuel consumption (year 2002) by industry sector. Data presented here includes consumption by paper, pulp, newsprint, and paperboard mills. Original data in BTU, converted to T by using approximate heat value of wood and bark of 6,500 BTU/lb [350] and of black liquor of 11 million BTU/US ton. Data and heat value for black liquor provided by Robert Adler, Survey Director, EIA. Personal communications, April 22 2005 and May 11, 2005. Tables available at *http://www.eia.doe.gov/emeu/mecs/mecs2002/table3.5.xls* and *http://www.eia.doe.gov/emeu/mecs/mecs2002/table3.6.xls*. Waste oil consumption withheld by EIA to avoid disclosing data for individual establishments.

‡ Extrapolated assuming NY and NJ represent 9.5% of US consumption (based on population), and Watershed represents 5.8% of US consumption (population, adjusted by economic activity).

§ Assuming EF of 0.07 μg/T fuel for boilers burning black liquor, sludge, and wood (UNEP Toolkit) [350].

¶ Releases to air (fuel not specified) reported by three mills in the Watershed. TEQ amounts calculated using congener distribution provided by each of these three facilities.

The pulp and paper cluster rule establishes standards for this source, including effluent standards for dioxins for pulp mills using bleaching processes with Kraft and soda, or sulfite processes [10]. Dioxin releases to water, sludge, and products can be prevented by substitution of the bleaching agent, for example, from elemental chlorine (EC) or elemental chlorine free (ECF) (which still generates some dioxins) to chlorine-free agents (TCF). The switch to ECF and TCF is tied to demand for TCF paper, which is more expensive [36]. Recycled paper contains less lignin (because it has already undergone delignification) and therefore requires less bleaching. The cost difference between ECF and TCF is only that of bleaching, which could be twice as much for TCF; but TCF also allows for recycling of cheaper paper, which can compensate for the bleaching costs [36]. Expansion of markets for TCF paper is key to the widespread switch to TCF processes.

Specific recommendations include:[521]

- Ensure compliance with federal rules requiring air and water pollution reductions.
- Encourage energy conservation and efficiency measures at pulp and paper mills.
- Switch to total chlorine-free (TCF) processes, or evaluate the cost and benefits of substituting TCF for ECF bleaching agents adding oxygen delignification in addition to ECF bleaching.
- Support the development of markets for chlorine-free paper products.
- Encourage the purchase of alternative, chlorine-free paper, including by local and state government agencies.

## Chlorine and Chlorinated Chemicals

The manufacture of chlorine and certain chlorinated chemicals (mostly organic) can generate and release dioxins. In addition, several of these products contain dioxins as impurities. As a result, further releases may occur during their use and disposal.

### PCP-Treated Wood

Pentachlorophenol (PCP) is a chlorinated chemical that has been used as a biocide since 1930, (e.g., in paper production or to treat wood) [334]. PCP is moderately persistent and bioaccumulative, it is toxic, and it has been classified as a B2 probable human carcinogen by the U.S. EPA Integrated Risk Information System (IRIS).[522] It is always contaminated with relatively high levels of dioxins, which are by-products of its production. Before 1987, concentrations were

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[521] These recommendations reflect those put forward by other states, such as New Hampshire and the Great Lakes states [168].

[522] Based on inadequate human data and sufficient evidence of carcinogenicity in animals [295].

~4.1 mg TEQ/kg technical grade PCP; since then they have been reduced to ~0.8 mg TEQ/kg PCP [71].

Since 1987, the only approved use of PCP is as a wood preservative for outdoor applications [334], and most of it (~93%) is used to treat utility poles (creosote and arsenates are alternative treatments) [86]. Wood is treated with PCP by injecting it under pressure, but PCP does not bind to or react with wood.

Releases of dioxins (and PCP) can occur during PCP production, wood treatment processes, and use and disposal of treated wood (especially if this wood is burned). Many Superfund sites have resulted from poor operation at wood treatment plants. There are no wood treatment plants currently operating in NY or NJ. Utility poles are typically used for 40–50 years [86] and represent a stock of dioxins that has the potential to be slowly released to the environment during use, and to eventually end up in the waste stream.

The magnitude of dioxin releases to air and surrounding soil and groundwater during use of PCP-treated wood remains a subject of debate.[523] PCP-treated wood was used in barns prior to the 1980s [34], where animals could be exposed by licking, chewing, or rubbing against the wood [101]. This resulted in some cases of food contamination that led to the removal of the wood [34]. Currently, PCP cannot be used in farms, and it is likely that little PCP-treated wood remains in these settings. Although a 2002 paper identified PCP-treated wood as one of the major sources of dioxins to cattle, other assessments point at animal feed as the main source [34] (see section on Food and Animal Feed).

Currently, the biggest concern is the fate of this wood at the end of life. Treated wood is not considered a hazardous waste; therefore, it can be disposed of in municipal solid waste landfills. Poles taken out of service, if in relatively good condition, can be sold or given to secondary users; otherwise they are landfilled.[524] These poles can be reused in outdoor structures or as soil containers for plants [279]. A consumer information sheet is provided when poles are transferred to individuals, warning about the toxic nature of the wood, precautions needed, and instructions on disposal (as solid waste).[525] A survey by the *Utility Solid Waste Activities Group* (USWAG) indicated that the reuse of treated wood is common in the US (~65% of utility poles taken out of service are sold or donated to the public, 27% are landfilled, and <2% are incinerated or used for energy recovery)[526] [98,99].[527] However, if the toxicity characteristic leaching procedure (TCLP) test for PCP exceeds 100 mg/L, this wood should be handled as hazardous waste. In this case, it should be either disposed of in an RCRA landfill or burned in an approved incinerator [279].[528] Military installations have large stocks of PCP-treated wood—used as ammunition containers—and dispose of it by either sending it to landfills or shredding and composting it for use as mulch [279].

### Local Estimates

The U.S. EPA estimates that approximately 400,000 metric tons (T) of technical grade pentachlorophenol (PCP) were used in the US between 1970 and 1995 to treat wood [334]. During this period, approximately 36,000 g TEQ dioxins were incorporated annually in treated wood until 1987, and since then approximately 8,400 g TEQ per year for the new formulation [334]. The EPA estimates that 7,325 T of PCP were used in the US in 2000 [334]. Another estimate is given by 1997 data: ~7,800 T of PCP.[529] Extrapolating to the Watershed, 176 T of PCP (containing 148 g TEQ dioxins) would be used annually in the region.[530]

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[523] A study conducted to examine the potential for dioxin release from pentachlorophenol (PCP)-treated utility poles found that the dioxin concentrations were consistently higher in the outer portions of the poles than in the center [140]. Although this may suggest that PCP did not penetrate the wood during treatment, this trend tends to be most marked in older poles and for the lower chlorinated congeners and may be indicative of migration within the poles, which may result in some environmental releases [140]. Another study found dioxins in farm and railway ditch water that were close to utility poles, while dioxins were nondetectable in samples from a control site [356]. This study found that dioxin concentrations were much higher in water adjacent to utility poles (13,142 ng/L) than downstream (4,880 ng/L) or upstream from the utility poles (2.72 ng/L), leading the authors to conclude that utility poles and railway ties are a source of dioxins to surrounding sediments and water. Although the volatility of dioxins from PCP-treated wood is low, it is speculated that volatilized PCP could undergo photochemical transformations in the environment, yielding dioxins. A laboratory experiment has found that ultraviolet (UV) light transforms PCP in soils into mostly octa-CDD and some hexa-CDD [136].

[524] Such as to employees or individuals (including farmers) on whose properties the poles were located. Jim Roewer, Executive Director, Utility Solid Waste Activities Group (USWAG). Personal communication, May 11, 2005.

[525] This wood should not be used in places close to animal or food production. Ibid.

[526] The remainder is reused by utilities, given or sold to employees, or burned for fuel recovery.

[527] Con Edison landfills all retired poles. David Roche, Senior Scientist, EH&S, Consolidated Edison of New York. Personal communication, September 27, 2005.

[528] In-service PCP-treated wood would normally not exceed that concentration. David Roche, Senior Scientist, EH&S, Consolidated Edison of New York. Personal communication, March 16, 2006.

[529] In 1997, ~8,300 T of PCP were produced in the country, of which ~500 T were exported to Canada. Herbert Estreicher, Keller and Heckman LLP. Personal communication, April 26 2005. Original source of the information: International Agency for Research on Cancer (IARC) Monographs Volume 71, p.772 referencing a communication from the Penta Task Force.

[530] Watershed values were extrapolated by percentage of poles within the Watershed (~ 2%) [220]. Dioxins in PCP: 0.84 g TEQ/T [71].

### Table Ap.C. 17. Dioxin stock and releases associated with PCP-treated utility poles

| Number of poles & PCP content | Total NY & NJ | Watershed§ | Units |
|---|---|---|---|
| Utility poles (all types) (2005) [86,220] | 5,065,220 | 2,599,714 | poles |
| PCP utility poles in service (2005)* | 2,279,349 | 1,169,871 | poles |
| Tons of PCP in utility poles† | 12,217 | 6,271 | T |
| Dioxins in poles in use† | 37,715 | 19,357 | g TEQ |
| Dioxins released to air during use‡ | 0.6 | 0.3 | g TEQ/yr |
| Dioxins released to soil during use‡ | 3.0 | 1.5 | g TEQ/yr |
| Total dioxin release during use | 3.5 | 1.8 | g TEQ/yr |
| Dioxins in poles taken out of service per year** | 940 | 483 | g TEQ/yr |
| **Total dioxin release after disposal (burning)** | **<0.08¥** | **<0.04¥** | **g TEQ/yr** |

* In 1995, ~45% of utility poles in the US were treated with PCP, 42% with inorganic arsenicals, and 13% with creosote [86]. It was assumed that these data are representative of the local scenario. A phone survey of local utilities, conducted by the Harbor Project, indicated that 57% of them are currently replacing their poles with creosote.[531]

† Pole volume: 0.67 $m^3$; wood contains 8 kg $PCP/m^3$ [72]. Dioxin content in PCP: 4.05 and 0.84 mg TEQ/kg PCP for PCP manufactured before and after 1987, respectively [71]. It was assumed that 30% of the poles contain post-1987 PCP formulation and the remaining 70% contains pre-1987 formulation [72].

‡ EFs to air: $7.8 \times 10^{-9}$ and $3.5 \times 10^{-7}$ g TEQ/pole/yr for post- and pre-1987 PCP formulation, respectively [71]. EFs to soil: $1.3 \times 10^{-6}$ g TEQ/pole/yr for both formulations [71].

§ Utilities servicing the Watershed possess ~51% of all the poles in NY and NJ [220].

** Approximately 1.9% of poles in use [72].

¥ Assuming that 50% of the poles retired yearly are given out to individuals for reuse and that between 1% and 5% are burned. Retired poles are trimmed and weigh ~0.5 T/pole. EF for C&D wood waste was applied: 173 µg TEQ/T wood [126] (worst-case scenario).

The estimated amount of dioxins in PCP-treated poles currently in service in our region, and associated releases during use, are based on the number of utility poles in use in 2005 [220]. These numbers are summarized in Table Ap.C. 17.

While emissions to air and soil during use are relatively small, the amount of dioxins associated with poles taken out of service each year in the Watershed can be very large (Table Ap.C. 17). However, these dioxins have a low potential to reach the Harbor.[532] One concern regarding the reuse of poles is that people may ignore the instructions and may use or dispose of them improperly, including burning them, for instance, in outdoor wood boilers (see Appendix C, Other Combustion Sources), burn barrels, or piles. However, even assuming the highest EFs for wood burning (the higher EFs available for C&D wood waste), this activity would represent a negligible amount of dioxins released to air (Table Ap.C. 17). Therefore, these emissions were not considered in this inventory.

## Measures to prevent or reduce dioxin emissions associated with PCP-treated wood poles

Most types of wood are susceptible to degradation when exposed to the environment. Wood preservatives are pesticides applied to wood to increase its resistance to decay. The most common ones are described in the Table Ap.C. 18.[533]

There are limited studies of preservative releases from wood during use. In general, increases in PCP and creosote have been measured in soil and water in contact with treated wood [282]. Some adverse effects to biota were noticed only close to the treated wood, although researchers tended not to link these effects directly to the chemicals [282].

Chromated copper arsenate (CCA) is widely used in the US [127], although it was phased out in 2003 for residential use [291]. Some utilities are replacing PCP-treated utility poles with CCA. Elevated arsenic concentrations compared to background concentrations and regulatory levels have been found in soil

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531. Consolidated Edison of New York (Con Ed), servicing New York City and Westchester, estimates that it has ~210,000 poles in service and a similar number of cross arms, but the proportion of PCP-treated wood is not available. Prior to 1975, only creosote-treated wood was purchased, but these poles would have been mostly replaced by now or are nearing the end of their life span. From 1975 until 1995, the company has used PCP. Since 1996, only wood treated with chromated copper arsenate (CCA) has been purchased for new service and replacements. David Roche, Senior Scientist, EH&S, Consolidated Edison of New York. Personal communication, September 27, 2005.

532. Approximately half of the retired poles are landfilled. In order to reach the Harbor, dioxins need to be released from the wood into landfill leachate. These will be slow processes, with a low impact to the Harbor.

533. Others include: (1) oilborne: copper naphthenate, chlorothalonil (CTL), chlorothalonil/chlorpyrifos (CTL/CPF), oxine copper (copper-8-quinolinolate), and zinc naphthenate; (2) waterborne: ammoniacal copper zinc arsenate (ACZA), ammoniacal copper citrate (CC), alkaline copper quaternary compounds (ACQ), copper azole (CBA), and copper dimethyldithiocarbamate (CDDC).

and groundwater around treated wood [119]. A recent study found that approximately 5% of the arsenic leaches from CCA-treated decks per year, and up to 40% throughout the useful life [119]. This arsenic is found in runoff and rainwater that infiltrates the soil [119]. This is of particular concern given the large amounts of CCA in treated wood.[534] Although CCA contains arsenic V, soil microorganisms can convert it to arsenic III, which is more soluble and mobile, increasing the potential to reach groundwater. Other studies have also found elevated levels of chromium and copper around CCA-treated wood [127]. At the end of its life, treated wood can be disposed of as solid waste and some will find its way to construction and demolition (C&D) landfills, which typically have less stringent requirements for liners, and CCA could potentially continue to leach to groundwater.[535]

Wood utility poles have many advantages, including: (1) storage and shipping: wood poles can be piled with no protection (concrete, fiberglass, and steel poles require keeping poles separated during storage and more careful handling to avoid breakage); (2) ease of installation: stronger tools are needed to drill materials other than wood; (3) maintenance: workers can easily climb wood poles using gaffs or hooks, while other types of poles need steps or ladders [359]. These advantages, however, must be weighed against the dangers posed to humans and the environment throughout the poles' life cycle. Nonchemical and nonwood alternatives should be carefully considered. Table Ap.C. 19 summarizes some of these alternatives.

The cost (including installation) of poles made of alternative materials tends to be higher, especially for fiberglass; but the poles last longer and require less or no maintenance [86]. These alternatives could be economically viable and could possibly become more cost competitive if the demand increased. Nevertheless, the environmental impacts of alternative materials should be weighed against PCP (and other wood preservatives) throughout production, wood treatment, storage, use, and disposal. The cost of burying lines underground is substantially higher, and this option is feasible only in areas with very high population density.

Recommendations to avoid the use of treated poles:

- Evaluate the overall advantages (life cycle costs and risks) of using alternative materials to PCP and other chemicals in the production of telephone or electricity poles, such as steel, reinforced concrete, fiberglass, artificial wood, and naturally resistant types of wood.[536]
- Determine the feasibility and environmental impacts of using buried or underground conduits for electrical and communication transmission applications.

**Table Ap.C. 18. Characteristics of common wood preservatives**

| Preservative | Common uses | Pros | Cons |
|---|---|---|---|
| PCP (typically 5% solution in petroleum-based solvents) | Poles (can be used for bridge and mine ties, timber, and lumber) | Effective against wide variety of organisms (fungi, mold, insects) | High toxicity. Not for use if contact by humans, animals or plants is likely. Ineffective against marine borers. |
| Creosote (complex mixture, mostly PAHs) | Heavy timbers, poles, piles, railroad ties | Effective, persistent (low solubility and volatility), easy to apply, low cost | Bad appearance, cannot be painted, vapors harmful to plants, workers must avoid exposure |
| CCA (chromated copper arsenate: water-based solution of Cr, Cu and As oxides)* | | Wood is clean, paintable, and odorless. Effective against marine borers. | Toxicity requires precautions when using and handling wood. |
| Borates (water solutions of boron salts) | | Effective against fungi and insects | Is water soluble and can leach out of wood |

Source: USDA [282].

* Other forms of chromium (Cr), copper (Cu), and arsenic (As) can be used.

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[534] Above-ground applications, utility poles, and marine pilings contain ~4, 10, and 40 kg CCA/m$^3$, respectively [119].

[535] In our region, these landfills are required to have at least a single composite liner with a leachate collection and removal system.

[536] A consulting firm prepared a report for the USWAG and determined that wood poles are more energy efficient than other alternatives. However, this study did not include other impacts during their life cycle such as toxicity.

## Table Ap.C. 19. Alternatives to wood preservatives

| Material/description | Advantages | Disadvantages |
|---|---|---|
| Redwood (e.g., cedar and cypress) | Natural resistance to decay and insects, aesthetics, never needs sealing or staining, easier to saw and nail | Expensive, surfaces are soft (susceptible to denting and scratching), susceptible to moisture |
| Exotic hardwood (e.g., mahogany and ironwoods) | Durable, natural resistance to decay and insects, never needs sealing or staining, aesthetics, virtually knot free, impervious to water | More expensive, difficult workability (requires predrilling for fasteners), environmental concerns (i.e., depleting supplies) |
| Steel<br>Poles are galvanized or coated with a sealant | Longer life (~80 yr), strength, can be recycled, reduced risk of fires, better appearance, lower installation and maintenance costs. | Energy use and pollution associated with steel production/recycling.<br>Higher initial cost.† |
| Concrete<br>Steel reinforcement | Longer life (80–100 yr), reduced risk of fires, better appearance | Energy use and pollution during cement production. Higher initial and install. costs. Heavier. |
| Fiberglass reinforced composite | Up to 80 yr life, low maintenance, lighter than wood | Higher costs. Resins needed to prevent UV degradation |

Sources: U.S. EPA and National Coalition Against the Misuse of Pesticides [86,291].

† The overall cost is comparable because of strength and lower installation and maintenance costs.[537]

### Polyvinyl Chloride (PVC)

This sector was developed in the Technical Report. Complementary information regarding environmental issues (other than dioxins) associated with the production, use, and disposal of PVC are presented here.

PVC production involves several steps. Chlorine gas ($Cl_2$) is produced at chloralkali facilities and is used to chlorinate ethylene (purified from petroleum or natural gas), resulting in ethylene dichloride (EDC). EDC is later converted to vinyl chloride monomer (VCM), which is then polymerized into raw PVC resin. Finally, the resin is combined with additives and shaped into the final products.

Chlorine itself is a hazardous, corrosive gas posing danger in the event of an accident during production or transportation, as proven by recent events.[538] Chlorine is produced by electrolysis of sodium chloride (table salt), one of the most energy-intensive industrial processes, contributing to all environmental impacts associated with energy generation.[539] Although other methods are available, ~10% of chlorine is still manufactured using mercury cells [257]. Recent yearly mercury releases reported to TRI were ~15 T [257]. However, larger amounts are "consumed" during manufacturing and purchased by these facilities. These unexplained gaps suggest that actual releases might be up to over 100 T/yr [257].[540] PVC is the single largest consumer of chlorine, using ~40% of all production [222], and is estimated to consume 20% of the chlorine manufactured in mercury cells [257], being directly responsible for ~3–26 T of mercury releases/yr. In addition, $Cl_2$ is very unstable and readily reacts with any organic contaminants that may be present during the process, to form organochlorines, including dioxins.[541]

VCM is a known human carcinogen, while EDC is a suspected carcinogen [26]. These intermediates pose a serious health hazard to workers and people living close to the production facilities. VCM is a gas, and it is often burned in production plants as a way of reducing its emissions to air. This incineration process increases emissions of dioxins during production.

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[537] PowerPoint presentation by the American Iron and Steel Institute: Technical Session Steel Distribution Poles—The Material of the Future: The Steel Pole Advantage. Posted online at *http://www.steel.org/AM/ Template.cfm?Section=Case_Studies&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=4842*

[538] Two of the most recent such accidents took place in January 2005, when a tanker car broke in South Carolina and in mid-2004 when another tanker derailed in Texas. Both accidents killed several people, sickened a larger group, and required evacuating nearby communities. Chlorine gas has been used as a chemical weapon, but this use was banned after World War I [258]. It is argued that many of the steps of PVC production as well as the transportation of raw materials are a potential threat to national security [258].

[539] Including generation of greenhouse gases, air pollution, acid rain, mercury emissions, generation of radioactive and other wastes [268].

[540] For comparison, coal-burning utilities reported mercury releases of ~50T/yr the same year.

[541] Graphite electrodes were found to produce large amounts of these chlorinated substances and were replaced by titanium ones. However, impurities (from plastic pipes and valves) still result in some organochlorine generation [268].

PVC plastics require a significant amount of additives because raw PVC resin is very brittle and degrades easily. Phthalates are plasticizers added to soften PVC, giving it useful mechanical properties, while toxic heavy metals such as cadmium and lead are added to minimize PVC degradation by sunlight or heat.[542] Other additives include organotins, flame retardants (chlorinated or brominated organic compounds), and antimony. Phthalates and other compounds volatilize from the plastic throughout its life and are responsible for the "new smell" of cars and shower curtains. Phthalates associated with PVC have been detected in dust in cars and homes [96,239][543] and are known to leach from PVC products—for instance, from IV bags and tubing—into the fluids they contain, as proven by the elevated levels of phthalates that have been found in the blood of premature babies kept in intensive care.[544] Phthalates are carcinogenic and teratogenic, toxic to the testes, and affect development and reproduction in rodents [15]. Recent data suggests that prenatal exposure to phthalate at environmental levels can adversely affect male reproductive development in humans [261]. Metals also leach from the plastic. Organotins, which were introduced to replace metals used as stabilizers, have also been shown to leach and are also toxic. Landfilled PVC residues may leach these toxic additives, and the risk is greater for construction and demolition landfills, which have less stringent requirements for liners than MSW landfills do. In certain applications, PVC is combined with other materials that pose additional hazards. For instance, vinyl floors are made of a copolymer of vinyl chloride and vinyl acetate (which is explosive and carcinogenic).[545]

It is extremely difficult to recycle PVC into products of similar quality to the original because each application requires different kinds and amounts of additives. As a result, only 0.1–3% or PVC is recycled [26], and most of it is preconsumer waste. Alternatively, postconsumer PVC may be "down-cycled" into products of lower quality [268]. The main problem with down-cycling is that it does not decrease the need for virgin PVC production. Moreover, it extends PVC use into applications where it was not present before, such as fence posts and speed bumps [268].

## Chlorinated Pesticides and Herbicides

Certain organochlorine pesticides and herbicides may be contaminated with dioxins as a result of the manufacturing process [350]. Releases to the environment can result from the production, use, and disposal of these products. Many of these substances, such as DDT (dichlorodiphenyltrichloroethane, a pesticide), have been banned in the US, but others are still being used. For instance, 2,4-dichlorophenoxyacetic acid (2,4-D) is one of the 10 most used herbicides in the US, as an active ingredient in many common formulations, including weed killers [168]. It has been estimated that ~26,000 T of 2,4-D have been used in the US in 2001.

### Local Estimates of Dioxins in 2,4-D

Estimates of dioxins associated with 2,4-D applied to land within the Watershed yearly suggests that dioxin loads are relatively low in any given year (Table Ap.C. 20). However, this is a rough estimate because local usage was extrapolated from US data. Nationwide, over half the pesticide use was agriculture related (Table Ap.C. 20), while most pesticide use in NY and NJ takes place in urban and suburban settings [66-68,101]. We tried to account for these differences (see captions for Table Ap.C. 20). Although some data on 2,4-D use are available for NJ (at least 50 T/yr were used recently for some applications),[546] the same level of detail is not readily obtainable for NY.[547]

Although this is a minor source to the Harbor itself, its local impacts may be relevant. Workers applying the herbicide might be exposed to high levels.[548] Furthermore, repeated applications may pose a cumulative impact. Pesticides and herbicides, including 2,4-D, are carried inside homes by pets and people walking through areas where these chemicals have

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[542] PVC accounts for ~90% of all phthalate applications in the US. PVC contributes ~95% of the phthalates found in waste, ~10% of the cadmium, and ~1–30% of the lead [26].

[543] Dust is also a significant source of exposure to brominated flame retardants, especially in toddlers [252,363].

[544] "Environmental Toxicants and Neuro-Developmental Impairment in Inner City Children." Presentation by Mary S. Wolff, Mount Sinai School of Medicine at US EPA Region 2 Science Day. November 18, 2004.

[545] On April 2004 an explosion and fire took place in a PVC flooring factory in Illinois, affecting a nearby community [258] and posing immediate and long-term risks to workers, firefighters, and the population at large.

[546] Data includes uses in agriculture, golf courses, and lawns in 2000, 2002, and 1998, respectively [184-186].

[547] Data available for NY is reported in volume or weight of final product sold—i.e., it includes the active ingredient (2,4-D) plus any inert substances (e.g., the vehicle and emulsifiers). Translating this data into active ingredients requires identifying each of the commercial names of products that contain 2,4-D and their active ingredient concentrations, and then locating those products in extensive NYS DEC Pesticide Sales and Applications databases that are not straightforward to use.

[548] A study found elevated levels of 2,3,7,8 TCDD (77 ppt, lipid basis, which is >10 times the median concentration in the US population) in fat in a worker that used to apply 2,4-D, measured fives years after the last exposure [270].

## Table Ap.C. 20. Dioxins applied to land with 2,4-D

| | 2,4-D use (T/yr) | | | |
|---|---|---|---|---|
| | Agriculture | Industrial/ commercial/ government | Home/garden | Dioxins in applied 2,4-D (g TEQ/yr)* |
| US [329] | 13,835 | 7,711 | 4,309 | 18.1 |
| **Watershed** | **11†** | **447‡** | **250‡** | **0.5** |

* Assuming a concentration of dioxins of 700 µg/T of 2,4-D [350].

† NJ: 0.7 T used within the Watershed in 2000 (this represents 12% of all 2,4-D used in NJ) [185]. NY: Based on 1997 data, we assumed that 0.6% of US 2,4-D consumption for agriculture was used in NY [162], and 12% of this (as in NJ [185]) was assumed to be used within the Watershed (i.e., 10 T 2,4-D).

‡ Extrapolated by Watershed population, adjusted for economic activity (5.8%).

been applied, increasing exposure levels by a factor of 10 compared to pre-application levels [177].

Recommendations include:

- Require reporting of pesticide use (active ingredient) in a user-friendly format, similar to that available for NJ.
- Ensure proper use, storage, and disposal of pesticides to prevent accidental releases.
- Promote alternatives to chemical pesticides, such as an integrated pest management (IPM) approach.

### Dyes and Pigments

About 40% of textile dyes and pigments are chlorinated or brominated organic compounds. The synthetic processes are complex and can result in formation of dioxins [18]. Further dioxins are generated during dyeing of textiles [18]. This may be explained by the high temperatures and alkaline conditions during dyeing. The homologue pattern of dioxins in dyes is similar to that found in laundry and domestic wastewater, sewage sludge, dry cleaning residues, and certain textile samples [18], which indicates that there is a correlation between dyed textiles and dioxins in wastewater. Many printing inks can also be contaminated with dioxins. Some of the pigments and dyes are used for lacquers and to color polymers [350].

Releases to the environment can be expected from production process effluents as well as from the use of the pigments, inks, and dyes and the use (including washing of textiles), disposal, or recycling of the products. At least part of these dioxins will find their way to POTWs in industrial discharges from producers, users, recyclers (e.g., paper recyclers), and domestic wastewater. End products (e.g., textiles, plastics) will eventually end up in a landfill or incinerator, or enter the recycling loop. In the Watershed, there are 22 facilities manufacturing synthetic organic dyes and pigments (2 in NY and 22 in NJ) [219]. Unfortunately, there are not enough measurements of dioxins in pigments, emission factors for the different sectors involved, or rates of release from products to estimate the contribution of this source to the Harbor.

### Chlorophenols

Chlorophenols are a group of pesticides or intermediates for other pesticides and chemicals. Dioxins and furans can be formed by condensation of chlorophenols and other impurities. In general, the higher the chlorination degree, the higher the dioxin and furan concentrations. Since the late 1980s only 2,4-dichlorophenol (2,4-D, a herbicide) and pentachlorophenol (PCP, a wood preservative) are still being produced in the US. Today, there is only one facility producing PCP in the US (in AL), and there are no wood treatment facilities using PCP within NY and NJ. Dioxins and furans associated with PCP-treated wood and 2,4-D were addressed above.

### Chlorobenzenes

Chlorobenzenes have been produced as raw materials for phenols, anilines, and pesticides. Manufacturing methods for phenols and anilines have changed, and many chlorinated pesticides have been banned. As a result, production of chlorobenzenes has been declining. The method currently used in the US does not create the necessary conditions for dioxin and furan generation. In addition, the two main products are mono- and dichlorobenzene, which, according to the limited available information, are not contaminated with dioxins and furans. Therefore, this is not considered to be a significant source.

### Chlorine

The chloralkali process is used to produce chlorine gas and caustic soda. There are three methods currently employed: diaphragm, membrane, and mercury cells. Until the late 1970s, the main method of producing chlorine involved the electrolysis of brine using mercury cells with graphite electrodes. High amounts of furans have been found in graphite electrode sludge from European facilities, most likely associated with the chlorination of aromatic compounds in the coal tar used for binding. Graphite electrodes have been replaced with titanium, and it is currently thought that no US facility uses graphite. Nevertheless, when using titanium electrodes, furans were still detected in sludge at similar levels to those observed with graphite. It has been speculated that furans result from the chlorination of PAHs from the rubber linings of the mercury cell or from impurities from plastic pipes and valves [268]. Furans from chlorine production are associated with residues or sludges. There is not enough information to calculate an emission factor.

There was one chloralkali plant in the Watershed in NJ (Hudson County) listed in the 2001 Census, but not in 2002.[549] This facility did not use mercury, and as noted before, it is believed that US facilities do not use graphite electrodes; therefore, the potential for dioxin formation is low.

### Inorganic Chlorine Products

There are limited dioxin measurements of the products that are derived from chlorine (e.g., bleach and hydrochloric acid). Available data suggests that bleach contains very low, if any, dioxins and furans. One sample showed a concentration of 4.9 pg TEQ/L. Chloride salts might contain hepta- and octa-CDF in the $\mu$g/kg (ppb) range.

## Coke Production

Coke is produced by pyrolysis of coal (there is no chlorine added and no oxygen excess), in conditions that do not favor dioxins and furans formation. Any chlorine released from the coal or alkyl chloride radicals should, in theory, be scavenged by nascent hydrogen generating HCl and low-molecular weight organochlorines. There is very limited data on dioxin and furan emissions from the coke sector. UNEP factors for air emission are 0.3 or 3 $\mu$g/T coke produced (~0.23 $\mu$g/T coal processed) with or without afterburner and dust removal equipment. There are no coke/tar plants within the Watershed. There is only one plant in Tonawanda, NY (Niagara County).

## Ball Clay

Ball clay is a kind of clay used for ceramic manufacture and as an anticaking additive in animal feed.[550] The presence of high levels of dioxins in animal feed led to the discovery of ball clay as the source. Use as a feed additive has been banned in the US. Although the origin of these dioxins has not yet been confirmed, many scientists believe they are the result of natural processes [334]. The congener pattern measured in ball clay samples from Mississippi is unlike that of known anthropogenic sources, and has a very high level of 2,3,7,8 TCDD and 1,2,3,7,8, penta-CDD, but not of the corresponding furans [334]. The mean concentration was 1,513 pg/g, up to three orders of magnitude higher than levels typically found in soils [334]. Clays from deposits in Germany presented a similar congener pattern, and dioxins and furans have been found in many other ball clay deposits. Ball clay in the US is mined in four states: Tennessee, Texas, Kentucky, and Mississippi [354]. In 2003, 1.3 million T of ball clay were mined in the US, of which ~1.2 million T were used domestically [354]. Assuming the average dioxin concentrations measured in US clay, these would contain ~1.7 *kg* TEQ.

Ball clay is used to manufacture ceramic products including floor and wall tiles, sanitary ware, china and dinnerware, fiberglass, mineral wool, and miscellaneous ceramics [354]. Most manufacturing processes involve vitrification at extremely high temperatures that would volatilize and destroy any dioxins and furans present [334]. The final products are thus unlikely to contain and/or release significant amounts of dioxins and furans. However, there are no measurements in products to support or refute this hypothesis [108]. It is unclear, however, whether the mining and handling of ball clay can result in releases to the environment or exposure of workers. Measurements at manufacturing plants are not available to determine whether the vitrification process might result in releases [334].

## Oil Refineries

Oil refineries use platinum or platinum/rhenium catalyst during the reforming process to obtain high-oc-

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[549] U.S. Census Bureau. County Business Pattern. *http://www.census.gov/epcd/cbp/view/cbpview.html.* Accessed April 27, 2005.

[550] Especially for poultry feed, but also for fish and other animals.

**Table Ap.C. 21. Dioxin emissions from oil refineries by facility**

| County | Catalytic reforming capacity (barrels/day)† | Emissions to air (g TEQ/yr)‡ | 2004 TRI releases to air | | | |
|---|---|---|---|---|---|---|
| | | | Air | Water | Landfills | Units |
| Union | 29,000 | 0.00001 - 0.03 | 0.00001 | — | 0.08 | g TEQ§ |
| Gloucester | 30,000 | 0.00001–0.03 | — | — | — | |
| Gloucester | 24,000 | 0.00001–0.03 | 0.1 | 0.2 | — | g |
| **Total** | **83,000** | **0.00003–0.09** | | | | |

† Data for 2004 from Mid-Atlantic Regional Air Management Association [154]
‡ EF: 0.001–3 ng TEQ/barrel [334].
§ TEQ amounts were calculated based on congener distribution provided by each facility.

tane fuels, which causes the catalyst to be eventually covered by coke. To regenerate the spent catalyst, it is typically burned and reactivated by heating at high temperatures. This process can generate and release dioxins to air, wastewater, and sludge. Although dioxins have been detected in all of these vectors, currently available information is limited and emission factors have only been suggested for air emissions.

There are three oil refineries in NJ, one of them in the Watershed (Table Ap.C. 21). Based on catalytic reforming capacity for these plants, we estimate that emissions to air are negligible (Table Ap.C. 21). As reported in 2004 to TRI (Table Ap.C. 21), there seems to be more dioxins in waste streams than in releases to air. Thus, further research is advisable to better characterize dioxins in wastes from petroleum refineries.

## Other Production Sources

Other possible sources that need to be investigated in the region include: asphalt mixing, production of lime, glass, ceramics, and bricks. Metal shredding facilities operate large machines that use hammers to fragment the scrap material. Dioxins can originate from contamination of the material (e.g., PCBs) or locally high temperatures in the system.

## Nonindustrial Sources

### Food and Animal Feed

Intake of dioxins in food, particularly animal products, accounts for ~95% of human dioxin exposure [307]. Dioxins in animal products originate in their feed. Several animal feed additives have been identified as sources of dioxins in feed, including ball clay, recycled fats, and by-products from several industries.

Cases of animal feed contamination (as well as exposure other than through food or feed) are discussed in Appendix B and point to the risks and limitations of reusing and recycling industrial by-products and wastes, especially into feed or food products.

Dioxins may be present in feed components other than additives, but limited data are available. Grains are thought to have little potential for contamination, except for grain and vegetable by-products and recycled grains [34]. Grasses and forages may contribute dioxins via atmospheric deposition, especially when animals graze (as opposed to when they are fed harvested grass), since they can also ingest soil and lower parts of the plants where dioxins may concentrate as rain washes them off from the vegetation above [34]. Dioxins in soil may also be applied with soil amendments such as sludge or biocides such as 2,4-D and are expected to be ~20–40% bioavailable.

The U.S. EPA, as part of the Dioxin Exposure Initiative, is conducting a study—the National Study on Animal Feeds—to determine which animal feed ingredients contribute the greatest amounts of dioxins to animals [281]. As part of this study, the EPA is attempting to establish whether dioxin deposition from air to leaves accounts for significant amounts of dioxins in animals. In collaboration with the EPA, the FDA is analyzing animal feed ingredients that contain animal fats (fat from beef, pork, mixed animal species, or other sources; meat and bone meal; poultry by-product meal; fish meal) or that are likely to contain dioxins (deodorizer distillates that are by-products of the commercial refining of vegetable oils and likely contain PCBs; molasses, which might be contaminated by air deposition; soil contamination on beets or by fire during cane harvesting) [281]. The US FDA does not test for dioxins in imported animal feed on a regular basis [281]. In 1999, FDA began testing dioxins annually as part of the Total Diet Study, which measures pesticide, residue, and nutrient levels in food [281].

An EPA/FDA study of dairy cows in one farm found that dioxins were about equally divided among fodder (plant material) and nonfodder feed ingredients, which typically include animal products. This led to a survey of dioxin levels in several feed ingredients including beef and pork fat, poultry by-product, and various fish meals, minerals, vitamins, and wood products.

Of particular concern is the use of animal fats and other animal products as feed ingredients, because animals bioaccumulate dioxins in their body fat (this is also true for other PBTs). Therefore, animal products are an already-concentrated source of dioxins directly fed to other animas that will continue bioaccumulating these toxics and magnifying dioxin levels in human food. Some animal ingredients (e.g., protein and blood) have already been prohibited in animal feed to prevent the establishment and amplification of bovine spongiform encephalopathy (BSE) or mad cow disease.[551] However, animal fats are not regulated.

Processed animal waste (manure and litter, including bedding material) has been used as a feed ingredient for decades because of the high level of protein, minerals, and other nutrients. This is done locally because manure transportation over long distances is too costly. The FDA does not regulate the use of animal wastes in feed (such regulation is done by the states) . Animal wastes are **not** classified as a "generally recognized as safe" (GRAS) or approved feed ingredient.

Animals may also be exposed to dioxins by chewing wood poles that have been treated with PCP [94]. Although the use of PCP-treated wood in animal operations has been banned, there may still be PCP-treated wood within animal reach in some animal operations.[552]

A rough idea of the amount of dioxins entering the Watershed associated with food is given by applying the daily dioxin intake (41 pg TEQ/day/person [307]) to the ~17.9 million people in the Watershed area, which results in ~0.25 g TEQ/yr. This is a small amount, even assuming that all of it reaches the Harbor. Additional dioxins in food leftovers are disposed of as municipal solid waste and either incinerated or landfilled (and were considered in the respective sections of the technical report). Dioxins remaining in the body will eventually be cremated or buried.

### Measures to reduce dioxin releases to animal food and human exposure

There are currently no regulations addressing acceptable dioxin levels in food or feed. In 1999, the Food and Drug Administration (FDA) announced the availability of guidance [83] to notify members of the feed industry of recent findings regarding the presence of dioxins in mined clays that may be used as anticaking agents in animal feeds and to offer general advice regarding monitoring of these clays. Further studies are needed to assess best measures to curb dioxin accumulation in food.

The most significant leverage points to reduce dioxin exposure from food are:

- **Dioxins sources:** Control sources of airborne dioxins that can deposit on soil and plants later consumed by animals [34].
- **Food production**
  - Develop voluntary guidelines for food producers to reduce dioxin contamination of animal feeds and limit or eliminate the use of animal fats in animal feed.
  - Establish limits for dioxins in food and feed. Periodically test these products to ensure that limits are not exceeded, and follow trends in dioxin concentration in food.
- **Food consumption:** The National Academy of Sciences [34] recommends the following measures to reduce dietary exposure to dioxins that are likely to have additional health benefits (a reduction in animal fat consumption also reduces heart disease incidence and obesity-related problems):
  - Increase availability of foods low in animal fat, including through government-sponsored food programs.
  - Analyze the impact of limiting the amount of fat in food served at schools.
  - Promote dietary guidelines on fats for Americans.

## Cooking

Dioxin have been measured during meat grilling using charcoal briquettes [108]. It was estimated that 6 to 15 ng TEQ/kg charcoal were emitted to air [108]. Although no measurements or references are provided, the report notes that dioxins may also be generating during other cooking operations such as frying. Restaurant operations, especially those involving

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[551] The US FDA implemented a final rule August 4, 1997 (Title 21 Part 589.2000 of the Code of Federal Regulations) that prohibits the use of mammalian protein as feed to ruminant animals in most cases [346].

[552] See section on PCP, above for further details.

charbroiling, emit particulate matter and PAHs to air. However, we know of no studies that have established the presence or measured the levels of dioxins in these emissions. Therefore, there is not enough data to confirm and estimate emissions from this potential source.

### Fireworks

Fireworks also have the potential to create and release dioxins. Additives to give color to the fireworks include chlorinated substances, metals, and pulverized PVC [334]. A British study found dioxin levels in air increased fourfold after a fireworks event, although it is possible that this might have been, at least in part, the result of bonfires [334]. Not enough data is available to estimate emissions from this source.

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