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POLLUTION PREVENTION AND MANAGEMENT STRATEGIES FOR POLYCHLORINATED BIPHENYLS IN THE NEW YORK/NEW JERSEY HARBOR

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A Report from the
Harbor Consortium of the
New York Academy of Sciences

POLLUTION PREVENTION AND MANAGEMENT STRATEGIES FOR POLYCHLORINATED BIPHENYLS IN THE NEW YORK/NEW JERSEY HARBOR

February 2005

by
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Authors' Note

This report is the result of an intense collaboration between the authors, the Harbor consortium and consultants. Dr. Marta Panero conducted the industrial ecology assessment, including researching historical production and fate of PCBs and sources and pathways of PCB mobilization in the NY/NJ Harbor Watershed. Dr. Susan Boehme consolidated and integrated the commissioned research, including the ongoing discussion on contaminated sites. Gabriela Muñoz was involved in the scientific research, including PCB effects in wildlife, remediation technologies, fluff in landfills, open burning and waste incineration processes. Dr. Lisa Totten conducted the PCB mass balance, which is included in Appendix A.

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PREFACE

What could be interesting about a report that tries to parse whether, and if so how, a class of chemicals whose manufacture was voluntarily ended and then banned in this country more than a quarter of a century ago is still adversely affecting the health of the New York/New Jersey Harbor? That sounds like last century's problem. Frankly, I originally thought efforts to define pollution prevention for PCBs as they affect today's Harbor might not prove very challenging.

But that initial perception was wrong. First, the challenge of managing PCBs is very much with us, as we hear from those who seek to keep our Harbor's waterways navigable and spend more resources attempting to deal with sediment contaminated with those PCBs than on any other environmental challenge to the Harbor. One of the nation's largest corporations has now agreed to devote enormous resources to address some of the ways that its disposal of PCB's in the Upper Hudson decades ago continues to affect the Watershed including the Harbor. And a variety of public agencies and public groups, equally riveted on the Upper Hudson PCB issues, believe more should be done.

But the challenges are even more scientifically complex than resolving Upper Hudson cleanup issues. Those of us in the tri-state area, who had thought that the remaining problems associated with PCBs were regulatory and political, need to read this report with great care. It is, in fact, an unexpectedly brain-twisting tale, or put differently, a breathtaking read, replete with hairpin turns and surprises. Just when you think you know enough to reason from an emerging picture of a complex environmental hazard to what needs to be done, you are led through unexpected uncertainties about where the chemicals are. Indeed, we learn here that for a large and diverse group of institutional players in the region (utilities, sewer commissions, and river keepers alike) tracking and understanding the ways in which these chemicals move in and through this extraordinary estuary remains a major challenge.

Take a step back. Because PCBs were banned 25 years ago, we assume that we know most of what we need to know about their adverse effects. Not so. The types of organisms that are affected and the ways they may be harmed by PCBs keep expanding, and the effort to pin down what we think is scientifically established about what makes PCBs harmful and the severity of their toxicity also continues. In addition, a key confounder here is that the molecular weight differences among the different PCB compounds matters because those differences affect not only their toxicity but also how they behave and move in the environment. What different PCBs do and do not bind to–in biota and the environment through which they move–will also surprise you. These factors make assessing the significance of PCB harm and the task of determining the best practices for preventing them from getting into the Harbor very complicated.

You also might suspect that because these materials have not been made in this country for more than 25 years and because we know how much was made, we must know where most of them are and that we have developed effective ways of tracking them until we finally destroy or sequester them. Not at all. Time and again when reading this report you will realize that easy assumptions about what PCBs were used for, and where they currently are, do not suffice. What quantities to look for are similarly confounded. For example, because PCBs bind to the products that contain them just knowing the volumes of those products (officially called "PCB containing materials") tells you little about how much of the actual stock of PCB's is still out there, or where it is.

This third report of the Harbor Consortium of a third toxicant is not, then, an encore. It is far more than a repetitious analysis, combining industrial ecology methods and other environmental measurement techniques to say for a third time what we should do to protect our Harbor. We continue to find with each toxicant examined that understanding the fate of the materials in the regional environment and then in the Harbor itself requires a different design for action. As a Consortium, we looked first at mercury and found how elemental mercury gets transformed under specific environmental conditions present in our Harbor into methylmercury, a form that is more toxic than elemental mercury, and allows it to accumulate in and move up the food chain more rapidly. In contrast, we found that for cadmium, our second contaminant, the Harbor tends partially to cleanse itself because much of the cadmium binds to lighter particles that are swept through the Harbor and out into the wider marine environment. At current levels, it poses a lesser problem for the Harbor than for some other environments. We find that the suite of compounds we label PCBs seem to be both sequestered and released in more complex ways than either mercury or cadmium.

This report does, however, reaffirm the Consortium's earlier conclusions about the priority that must be given to both designing information and implementing management regimens adequate for tracking the sources and disposition of these contaminants in ways that take account of not only how and where they were used but also how they move and persist differently in the environment. As those information management regimens are evolving, the required regulatory processes for assuring that they yield the needed information must do better than they do today. We simply cannot protect the Harbor, or do so cost-effectively, when our efforts to restrict and manage these contaminants are undertaken with so little data about their whereabouts. We have in this report gathered an enormous wealth of information, but often we have had to make inferences from historical and incomplete national inventories when regional information was lacking.

The authors of this report, and now the members of this Consortium, have become painfully aware that we are doing our risk management, while not blindly, surely with a very blurry picture of what is happening and is needed. In this report, in fact, we find that we never anticipated the unintended consequences of what was clearly a worthy regulatory policy – banning the manufacture of these chemicals. The banning has paradoxically made even more complicated tracking the pathways of PCB's that were already in commerce as they moved in the environment. Why? It did not have to be that way. But we did not design such information feedbacks to replace or substitute even for what little we usually know about where materials go when they are still being used commercially. Hence, we lost track of perhaps most of the PCB material and, when this information gap is linked to the special PCB properties of persistence and complex mobility, we now face a whole new set of conundrums. And as you will see in this report, the contemporary task of designing and evaluating approaches that identify ways to cut off harmful flows to the Harbor is actually more and not less challenging than we have faced with other toxicants.

Still, there are some common themes emerging from all of the Consortium's work. In the preface to the Consortium's second major report on cadmium (2003) I wrote: "It has become quite clear to the members of the Consortium that the knowledge base needed for nimble management of materials entering the Watershed from the numerous and changing mix of activities and supporting materials of contemporary life is not only missing, but may even be becoming less robust than it has been in the past." The members of the Consortium clearly sense the importance of encouraging diverse efforts to articulate at least some of the formats for information management systems that will be required. Furthermore, the Consortium has increasingly focused its attention on the priority of linking these data definition techniques to the specific behaviors of chemicals in specific environmental media, and then to utilize those techniques in a Watershed-wide monitoring system so that we really can track these materials as they enter the Harbor. In the next stage of our work, we will undoubtedly want to see if we can identify which institutions, existing or new, are needed to take on the stewardship of this information management task, whether it be monitoring that focuses on the Harbor or materials tracking more generally.

I want to draw attention to how the Consortium self-consciously tied its focus on long-term monitoring in this report to what it is and is not saying about the long struggle that has taken place over the PCBs in the upper Hudson and specifically to the recent decisions related to Superfund actions required of General Electric to address PCB-contaminated sediments there. Even as that agreement is being turned into a remedial design, many differences persist as to whether the scope, approach, and necessity of what is scheduled will be adequate or effective.[1] The Consortium as a group decided at the beginning of its PCB work to focus attention on PCB sources close to the Harbor itself since they have not been under recent scrutiny. And in any event, the consortium knew it had no special insight into what will and will not be achieved through the intense regulatory process upstream. Still, given its focus on the health of the Harbor, the Consortium agreed as it reviewed an earlier draft of this report that it remains vitally important to be able to quantify what is achieved in the upper Hudson as it is related to what ends up in the Harbor. The strong recommendations related to the need for monitoring (see Contaminated Sites section of the report) are the result of that focus.

I want to again express my admiration to the very diverse and committed members and financial supporters of this Consortium who bring such an incredible wealth of knowledge, talent, sound judgment, and good will that continue to allow this Consortium to explore, with scientific rigor, very major concerns and interests that are mirrored in the region generally. Happily the social fabric of the Consortium is unique, and the fact that we can issue technically superior (award-winning, in fact) consensus reports that are meaningful is something about which we are all very proud. A fundamental reason for this has to do with the willingness of the New York Academy of Sciences' staff not only to distinguish themselves with their ability to gather and synthesize information but also–in dialogue with the Consortium–to go back again and again to find better ways to specify what are the appropriate inferences for action that emerge from the work.

Charles W. Powers
Chair

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[1] The reader can get the very different views on those matters that exist to this day among entities active in the Consortium by reading, for example, how the federal government has defined the site in its Record of Decision, how GE views what is and is not covered by the decision, and how concerned citizen groups view the scope and adequacy of that remedy (see *http://www.epa.gov/hudson/RecordofDecision-text.pdf, http://www.clearwater.org/pdf/011805_cw_pcb_statement.pdf, http://www.hudsoninformation.com,* and Appendix B).

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GLOSSARY OF TERMS

Aroclor	trade name used by Monsanto to commercialize PCB mixtures.
Askarel	trade name for transformer fluid blend consisting of 40–60% PCB and a solvent (trichlorobenzene)
ATSDR	Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
CARP	Contaminant Assessment and Reduction Program
CAS (registry) number	A number assigned by the Chemical Abstracts Service that uniquely identifies a chemical substance
CCMP	Comprehensive Conservation and Management Plan
CCP	Carbonless Copy Paper
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHG&E	Central Hudson Gas and Electric Corporation
CIP	Community Interaction Program
CSOs	Combined Sewer Overflows
CWA	Clean Water Act
cy	cubic yard
DEW	Distant Early Warning
DOC	Dissolved Organic Carbon
DRBC	Delaware River Basin Commission
EMC	Event Mean Concentration
g	gram
GE	General Electric
GEF	Global Environment Facility (United Nations organization)
HAP	Hazardous Air Pollutants
HEP	Harbor Estuary Program
HRF	Hudson River Foundation
HVU	High Voltage User
IE	Industrial Ecology

kg	kilograms (1000 g)
L	liter
lb	pounds
LCA	Life Cycle Analysis
MARAD	US Maritime Administration
MFA	Material Flow Analysis
mg	milligram (10^{-3} g)
µg	microgram (10^{-6} g)
MPCA	Minnesota Pollution Control Agency
MSW	Municipal Solid Waste
MW	Molecular Weight
NAICS	North American Industrial Classification System
NCP	National Contingency Plan
NCR	National Cash Register Co. (This Company manufactured carbonless copy paper, which was sold as “no carbon required” or NCR).
NEI	National Emissions Inventory
ng	nanogram (10^{-9} g)
NIOSH	National Institute for Occupational Safety and Health
NJADN	New Jersey Atmospheric Deposition Network
NJ DEP	New Jersey Department of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	National Response Center
NSSS	National Sewage Sludge Survey
NYS DEC	New York State Department of Environmental Conservation
NYS DOH	New York State Department of Health
NYS DOT	New York State Department of Transportation
NYSEG	New York State Electric and Gas Corporation

GLOSSARY OF TERMS (cont.)

OPPT	Office of Pollution Prevention and Toxics
ORU	Orange and Rockland Utilities
OSHA	Occupational Safety and Health Administration
P2	Pollution Prevention
PAHs	Polycyclic Aromatic Hydrocarbons
PANYNJ	The Port Authority of New York and New Jersey
PBTs	Persistent, Bioaccumulative Toxics
PCBs	Polychlorinated Biphenyls
PCDFs	Polychlorinated Dibenzo Furans
PCDDs	Polychlorinated Dibenzo Dioxins
PEL	Permissible Exposure Limit
pg	pictogram (10^{-12} g)
POPs	Persistent Organic Pollutants
POTWs	Publicly Owned Treatment Works (i.e., wastewater treatment facilities)
ppb	parts per billion (µg/kg or µg/L)
ppm	parts per million (mg/kg or mg/L)
ppq	parts per quadrillion (pg/kg or pg/L)
ppt	part per trillion (ng/kg or ng/L)
PSEG	Public Service Enterprise Group
PVC	Polyvinyl Chloride
PVSC	Passaic Valley Sewerage Commissioners
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
REMAP	Regional Environmental Monitoring and Assessment Program
ROD	Record Of Decision
SCC	Source Classification Code
SIC	Standard Industrial Classification
SOCs	Semi-volatile Organic Compounds
SPDES	State Pollutant Discharge Elimination System
TRI	Toxic Chemical Release Inventory
T	metric ton (1,000 kg)
TMDL	Total Maximum Daily Load
TSCA	Toxic Substances Control Act
TSDFs	Treatment, Storage, or Disposal Facilities
URD	Underground Residential Distribution
US EPA	US Environmental Protection Agency
USLE	Universal Soil Loss Equation
WPCPs	Water Pollution Control Plants
WTE	Waste-To-Energy

BACKGROUND ON THE HARBOR PROJECT

The project *"Industrial Ecology, Pollution Prevention, and the New York/New Jersey Harbor"* addresses ongoing contributions of toxic inputs to the Harbor Watershed[2] that compromise the estuary's biodiversity, human recreational activities, and business endeavors. The New York/New Jersey (NY/NJ) Harbor Estuary is both an environmental and an economic asset. It is home to diverse marine and bird species including terns, egrets, black skimmers, herring gulls, and night herons, as well as horseshoe crabs, striped bass, bluefish, weakfish, cunner, and scup. The estuary is also an international and regional tourist attraction and provides recreational fishing, boating, and swimming opportunities for the more than 20 million inhabitants living in the region. The Port of New York and New Jersey is the largest port on the East Coast of the United States and one of the largest in the world. In 2003, $100 billion dollars of cargo were shipped through its waters [1]. Cargo from the port provides manufactured and raw materials to the NY/NJ region as well as communities across the country.

Toxicant inputs to the Harbor Watershed threaten the quality of water and sediments. Clean water is the basis of healthy environments with resilient flora and fauna, and, at the top of the food chain, healthy humans. Toxicants in sediments also add to the cost of dredged material disposal. Improving water quality and promoting clean sediments are critical factors that can ensure the sustainability of the estuary and the resources and activities that depend on it. Although this extraordinary natural resource can never be restored to its pristine condition, much has been done to improve the water quality and habitat in the estuary. Led by the passage of the Clean Water Act in 1972 and other regulatory measures, permit programs now control the major sources of pollution. Industrial pretreatment programs have helped reduce discharges of industrial wastes to municipal sewage systems and directly to the Harbor resulting in substantial reductions in loadings of several toxic chemicals. Despite these improvements, many problems remain. There are inadequately controlled sources, such as atmospheric deposition, combined sewer overflows, stormwater, and nonpoint source runoff. Many water bodies and the organisms that depend on the receiving waters are still negatively affected.

Given the stated problem, the Academy's project is working to evaluate the flows of contaminants (mercury, cadmium, polychlorinated biphenyls [PCBs], dioxins, and polycyclic aromatic hydrocarbons [PAHs]) through the whole NY/NJ Harbor Watershed system. The overarching goal of the project is to identify the best strategies to keep new pollutant inputs from entering this ecosystem and from having an impact on the rivers, sediments, wetlands, and coastlines of the Watershed. To pursue this goal, the project analyzes the entire system by which resource inputs to the different sectors of the regional economy (e.g., production, service, households) are transformed into outputs that then enter different environmental media and have a negative impact on the Harbor Watershed. By undertaking this process as a consortium of stakeholders, the project is, in a sense, a collaborative network, drawing on all sectors to help develop strategies to prevent pollution discharge. We follow a threefold approach that incorporates scientific, technological, and socioeconomic data to achieve reductions in toxicant releases:

(1) Applying new and traditional frameworks of analysis, such as material flow/fluxes analyses (MFA), industrial ecology (IE), and mass balance assessments, to identify the locations in selected toxicant cycles where pollution prevention (P2) would most efficiently contribute to long-term (decadal) reductions in loadings of toxicants to the NY/NJ Harbor. For each contaminant, the mass balance identifies system wide sources to the Harbor, pathways, remobilization through different media, and sinks. The IE assessment helps identify contaminant input to the regional economy; the usage and releases during production processes and consumption activities; and post consumption patterns to determine the fate of the contaminants at the end of life of products. This step may entail a watershed-wide emissions model that is based on scientific information, engineering rates, and economic and demographic data.

(2) Identifying P2 strategies, including process/product modification and re-engineering, identification of clean technologies, as well as best management practices and waste minimization measures. This step includes consultation with industries or sectors involved in releases; consultation with those stakeholders affected by releases or products; early adopters of technological innovations; and a socioeconomic assessment (when viable) of proposed P2 options.

(3) Working with all stakeholders (regionally, and where warranted, nationally) to encourage the development and implementation of the most practical P2 strategies to reduce toxicant releases to the Harbor. At the core

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[2] The New York/New Jersey Harbor Watershed covers an area of 42,128 km^2 (16,456 square miles) . The water surface encompasses ~811 km^2 (see Figure 2 in Appendix A). The estuary is a mixing zone for 4 major rivers: Hudson, Passaic, Hackensack, and Raritan.

of the project sits a consortium of stakeholders that includes scientists, environmental groups, state and local governments, labor, industry, business associations, and community groups (see attached list of Consortium members), that recommends and implements the action plans. Our process helps to synthesize research findings and link them to the decision-making process. This innovative approach and sector-specific strategies for information dissemination are needed to have an impact and to promote implementation.

Summary of Findings and Recommendations from This Report

As you read this document, it will become clear how different our overall understanding of PCBs is from our previous efforts on mercury and cadmium. For example, the most startling point about PCB-containing equipment, materials, and processes is that, society-wide, we have almost no updated data today on how much PCBs remain in products, how much has been released to the environment, and how much has been properly disposed of or placed in landfills. What we have are calculations based on some global or national estimates (mostly from the 1980s) and very little actual regional data. What this means is that there is no precise way to estimate pathways to the Harbor and then prioritize these sources based on quantity of PCBs or the pathways of PCBs to the Harbor. Therefore, our major overarching recommendation is a call for updated inventories on a regular basis to determine what products contain PCBs, where they are, how and when they are being disposed of, and what happens during and after disposal. A comprehensive inventory will help us to track how PCBs are used, managed, and/or mobilized in the Watershed region. To establish a strategy for dealing with the ongoing flows of PCBs through the region, and to move toward data collection and away from calculations, we need comprehensive reporting on the rates of retirement and proper disposal as well as PCB concentration from all PCB-containing equipment and products.

The document also makes it clear that more than 25 years after the PCBs' general prohibition, these contaminants continue to be redistributed and dispersed through processes such as disposal, recycling, and volatilization. Thus, the second step is to better understand the fate of PCBs during these processes and to identify ways to track and fully account for PCBs from product through disposal. Where possible, we have tried to identify some of the most likely pathways of PCBs to the Harbor. These sources may be the best candidates for further study. Furthermore, an evaluation of the PCB regulatory experience after three decades may help draw lessons that may be applicable to emergent contaminants.

Finally, in a few cases we found opportunities in which a precautionary approach made the most sense in terms of stemming releases of PCBs. These are probably not the largest sources of PCBs to our region, but they provide opportunities to act proactively, such as closing regulatory gaps, reconsidering the reuse of PCB-containing materials (e.g., oil, kaofin) and identifying and halting sources of inadvertently produced PCBs.

Some of the main findings of this report are:

1. Upper Hudson River inputs including the Hudson River Superfund site represent greater than 50% of the load to the Harbor. PCB inputs to the NY/NJ Harbor from the Upper Hudson River include the Hudson River Superfund site, as well as from NYS Superfund sites (e.g. Hastings; Fort Edward; Hudson Falls) other contaminated sediments, and potential inputs from floodplains, dredge spoils and remnant deposits.
2. There are differences in the congener mixtures seen entering the Harbor from the Upper Hudson and the remaining local input.
3. The mass balance indicates that the Hudson River is the major load of PCBs to the NY/NJ Harbor representing ~56% of the total loads. The next largest contributions are from combined sewer overflows (CSOs) and storm water runoff, each accounting for ~17% of the total loads.
4. Contaminated sites within the Watershed and beyond are likely contributors of PCBs to the Harbor via runoff, CSO, and volatilization.
5. In the US, dielectric fluids accounted for ~70% of the PCB domestic production and were commonly used in transformers and capacitors.
6. The majority (70%) of Askarel-type[3] PCB transformers in use in 1983 were at nonutility facilities. All facilities were required to report their PCB transformers to the EPA Registry by 1998. The registry includes a much smaller percentage of non-utility transformers than 70%, suggesting that either these units either have been taken out of service or are underreported.

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[3] Askarel is the trade name used in the US to commercialize the fluid blend of PCB and trichlorobenzene used for transformers and capacitors. For regulatory purposes, other transformers are also denominated as PCB transformers, such as mineral oil transformers inadvertently contaminated with PCB at concentrations ≥500 ppm.

7. The law requires PCB waste to be managed properly but testing to determine PCB concentrations is not mandated. A regulatory gap (PCB concentration assumptions during use no longer apply once units are taken out of service for disposal) hinders EPA's ability to enforce against improper disposal. As a result some transformers may be disposed of without determination of their actual PCB content.
8. Small PCB capacitors in household appliances and demolition debris enter the municipal solid waste (MSW) stream each year. There are no current inventories of these units and their disposal is poorly quantified. Approximately 20% of the MSW in the NY/NJ Harbor region is incinerated.
9. Inadvertently produced PCBs in the Watershed region are entering the Harbor and may constitute 5 to 10% of the harbor input.
10. Although PCB domestic production sold in the US only amounted to approximately half a million tons (568,000 T)[4] of pure PCBs, bulk waste contaminated with PCB in the US has been estimated to range from 168 million to 600 million tons.

Based on the findings above and extensive discussion, the consortium has categorized the recommendations into two groups.[5] The bolded recommendations are for the actions that are considered the highest priorities. Suggestions for PCBs associated with smaller contributions to overall releases are denoted by italicized text. All of the recommendations discussed throughout the report are summarized here.

RECOMMENDATIONS for electrical equipment (excluding small capacitors):

Measures to ensure an accurate Watershed inventory:

- **To develop a regional inventory, owners of PCB electrical equipment should, report yearly (or continue to report if already reporting)[6] on:**
  - **Number of units in operation, by category (PCB-, PCB contaminated-, and non-PCB-units)**
  - **Estimate of the amount of PCBs contained in units (>50 ppm) in operation**
  - **Number of units retired, by category**
  - **PCBs content of retired electrical equipment[7]**

Measures to ensure proper management and disposal

- **A regulatory gap (PCB concentration assumptions during use no longer apply once units are taken out of service for disposal) hinders EPA's ability to enforce against improper disposal. Therefore, it is possible that some facilities might dispose of liquid-filled transformers without determination of their actual PCB content.[8]**
  - **Close the regulatory gap that hinders deterrence of improper disposal of untested transformers.**
  - **Estimate PCB content in all unlabeled and untested transformers manufactured before July 1979 at end of life.[9]**
- **Monitor PCB concentrations in air, water, soils at dismantling, fragmentizing, storage, and disposal facilities.**
- **Assess the cumulative effect of small spills (assumed to have released <1 lb PCBs) to determine whether these spills could result in significant soils or sediment contamination. If found to be significant, reevaluate the federal and state *"de minimis"* rules for spill reporting that exempt certain oil spills (e.g., spills assumed to have released <1 lb PCBs).**

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[4] Metric tons (T) are used throughout the report, unless specified otherwise (e.g., U.S. tons, which are expressed as U.S. T).

[5] Participation in development of the report, like membership in the consortium itself, does not necessarily mean that each participant agrees with all of the report's recommendations. Nevertheless, the consortium consensus process has achieved a new level of agreement on many issues and a commitment to the overall thrust of the report.

[6] We are not asking for additional reporting. If the reported data is already available at public entities, this information can be gathered from them. We have not defined who should gather the regional inventory data.

[7] When these units are sent for disposal in some cases they are assumed to be PCB equipment, disposed of as such, and are not tested. In such cases, their PCB content could be estimated and reported.

[8] TSCA PCB regulation, 40 CFR, §761.2 describes assumptions for use. However, once an untested transformer is designated as taken out of service for disposal, the assumptions no longer apply. The regulations still require proper disposal. However, enforcement against improper disposal is difficult to apply because there is no *explicit* requirement to test the transformers. Facilities engaging in improper disposal do so at their own risk and face penalties if caught.

[9] A waste generator can choose to assume that a piece of equipment contains >500 ppm PCBs, and properly dispose of it without determining its actual PCB concentration. Nevertheless, for the purposes of an inventory, it would be useful to have an estimate of its PCB content.

RECOMMENDATION for Small Capacitors

- **Quantify and track the fate of PCB capacitors that are entering the waste stream (e.g., disposed of at demolition sites, recycling, dismantling, and metal recovery facilities, household waste collection, and consolidation centers)**

RECOMMENDATIONS for Open Applications

PCBs in paints and other plasticizer applications

- Follow up monitoring and track-down studies would be useful to determine the source(s) of PCBs in this area.

Carbonless copy paper

- Further research is recommended to understand the impact of this and other paper recycling operations and alternative technologies.

RECOMMENDATIONS for Inadvertent PCB production

- Because ferric chloride is the only source of PCB 209 that we have been able to identify, it may be useful to time the effluent sampling to coincide with the POTW's use of this product and to also measure PCB concentrations in the sludge because higher MW PCBs have a greater affinity for particles.
- Inadvertently produced PCBs tend to be identified during POTW effluent sampling[10]; however, the POTW is not the primary source of these PCBs. PCB loadings may be sporadic (e.g. tied to industrial processes, treatment plant activities, storms events). Therefore targeted track-down efforts that are informed by an inventory of the industrial processes and schedules, rainfall, etc. in the region could help to pinpoint specific sources. Track-downs should also include measurements of PCBs associated with suspended solids and sludge to account for the total PCB loads to the system as well as the fate of those PCBs.

RECOMMENDATIONS for Incidental Releases through Recycling and Remanufacturing of PCB contaminated material

Paper Recycling

- Although the concentrations may be low in any of the individual by-products, the overall quantities and the potential for wide distribution of these products suggests that further research is warranted to identify the specific source of these PCBs (e.g., inks/pigments), whether the source is current or historical, and their contribution to PCB loadings to the Harbor and to the nation as a whole.

Oil Recycling

- Dioxins and furans can form during combustion unless specific incineration practices are strictly followed. Ensure enforcement of guidelines to prevent emissions of dioxins and furans during combustion of PCB-contaminated mineral oil (PCB concentrations between 2 and 50ppm).

Scrap Tires Used as Fuel

- There are many alternative uses for shredded tires that do not involve energy recovery via combustion including roadbed construction, drainage material, and insulation around building foundations. These uses could be prioritized over incineration.

RECOMMENDATIONS for PCBs in Municipal Solid Waste

Open Burning

- New Jersey already bans open burining of solid waste. Support efforts to ban open burning in New York State and nationally.
- Recommendation for solid waste: Identify and promote strategies to prevent PCB-contaminated products from entering the waste stream.

RECOMMENDATIONS for Contaminated Sites

- **Determine the importance of contaminated sites (especially land sites) to the inputs of PCBs (as well as other contaminants) to the NY/NJ Harbor (e.g., via air emissions, runoff, groundwater, erosion).**
- **Support an ecosystem/watershed-wide sustained and long-term monitoring effort to determine whether remediation, pollution prevention, and best management practices are having an impact on the health of the Harbor.**

These recommendations are the first step to determining specific actions that would lead to the greatest decreases in PCB releases. The stakeholders of the Harbor Watershed could move implementation of recommendations forward by continuing to discuss how these actions should be undertaken, who should be the main implementers, and what resources should be allocated to implement these actions.

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[10] PCBs measured in the effluent generally only represent a portion of the PCBs entering the POTW. PCBs are particle reactive and therefore are likely to end up in the sludge.

INTRODUCTION

The Harbor Consortium chose polychlorinated biphenyls (PCBs) as the third contaminant to be addressed with a full industrial ecology (IE), pollution prevention analysis. Compared with our previous abatement proposals for mercury and cadmium, the application of IE to study PCBs presents new challenges. In contrast with these two metals, PCBs play a much-reduced role in today's economic structure, and thus there are limited economic statistics on current PCB usage. Furthermore, because their production has been banned, there are no (intentional) designs for material integration between industries (where one facility may use the waste of another as feedstock to its own production process).[11] Yet, opportunities for pollution prevention and best management practices still exist.

Our research attempted to determine all ongoing sources of PCBs to the NY/NJ Harbor with the goal of establishing pollution prevention and best management recommendations to decrease PCB pollution in the Harbor. We concentrated on the products and processes that continue to release PCBs to the regional environment as well as historically contaminated sites in the entire Watershed that appear to contribute to the remobilization of PCBs. The first step was to undertake the mass balance to understand the large-scale flows of PCBs into the Harbor. We then focused on the regional economy, analyzing different sectors' management and disposal patterns of PCBs. This research complements several ongoing investigations and sampling activities in the NY/NJ Harbor Estuary, which focus on determining the level of PCB pollution in the Harbor and its major pathways (e.g., river inputs, air deposition, and volatilization).

It may be argued that the general prohibition on production, distribution, and commercialization of PCBs in 1978 was a significant step toward preventing PCBs pollution. The use of certain products containing PCBs continued to be allowed[12] pursuant to proper maintenance and upkeep of such equipment. PCB usage for manufacturing of open applications was discontinued and PCB products were regulated for safe disposal. Superfund legislation was enacted with the goal of addressing previously contaminated sites.

Nevertheless, more than 25 years later, releases and remobilization of PCBs continue to be a concern in many watersheds, including the NY/NJ Harbor. Between 1993 and 2004, PCB fish consumption advisories have more than doubled, increasing from 319 to 884 nationally [2,18]. PCB pollution results in ecological as well as economic costs, imposing additional expenses on communities for dredging of navigational channels[13] or losses to the commercial fishing industry. In the Hudson River, for example, recreational fishing was closed in 1976 in the Upper Hudson above Troy, and commercial take of striped bass was banned. The upper Hudson is still restricted to catch and release. Approximately 200 miles of this river have been designated as a Superfund site [3]; and as the maps in the Contaminated Sites section below attest, there are numerous other Superfund, Brownfields, and contaminated sites that are either known to or are suspected to impact the Hudson River. This Hudson River Superfund area remains under a human health advisory (no-consumption or once-per-month consumption)[14] for specific fish and wildlife, primarily because of PCB concentrations in these organisms and the potential harm to the human population consuming them [4]. PCBs not only bioaccumulate but also can cause negative impacts on fish and other animals (such as marine birds and certain mammals), including immune, reproductive and behavioral impairments, and several endocrine disruptions [5]. PCBs are persistent chemicals and do not readily break down in the environment.

Ongoing releases and mobilization of PCBs occur for a variety of reasons. Some of these include:

1. Remobilization from contaminated sites via runoff, volatilization and leaching.
2. Releases from disposal of PCB products such as small PCB capacitors. These items continue to be sent to municipal waste incinerators and landfills and releases may occur during collection and disposal.
3. Accidents, spills, leakages, and fires involving PCB-containing electrical equipment.

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[11] In general, this limitation applies to most toxic materials, although some recycling was possible in the cases of mercury and cadmium. Notice that no industry seeks to purposely recycle PCBs, although some recycling of materials contaminated with PCBs (e.g., oil, sludge, metal, paper) may take place in the Watershed region.

[12] PCB stocks were allowed to be used in the manufacture of certain closed applications until about 1982. Because other countries continued to produce PCBs until the late 1980s and even early 1990s (USSR), some imported products containing PCBs may have continued to be commercialized in the US up to 10 years after the federal ban.

[13] For example, the navigational channels within the NY/NJ Harbor or the Champlain Canal in the Upper Hudson River.

[14] Note that American Shad fall under the general advisory of once-per week consumption which applies when the fish has either not been tested or may contain other contaminants. *http://www.health.state.ny.us/nysdoh/fish/fish.pdf*

4. Possible mobilization during use, disposal, or storage of electrical equipment due to lack of information/monitoring of non-utility or privately owned transformers.
5. Open applications of PCBs such as painted surfaces, metal coatings, adhesives, and wood preservatives [6]. As these materials are discarded and enter the waste stream, they contribute to PCB remobilization.
6. The inadvertent production of PCBs during certain ongoing manufacturing processes also contributes to PCB releases to the environment. These include the generation of PCBs from pigment and ink manufacturing, as well as from the production of chlorinated solvents, detergents, plastic materials, agricultural chemicals, and other products.
7. PCBs' incidental releases may also take place during the recycling and remanufacturing of PCB-contaminated materials, such as paper or metal.

Although 60% of the total worldwide production of PCBs (and 77% of the domestic U.S. production) was used in the manufacture of transformers and capacitors, only 10% of the PCB waste generated is from reported disposal of this electrical equipment. The US EPA (2000) indicates that 90% of the PCB waste generated since 1994 is "bulk" waste (mostly from remedial actions and cleanup projects). A small quantity of dispersed PCBs in the environment has the potential to generate large amounts of PCB-contaminated waste. Most of the PCB bulk waste is sent to hazardous waste or PCB waste landfills or other treatment, storage, or disposal Facilities (TSDFs). In some cases, these landfills and TSDFs have been cited for remedial action or added to the list of PCB-contaminated sites.[15] In the Watershed region, there are at least 60 PCB-contaminated landfills[16] as well as 174 Superfund sites and 550 "brownfield" designated locations.[17] Thirty-five percent[18] of current PCB Superfund sites in the Harbor Watershed are associated with past improper waste management.

The present document offers a picture of PCB usage and disposal and attempts to estimate how much PCBs are still being used in the regional economy and the amount of current releases. Section A provides a general background on PCBs, including a brief summary of their toxicity and regulatory initiatives. In Section B, a discussion of the worldwide PCB historical production provides a context for understanding the magnitude of the flows through the economy of this region. Section C first focuses on the mass balance of PCBs for the NY/NJ Harbor Region and then on specific sources such as products, processes, and contaminated sites. Based on our "current state of knowledge," recommendations to prevent ongoing releases and remobilization of PCBs are also put forward in this section.

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[15] There are 60 landfills in New Jersey that have been classified as being contaminated with PCBs. Information on the number of inactive hazardous waste sites in NY is available at *www.dec.state.ny.us/website/der/info/publications.html*. Little information is available about the number of PCB-contaminated landfills in New York. An internal report from NYS DEC suggests that a few landfills accepting "fluff" material from car shredding operations, exhibit higher levels of PCB [7].

[16] This list includes only sites in New Jersey. Other PCB-contaminated landfills may also be located in the New York side of the Harbor Watershed, but have not been presently identified.

[17] Data about brownfields is for New Jersey only. NY State has been updating its list; therefore, it is not presently available.

[18] A categorization (by type) of Superfund sites in the Watershed region indicates that 27% are sites previously operated as "waste storage and treatment facilities," and 8% as "waste-recycling facilities."

A. BACKGROUND ON PCBS

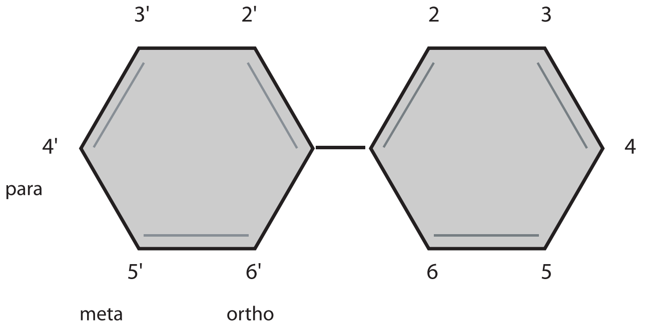
A1. Characteristics and Uses

PCBs are a group of man-made[19] chemicals that were widely utilized for a variety of industrial uses. As electricity demand grew in the first half of the 20th century, electrical equipment suppliers became the major consumers of PCBs because these stable compounds are fire-resistant and do not conduct electricity. Characteristic properties of PCBs include chemical inertness, thermal stability and low vapor pressure [6].

These synthetic chemicals were manufactured by combining two attached benzene (carbon) rings with one or more (up to 10) chlorine atoms [8]. The general molecular formula of PCBs (CAS[20] 1336-36-3) is $C_{12}H_{10-n}Cl_n$, where *n* may be any number from one to ten [9]. The basic PCB structure allows for 209 different chlorination patterns; thus, there are 209 recognized PCB compounds (congeners), with varying levels of associated toxicity. Each congener can be identified by its chemical name, PCB and CAS number. For example, 3,3'-dichlorobiphenyl is also referred to as PCB 11 (CAS number 2050-67-1). Congeners containing the same amount of chlorine atoms but in different positions in the molecule are isomers and constitute a homolog group. For instance, the dichlorobiphenyl homolog group contains 12 isomers (each with two chlorine atoms). Finally, there is a group of PCBs that is similar in structure and toxicity to dioxins and furans (e.g., coplanar PCB compounds with no chlorine atoms in ortho-positions[21]) [10,11].

Generally, PCBs were not produced as pure compounds but as mixtures varying in the average degree of chlorination. In the US, Monsanto used the trade name of "Aroclor" to commercialize specific PCB mixtures. Askarel is the trade name for transformer fluid blend of PCB (40–60%) and a solvent (trichlorobenzene) [11].[22] Aroclors were identified by a string of four numbers, such as Aroclor 1242, where the first two digits indicate that the molecule contains 12 carbon atoms as well as the type of mixture (mono- through heptachlorinated homologs).The last two digits represent the approximate chlorine content as a percentage by weight (42%). Aroclor 1016 is an exception to this code, with mono- through hexachlorinated homologs, and 41% chlorine [6].

Figure 1. Structure of Polychlorinated Biphenyl (PCB) Molecule



Depending on the degree of chlorination, PCB compounds range in consistency from heavy oily liquids to sticky resins, or melting crystalline solids [6,12]. These synthetic compounds are odorless, colorless to light yellow or amber, and very stable and have relatively low volatility at ambient temperatures. They resist breakdown from high temperatures, aging, or oxidation and are not readily biodegradable and instead they persist in the environment.[23] PCBs are very stable organic chemicals, yet despite their low vapor pressure they may volatilize from water, in part because they are hydrophobic compounds. They also easily associate with the organic components of soils, sediments, biological systems, or the dissolved organic carbon in aquatic environments. Because of their chemical structure, PCBs may be transported globally.[24] [11].

A2. Environmental Impacts

The first study that identified PCBs in wildlife was published in 1966 [14]. Subsequent studies revealed that PCBs are now ubiquitous in the environment. PCBs accumulate in fatty parts of organisms because they are lipophilic, and biomagnification occurs up the food chain, as small organisms become food for larger animals and eventually peo-

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19. Virtually all PCBs have been intentionally produced by synthetic means.
20. CAS stands for Chemical Abstracts Service. The CAS number is a number assigned by the Chemical Abstracts Service that uniquely identifies a chemical substance.
21. Mono-ortho substituted PCBs are also considered coplanar (with just one chlorine in only one of the four ortho-positions).
22. Information confirmed by David Roche and Barry Cohen, Con Edison, personal communication, November 12, 2004 and December, 9, 2004, respectively.
23. In general, higher PCB chlorine content corresponds to greater resistance to chemical degradation [12]. The US EPA classifies PCB compounds as persistent, bioaccumulative toxics (PBTs) [13].
24. PCBs may have been transported to the Arctic through the atmosphere, although they may also be found there because PCBs were used at military bases, to protect external equipment from inclement weather.

ple [15]; thus, PCB concentrations are higher for organisms that are higher in the food chain. Freshwater invertebrates[25] in some cases have been shown to biomagnify PCBs by a factor of up to 100,000; the bioaccumulative factor for fish consuming these invertebrates may be as high as 274,000. Bioaccumulation factors are affected by the number and position of chlorine atoms in the PCB molecule, lipophilicity, and length of contact [17]. PCB concentrations in aquatic organisms may be 2,000 to more than one million times higher than concentrations in the water [18].

A growing body of scientific evidence suggests that environmental chemicals, including PCBs, may interfere with the normal functioning of endocrine systems. The endocrine system (both in humans and wildlife) regulates all biological processes in the body from conception into old age. Some of its many wide-ranging roles include the development of the brain and nervous system, the growth and function of the reproductive system, metabolism, and maintenance of homeostasis. Endocrine disrupting manmade chemicals affect hormonal systems by various mechanisms, including mimicking or blocking natural hormones that regulate essential functions of endocrine glands such as thyroid, ovaries, and testes. They can also either stimulate or inhibit the synthesis, secretion, transport, binding to hormone receptors, and clearance of natural hormones. These endocrine disruptors may, therefore, cause a variety of problems with development, behavior, and reproduction and may result in immune suppression. They are also suspected to induce several kinds of cancers, as well as endometriosis.[26] They pose the greatest hazard in the earliest phases of life because hormones orchestrate development and because fetal development is extremely sensitive to small variations in hormones. Chemicals can cause endocrine effects at levels far lower than those associated with other toxicological effects because even small disturbances can have an impact on the delicate equilibrium of the endocrine function. This is especially true during highly sensitive prenatal periods when small changes in endocrine status could cause delayed consequences that are evident much later in adult life or in a subsequent generation. Incidences of endocrine disruption in fish and wildlife species have been seen in many locations. Various chemicals are associated with intersex[27] in fish in our estuaries.[28] PCBs effects in wildlife are well documented. Specific examples, some of which may be the result of endocrine disruption, include[29]:

1. Adverse effects in birds:
   - Reduced egg hatchability and live births
   - Reduced avoidance response
   - Altered mating, reproductive, parenting, and nesting behavior
   - Suppression of immune response due to prenatal exposure and morphological changes in immune system–related organs
2. Adverse effects in fish:
   - Reduced hatchability in eggs
   - Altered muscle coordination
   - Depressed immune system with increased susceptibility to infections
   - Loss of fins and tails in flatfish
3. Adverse effects in mammals:
   - Loss of embryos and fetuses and reduced live births
   - Alteration in organs of the immune system in mink, increased susceptibility to diseases in sea lions, depressed immune system in seals
   - Tumors and deformities of skeleton and skin in seals
   - In monkeys, several effects were found: chloracne, changes in sebaceous glands, damage to skin, hair (including hair loss), and nails.
   - Alterations in toenails were also observed in ferrets.
   - Behavioral deficits and retarded learning (prenatal exposure) in monkeys
   - Neurodevelopmental deficit and altered sexual maturation in rats, linked to thyroid hormone system

There is some evidence that PCB exposure is linked to birth defects and declines in fertility of fish, birds, amphibians,

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[25] It was originally believed that PCBs and dioxins did not have an impact on invertebrates, but recent research suggests that this needs to be reevaluated. Laboratory research of the effect of dioxins on finfish and bivalve invertebrates has shown effects on their reproductive system and severe abnormalities of fish embryos on species found in the NY/NJ Harbor [16]. PCBs are complex mixtures of the 209 congeners, 12 of which are coplanar and considered to be dioxin-like, and always contain polychlorinated dibenzofurans (PCDFs), a by-product of PCB synthesis. The toxicity of PCDFs and dioxin-like PCBs is mediated by the same mechanisms as dioxins. Therefore, further research in this area is needed to determine the effects of PCBs on invertebrates.

[26] The presence and growth of endometrial tissue in places other than the uterus that may lead to severe pain and infertility.

[27] An individual with sexual characteristics in between those of typical females and males.

[28] The preceding paragraph was adapted from ATSDR, 2000 [6] and information provided by Judith Weis, Rutgers University.

[29] Summarized from ATSDR, 2000 [6].

seals, and polar bears [19]. Little is known about the effects of PCBs in the ocean, which is the largest natural sink for these compounds. However, there is evidence that phytoplankton communities are affected by PCBs, and such communities are the basis of the ocean food chain [20].

A3. Toxicity and Human Health Effects

The first indication that polychlorinated biphenyls posed a systemic hazard to human health occurred in Japan in 1968, when a heat exchanger in a processing plant leaked PCB oil onto rice. The high temperatures associated with the heat exchanger increased the usual concentration of dibenzofurans (PCDFs), which are always present in PCBs. When the contaminated rice was subsequently ingested, it poisoned more than 1,600 local residents (the Yusho incident) [6,21]. Shortly afterward, similar exposures took place in Taiwan (the Yu-Cheng incident) [22]. No acute fatalities were recorded but many people exhibited the typical symptoms of acute exposure to PCBs, including severe skin rashes and lesions, irritation to eyes, mouth and throat, and gastrointestinal disorders. In both these incidents, the PCB oil had been heated before contaminating the food, resulting in the formation of dibenzofurans, which were also formed by cooking the oil. Although dibenzofurans were present in the oil, PCBs were 100–500-fold greater in concentration [6(page 36)]. PCDFs 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. In addition, later studies have attributed some of the subtle effects to non–dioxin-like PCBs [23,24].

The 209 different PCB congeners vary in toxicity, but there is general agreement that PCB compounds are toxic and hazardous to human health. The EPA has classified PCBs as "B2 probable human carcinogen"[30] [26], in particular, with respect to the liver. PCBs may enter the body through the gastrointestinal tract, the lungs, and the skin [6]. The human health effects of PCBs depend on the level and length of exposure. Acute effects are short lived and include eye, nose, and throat irritation, vomiting, stomach pains, loss of appetite, and fatigue. Acute effects are mainly seen in occupational exposures or during electrical equipment fires. Chronic effects range from cancer to swelling of the eyelids and joints and excessive pigmentation of the skin. A typical severe skin rash related to PCBs exposure is "chloracne," which may last briefly or cause permanent disfigurement [6].[31] PCB exposure from ingestion of contaminated fish from the Great Lakes has been associated with neurodevelopmental impairment [27,29].

The major sources of PCB exposure to humans include consumption of contaminated fish, inhalation, or skin contact under occupational settings. High-risk populations include women of child-bearing age and infants, who are most susceptible to diverse development and reproductive disorders, as well as exposed workers, who may present the typical signs of PCBs' skin irritations, severe rashes, and burning of the eyes [9]. PCBs are also among several chemicals considered environmental endocrine disruptors. Endocrine active substances are suspected to cause decreases in human sperm counts, increases in birth defects in reproductive organs, and greater incidence of breast, prostate, and testicular cancers [6].

A4. PCBs Regulations and Initiatives

Most countries prohibited the manufacturing and commercialization of PCBs after their toxic nature and detrimental human and environmental effects were documented. In the US, PCB production voluntarily ceased in the mid-1970s [9] and was subsequently prohibited [12,28]. In addition, many regulations at all levels of government address the need to prevent PCB mobilization. This section provides a brief outline of international, national, and local regulatory measures. It is included to give an overview of the types of actions that have been established to control PCBs.

International Stockholm Convention

PCBs are among 12 persistent organic pollutants (POPs)[32] banned by an international treaty that was signed in 2001 and agreed upon in May 2004. Various governments' representatives will meet in May 2005 to ratify the Stockholm Convention on POPs.[33] This process has given new momentum to PCB elimination efforts. International organizations such as the UN Global Environment Facility (GEF) are providing technical advice and funding, with the goal of implementing the POPs' Convention

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[30] EPA classifies chemicals into one of five possible cancer categories (A through E). Category B means "probable human carcinogen," the number 2 indicates that there is sufficient evidence in animals but inadequate or no evidence in humans [25].

[31] Other effects attributed to PCBs include thyroid dysfunction, headaches, dizziness, and nervousness, as well as low birth weight and poor infant habituation. Possible effects include liver and kidney damage, reproductive damage, respiratory illnesses like asthma, as well as depression/aggression [5].

[32] These pollutants are highly stable organic compounds that persist in the environment, accumulate in the fatty tissues of most living organisms, and are toxic to humans and wildlife.

[33] Governments will convene for the first meeting of the Conference of the Parties to the Convention (COP 1) in Punta del Este, Uruguay in May, 2005.

internationally, and eliminating all PCBs by 2025.[34] The Protocol's ultimate aim is to eliminate discharges, emissions, and leaks of POPs.

The POPs Convention requires the following actions on PCBs at the international level (many countries have already acted on these requirements) [30]:

- Immediately eliminate the production of PCBs [Article 3 1.(a)]
- By 2025, eliminate the use of PCBs in equipment [Part II (a)]
- Eliminate the export or import of equipment containing PCBs except for "environmentally sound waste management" [Part II (c)]
- Immediately eliminate the recovery of liquids containing PCBs at levels above 50 ppm for reuse in other equipment, except for maintenance and servicing operations [Part II (d)]
- Within two years, develop an action plan with the goal of the "continuing minimization and, where feasible, ultimate elimination" (through methods such as incineration) of the release of PCBs from unintentional production [Article 5 (a)]. "Best available techniques" and "best environmental practices" are to be used for existing and new sources of releases. For Canada, Mexico, and the US, it is expected that this action plan will be developed through the North American Regional Action Plan system.
- Develop inventories of PCBs in use and in stockpiles [Article 6 (a)]. Dispose of PCB wastes "in such a way that the persistent organic content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic content is low" [Article 6 1.(d)]
- Develop strategies to identify sites contaminated by PCBs and "if remediation of those sites is undertaken it shall be performed in an environmentally sound manner" [Article 6 1.(d)]

Current protocols include a global ban on production of most POPs and limitations on the uses of PCBs. The Ordinance on Hazardous Waste for PCBs covers the management of PCB equipment as well as PCB-contaminated oils from transformers and capacitors. There are no numerical standards in the regulation, but as guidance, all oils containing less than 50 ppm PCB are permitted for use during the normal lifetime of the equipment in which they are housed. (In contrast, the Swedish government advocates that oils containing more than 2 ppm are regarded as hazardous waste.) The current European Union directive sets the limit at 50 ppm [19]. This international convention also aims to clean dumpsites and stockpiles of toxic chemicals and pesticides [30,31].

Linked to the European phase-out of PCBs, there have been continuous monitoring programs particularly in the Baltic Sea.[35] In addition, the United Nations Environmental Program has been commissioning research to analyze the available global capacity for the permanent destruction of PCBs [11].

United States–Federal Regulations

In 1976, Congress enacted the Toxic Substances Control Act (TSCA Public Law 94-469 -1976) to identify and control toxic chemical hazards to human health and the environment. This Act constitutes the principal regula-tory framework for PCBs and has been instituted to prevent unreasonable risks. The US EPA has the authority to "select from a broad range of control actions under TSCA; from requiring hazard warning labels to outright bans on the manufacture or use of especially hazardous chemicals" [34]. TSCA PCB regulations, codified at 40CFR part 761, "apply to all persons who manufacture, process, distribute in commerce, use, or dispose of PCBs or PCB items, including dielectric fluids, contaminated solvents, oils, waste oils, heat transfer fluids, hydraulic fluids, paints, sludges, and spill contaminated soils. TSCA regulations apply as well to items that have been in contact with PCBs" [35]. Specific rules addressing the use and disposal of PCBs are provided in the federal regulations. PCB releases are also regulated by the Clean Water Act (CWA), Clean Air Act (CAA), and Resource Conservation and Recovery Act (RCRA), and PCB releases are reported in the Toxic Chemical Release Inventory (TRI) and to the National Response Center (NRC). Some measures (under various laws and regulations) of importance to this region are outlined below [36]:

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[34] The Convention's Annex A Part II envisages the elimination of the use of PCBs in equipment by 2025 without stipulating the concentration level below which no action would be required. However, it does go on to set priorities for such action. Thus, it requires "determined efforts" to remove from use all equipment containing ≥500 ppm PCBs and has issued a directive to endeavor to remove from use equipment containing ≥50 ppm by 2005. Further information on the Convention and actions on PCBs it requires is available on the Convention's web site at *www.pops.int*, Articles 3, 5, and 6, Annex A Part II and Annex C.

[35] Since the early 1970s, there has been a decrease in PCB levels in biota. For DDT the decrease has been even larger [32,33].

- Prohibition of manufacture, sale, and distribution of PCBs in US
- Use of PCBs limited to certain “totally enclosed” uses, such as transformers and capacitors
- PCBs regulated for safe disposal (according to a concentration-based hierarchy)
- Required reporting on certain accidental releases of PCBs
- Specifications that labels be used to identify certain electrical equipment containing over 500 parts per million. Two types of labels are used, a large PCB sign, or a small PCB sign.[36] The vault or machinery room door, or any other means of access to PCB transformers (except grates and manhole covers) must also be marked with PCB labels.
- PCB transformers that contain ≥60,000 ppm PCBs must be inspected for leaks quarterly. PCB transformers with <60,000 ppm PCBs, and those with appropriate secondary containment must be inspected for leaks at least annually. Action to address leaks is required to commence as soon as possible and no later than 48 hours of discovery of the leak.
- To prevent PCB fires, EPA requires that high-voltage network PCB-containing transformers be removed or reclassified and that enhanced electrical protection be added on many types of PCB transformers in, or within 30 meters, of commercial buildings.
- By December 1998, all known transformers containing PCBs 500 parts per million or greater were required to be registered with EPA.[37]
- All transformer locations (≥500 parts per million PCB) must be cleared of stored, combustible materials (solvents, paints, paper, etc.)
- Small nonleaking PCB capacitors may generally be disposed of as municipal solid waste (TSCA 40CFR, part 761.60 subpart D–Storage and Disposal).

Other Federal Regulations

1. The Food and Drug Administration has PCB concentration limits on certain foods [37,38]. Some of these limits are milk and cheese (fat basis 1.5 ppm), eggs (0.3 ppm), meat (3 ppm), poultry (3 ppm), and fish (2 ppm); as summarized in page 620 of ATSDR [6].
2. The US EPA sets a maximum contaminant level for PCBs in drinking water of 0.0005 mg/L [39]
3. The US EPA sets risk based fish consumption limits based on fish tissue concentrations. Limits vary depending on whether cancer (1 in 100,000 risk level) or noncancer effects are taken into account. For instance, for noncancer effects, if fish contains 0.094-0.19 ppm PCBs, the consumption limit is one meal (227 g or 8 oz) per month. For cancer protection, the limits are more stringent: no more than one meal of fish containing 0.023 to 0.047 ppm PCBs should be eaten per month, and none should be eaten if the fish contains > 0.094 ppm [40].
4. The Occupational Safety and Health Administration (OSHA) has standards for two types of Aroclors, based on an 8-hour time-weighed average [41][38]:
   - The permissible exposure limit (PEL) for chlorodiphenyl (42% chlorine, or Aroclor 1242) is 1 *milligram* per cubic meter of air (1 mg/m3).
   - The PEL for chlorodiphenyl (54% chlorine, or Aroclor 1254) is 0.5 mg/m3.
5. The National Institute for Occupational Safety and Health (NIOSH) establishes a *recommended exposure limit* (REL) for Aroclor 1242 and 1254 of 1 *microgram* per cubic meter, based on a 10-hour time-weighed average [42].

New York State Regulations

New York State Department of Environmental Conservation has set the following ambient water quality standards:

- For the protection against cancer in humans eating fish of 1 pg/L (ppq)
- For the protection of aquatic/wildlife resources: 0.12 ng/L (ppt) for both freshwater and estuary/coastal waters (saline)

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[36] The large label reads “Caution: Contains PCBs, a toxic environmental contaminant requiring special handling and disposal in accordance with US EPA regulations 40 CFR 761. For disposal information contact the nearest EPA office. In case of accident or spill, call toll free the US Coast Guard National Response Center.” The small label states, “Caution: Contains PCBs. For proper disposal contact US EPA.”

[37] Reporting of transformers known to contain PCBs was required “by” December 1998. Additional units found by registrants after this date do not have to be reported. PCB transformers found at facilities that had not yet registered need to be reported within 30 days of being identified as PCB units.

[38] Both of these standards were developed before it was known that PCBs can cause cancer and reproductive effects, and they do not cover many other forms of PCBs.

New Jersey State Regulations

New Jersey Department of Environmental Protection provides the following surface water quality criteria (NJ AC7, 9B regulation):

- For human health protection against cancer: 170 pg/L
- For freshwater aquatic/chronic criteria: 14 ng/L
- For saline (estuary/coastal) aquatic/chronic criteria: 30 ng/L

B. HISTORICAL PRODUCTION AND THE FATE OF PCBS

B1. Global and US Production

PCBs were first created in 1881, and commercial manufacturing began in 1929 [43]. PCBs were produced worldwide for a variety of industrial uses and employed either in closed applications (transformers, capacitors, circuit breakers, heat transfer systems, and other electrical equipment) or in open or semiopen applications (paints, plastics, adhesives, surface coatings, wood preservatives, pesticide extenders and pressure-sensitive copying paper [6], and hydraulic systems, compressor units, and vacuum pumps [44]). One report estimates that ~60% of PCBs total global production was used as dielectric fluids, ~12% as hydraulic and heat transfer fluids, and ~28% as ingredients used in manufactured products (e.g., plasticizers, paints, and coating materials) [44].

The major producers of PCB compounds include the multinational company Monsanto and its Belgium-based subsidiary Solutia Chemical Division; the German company Bayer AG; the French consortium Prodelec; as well as Kanegafuchi Chemicals Industry Co. Ltd., and Mitsubishi in Japan; and Orgsteklo and Orgsintez in the former USSR [45]. From the late 1970s to 1993 (depending on location) these companies ceased to produce PCBs and industrialized countries gradually banned their manufacture [46]. Their PCBs compounds were marketed under diverse trade names, including those listed in Table B1.

PCBs in various products such as transformers and capacitors were often identified by their trade names, which appeared on product labels or manufacturers' nameplates. In the US, the most common commercial name used was "Aroclor." "Askarel" was the commercial name used for synthetic liquid blends employed for transformers [12], containing PCBs (40–60%) and solvents such as trichlorobenzene [47]. Two of the most common PCB compounds are Aroclor 1242 (significant in the Hudson River) and Aroclor 1254 [9]. Table B2 describes applications classified by Aroclor-type used prior to 1971, when PCB sold in the US were voluntarily restricted to closed systems (e.g., transformers, capacitors).

PCBs were used in coolant or dielectric fluids used in transformers and capacitors or as heat transfer fluids (because of their high boiling point and low flammability). PCBs were also used in open applications (e.g., paints) because of their potential to protect materials from harsh weather conditions, to resist moisture in underwater structures, or as flame-retardant coatings [48].

The Monsanto Industrial Chemicals Company was practically the only domestic manufacturer of PCBs in the US [12], with annual sales averaging ~15,000 tons[41] (peak production in 1970 was ~85 million pounds or 38,600 tons) [9]. Monsanto's total production of pure PCB from 1929 to 1977 was ~636,000 tons[42] [49,50]. Another company, Geneva Industries, manufactured PCBs in the US for a short time, from 1971 to 1973, with its total production reaching only 413 tons[43] [33].[44] In the

Table B1. Trade names and other synonyms used to commercialize PCBs

Trade names of various PCB mixtures	Country where sold
Aceclor, Phenoclor, Pyralene	France
Santotherm	France, UK
Therminol	France, USA
Clophen	Germany
Apirorlio, DK, Fenchlor	Italy
Kanachlor, Kanechlor	Japan
Ducanol, Plastivar, Pyroclor	UK
Askarel,* Aroclor**	UK, USA
Asbestol, Bakola 131, Chlorextol, Diaclor, Dykanol, Elemex, Hydol, Hyvol, Inerteen, Noflamol, Pydraul, Pyranol, Saf-t-Kuhl	USA
Sovol, Sovtol	Former USSR

Source: Washington State Department of Ecology, 2000 [47].

*Askarel is the trade name for transformer fluid blend of PCB and trichlorobenzene.[39]

**Aroclor is Monsanto's commercial name for specific PCB mixtures and is the standard for gas chromatography analysis of PCB concentration, rather than congener number.[40]

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[39] Information from David Roche, Con Edison, personal communication, November 12, 2004.

[40] Ibid.

[41] Throughout the text, tons are metric tons, unless specified as *US tons.*

[42] A few references report this quantity as 700,000 *US tons,* but is given in our text as metric tons.

[43] This reference reports the quantity manufactured by Geneva industries as 454 *US tons.*

[44] The "Geneva Industries" facility in Houston, Texas, manufactured biphenyl, polychlorinated biphenyls (PCBs), phenyl phenol, naptha, and Nos. 2 and 6 fuel oils. In June 1967, Geneva Industries started manufacturing biphenyl. Toluene and fuel were produced as by-products. In 1972, this refinery began to produce phenoxy phenol. PCBs were produced primarily as a by-product. In November 1973, Geneva Industries declared bankruptcy. The site has been investigated for soil contamination. Five different corporate entities have owned the facility since 1967. Prior to 1967, the land was used for petroleum exploration and production [51].

Table B2. Common applications and Aroclor usage (prior to 1971*)

	Aroclor								
Application	**1016**	**1221**	**1232**	**1242**	**1248**	**1254**	**1260**	**1262**	**1268**
Electrical capacitors	✓**	✓		✓		✓			
Electrical transformers				✓		✓	✓		
Vacuum pumps					✓	✓			
Hydraulic fluids			✓	✓	✓	✓	✓		
Gas-transmission turbines		✓		✓					
Plasticizer in resins					✓	✓	✓	✓	✓
Plasticizer in rubber		✓	✓	✓	✓	✓			
Adhesives		✓	✓	✓	✓	✓			
Wax extenders				✓		✓			✓
Pesticide extenders						✓			
Dedusting agents						✓	✓		
Sealants/caulking material						✓			
Inks						✓			
Lubricants						✓			
Cutting oils						✓			
Carbonless copying paper				✓					
Heat transfer systems				✓					
Galbestos									✓

Source: Adapted from ATSDR, 2000, and US EPA 1987 [6,12].

*Use of PCBs in open applications started in 1957; before that date most of the PCB production had been used for closed systems. In 1971 Monsanto restricted sales of PCBs to closed applications only.

**Aroclor 1016 was used to manufacture capacitors (for further information, refer to ATSDR, 2000 [6]; chapter 5, table on p.470).

period from 1929 to 1977, an estimated 568,000 tons[45] of PCBs were sold in the US for electrical equipment and other uses. In addition, ~68,000 tons[46] [52] of PCBs were exported, including 44,000 metric tons to Canada.[47] Scant information is available about PCBs imported to the US, except that in 1972 ~300 to 500 tons of PCBs were imported from Italy to use in a "wax casting" process [12].[48]

Until 1957, virtually all the produced PCBs had been used in manufacturing transformers and capacitors. Since then, PCBs were also used for other industrial applications, such as semiopen and open applications (e.g., plasticizers). Tables B3 and B4 show the distribution of US domestic sales from 1957 until 1975 by Aroclor type and in terms of application. The national data (and watershed estimates extrapolated[49] from them) may be useful for track-down programs.

PCB production declined once their harmful effects as well as bioaccumulation in the environment and organisms became evident. In 1971, Monsanto (the virtual sole producer of PCBs in the US) restricted sales of PCBs to closed systems [12,54]. Approximately 98% of Monsanto's production *since* 1970 at a facility in Sauget, Illinois, consisted of seven types of Aroclors (1016, 1221, 1232, 1242, 1248, 1254, and 1260) [9]. In 1976, the US regulated PCBs under the Toxic Substances Control Act (TSCA) and subsequently prohibited their production, sale, and distribution. However, their usage continued to be allowed under special conditions, such as in totally enclosed applications [55].

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[45] This quantity has also been reported as 625,000 US tons.

[46] Or 75,000 US tons.

[47] No PCBs were produced in Canada [53].

[48] PCBs were used as fillers to investment (molding) casting waxes to reduce the wax content and better control the volumetric shrinkage of the ceramic mold.

[49] Calculated by adjusting the national data for the national economy by the level of economic activity represented by the Watershed region. Some may argue that the current level of economic activity used here (5.8% of the national) is lower now than when the equipment was being commercialized, and thus our calculation probably underestimates the actual quantities sold in the Watershed region.

Table B3. US Domestic sales of selected Aroclors 1957–1975* (metric tons)

Aroclor type	Nationwide	Watershed	Percentage of total production#
1242	196,007	11,368	54.2%
1254	56,239	3,262	15.6%
1260	41,613	2,414	11.5%
1016	31,692	1,838	8.8%
1248	26,912	1,561	7.4%
1221	3,420	198	0.9%
1262	3,261	189	0.9%
1268	1,310	76	0.4%
1232	926	54	0.3%
Total	**361,380**	**20,960**	**100.0%**

Source: North American Commission for Environmental Cooperation, 1996 [50].

* Production in the US started in 1929. Data through first quarter 1975 only.

Watershed sales are 5.8% of national sales. Therefore, these percentages apply to both.

Table B4. US Domestic sales by application 1929–1975 (metric tons)

Application	Nationwide	Percentage of total production	Reliability of estimate (%)	Watershed estimate
Capacitors (large & small)	286,364	50.3	±15	16,609
Transformers	152,273	26.7	±10	8,832
Plasticizer applications	52,273	9.2	±5	3,032
Hydraulics/lubricants	36,364	6.4	±20	2,109
Carbonless copy paper	20,455	3.6	±15	1,186
Miscellaneous industrial	12,273	2.2	±10	712
Heat transfer	9,091	1.6	±20	527
Petroleum additives	455	0.1	±50	26
Total	**569,545***	**100.0**		**33,034**

Source: US EPA, 1997 and Versar, 1976 [52,54]. Information may be found at: http://www.chem.unep.ch/pops/indxhtms/cspcb02.html.

* Note that this total is higher than the total from Table B3 because it includes production since 1929 and includes all PCBs, not just the Aroclor blends reported in Table B3 from 1957 to 1976, 70% was dielectric fluid for transformers and capacitors, 7% fluids in hydraulic and heat transfer equipment, 3% plasticizers in copy paper, and 20% other uses.

Total worldwide PCB production from 1929 to 1989 has been estimated as 1.5 M tons [46] with an average of 26,000 tons produced globally each year. Another study estimates that ~1.3 M tons of PCBs were produced worldwide, with ~70% of this production allocated to the tri-, tetra-, and pentachlorinated biphenyls [45].[50] It is also estimated that ~97% of the global historical uses of PCBs took place in the Northern Hemisphere [45]. Even after the US took regulatory measures to prevent PCBs manufacturing, sale, and distribution, worldwide production averaged 16,000 tons per year from 1980 to 1984 and then ~10,000 tons

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[50] This estimate does not consider production from factories in Poland, Eastern Germany and Austria where PCBs were produced in unknown amounts [45].

[51] This 1998 report indicates that the production of PCB has not completely stopped in all countries of the world.

per year from 1984 to 1989 [11],[51] with some countries continuing production until 1993.[52]

B2. Fate of PCBs Produced in the US and Globally

Although most industrialized countries prohibited their production ~25 years ago, PCBs still remain a problem because they are persistent, bioaccumulative, and toxic (PBT) compounds that were broadly distributed through worldwide commercialization. It is estimated that of the total *global* production (~1.3 M tons), 31% is found in the environment[53], 4% has already been destroyed, and 65% remains in use or in storage [44].[54] A 1998 report pointed out that, at the global level, "the potential damage that may result from current PCB usage is double the damage caused until today" [11].

In the US, the US EPA estimated in 1976 that of the Monsanto PCB production sold domestically (>568,000[55] metric tons) ~60% (or 340,000 metric tons) remained in use, whereas 23% (or 132,000 metric tons) had been sent to landfills; 12% (or 68,000 metric tons) had been released to the environment; and 5% (or 28,000 metric tons) had been destroyed (incinerated) [12,50]. The agency also evaluated that approximately half of the manufactured PCBs were disposed of before the regulatory general prohibition took effect in 1978 [55]. Table B5 summarizes this information, and Table B6 shows the estimated direct releases of Aroclors to the US environment from 1930 to 1974, which does not include the 132,000 tons sent to landfills. In 1991, it was estimated that the total amount of PCB *bulk waste* in sites identified as contaminated with PCBs, ranged from 168 to 597 million tons. By 1988, the PCBs in use had decreased drastically, to 127,000 metric tons. In addition, EPA estimates that 26 million cubic meters of soils are contaminated with PCBs [57].

Estimating current distribution of PCB domestic production sold in the US

To understand the fate of total PCB sold in the US and more significantly how much remains in use today, it is important to have either (1) an updated inventory of PCBs in current use, or (2) an estimate of how much has been already released and sent for disposal since the last usage inventory.

The last broad assessment of PCB use in the US estimated that by 1988 ~127,890 metric tons (141,000 US tons) of pure PCBs remained in use [43,50,57]. No comprehensive inventory for PCBs remaining in use has been conducted in recent years. It is, therefore, difficult to accurately assess the amount of PCBs that are in use today in electrical equipment and other applications [50].

Releases may be estimated from the US EPA Toxic Chemical Release Inventory (TRI) database (which attempts to account for releases of pure PCB compounds) or from the National Emissions Inventory (NEI), as well as from information on waste management. PCB releases may also be estimated by applying release factors to in-use PCB electrical and other equipment. This type of estimation is conducted later for the Watershed region when discussing releases from electrical equipment for which PCB release coefficients are available.

Calculating releases from TRI and waste management reports

The US EPA TRI reports that the amount of PCBs that have been released (on- and off-site) in the United States from 1988 to 2002 is ~11,000 metric tons (see Table B7). Comparing this quantity to the amount of PCB estimated to remain in use in 1988 suggests that ~116,890 metric tons of PCB may still be in use in the US today.[56] However, the TRI data do not cover all PCB releases that may have taken place since 1988. Reporting to TRI is required only from facilities that fall under certain standard industrial classification (SIC) categories, have 10 or more employees and indicate manufacture, process, or usage above certain thresholds. The main challenges in using the TRI database for the PCB flow analysis can be summarized as the following:

- TRI includes estimates of PCB content in *contaminated* materials from remedial actions (e.g., soil, sludge, or dredged materials) sent to commercial "treatment, storage and disposal facilities" (TSDFs) or other authorized waste management services. Most estimates of PCB content of bulk waste are based on concentrations resulting from testing of limited samples. Therefore, its PCB content is not generally known, and, thus, it is not possible to estimate accurately the amount of PCB being discarded or released.
- Beginning in 1998, TSDFs became subject to TRI reporting and began to report estimates of PCB quantities disposed of "on-site" (quantities incinerated,

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[52] Such as Russia, as stated in Breivik, 2002 [45].

[53] No information about how much of the PCBs produced globally were incinerated, sent to landfills, or released to air, water, or soil was found.

[54] The uniform distribution of PCB in both hemispheres suggests that the atmosphere is a particularly important medium for the transport of PCBs. In fact, atmospheric transport has been cited as the most important mechanism of global transport of PCBs [56].

[55] Note that estimates from Table B4 sum to >569,000 metric tons, not 568,000 metric tons.

[56] In particular in 2002, the last year for which data have been obtained from TRI, *www.epa.gov/tri*.

Table B5. Production, uses, and fate of PCBs in the US, in metric tons (as of 1976)

- Produced*: 636,000
  - Exported: 68,000
  - Used: 568,000
    - Remaining in use: 340,000
    - Sent for disposal/ Entered environment: 228,000
      - Landfill: 132,000
      - Air, water, soil: 68,000
      - Incinerated: 28,000

From US EPA, 1997 [52].

* From 1957 to 1976, 70% was dielectric fluid for transformers and capacitors, 7% fluids in hydraulic and heat transfer equipment, 3% plasticizers in copy paper, and 20% other uses.

Table B6. Selected Aroclor estimated releases to the US environment (metric tons)

Year	Aroclor 1016	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260	Total
1930–1956	—	8,400	2,500	2,300	1,600	14,800
1957	—	900	300	300	400	1,900
1958	—	650	500	400	350	1,900
1959	—	1,000	700	500	500	2,700
1960	—	1,350	550	450	550	2,900
1961	—	1,850	800	600	600	3,800
1962	—	1,800	650	550	600	3,600
1963	—	1,650	950	500	700	3,800
1964	—	2,100	1,000	550	750	4,400
1965	—	2,700	1,000	650	500	4,900
1966	—	3,200	900	500	500	5,100
1967	—	3,400	800	500	500	5,200
1968	—	3,600	850	750	450	5,500
1969	—	4,200	1,000	1,000	450	6,600
1970	—	4,500	700	1,200	500	7,000
1971	100	1,500	50	300	100	2,000
1972	500	20	—	100	10	600
1973	500	100	—	200	—	800
1974	500	100	—	150	—	800
Total	**~1,500**	**~43,000**	**~13,000**	**~11,500**	**~9,000**	**~78,000**
% of total	**2%**	**55%**	**17%**	**15%**	**11%**	**100%**

Adapted from Versar 1976 [54]. The author reports many significant figures, which are rounded here. The term *environment* includes PCBs sent to landfills, air, water, soil, and incineration.

Table B7. US EPA TRI–US releases of PCBs expressed in pounds

Year	Total air emissions	Surface water discharges	Total on-site disposal or other releases	Total off-site disposal or other releases	Total on- and off-site disposal or other releases
1988	6	10	768	410,996	411,764
1989	0	264	264	469,526	469,790
1990	15	0	71,381	286,694	358,075
1991	0	0	0	112,850	112,850
1992	0	0	1	427,320	427,321
1993	0	0	265	164,205	164,470
1994	0	0	0	94,962	94,962
1995	0	0	0	34,432	34,432
1996	255	0	9,460	51,086	60,546
1997	0	0	6,794	980,846	987,640
Change in reporting (different on-site and off-site release categories from previous years)†					
1998	446	251	3,742,838	17,971	3,760,809
1999	531	2	10,165,009	21,852	10,186,861
2000*	1,154	29	1,415,212	34,426	1,449,638
2001	1,360	3	3,557,613	58,693	3,616,306
2002	5,201	31	1,250,363	762,174	2,012,536
Total in lb	**9,000 lb**	**590 lb**	**20,000,000 lb**	**3,900,000 lb**	**24,000,000 lb**
Total metric tons (T)	**4 T**	**0.3 T**	**9.2 T**	**1.8 T**	**11 T**

These figures are shown exactly as reported by EPA's TRI database, except for the conversion to metric tons.

* The threshold for reporting releases changed in 2000, to 10 lb.

† After 1998, total off-site disposal or other releases estimates may be included in the reported estimates of total on-site disposal or other releases thus, some double-counting may take place.

buried in approved PCB and/or hazardous waste landfills, or disposed of by other approved methods"[57]) and "off-site releases" (rarely equates to dispersal in the environment, but rather to transfers [e.g., to TSDFs]). Thus, except for that small amount of PCB "release" due to spills, the reported off-site transfers (releases) by industrial facilities are shipments of PCB waste for destruction by incineration, burial in an approved PCB landfill, or other approved PCB disposal. "On-site releases" reported by TSDFs are likely the burial of PCB waste in EPA-approved PCB landfills or hazardous waste landfills, or destruction of PCB waste in approved incinerators or by other approved alternate means. This new reporting system does not allow us to differentiate between PCB quantities released to land related to spills or discharges and estimated PCB content in bulk waste being reported by TSDFs, which are considered on-site "releases (releases to land)," even when PCBs are being stored at such facilities.

- Until 2000, the PCB reporting threshold was 25,000 lb per year for manufacturing and processing, or 10,000 lb for *"otherwise use."* Thus, the amount of pure PCBs reported by facilities manufacturing or processing or using PCBs below this thresholds was not accounted for and cannot be subtracted from the last inventory in order to estimate current usage. Notice that starting in 2000 the PCB reporting threshold (e.g., for manufacturing, processing or use) is 10 lb per year.

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[57] Thus, quantities reported under "on-site" releases increased, whereas those for off-site releases decreased.

Addressing the first two challenges above will facilitate the use of TRI when conducting material flow analyses of PCBs and will likely result in a better approximation of actual PCB release and/or current usage.

A different database reports air releases of different hazardous air pollutants (HAPs) for certain years only. For 1999, the EPA's National Emissions Inventory (NEI) reports that 67,132 lb or ~30.5 tons of PCBs were released to air in the US.[58]

Estimates of the amount of PCB-contaminated waste material are available since 1990. The US EPA estimates that between 1990 and 1994 ~3.4 million tons of wastes containing PCBs were sent to TSCA-permitted facilities nationwide, such as commercial TSDFs. The annual average of 68,000 tons per year has since decreased, with the 1998 reported quantities sent to TSDFs being only 5,858 tons of bulk waste contaminated with PCB (see Table B.10). Notice that the waste stream is expressed in terms of bulk waste containing PCBs and not the amount of pure PCBs actually discarded. Ninety percent of this PCB-containing waste is from remediation activities, including removal of contaminated soils, sludge, and sediments. The remaining 10% relates to PCB article containers (PCB waste containers), small capacitors, drained transformers, and other items.[59]

In summary, of the 127,000 metric tons of PCBs in usage nationwide in 1988, only ~11,000 metric tons of PCBs are accounted for today by the TRI database. It would be erroneous to assume that the balance (~116,000 tons) is still in use today. Since 1990, at least 3.4 million tons of waste material contaminated with PCBs have been recorded as sent to disposal facilities nationwide. Because the PCB content is not known, it is not possible to account for the PCB remaining in use today by subtracting quantities already released or sent for disposal from the last usage inventory.

Estimating Releases of PCBs in the Watershed Region

The US EPA TRI reports that an estimated ~2,500 tons of pure PCBs (~650 tons in the Watershed) have been reported as releases[60] in New York State from 1988 to 2002 (Table B8).

In New Jersey, the TRI database reports for the years 1990, 1993, and 2000 to 2002 indicated that 6 tons were reported as releases (off-site transfers); however, information is not available for 8 years in the period from 1988 to 2002 (see Table B9).

EPA's 1999 National Emission Inventory (NEI) indicates that 2,292 pounds (>1 ton) of PCB (Aroclor) was emitted to *air* in New York and New Jersey in 1999. Almost all of these PCBs were from the source category coded SCC 2610030000, which is described as "waste disposal, treatment, and recovery - open burning (residential, household wastes)."[61] Emissions to air from Superfund site cleanups are not included in the NEI unless a state reports the emissions to EPA.

Various NYS DEC Hazardous Waste Reports [59] specify that ~418,000 tons of waste ***containing*** PCBs were sent to commercial TSDFs from 1994 to 2000. No estimate of the amount of pure PCB in this bulk waste is available. In addition, during an approximate 30-year period ending in 1977, General Electric (GE) used PCBs in its capacitor manufacturing operations at its Hudson Falls and Fort Edward, NY, facilities.[62] It has been estimated that over 600 tons of PCBs (1,330,000 lb) were discharged into the Hudson River from these two plants from the 1940s to 1977 [60].

Table B10 summarizes the available information about PCB production and fate. If data gaps were researched and filled in, this table would add significantly to the understanding of how much PCB remains in use today and how much has been sent to disposal or released to the environment already. Therefore, this picture remains incomplete to determine the fate of PCB sold in the US and the Watershed.

The lack of a systems view approach about the total universe of PCB remaining in use prevents management and monitoring of proper disposal. Data gaps need to be addressed in order to decrease the uncertainty surrounding the fate of polychlorinated biphenyl compounds in the US and the Watershed region. Actual data, both at the regional and national level, will support efforts in pollution prevention and best management practices by providing key information to help determine priorities for action.

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[58] Information from the US EPA National Emissions Inventory, data query from *http://www.epa.gov/air/data* Data retrieved in October 2004.

[59] National estimates indicate that a record number of transformers and capacitors were retired between 1990 and 1994. Thus, the proportion of discarded PCB article containers, equipment, etc. may be even smaller today [58].

[60] Note that releases could include proper disposal as noted in the section *"Calculating releases from TRI and waste management reports"*, second bullet point.

[61] This information is available from AIRData at *http://www.epa.gov/air/data.*

[62] PCB oils were discharged both directly and indirectly from these two plants into the Hudson River. This included both permitted and nonpermitted discharges.

Table B8. On- and off-site releases of PCBs in New York as reported by TRI (in lb)

			New York*		
Year	Total air emissions	Total Surface water discharges	Total on-site disposal	Total off-site disposal	Total on- and off-site disposal
1988	0	0	0	32,700	32,700
1989	0	0	0	56,213	56,213
1990	0	0	0	0	0
1991	0	0	0	0	0
1992	0	0	0	0	0
1993	0	0	0	18,691	18,691
1994	0	0	0	2,899	2,899
1995	0	0	0	8,238	8,238
1996	0	0	0	4,382	4,382
1997	0	0	4,000	978,052	982,052
			Change in reporting[¥]		
1998	1	1	870,002	1,067	871,069
1999	2	1	1,640,003	11,402	1,651,405
2000**	11.5	1.03	499,313	1,085	500,398
2001	235.96	0.24	1,068,966	3,955	1,072,921
2002	134.3	0.02	241,034	94	241,128
Total lb	**384.76**	**3.29**	**4,323,318**	**1,118,778**	**5,442,096**
Total Tons	**0.2 tons**	**0.001 tons**	**1,965 tons**	**508 tons**	**2,474 tons**

* Data compiled from the Toxic Release Inventory database, TRI Explorer, *http://www.epa.gov/tri*. Zero (0) indicates the report indicated zero releases. Values are given in pounds, as reported in the TRI.

¥ Since 1998, several facilities previously reporting as “off-site releases” (e.g., TSDFs) started reporting under the “on-site releases” category. After 1998, total off-site disposal or other releases estimates may be included in the reported estimates of total on-site disposal or other releases, thus, some double-counting may take place. Notice that the waste sent for offsite disposal by NY facilities may be sent to disposal facilities outside NY State.

**The threshold for reporting releases changed in 2000, to 10 lb.

Table B9. On-site and off-site releases of PCBs in New Jersey as reported by TRI (in lb)

			New Jersey*		
Year	Total air emissions	Total Surface water discharges	Total on-site disposal	Total off-site disposal	Total on- and off-site disposal
1988	0	0	0	—	0
1989	0	0	0	0	0
1990	0	0	13,188	22,183	35,371
1991	—	—	—	—	—
1992	—	—	—	—	—
1993	0	0	0	255	255
1994	—	—	—	—	—
1995	—	—	—	—	—
1996	—	—	—	—	—
1997	—	—	—	—	—
			Change in reporting¥		
1998	—	—	—	—	—
1999	—	—	—	—	—
2000**	0.49	2.63	18	21	39
2001	0.61	0	0.6	21	22
2002	0.83	0	0.8	24	25
Total lb	**1.93**	**2.63**	**13,207**	**22,504**	**35,711**
Total metric tons (T)	**0.001 T**	**0.001 T**	**6 T**	**10 T**	**16 T**

* Data compiled from the Toxic Release Inventory database, TRI Explorer, *http://www.epa.gov/tri.* Dashes indicate that no reports were submitted by New Jersey facilities (e.g., if they used PCB in quantities below the threshold). Zero (0) indicates the report indicated zero releases.

¥ Since 1998, several facilities previously reporting as "off-site releases" (e.g., TSDFs) started reporting under the "on-site releases" category. After 1998, total off-site disposal or other releases estimates may be included in the reported estimates of total on-site disposal or other releases, thus, some double-counting may take place. Notice that the waste sent for offsite disposal by NJ facilities may be sent to disposal facilities outside NJ.

**The threshold for reporting releases changed in 2000, to 10 lb.

Table B10. Allocation of manufactured PCBs between use and disposal, in metric tons (T)

	Production	Still in use	Estimated releases of pure PCBs	PCB-contaminated waste sent to TSDFs
Worldwide	1.2 M–1.3 M T	Undetermined	360,000–370,000T by 1969 600,000 T by 1976	Undetermined
US Total	Total Produced **~636,000 T** (up to 1976) Exported **~68K T** Sold Domestically **~568,000 T**	340,000T (1976) **127,000 T** (1988) [50] of pure PCB	TRI data, 1988–2002*† **11,000 T** NEI Data (1999): **30.5 T**	EPA (1990–94) [58]] Bulk weight: **3.4 M T**** (68K T average/yr, but in 1998 ~6K T)
NY/NJ	Estimate of PCB sold in Watershed before 1976: **33K T**¥	Total (1988): **7,366 T**¥	GE discharges **600 T** TRI data (1988–2000):† NY 2,500 T NJ 16 T **NEI Air Data (1999): >1 T** (NY: 860 kg; NJ: 181 kg)	NYS DEC (1994–2000) [61] Bulk weight with unknown PCB content: **418,000 T**§

* US EPA, TRI, data compiled from individual annual reports (1988–2001).

** This estimate indicates bulk weight, not PCBs; 90% of the PCB-containing waste is bulk waste and 10% is waste from PCBs containers, transformers, capacitors, etc. TRI is reporting estimates of pure PCB while TSCA reports bulk waste contaminated with PCBs.

† The amount released as described by TRI does not necessarily always imply a release to the environment. These TRI release estimates for pure PCBs are likely to be a measure of approved disposal to and by TSDFs.

¥ Extrapolated from the national data to the regional population adjusted by the level of regional economic activity (5.8%).

§ Quantities in original report are expressed in U.S. tons and have been converted to metric tons

C. SOURCES AND PATHWAYS OF PCB MOBILIZATION IN THE NY/NJ HARBOR WATERSHED

To try to stem the ongoing inputs of polychlorinated biphenyls to the Harbor today, it is important to identify the sources contributing to current PCB mobilization. The inputs of PCBs to the Harbor may be linked to products, processes, and activities as well as to remobilization and releases from contaminated sites. Potential sources of PCBs include manufacturing facilities, utility and nonutility transformer stations, and regulated and unregulated disposal sites [62] and other contaminated areas. The use of products containing PCBs is still permitted for certain "closed" applications (i.e., transformers, capacitors); yet, PCBs in such products may be transported to the environment by accidental leaks or fires, spills during routine maintenance, or through improper disposal. Other processes contributing PCBs to the NY/NJ Harbor Watershed include incidental releases to the environment (water/air) from industrial processes such as the inadvertent generation of PCBs during pigment manufacturing; or the usage of contaminated products (e.g., ferric chloride); or from recycling of PCB-contaminated materials (e.g., metals and carbonless copy paper[63]).

At present, most of the PCBs enter the Harbor through runoff, tributary inputs, volatilization, and deposition as well as remobilization from previously contaminated sites (e.g., Superfund, brownfields, and sediments[64]). Section C1 reviews the pathways of PCBs to the Harbor and summarizes the findings from the regional mass balance assessment. The full mass balance analysis is included in Appendix A. Section C2 discusses specific sources of PCBs in the Harbor Watershed, such as products, processes, and contaminated sites.

Because of the impacts of PCBs on the NY/NJ Harbor Watershed, there has been a significant effort to understand where the PCBs are in the Harbor sediments, biota, and atmosphere. In fact, this report will be the second report on PCBs from the New York Academy of Sciences. In 1988, the New York Academy of Sciences published a report from the New York Bight Initiative titled "Managing PCBs in the Hudson/Raritan Estuary and the New York Bight System" [63]. This document was the result of a similar process to this current one, where a diverse group of individuals representing all sides of the PCBs issue were brought together to try to reach consensus on managing the New York Bight. The document includes management recommendations and research priorities, some of which have been accomplished in the 16 years since this report was published; however, there is still a long list of actions that will be reiterated in this current report.

One of the largest and most comprehensive ongoing programs is the New York–New Jersey Harbor Estuary Program.[65] Through its Comprehensive Conservation and Management Plan (CCMP) the program has specific goals for reducing PCBs inputs in the Harbor as part of its overall goal "to establish and maintain a healthy and productive ecosystem with full beneficial uses." The Contaminant Assessment and Reduction Program (CARP) "is attempting to understand the fate and transport of contaminants discharged into the entire estuary, and use this information to take necessary action." Through the CARP program, there has been an extensive data set collected on PCBs concentrations throughout the Harbor (and an array of other contaminants).[66] These data along with data collected from previous studies are being used to track sources and model Harbor contaminants.[67]

The EPA's Regional Environmental Monitoring and Assessment Program (REMAP) was undertaken to fulfill the data needs of the Hudson Estuary Program. REMAP data (1993–1994 and 1998–1999) include sampling of surficial sediments for contaminants (including PCBs), toxicity, and community structure.[68]

The New Jersey Atmospheric Deposition Network (NJADN) is part of a national monitoring program to look at the atmospheric deposition and exchange of a suite of contaminants including PCBs. This project is pro-

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[63] Carbonless paper containing PCBs may enter the recycling stream at paper recycling operations. Yet, it is estimated that only 1% of the carbonless paper containing PCBs remains in circulation today. This estimate was provided by Paul Peterman, Analytical Chemist, USGS, Columbia, MO; ppeterman@usgs.gov Personal communication November 19, 2003.

[64] Although the disposal of PCBs in rivers was mostly reduced by the 1979 general prohibition of PCB production, distribution and commercialization, and any current discharges are subject to federal or state permits such as the National Pollutant Discharge Elimination System (NPDES) or State Pollutant Discharge Elimination System (SPDES), once released to the environment PCB persist in river sediments.

[65] NY/NJ Harbor Estuary Program (HEP), *http://www.harborestuary.org/*, and Steinberg, 2004 [64].

[66] The CARP sediment and contaminated transport and fate model for NY-NJ Harbor is expected to be completed by the end of 2005.

[67] Further information about these studies is summarized in the Hudson River Foundation's web site, *http://www.hudsonriver.org/carp.htm*

[68] This information is available from EPA's Remap Region 2 NY/NJ Harbor System, web site page: *http://www.epa.gov/emap/remap/html/docs/nynjharbor.html*

viding a systematic view of the atmospheric fluxes of PCBs to the Harbor–something that was not included in previous mass balance efforts because there were no available data.

C1. Mass Balance of Ongoing Sources of PCBs to the NY/NJ Harbor

As the first step to understanding PCB loadings[69] to the Harbor, a mass balance of the major sources and sinks of PCBs has been constructed.[70] While the conclusions of the mass balance are in some cases constrained by the lack of data, this region is much more data-rich than many other watersheds (see above description of some of the major PCB data collection programs in the region). This puts this region in a unique position to be able to have a better understanding of the major pathways as we define pollution prevention strategies.

The purpose of this mass balance in the context of the larger industrial ecology/pollution prevention analysis is to first help identify the largest ongoing inputs of PCBs in the region (the medium of conveyance of PCB to the Harbor) so that we can most effectively focus our recommendations into the specific primary sources of these PCBs. For example, in our mercury study [66], we found that the amount of mercury entering the Harbor from atmospheric and wastewater inputs were nearly equal; however, when one considered the pathways and the likelihood of methylation of that mercury, the wastewater pathway became more important, and thus our pollution prevention efforts prioritized these sources.

As is the case for many contaminants in the Watershed, PCBs have an affinity to particles and therefore are most often transported downriver via particles. Therefore, to construct a mass balance requires an understanding of the overall sediment transport and how much material is entering the Harbor via each of the major tributaries (including the Hudson). Sediment mass balances have been previously constructed and these were used in the mass balance analysis. What is not yet well defined is how materials move around within the Harbor. This is crucial to understanding sediment (and therefore contaminant) redistribution within the Harbor and to understand where areas of high resuspension and deposition may occur. With the advent of new technologies that allow for less costly and less labor-intensive data collection, more research is under way to quantify sediment transport within the Harbor and in its major tributaries.

Sources of PCBs to the NY/NJ Harbor considered in our mass balance report include:

- Tributaries (including the Hudson River)
- Atmospheric deposition via wet and dry particle deposition and gross gas absorption
- Wastewater treatment plant discharges
- Combined sewer overflows
- Leachate from landfills
- Runoff

As noted in the full mass balance analysis (see Appendix A), other processes could also be important sources of PCBs to the NY/NJ Harbor. Because there are no data on these sources from the region, we attempt to evaluate their importance in the industrial ecology assessment in the next section. These include unidentified point sources (e.g., pigment manufacturing processes [67]); runoff of PCB-laden soils and dust from contaminated sites (e.g., Superfund sites, rail yards); and leaking/spills from PCB-containing transformers and capacitors; and ship paint [68-70]. In the mass balance, these processes are partially accounted for in the tributary inputs, assuming these sources are found along the tributaries and upstream. Runoff from contaminated sites within the Harbor boundaries itself may be partially addressed in the estimates of runoff. Leaching of PCBs into groundwater and subsequent transport into the NY/NJ Harbor is thought to be unimportant, as most of the PCBs are expected to remain associated with the large amount of solids in the aquifer rather than in the dissolved phase and leach into the estuary.

Processes considered in this report that remove PCBs from the water column of the NY/NJ Harbor include:

- Advection of dissolved or suspended sediment-bound PCBs out of the NY/NJ Harbor into the coastal Atlantic Ocean
- Volatilization of dissolved PCBs into the atmosphere
- Removal of sediment-bound PCBs via disposal of dredged sediments outside the NY/NJ Harbor
- Accumulation or burial of sediment-bound PCBs with sediment in the NY/NJ Harbor*

* Although accumulation of sediment-bound PCBs in the estuary can remove them from direct exposure to the water column, it does not remove them from the estuary itself and therefore is not truly a loss process, especially because they may still be available to sediment-dwelling

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[69] Loadings = inputs. Thinking of the Harbor as a box, loadings are the addition of PCBs to that box, either from air, water, or groundwater or associated with particles [65].

[70] The full mass balance document [65] is appended to this report for those who would like more detail about the mass balance.

organisms. Any activity or event that disturbs the sediments can potentially re-expose the sediments to the water column, and in some cases they can become a source rather than a sink of PCBs.

PCB Annual Budget

Loadings of PCBs to the NY/NJ Harbor are dominated by inputs from the Hudson River at the Newburgh Bridge, which constitute ~56% of the total. This includes loadings at the Troy Dam, the Mohawk River, and potentially the lower Hudson River. It is estimated that PCB inputs at the Troy Dam represent about half the PCB loads to the Estuary [65,71] and therefore dominate the inputs at the Newburgh Bridge. This conclusion is also similar to the findings of a 1997 US EPA report [72] that estimated that 54% of the PCB load in the Estuary was derived from the Upper Hudson (at Troy Dam). Combined Sewage Overflows (CSOs) and runoff from the urban area surrounding the estuary are the second most important sources of PCBs to the estuary, each contributing ~17% of the total PCB load. Wastewater and atmospheric deposition are of roughly equal importance, each composing ~5% of the total PCB load. Approximately half of all the *PCB losses* from the NY/NJ Harbor are caused by volatilization.[71] Accumulation in the sediments represents 20% of the PCB removed from the water column, whereas removal via dredging accounts for another 20% of the PCB losses in the system. Tidal exchange with the Atlantic Ocean accounts for ~14% of the PCB losses.

The loadings and losses are associated with varying degrees of uncertainty. The Hudson River load is known with more certainty because of decades of measurements. The other loads rely on fewer data points and are based mostly on the CARP data [73]. In general, loadings and losses are calculated by multiplying a concentration by a flow rate. In most cases, the concentration term is associated with the largest uncertainty because a limited number of measurements can never capture the natural variability in a system as large and dynamic as the NY/NJ Harbor Estuary. More measurements can always reduce uncertainty, but, as noted above, the NY/NJ Harbor Estuary is perhaps the most studied system in the world with respect to PCB contamination. Thus, there are only a few areas where an additional 10 or 20 PCB samples will greatly reduce uncertainty in the PCB mass balance for the Estuary. The notable exception is stormwater, which may represent the second largest loading and for which very few measurements are available. In contrast, flow rates are much less uncertain than PCB concentrations for the important tributaries and for wastewater and CSO inputs. However, flow is still uncertain, and a better estimate of stormwater inflows to the estuary would reduce the uncertainty in the stormwater PCB loading. In other words, the stormwater PCB load is highly uncertain *not only* because of the scarcity of PCB concentration data, *but also* because of the uncertainty in the stormwater flow. However, more PCB stormwater data are currently being gathered by NYS DEC for the CARP program. Stormwater flow data are inherently difficult to measure, but efforts are under way to better quantify these flows for the region.

Overall, the inputs of PCBs to the NY/NJ Harbor are estimated to be 444–883 kg/yr. Losses from the NY/NJ Harbor are estimated to be 746–1,631 kg/yr.[72] Possible interpretations of these loading and losses are:

1. Loadings of PCBs in the Estuary equal losses (i.e., the mass balance is closed), suggesting that the true inputs to the system are near the upper end of the estimates and/or the true losses to the system are near the lower end of the estimates.
2. The true loadings and losses of PCBs in the Estuary are closer to the median estimates, suggesting that PCBs previously stored in the estuary are now being lost from the system or buried in sediments.

To gain a better understanding of the system, it is important to examine the loads and losses by homolog. When the mass balance is broken down into homolog groups, a different pattern emerges. Although the mass balance may not be closed for the sum of PCBs, it is essentially closed for homologs 6–9. Losses appear to exceed inputs only for homologs 3, 4, and perhaps 5. These are the same homologs most susceptible to volatilization. They are also the homologs most prevalent in the Hudson River load. In other words, both the sources and losses are very different for the low molecular weight (MW) PCBs versus the high-MW PCBs. Approximately 82% of trichlorobiphenyls (homolog 3) and 66% of the tetrachlorobiphenyls (homolog 4) in the estuary come from the Upper Hudson. Approximately half of all the losses of these two homologs are caused by volatilization, and the mass balance is probably not closed. The median estimates would suggest that perhaps 400 kg of tri- and tetrachlorobiphenyls, which

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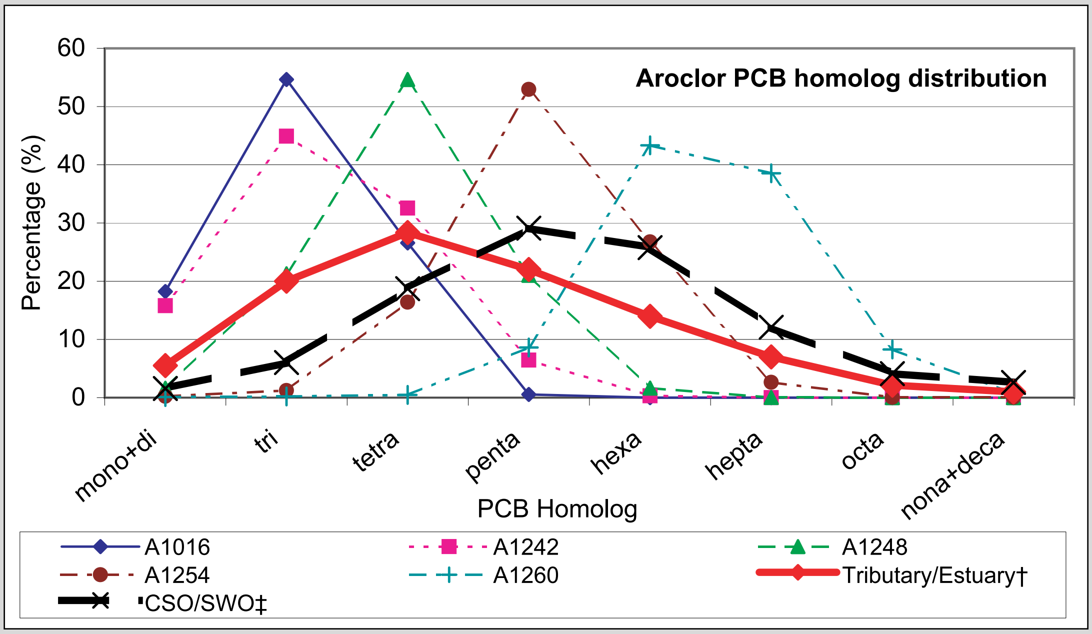
[71] Using the Harbor box analogy, a loss means any PCBs that leave the Harbor box. This does not imply destruction or safe disposal; it simply means that we define the Harbor geographically and losses are PCBs that have left that specific geographic area.

[72] See complete mass balance document in Appendix A for the details of these estimates.

PCB CONGENER PATTERN ANALYSIS

PCB congener pattern analyses may assist in track-down efforts. The figure below shows the distribution across homologs for five of the most common Aroclors. Aroclors are made up of different congeners, which group into homologs based on the degree of chlorination (e.g., tetra refers to PCBs with four chlorine atoms). The percentage (by weight) of each homolog that makes up each Aroclor is represented by the different lines on the graph. For instance, Aroclor 1016 is made up of ~ 18% mono and di-, 55% tri-, and 27% tetra-chloro biphenyls. This information may be useful to compare with the homolog (or congener) patterns seen in the environment, to try to identify specific Aroclors (and therefore possibly sources).

For example, the figure also shows the mean homolog composition of preliminary tributary/estuary whole water and CSO/SWO (storm water overflow) data from NJ.



Homolog distribution data for Aroclors from EPA *http://www.epa.gov/toxteam/pcbid/aroclor_comp_frame.htm*

Mean Tributary/Estuary and mean CSO/SWO data from NJ Toxics Reduction Work Plan (NJTRWP): Preliminary data provided by Joel Pecchioli, personal communication, November 29, 2004 and February 7, 2005.

†Loadings below head of tide. Mean of the mean distributions of the samples at each of 19 sampling stations, it assumes that 75% of the PCBs are in the suspended fraction and 25% in the dissolved fraction.

‡Overall mean of the PCB homolog distribution for all of the individual NJ/CARP CSO and SWO samples (29 samples).

A visual inspection of the figure reveals that Aroclor 1260 is probably not an important component of tributary/estuary samples. The homolog pattern may be explained by some combination of the other Aroclors (1016, 1242, 1248, and 1254).

CSO/SWO samples are shifted toward higher molecular weight congeners. Aroclors 1016 and 1242 do not seem to be major components of these samples. The different homolog pattern may be pointing to different sources for tributary loadings vs. CSO/SWO.

It should be noted that this approach does not unequivocally identify specific sources because Aroclor uses overlap, not all Aroclors are represented, and this approach does not take into account changes in Aroclor composition with time (weathering).

were previously stored in the sediments, are being lost to the atmosphere each year. This process is primarily occurring in the area surrounding the Tappan Zee Bridge (Tappan Zee and Haverstraw Bay), where high concentrations of low-MW PCBs from the Hudson River and a large surface area combine to produce large PCB volatilization losses. Farley et al. [71] reached a similar conclusion. Their model results indicated a net loss of PCBs from the estuary of ~250 kg in 1997. The Farley study defined the area of the estuary more broadly, such that the surface area of the model segments totaled approximately 18,500 km^2 and included large portions of the Bight. Their study nonetheless corroborates the finding of this report, that the estuary is experiencing a net loss to the New York Bight and beyond of hundreds of kilograms of low-MW PCBs each year.

For the high-MW PCBs, which account for 7–9% of the total PCB load to the Harbor, the picture is very different. CSOs and runoff account for about 80% of the inputs of homologs 7, 8, and 9 into the estuary. Volatilization of these homologs is negligible, and their association with sediments largely determines their fate. Approximately 80% of the mass of these homologs that enters the Estuary is either stored in the sediments or removed via dredging. The estimates for sedimentation rates suggest that high-MW PCBs are accumulating in the sediments of the Estuary at a rate of about 10–25 kg/yr. However, if the "low" values for these homologs are used, inputs and losses are in balance.

Although there is a great deal of uncertainty about the size of the runoff and CSO loads, several lines of evidence suggest that significant sources of higher MW PCBs exist in NY/NJ Harbor Estuary. First, an analysis of PCB congener patterns in water and sediment samples in the Hudson River system for the US EPA [74,75] suggested that higher MW PCBs were more prevalent in the southern areas of the estuary, leading the authors of the report to conclude that a source of higher MW PCBs existed in the estuary near River Mile 10. These authors also concluded, however, that this source was small in comparison with the Hudson River (at Troy Dam) source. Second, Simon Litten of NYS DEC has carefully examined the data from the CARP project and has noted that (a) the average MW of the PCB mixture in samples throughout the Hudson River systematically increases in samples collected further downriver, and (b) congeners which are markers for heavier PCB formulations (Aroclor 1248 and higher numbers) are likewise present in higher concentrations in down-river samples. Because the GE plants in the Upper Hudson released primarily Aroclor 1242 [76], the shift in congener patterns in the southern portions of the Estuary strongly suggests a source of higher MW PCBs in the southern portion of the estuary. It has been proposed that the shift in PCB congener patterns may also be caused by volatilization of the lower MW congeners.[73]

Gigliotti [77] conducted a statistical analysis on congener patterns from water samples collected in Raritan Bay and concluded that more than half of the variability in PCB congener concentrations was caused by a source with a congener profile similar to Aroclor 1248. In the statistical analysis, this source could be clearly differentiated from PCB sources from the Hudson River at Troy Dam. This analysis again suggests the presence of sources of higher MW PCB formulations in the southern portion of the estuary. These three lines of evidence suggest that such source/s are large enough to significantly shift the congener patterns in the lower portion of the estuary, suggesting that it must contribute a mass of PCBs to the estuary each year which is similar to the loading from the Upper Hudson, that is, on the order of several hundred kilograms of PCBs per year. Thus, it seems plausible that this source is CSO flows and runoff from the urban zone surrounding the estuary, which here are estimated to contribute 103–288 kg of PCBs to the estuary each year, and which contain a PCB mixture having a higher average MW than the Hudson River (at Newburgh Bridge) PCBs. It is also possible that other, significant sources of PCBs exist in the estuary that have not been identified in this report.

The main findings of the PCB mass balance assessment are:

1. Despite the uncertainty in some loadings estimates, the results of this mass balance demonstrate that the Upper Hudson River is the largest single source of PCBs to the NY/NJ Harbor.
2. The load of PCBs from stormwater runoff is the process associated with the greatest uncertainty. To reduce this uncertainty, additional measurements of PCBs in runoff are needed, as is a better estimate of the flow of stormwater into the Estuary. NYS DEC is currently in the process of analyzing more stormwater data to help fill this data gap.
3. Volatilization is the most important loss process for low-MW PCBs in the NY/NJ Harbor. Estimates of volatilization are highly uncertain because of the uncertainty associated with the mass transfer coefficient, K_{OL}. Better estimates of K_{OL} would greatly aid

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[73] Joel Pecchioli, NJ Department of Environmental Protection, personal communication, November 21, 2004.

efforts to understand the ultimate fate of PCBs in the NY/NJ Harbor Estuary (and in virtually all aquatic systems).

4. The NY/NJ Harbor Estuary is probably releasing at least several hundred kilograms of historically sediment-bound low-MW PCBs to the water column and thence to the regional atmosphere each year. These sediments have served as a reservoir for a substantial fraction of the PCBs from the Hudson River and are now releasing part of this PCB burden back to the water column, where much of it volatilizes. This process is occurring primarily in the Tappan Zee Bridge and Haverstraw Bay areas.
5. High-MW PCBs (homologs 7–9) enter the estuary primarily via runoff, CSOs or possibly other unidentified sources. More than 80% of the mass of these homologs that enters the Estuary is either stored there in the sediments or removed via dredging. The mass balance for these PCBs is closed; that is, it is reasonably certain that no major loadings or losses of these PCBs exist which were not addressed in this report.
6. Loadings from tributaries other than the Hudson River, from wastewater treatment plants, and atmospheric deposition are relatively small. Combined they account for ~10% of the total PCB loads to the estuary.[74]

The mass balance offers a picture of the medium of conveyance of PCB to the Harbor (e.g., atmospheric deposition, tributaries, and wastewater inputs). The next section examines the primary sources contributing to PCB mobilization and attempts to develop PCB release estimate for different products and processes involving PCBs.

The mass balance gives us an overview of what amounts of PCBs are entering the Harbor and an estimate of the importance of specific pathways. The next step is to follow the PCBs from their sources to these pathways and how they become available to be released to the Harbor. Generally, releases from these sources into the environment may occur because of:

- Spills from devices containing PCBs, such as transformers, capacitors, and other electrical equipment
- Combustion of materials and equipment containing PCBs
- Remobilization of past PCB contamination (runoff, CSOs, volatilization)
- Inadvertent generation during production processes
- Releases during the process of disposal of PCB waste and PCB-contaminated materials
- Releases at storage, treatment, and disposal facilities

The lack of updated data and uncertainties surrounding available estimates render this type of assessment a challenge and leads to specific recommendations regarding data collection and monitoring efforts.

C2. Industrial and Commercial Usage of PCBs

PCBs were used in a wide variety of industrial uses from 1929 until 1977. Closed applications were very common, whereby the PCB fluid was totally enclosed within the electrical equipment (e.g., transformers, capacitors and small capacitors such as those in refrigerators, air conditioners, microwave ovens, and ballasts) [44,78]. PCBs were used as insulating material, flame-retardant materials, or as coolants and lubricants. These synthetic chemicals were widely utilized in electrical equipment, and they may be still found in old but currently operating equipment. Because of their nonflammable properties, PCBs were also used in semi-open applications, such as hydraulic fluids in underground pumps and mining operations [58]. PCBs have been used in compressors within gas pipelines.[75] PCB-contaminated oils also may have been injected as a fine mist to retard corrosion of underground metal gas pipes [79]. Open applications included plasticizers, pigments, dye carriers (carbonless paper and adhesives), pesticide extenders, and wood preservatives [6]. PCB oils were also used as a dust control agent and sprayed on roads and open ground surrounding utility work areas and railroad yards [12].

Although PCBs are no longer intentionally produced, the use of certain PCB-containing equipment (e.g., closed applications) is allowed. Similarly, the removal of PCBs in some open applications already in place (e.g., paint, coatings, caulking materials) was difficult to implement.

C2a. PCB Use in Closed Applications[76]

It is estimated that 60% of the total worldwide production of PCB was used in the manufacture of transformers and capacitors [80]. In the US, ~439,000 metric tons (77%) of

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[74] This is based on the assumption that PCB loads from minor tributaries are negligible. Although we believe this assumption is reasonable, the contribution from other sources would be different if minor tributaries added significant PCB loads.

[75] Gascape Reference Database, *http://www.gascape.org/Home.html*, then select the link for "PCB Work at Penn State University" (August 10, 1996); accessed on June 2004, or access the article directly at *http://www.gascape.org/index%20/PCB%20Work%20at%20Penn%20State%20Uni.html*

[76] Closed applications are defined as products where PCBs were completely enclosed or that were filled and then plugged (transformers). Transformers were sometimes delivered empty and filled on site.

the total PCBs sold domestically was used in dielectric fluids for transformers and capacitors [52]. A 1987 report [12] estimated that in the US ~160,000 metric tons (T) of PCBs remained in use in closed systems as of 1983 (see Table C1). This included ~159,846 metric tons of PCB in Askarel-type transformers and large capacitors operating in utilities and nonutilities. Extrapolating from this national estimate to the Watershed region suggests that by 1983, ~9,280 metric tons of PCB were in use in closed systems (including 9,271 metric tons in PCB transformers and capacitors) operating in the Watershed region.[77]

The 1987 report [12] also estimated "leakage" coefficients from all closed systems in use in 1983; the number of transformers, capacitors, and other electrical equipment in use, as well as upper limits of known PCBs, leaked or spilled. (These leakage coefficients are considered upper limits and therefore may overestimate leakage rates.) The leakage coefficient for transformers is 0.3 kg/ton (kilograms of PCB leaked per ton of PCB in use) and for capacitors is 4.2 kg/ton. The maximum estimate of PCBs spilled or leaked from electrical equipment nationwide was ~230 tons of PCBs per year (in 1983). Extrapolating (by population) to the Watershed area, it is estimated that the upper limit of PCB spilled or leaked was ~13 tons per year in 1983 (see Table C1). Since that time, many PCB transformers and capacitors have been retired or reclassified.

An attempt to estimate current releases from transformers and capacitors is discussed in the next two sections. The similar characteristics of these products lead to similar management and recommended actions, and therefore they have been combined. The third section discusses small capacitors, which have different characteristics than their larger counterparts and therefore involve a different approach regarding best management practices.

Transformers

A transformer is a device that converts a power generator's low-voltage electricity to higher voltage levels for transmission to the load center (e.g., a city) or converts high voltages to lower voltages to the end user (e.g., factories, residences, offices). This transfer is achieved through electromagnetic induction but without the use of moving parts. Transformers convert alternating or intermittent electric energy in one circuit into energy of a similar type in another circuit, commonly with altered voltage and current.[78] Transformers generally require some type of dielectric fluid. From 1930 to 1977, two different types of cooling fluids were typically used in their production, such as PCB blends and mineral oils. The PCB content of transformers varies with unit size, ranging from 235 kg to 2,932 kg (40–500 gallons) [12]. The dielectric fluids commonly used in transformers and capacitors, such as Askarel,[79] were a mixture of PCBs and trichlorobenzenes to achieve the required viscosity. Transformers commonly contained ~60% Aroclor 1260 and 40% trichlorobenzenes (Type A) or 70% Aroclor 1254 plus 30% trichlorobenzene (Type D) [81]. Information from Con Edison[80] suggests that their transformers typically contained Aroclor 1254 and 1260.

Transformers are classified for regulatory purposes, based on PCB concentrations, as[81]:

- PCB transformers: includes units filled with Askarel (PCB) oil or with mineral oil contaminated with PCB in concentrations 500 ppm or higher (the mineral oil was contaminated when shipped in containers also used to transport PCB oils, at manufacturing facilities (contaminated pipes) or during equipment servicing
- PCB-contaminated transformers: units filled with mineral oil containing 50–499 ppm PCBs (contaminated when shipped or stored in containers also used to transport or store PCB fluids)
- Non-PCB transformers, containing less than 50 ppm PCB, or plain mineral oil

Estimating the number of PCB and PCB-contaminated transformers

A national inventory estimated that more than 25.4 million transformers (Askarel and mineral oil combined) were in service in the US in 1983 [12]. Utilities operated ~30% of the Askarel transformers (~40,000 units), whereas 70% were operated by institutional, commercial, or other private facilities (~92,500 units) (see Table C.1). Among the 25.2 million mineral oil transformers, 80% were operated by utilities. This report indicated that about 2,750,000 mineral oil transformers (both utility and nonutility) either were PCB units (≥500 ppm) or were contaminated with PCBs (50–499 ppm). Their nationwide allocation in 1983 was as follows:

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[77] Calculated by extrapolation from the national to the regional population (5.2%), adjusted to reflect the level of regional economic activity (5.8%). This means that the national number is multiplied by 5.8% to derive the Watershed estimate.

[78] From The Sun's Joules glossary at *http://wol.crest.org/renewables/SJ/glossary/T*

[79] Askarel is the trade name used in the US to commercialize the fluid blend of PCB and trichlorobenzene used for transformers and capacitors.

[80] Presentation by Barry Cohen (Con Edison), NY Academy of Sciences' Harbor Consortium meeting, November 11, 2003.

[81] As defined in 40 CFR § 761.3 [82] Subpart A–General.

Table C1. Estimates of PCB leakage from closed systems

		Number of units in industry		% Units with PCBs Nationwide		Total pounds of PCBs		% Total PCBs	Estimated upper bound of PCBs leaked (lb/yr)‡	
Unit type	**Facility type**	**National**	**Watershed***	**≥50 ppm**	**≥500 ppm**	**National**	**Watershed***	**National**	**National**	**Watershed***
PCB transformers (Askarel)	Utilities (30%)	39,640	*2,299*	100	100	74,597,283	*4,326,642*	21.19	20,448	*1,186*
	Nonutilities (70%)	92,493†	*5,365*	100	100	174,060,327†	*10,095,499*	49.45	47,712	*2,767*
Large PCB capacitors§	Utilities (85%)	2,800,619	*162,436*	100	100	87,552,960	*5,078,072*	24.87	369,251	*21,417*
	Nonutilities (15%)	494,227	*28,665*			15,450,522	*896,130*	4.39	65,162	*3,779*
Mineral oil Transformers	Utilities (80%)	20,227,428	*1,173,191*	11.8	1.1	262,230	*15,209*	0.07	826	*48*
	Nonutilities (20%)	5,056,857	*293,298*			65,558	*3,802*	0.02	207	*12*
Mineral voltage regulators	Utilities (85%)	145,159	*8,419*	14	1.7	6,707	*389*	<0.01	5.0	*0.3*
	Nonutilities (15%)	25,616	*1,486*			1,184	*69*	<0.01	0.9	*0.1*
Mineral oil switches	Utilities	385,768	*22,375*	14	0	239	*14*	<0.01	80	*5*
Mineral oil circuit breakers	Utilities (85%)	180,939	*10,494*	1.8	0	12,685	*736*	<0.01	51	*3*
	Nonutilities (15%)	31,930	*1,852*			2,239	*130*	<0.01	9.0	*0.5*
Mineral oil reclosers	Utilities (85%)	170,158	*9,869*	0	0	410	*24*	<0.01	7.0	*0.4*
	Nonutilities (15%)	30,028	*1,742*			72	*4*	<0.01	1.2	*0.1*
Mineral oil electromagnets	Utilities (1%)	76	*4*	NA	NA	0.64	*0*	<0.01	NA	*NA*
	Nonutilities (99%)	7,524	*436*	NA	NA	63	*4*	<0.01	NA	*NA*
Mineral oil cable (miles)	Utilities (85%)	6,545	*380*	NA	NA	2,311	*134*	<0.01	NA	*NA*
	Nonutilities (15%)	1,155	*67*	NA	NA	408	*24*	<0.01	NA	*NA*
Lb						352,015,198	*20,416,881*	100.00	503,760	*29,218*
Metric tons						160,007	*9,280*		229	*13*

Source: US EPA, 1987 [12].

*By direct extrapolation from the national to the regional population, adjusted by regional economic activity (5.8 %).

†The original source states that nonutilities represent 70% of total units but does not provide estimates for # of units or PCB lb in use, as calculated here.

‡Estimated assuming leakage/spills occur at same rate for utilities and nonutilities.

§ Small capacitors are not listed in original source and are discussed later in this report.

NA, not applicable.

- Five percent of the total (or 132,000 units) were identified as Askarel units with PCB concentrations over the regulated 500 ppm.
- Approximately 1% (1.1%) of the utility-operated mineral oil transformers (or 222,500 units) were contaminated with PCB at concentrations of ≥500 ppm [58].
- About 12% (11.8%) of utility-operated mineral oil transformers (or ~2,387,000 units) were found to have PCB-contaminated oil, with concentrations between 50 and 499 ppm.
- Of the nonutility mineral oil transformers, 55,600 were found to be PCB units (≥500 ppm), and 597,000 were found to be PCB contaminated (50–499 ppm).

This allocation agrees with a comprehensive testing program conducted by the Puerto Rico Electric Power Authority, for mineral oil transformers. This program found that 1% of mineral oil filled distribution transformers had PCB concentrations in excess of 500 ppm, and from 5% to 8% contained contaminated oil (50–499 ppm).[82] Some utilities in the Watershed indicate that the share of PCB transformers and PCB-contaminated units is similar, albeit slightly higher.[83]

Table C1 shows the results of the 1983 account of PCB transformers, as well as other closed applications. Since 1983, it is assumed that many transformers have been retired.[84] Table C2 summarizes available information to estimate the number of transformers still in use in 2000, which is discussed below.

More than 125,000 PCB and PCB-contaminated transformers were retired from 1990 to 1994 [58]. An increase in the rate of retirement of transformers was observed in 1990 and 1991, with 4.8 million transformers containing PCBs disposed of in 1991 (30 times the total quantity disposed of in any other reporting year). This increase has been attributed to owners opting to reclassify or replace transformers because of stricter regulatory provisions coming into effect at the end of 1991, which required enhanced electrical protection on certain types of PCB transformers [58].

In 1994, the US EPA estimated that ~200,000 PCB transformers (≥500 ppm) remained in operation [83]. According to annual reports submitted to EPA by PCB disposers [84], more than 71,000 PCB transformers were disposed of between 1994 and the end of 2000. Applying this estimate to the 1994 baseline suggests that at the beginning of 2000 less than 129,000 PCB transformers (≥500 ppm) remained in operation. The reports from PCB disposers do not include PCB transformers that have been reclassified (retrofilled to PCB concentrations of <50 ppm, thus reclassified as non-PCB transformers). Therefore, the amount of PCB equipment retired or retrofilled since 1994 is likely higher and the amount remaining in operation is likely lower than the estimated 129,000 units.

Extrapolating from the national information to the Watershed area (by population) indicates that ~7,700 PCB[85] transformers may have been in service in the year 2000 in the Watershed region (see Table C2). However, a 1998 EPA mandatory registry of transformers *known* to contain PCBs showed that only about 20,700 such transformers are acknowledged to be still in service nationwide [85]. 1,045 PCB transformers have been reported to the US EPA registry for Region 2 (New York, New Jersey, Puerto Rico, and the US Virgin Islands). Of these 1,045 units, less than 160 PCB transformers have been reported for the Watershed region, including 80 PCB units registered by utilities.[86] See Appendix C showing the number of PCB transformers, by category.

In the Watershed region, utility companies operate many of the existing transformers. A New York City Department of Environmental Protection (NYC DEP) report indicates that before 2000 Con Edison[87] operated ~88,500 transformers, with nearly 50,000 units identified

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[82] Daniel Kraft, EPA, Region 2, personal communication; June 18, 2003.

[83] NYSEG has found between 10 to 15% of the mineral oil transformers were PCB contaminated (50–499 ppm).

[84] EPA began tracking disposal quantities and volumes in 1990, and the agency can calculate the weight of PCB wastes disposed of each year. The number of transformers and capacitors remaining in operation can be calculated by subtracting the units disposed of each year from the last accounting. Although the data are available, EPA has not compiled the data into a national report since 1994 but has indicated that it plans to do so in the near future [58].

[85] This estimate includes ~2,200 Askarel transformers and ~5,500 mineral oil units (≥500 ppm). See Table C.2.

[86] Various reasons have been given to explain the discrepancy between EPA's inventory and registry data, including: (1) The registry database is not updated regularly and is incomplete. The registry requested that PCB transformers be registered _by_ 1998, and this may have been interpreted as "no reporting" after that year. (2) The number of PCB transformers has been reduced because these have been removed or reclassified to non-PCB or PCB-contaminated status, for example, by replacing PCB-contaminated fluids with mineral oils. (3) Many transformers are not identified as containing PCBs because there is no comprehensive inventory, and there is no requirement to test transformers while in use, which may result in underreporting of PCB units. (4) Many transformers, such as those on power poles (pole-tops), which are difficult to test for (safety and ease of collecting the samples) are assumed to contain PCB-contaminated oil only and, therefore, are not required to be registered on the EPA list of PCB transformers.

[87] Consolidated Edison Company of New York (Con Edison), a subsidiary of Consolidated Edison Inc., one of the nation's largest investor-owned energy companies with $10 billion in annual revenues and approximately $22 billion in assets [86].

as containing some level of PCB, although currently all are below 50 ppm [87]. The remaining 38,500 were identified as "equipment certified by manufacturer as non-PCB."[88] Since the mid-1980s, Con Edison has been working on removing or retrofilling PCB and PCB-contaminated transformers, throughout their service territory (New York City, except the Rockaway Peninsula, and most of Westchester County) and reporting progress to NYC DEP (see Appendix D). Many of Con Edison's transformers are located in underground vaults and in underground silos. The units in silos are referred to as underground residential distribution (URD) transformers; ~4,500 are located in Staten Island and Westchester County. Con Edison also operates ~180,000 metering transformers, of which about 2,000 are oil filled and untested for PCBs, as well as ~40 capaciformers, electrical equipment that contains both a transformer and a capacitor.[89] It is also estimated that in New York City, Keyspan operates ~2,072 units, most of them in the Rockaway Peninsula.[90] The units manufactured before July 3, 1979 are assumed to be PCB contaminated.[91]

Other utilities operating in the New York State side of the Watershed have provided information on transformers. The New York State Electric and Gas Corporation (NYSEG) operational territory covers approximately one third of upstate central New York. In 1985 NYSEG started a program to reclassify PCB transformers, and all their distribution transformers in customer buildings, shopping malls, or plazas were retrofilled. Between 10 to 15% of these transformers were found to contain PCBs in concentrations above 50 ppm, and 2% had concentrations above 500 ppm. NYSEG manages 2,000 substation transformers and 250,000 distribution line units (e.g., pole-top transformers), assumed to be PCB contaminated but usually not tested for PCB content. In general, the oil content of such pole-top units ranges from 5 to 100 gallons, with a typical unit containing 50 gallons.[92]

Another New York utility is the Central Hudson Gas and Electric Corporation (CHG&E, a subsidiary of CH Energy Group, Inc.), which operates in the mid-Hudson Valley. Utility representatives have indicated that they

TRACKING PCB TRANSFORMERS

A utility in Tennessee, Elizabethton Electric System, launched an innovative program to identify PCB transformers. It compared the serial numbers of in-use transformers to a manufacturers' list of transformers that either contained PCBs or were likely to contain PCBs. Those transformers whose serial numbers match the manufacturers list were targeted for reclassification or retirement. A list of serial numbers for transformers suspected of containing PCB is available.* The Minnesota Pollution Control Agency (MPCA) has utilized this model. The agency worked with several local utilities to identify and phase out distribution transformers suspected to contain PCBs. The MPCA program included a financial incentive, by guaranteeing that the PCBs removed as part of this program would not be subject to state hazardous waste fees.**

A New York State utility has launched a similar program to identify PCB contaminated transformers, based on the serial number of retired mineral oil transformers found to have PCBs when tested before disposal.#

* This list may be requested from Elizabethton Electric System (EES), at *http://www.eesonline.org/programs/transformers.html* Further information on how the list was composed is available from Gary Richards, Risk Manager, EES.

** Information from Minnesota Pollution Control Agency (December 30, 2004) Phase-out of Distribution Transformers Suspected to Contain PCBs at Three Utilities in the Minnesota Portion of the Lake Superior Basin, Prepared by Carri Lohse-Hanson for the MPCA.

#Tim Hallock, Orange & Rockland Utilities, NY; personal communication, December 2004.

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[88] Information is from a NYC DEP report (PCB Abatement Progress Report, December 1998). A footnote in this report explains that "equipment certified by the manufacturer as non-PCB does not necessarily mean 0 ppm PCB. Non-PCB oil can range up to 50 ppm PCB. Very little sampling has been done by Con Edison on these "certified non-PCB transformers."

[89] Barry Cohen, Con Edison, presentation to the NY Academy of Sciences' Harbor Consortium (November 14, 2003).

[90] Lilly Lee, NYC-DEP, Bureau of Wastewater Treatment personal communication, October, 2003.

[91] Ibid.

[92] Barry Cohen, Con Edison, NYC, personal communication, November 5, 2004.

manage 70,000–80,000 mineral oil transformers. These units are tested for PCB content before disposal.[93]

Niagara Mohawk operates in 14 counties of the Watershed.[94] In the 1980s, this utility began a program to retire or reclassify PCB equipment. Approximately 29,000 PCB capacitors have been retired, and 600 to 700 transformers in substation networks have been retrofilled. Niagara Mohawk operates ~350,000 pole-top transformers, half of which were purchased after 1979 when the PCB ban took effect. Pole-top transformers purchased before 1979 are tested at retirement for PCB content. Niagara Mohawk has found that 7% of the tested units have concentrations of PCBs above 50 ppm and an additional 1% contained over 500 ppm PCBs.

Orange and Rockland Utilities (ORU), a subsidiary of Consolidated Edison Inc., operates in Orange and Rockland counties in New York and New Jersey. In the late 1980s this utility started a program to retire all PCB large capacitors, as well as to retrofill or retire Askarel type transformers. Currently, this utility reports that they operate approximately 60,000 pole top transformers. ORU has launched an innovative program to identify in-use PCB contaminated mineral oil transformers. The company records the serial number of retired transformers found to have PCBs when tested before disposal. In-use units that have similar serial numbers are then targeted for testing and/or early retirement. This novel approach could be replicated by other utilities, and is especially helpful to identify PCB or PCB contaminated pole top transformers, which are difficult to test during use.[95]

The Public Service Enterprise Group (PSEG) in New Jersey operates most of its distribution line transformers above ground. It is estimated that PSEG owns at least 200,000 units located on electricity poles (pole tops). These transformers remain untested for PCBs.[96] PSE&G has reported that since the onset of the PCB regulations, the company established a program to remove PCB-containing equipment from its electric distribution system. Highlights of PSE&G program include:

- Since 1978, permanent removal from service of over 107,000 PCB (≥500ppm) transformers and capacitors[97],
- Since 1998, permanent removal from service of over 2,300 PCB-contaminated (≥50 to 499 ppm) transformers
- Voluntary replacement or retrofill of approximately 2,000 PCB (>500ppm) and PCB-contaminated (>50 to 499ppm) 4kv voltage regulators.

Table C2 summarizes the calculations described above and estimates number of transformers still in use today nationally and regionally and estimates the total tonnage of PCBs still in use today.

The last section of Table C2 attempts to estimate the number of transformers operated by institutional or commercial (nonutilities) facilities. The 1983 inventory indicated that the majority (70%) of PCB (Askarel) transformers and 20% of mineral oil transformers (≥500 ppm PCB) were operated by nonutilities (see Table C1 above). Therefore, assuming that the same distribution held today, it is estimated in Table C2 that **~2,900** *privately owned PCB transformers* could remain in operation (~1,600 Askarel; ~1,300 mineral oil–type PCB transformers). Con Edison has assisted the NYC DEP in identifying ~90% of New York City's private owners with "high-voltage users (HVUs).[98] Appendix D, Table 2, indicates that ~173 PCB transformers are operated by HVUs. Adding another 10% to this figure to account for the remaining unidentified 10% brings the total estimate of HVUs in NYC to ~190 units. Assuming the same proportional distribution for transformers owned by HVUs as for public utilities (NYC utilities represent ~10% of the total, or ~90K of 900K), we estimate that there may be at least **1,900** *privately owned PCB transformers* in the entire Watershed region.

Table C3 provides a third estimate, showing the number of *nonsubstation* PCB transformers, by owner category, as reported at the end of 1984. This information suggests that ~6,055 nonsubstation PCB transformers were operated in the Watershed region in 1984. Assuming the same rate of disposal for PCB transformers from 1983 to 2000 (30% for Askarel; 33% for mineral oil–≥500 ppm), as shown in Table C2, suggest that about **1,800 to 2,000** *nonsubstation PCB transformers* may remain in operation.

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[93] Jeff Clock, Central Hudson; personal communication, October 2004.

[94] The New York State counties are: Albany, Columbia, Essex, Fulton, Hamilton, Herkimer, Montgomery, Otsego, Rensselaer, Saratoga, Schenectady, Schoharie, Warren, and Washington.

[95] Tim Hallock, Orange & Rockland Utilities; personal communication, December 2004.

[96] Russ Furnari, PSEG Services, NJ; personal communication, November 26, 2003.

[97] Including removal of all PCB (>500ppm) outside plant (poletop) capacitors 22 months ahead of the October 1988 regulatory deadline; as well as voluntary removal of PCB (>500ppm) inside plant (substation) capacitor banks. Information provided by Russell Furnari, PSE&G Services, NJ, January 2005.

[98] Information provided by Lily Lee, NYC DEP, Bureau of Wastewater Treatment, personal communication; December 2004.

Table C2. National and regional estimates of transformers and PCB content

National inventory

	Askarel units (PCB transformers)		Mineral oil units		
Reporting year	**Number of units**	***Total PCB (metric tons)***	**Units ≥500 ppm (PCB transformers)**	**Units 50–499 ppm (PCB contaminated)**	***Total PCB (metric tons)***
1983	132,133	*113,182*	275,000	2,710,000	*149*
1988	108,000(b)	*92,585*	250,000(b)	2,596,000(a)	*142*
1994	60,600	*51,951*	139,400	2,018,500*	*113*
2000	39,300	*33,691*	89,700	1,553,500*	*88*

Extrapolation from national inventory to Watershed

Reporting year	Askarel units	*Total PCB (metric tons)*	Mineral oil units contaminated with ≥500 ppm PCB	Mineral oil units contaminated with 50–499 ppm PCB	*Total PCB (metric tons)*
1983	7,664	*6,565*	15,950	157,180	*8.6*
1988	6,264	*5,370*	14,500	150,568	*8.2*
1994	3,515	*3,013*	8,085	123,540	*6.6*
2000	**2,279**	*1,954*	5,203	90,103	*5.1*

EPA Registry for PCB transformers (≥500 ppm only)

Year	Nationwide	Watershed
2000	~20,700 units	158 units (80 at utilities)

Watershed region–data on mineral oil transformers (units) (80% of mineral oil units were owned by utilities)

Utility Name (reporting year, 2004)	Total untested units manufactured before '79	PCB transformers (>500 ppm)[†]		% PCB contaminated (50–499 ppm)[†]		
		%, at disposal	**# of units**	**%, at disposal**	**Range contaminated units**	
Con Edison	2K metering units** (out of 85.5K)	1%	20	50–7%	100	140
Central Hudson	70K (or 80K)	1%	700	1%	700	700
Keyspan	2,000 untested	1%	20	5–7%	100	140
Niagara Mohawk	175K (out of 350K)	1%	1,750	7%	12,250	12,250
Orange & Rockland	Pole tops 60K[§]	1%[§]	600	2%[§]	1,200	1,200
PSEG	No inventory ~100K[§]	1%[¥]	1,000	5%[¥]	5,000	5,000
Total	**~ 600K untested (out of ~900K units)**		**6,090**		**39,350**	**49,430**

Table C2. National and regional estimates of transformers and PCB content (cont'd)

Watershed region–nonutility sector
(nonutilities owned 70% of all Askarel transformers and 20% of all mineral oil units)

Askarel units		**Non utilities–mineral oil units**	
Total Askarel units estimated above for year 2000 (Watershed)	**Nonutilities (70% of total)**	**PCB transformers (≥500 ppm) 20%**	**PCB-contaminated units (≥50-499 ppm) 20%**
2,279 (utilities, 30% of total = ~680?)	**~1,600**	**~1,300**	~10,000–13,000

Sources for different years: 1983: US EPA, 1987 [12] (adapted from Tables 16 and 17). 1988(a): North American Commission for Environmental Cooperation, 1996 [53]. 1988(b): Ross & Associates, 2000 [58]. 1994: US EPA, 1998, and Binational Toxics Strategy, 2002 [83,88]. 1998: NYC DEP, 1998 [87]. 2000: Binational Toxics Strategy, 2002 [88]. 2001: EPA registry for PCB transformers. Compiled from data query: *http://www.epa.gov/pcb/data.html*. 2004: Barry Cohen, Con Edison; Joe Simone, NYSEG; Chris Read, Niagara Mohawk; Jeff Clock, Central Hudson; personal communication, October – December, 2004.

§ From personal communication with representatives from Orange & County and from PSEG, information awaiting validation.

* The number of PCB-contaminated transformers in 1994 and 2000 was estimated by assuming the same average annual rate of disposal as from 1983 to 1988 (77,509 units per year).

**Includes only metering transformers that contain oil and is based on data from testing of pole-top transformers. Other documents have suggested higher proportions of transformers may be PCB-contaminated units (11.8%) [52]—see Table C1.

† These estimates were calculated based on the total number of units and the usual percentages of mineral oil units found to contain PCBs when tested before disposal, which were both reported by regional utilities.

¥ Assuming the same minimum distribution as other utilities.

Table C3. Ownership distribution of nonsubstation PCB transformers*

Ownership category	**Share (nonsubstation units only)**	**Total (nationwide)**	**Estimate for Watershed region**
Electric utilities	18%	18,291**	1,060**
Large commercial building owners	42%	43,206	2,510
Small commercial building owners	10%	10,749	624
Large industrial building owners	21%	21,394	1,241
Small industrial building owners	~5%	5,300	300
Public entities	5%	5,322	310
TOTAL	**100%**	**104,262**	**6,045***
Estimated units in 2000, assuming same rate of disposal from 1983 to 2000 as in Table C2 (30–33%)			**~1,800–2,000 units**

* End of year 1984, as reported by US EPA, 1985 [89].

**Utilities also operate substation transformers as well as network units.

The estimates from Tables C2 and C3 suggest that the number of *nonsubstation PCB transformers* (≥500 ppm) still in use in the Watershed ranges from **1,800 to 2,900**. However, the EPA's database indicates that only 25 nonutility PCB transformers have registered as PCB units in New York, whereas 53 such PCB transformers are registered to be in service in New Jersey.[99] These data suggest that many untested transformers, which may actually contain ≥500 ppm PCB, are not being reported. Nonutility transformers are not tracked or inventoried to the same extent that utility transformers are in this region, and, therefore, we have very little data from which to estimate their impacts on the region.

Given the data gaps between reported and estimated PCB transformers, efforts to develop an inventory of *all* PCB transformers, in particular, nonsubstation and privately owned units, should be encouraged. Considering that the majority of Askarel-type PCB transformers were nonutility units, ensuring their proper management and disposal could be crucial to prevent PCB releases in the Harbor Watershed region, in particular, because PCB transformers may be now reaching the end of their life cycle. A discussion about releases from transformers and capacitors is provided after the section on capacitors.

Capacitors

A capacitor is a passive electronic component used to store energy within an intrinsic electrostatic field. Capacitors may have two conducting plates that are separated by an insulating material known as a dielectric [90], which is a poor conductor of electricity yet capable of supporting electrostatic fields.[100] PCBs were used in capacitors precisely because of their dielectric properties.

Large Capacitors

PCBs were used in high voltage power capacitors operated by utilities, in low-voltage power capacitors (typically in large motors) installed at industrial plants, in institutional and other building compounds, in electric locomotives, and in wheel or skid-mounted power centers in coal mines and other underground operations [92].[101] The useful operating life of a large capacitor is estimated to be at least 20 years [12].

Table B4 indicates that 50% of the PCBs sold in the US were utilized for manufacturing capacitors (large and small). Another report indicates that approximately one third of the global production was used in manufacturing small capacitors, which would indicate that ~20% of the produced PCB may have been used for large capacitors [12].

It has been estimated that ~3.4 million large capacitors were manufactured before the production of capacitors using PCBs was prohibited [12,93]. Large capacitors used at utilities such as high-voltage units typically weigh 120 lb, each with ~25 to more than 30 lb[102] of PCB in content [12]. An estimated ~1.48 M large PCB capacitors remained in service in the US in 1994 [58]. Between 1994 and 2000 ~133,300 PCB capacitors were sent for disposal. After applying this to the 1994 baseline, the estimated number of units remaining in operation at the beginning of 2000 is less than 1,346,000 PCB capacitors [84].

Table C4. Estimated number of large capacitors

		Number of large capacitors		PCB content (metric tons)	
Year		USA	Watershed	USA	Watershed
1983	Utilities	2,800,619	162,436	39,381	2,284
	Nonutilities	494,227	28,665	6,950	403
	Total	3,294,846	191,101	46,331	2,687
1994	Utilities and nonutilities	1,480,000	85,840	20,811	1,207
2000	Utilities and nonutilities	1,346,700	78,109	18,937	1,098

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[99] A query of the EPA registry indicates that in the Watershed, 158 PCB transformers have been registered. On the NY side of the Watershed, the registry includes 6 PCB transformers at utilities, 7 at federal and state institutions and 18 at commercial facilities. On the NJ side, the registered PCB transformers are 74, 30, and 23, respectively. Reasons for underreporting were discussed in a footnote in the "Transformers" section above.

[100] "Dielectric constant is an expression of the extent to which a material concentrates electric flux. As the dielectric constant increases, the electric flux density increases. This enables objects such as metal plates to hold their electric charge for long periods of time" [91].

[101] The author has also suggested that substantial quantities of PCB-containing electrical equipment were abandoned underground before the advent of the PCB regulations in 1978, and that this may be the cause of underground PCB contamination.

[102] The US EPA 1988 assessment of PCB in electrical equipment (see Table C1) estimated an average of 31.26 lb PCB per large capacitor unit. This estimate is used here.

Table C4 indicates that in 1983 ~191,000 large capacitors (with ~2,687 metric tons of PCBs) were in operation in the Watershed region. Eighty-five percent of the high-voltage capacitors were owned by utilities, whereas 15% were associated with nonutility facilities. Extrapolating from the national number of capacitors remaining in operation in 2000 to the Watershed region[103] suggests that some **78,000 large capacitors,** containing **~1,100 metric tons of PCBs**, may have been in operation in the Watershed region in the year 2000.

Most utilities have been actively engaged in retiring PCB high-voltage capacitors in the last decade. Con Edison reports that all of the 400 large capacitors they operate are non-PCB as are ~60 oil-filled rectifiers that contain small PCB capacitors, as well as smaller capacitors within equipment in substations.[104] In the rest of the New York part of the Watershed, Niagara Mohawk has already retired all of its 29,000 PCB large capacitors, whereas NYSEG and Central Hudson have ongoing programs to retire PCB capacitors, but no information was provided about the number of retired capacitors and any remaining PCB units. Information about the number of large capacitors owned by PSEG (New Jersey) and Keyspan (New York) has not been provided. In addition, no information was found about the management or disposal of nonutility capacitors. Therefore, an estimate of how many units remain in operation today in the Watershed is not available. No comprehensive account has been conducted since 1983. To determine how much PCB is still in large capacitors and how much has been disposed of, an updated survey of remaining capacitors in operation would be needed, especially among utilities, which are estimated to have purchased 85% of the PCB units.

Potential release and exposure pathways from PCB transformers and capacitors

Releases of PCBs from transformers and capacitors may result because:

1. Electrical equipment can leak because of mechanical strain or component failure. PCB spills may disperse beyond the transformers or capacitors' site, with the potential to flow into sewage systems, soils, water bodies, etc. In addition, PCB electrical equipment may be knocked down (e.g., from pole tops) during traffic accidents. The spilled PCBs may volatilize or be transported during storm events and prior to cleanup activities.
2. Improper disposal of electrical equipment containing PCBs. Releases may be to soils, water bodies, and to the atmosphere.
3. Combustion processes: transformer and capacitor fires can transform PCBs into furans [94] and trichlorobenzenes into dioxins, as a result of incomplete combustion.[105] PCB-contaminated oils are sometimes used as fuel or are inadvertently combusted. This may release or remobilize the PCBs.

The following attempts to estimate how these three types of potential releases may affect the Watershed region.

1. Leaks and Spills

Leaks and spills of PCB oil are often associated with operating old electrical equipment. The average lifetime of PCB transformers and capacitors is estimated to be 30 [9] to 40 years.[106] The National Response Center (NRC) indicates that the number of PCB spills from operating electrical equipment reported each year continues to increase, in particular, spills associated with transformers and large capacitors. Table C5 describes national and regional trends in the number of reported spills from such electrical equipment. The increase in reported spills is believed to be associated with the deterioration of old equipment as well as to greater awareness of reporting requirements [95]. The number of spills reported in New Jersey has been constant over the last 4 years of reporting (1999–2003); however, this may not be a complete assessment of the total number of spills. A 2001 New Jersey amendment permits certain facilities, which have approved contingency plans for responding to discharges, to keep their own response records for limited discharges (<25 gallons, with <1 lb PCB) instead of immediate notification.[107]

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[103] Extrapolation from the national to the regional population (5.2%), adjusted to reflect the level of regional economic activity (5.8%). This means that the national number is multiplied by 5.8% to derive the Watershed estimate.

[104] David Roche, Senior Scientist, Environment, Health & Safety Department (EHS), and Barry Cohen, Section Manager, Remediation Programs, EHS, Con Edison, NYC; personal communication, November 2003 and November 2004.

[105] Firefighters and other emergency response personnel are at an especially high risk. For more information about protecting workers from workplace hazards, contact the AFSCME Health and Safety Program at 202-429-1228, or 1625 L Street, N.W., Washington, DC 20036. http://www.afscme.org/health/faq-pcbs.htm

[106] Utility representatives report that transformers are seen to last longer, often to 50 years. Information from personal communication with Barry Cohen, Con Edison; Russ Furnari (PSEG) during the June 2004 consortium meeting; as well as Joe Simone, Environmental Group, NYSEG, personal communication on October 27, 2004.

[107] NJ Environmental Protection, Division of Waste Compliance and Enforcement and Release Prevention; Dischargers of Petroleum and Other Hazardous Substances; Re-adoption with Amendments: N.J.A.C. 7:1E; Adopted New Rule: N.J.A.C. 7:1E-6.9; Proposed: May 7, 2001 at 33 N.J.R. 1255(a). Adopted: August 30, 2001, by Robert C. Shinn, Jr., Commissioner; NJ Department of Environmental Protection.

Table C5. Number of reported spills from electrical equipment*

	No. of spills reported nationwide	No. of spills reported in NY (Watershed)**	Gallons of oil spilled[†] in the NY Watershed area (PCB content unknown)	No. of spills reported in NJ (Watershed)*	Gallons of oil spilled[†] in the NJ Watershed area (PCB content unknown)
1998	80	6	42+	2	32+
1999	151	11	309+	3	170+
2000	200	21	2,193+	5	20+
2001	300	17	1,559+	6	122+
2002	323	37	3,762+	5	222+
2003	352	28	2,275+	6	126+
TOTAL	**1,406**	**127**	**10,140+**	**28***	**692+**

Source: National Response Center. Query/Download NRC Data [97].

* Most reported spills are linked to transformers still in use. The majority of spills reported in New Jersey are associated to pole transformers that fall down because of storm events or vehicle accidents.

**Watershed area only.

† Not all incident reports state quantities spilled, and very few report PCB content. A plus (+) sign indicates that certain incidents have reported quantities as "unknown."

The NRC requests reporting of PCB transformers fires, and only releases or spills of 1 lb or more PCBs (≥500 ppm) to the environment, as well as spills of oil at any PCB concentration directly discharged to sewers and/or waterways [96]. From a materials flow perspective, the current record-keeping and reporting requirements do not allow for the estimation of how much PCB is being released.

The leakage coefficients developed in 1983 suggest that the upper limit of PCBs leaked per year from Askarel type transformers in the Watershed region was 3,953 lb/yr or ~1.8 tons of PCB (see Table C1). Since then, many transformers have been removed or reclassified. Of the transformers estimated to remain in operation today, only ~2,300 PCB units may contain Askarel-type dielectric fluid, just 30% of those in operation in 1983. This suggests that the current upper limit of PCBs leaked from remaining *Askarel transformers* in the region is **~540 kg/yr**. Table C1 also includes estimates of the upper limit of PCBs leaked from more than 16,000 *mineral oil* PCB transformers and 173,000 PCB-contaminated transformers, as ~27 kg/yr. These types of transformers are estimated to have decreased, respectively, to 32% and 52% of the units in 1983. This suggests that **~9 to 14 kg/yr** may be released from PCB and PCB-contaminated mineral oil transformers in the Watershed.

An independent estimate is derived from the information in Table C2, which indicates that the amount of PCBs remaining in use in Askarel-type transformers is **~2,000 metric tons**.[108] Using the same leakage coefficient as above (0.3 kg/ton) suggests that the upper bound of PCBs spilled from *Askarel transformers* is **~586 kg/yr**, in good agreement with the calculation of 540 kg/yr above. The *mineral oil* PCB and PCB-contaminated transformers are estimated to contain **~15.8 metric tons** of PCB for the entire Watershed.[109] Applying the leakage coefficient for mineral oil transformers to all units in the Watershed indicates that the upper bound of PCB leaking from these units is **5.5 kg/yr**. Little is known about the fate of nonutility or privately owned transformers (estimated as 70% of the total Askarel transformers estimated in 1983), and some utilities in the Watershed region have not identified or tested all the transformers being managed. Therefore, some Askarel transformers may remain unreported.

The above leakage estimates for Askarel transformers (540 and 586 kg/yr) suggest that a priority for action is to properly manage and/or retire this type of PCB transformers.

Leakage coefficients for *capacitors* (4.2 kg/ton) indicate that in 1983 the estimated upper bound of leaks from ~2,700 tons of PCB in large capacitors in the Watershed was 11.5 tons/yr of PCBs (see Table C1). An estimated

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108. Table C2 estimates 1,954 metric tons of PCBs are in Askarel-type transformer units in the Watershed. The number is here rounded up to 2,000 metric tons.

109. Estimates from New York City indicate that approximately 1.5 tons of PCBs are located within mineral oil transformers in New York City alone (Appendix D). Scaling this estimate of ~52,000 transformers in New York City to all the reported units in the Watershed ~550K, suggest that approximately 15.8 tons of PCB are within all transformers in the Watershed. Thus, this estimate of 15.8 tons suggests that more than the above estimated 5 tons may be contained in mineral oil PCB and PCB-contaminated units.

national rate of capacitor disposal[110] suggests that more than 40% of large capacitors operating in 1983 remained in operation in 2000. Therefore, in the Watershed region, ~78,000 large capacitors may have remained in operation in 2000, containing ~1,000 tons of PCBs. The upper limit of PCBs calculated to have leaked from these large capacitors in the region is **4.2 tons PCBs per year**. Unfortunately, no updated inventory is available to corroborate how many large capacitors remain in operation in the region. The 1983 inventory indicated that 85% of the large capacitors were operated by utilities. Besides Con Edison, another regional utility has indicated that they have retired all large capacitors (29,000), because these units cannot be retrofilled.[111] Given the potentially large quantities of PCBs that could be released during the operation of capacitors, it is important to determine the exact number of large capacitors remaining in use today.

It is very difficult to determine the pathways from electrical equipment PCB leakage to the Harbor Watershed because the pathway is rarely direct (from amounts leaked to the Harbor). Many factors influence the fate of spilled PCBs, including geographical location of the spill, type, molecular weight of the PCB compounds, porosity of the surface onto which the PCBs are spilled, if and how fast spills are cleaned, and ambient conditions. Such diversity of factors makes it difficult to develop emission coefficients to estimate the amount of spilled PCB that enters the atmosphere, runs off to surface water, or is absorbed in soil [98].

2) Releases during disposal of transformers and capacitors:

a) In the Watershed region, mineral oil transformers classified as PCB and PCB contaminated are estimated to contain **~16 tons of PCBs**.[112] There are no regulations requiring owners to sample their transformers.[113] When retired, all units with unknown PCB levels (e.g., untested units manufactured before July 1979) should be tested for PCBs. If they are found to have PCB in concentrations ≥50 ppm they should be properly disposed of in accordance with the regulations. However, changes in the regulatory wording[114] regarding PCB concentration assumptions, which apply during *use* but not once transformers are taken out of service for disposal, may hinder monitoring agencies from enforcing proper disposal. Thus, it is possible that certain facilities may take the risk of sending untested transformers for disposal as nonhazardous waste, assuming that these units have no PCBs, when, in fact, they may contain PCBs at regulated levels.

b) Emissions can also take place during fragmentizing operations during recovery and metal recycling after decommissioning of transformers. Two studies have estimated emission factors: Berdowski [99] developed a population-based coefficient, whereas Harrad et al. [100] developed an emission coefficient using the amount of metal scrap being processed.[115] The first one is used here to estimate

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[110] At the beginning of 2000, less than 1,340,000 large PCB capacitors remained in operation nationwide [84].

[111] Only transformers and similar equipment can be reclassified, by retrofilling. It is not possible to retrofill capacitors.

[112] If the PCB content of all 550,000 mineral oil type–transformers in the Watershed is proportional to the 52,000 units in New York City (1.5 tons; see Appendix D), then all units may contain ~16 tons of PCBs.

[113] For regulatory purposes, EPA's regulations (1998 40 CFR, §761.2) consider all untested transformers manufactured before July 2, 1979 to be PCB-contaminated units (filled with mineral oil containing between 50 and 499 ppm), and not PCB units (≥500 ppm). Electrical equipment manufactured after July 2, 1979 is non-PCB (<50 ppm PCBs).

[114] Specifically, 40 CFR, § 761.2: A recent amendment to the regulation (i.e., the 1998 PCB Disposal Amendments) placed the PCB contaminated assumption requirement for untested oil-filled electrical equipment in a separate section entitled PCB concentration assumptions for use thereby limiting the scope of the assumption requirement to equipment that is in use. Previously, the assumption requirement was embodied in the definition of "PCB Contaminated Electrical Equipment" at 40 CFR § 761.3. This made the assumption requirement applicable throughout the life cycle of the equipment.

The Assumption Rule (40 CFR, §761.2) reads as follows:

PCB concentration assumptions for use (a)(1) Any person may assume that transformers with <3 pounds (1.36 kilograms (kgs)) of fluid, circuit breakers, reclosers, oil-filled cable, and rectifiers whose PCB concentration is not established contain PCBs at <50 ppm. (2) Any person must assume that mineral oil-filled electrical equipment that was manufactured before July 2, 1979, and whose PCB concentration is not established is PCB-Contaminated Electrical Equipment (i.e., contains ≥50ppm PCB, but <500 ppm PCB). All pole top and pad-mounted distribution transformers manufactured before July 2, 1979, must be assumed to be mineral oil filled. Any person may assume that electrical equipment manufactured after July 2, 1979, is non-PCB (i.e., <50ppm PCBs). If the date of manufacture of mineral oil-filled electrical equipment is unknown, any person must assume it to be PCB-Contaminated. (3) Any person must assume that a transformer manufactured prior to July 2, 1979, that contains 1.36 kg (3 pounds) or more of fluid other than mineral oil and whose PCB concentration is not established, is a PCB Transformer (i.e., 500 ppm). If the date of manufacture and the type of dielectric fluid are unknown, any person must assume the transformer to be a PCB Transformer. (4) Any person must assume that a capacitor manufactured prior to July 2, 1979, whose PCB concentration is not established contains ≥500 ppm PCBs. Any person may assume that a capacitor manufactured after July 2, 1979, is non-PCB (i.e., <50 ppm PCBs). If the date of manufacture is unknown, any person must assume the capacitor contains ≥500 ppm PCBs. Any person may assume that a capacitor marked at the time of manufacture with the statement "No PCBs" in accordance with §761.40(g) is non-PCB. (b) PCB concentration may be established by: (1) Testing the equipment; or*(2)(i) A permanent label, mark, or other documentation from the manufacturer of the equipment indicating its PCB concentration at the time of manufacture; and (ii) Service records or other documentation indicating the PCB concentration of all fluids used in servicing the equipment since it was first manufactured. [63 FR 35436, June 29, 1998, as amended at 64 FR 33759, June 24, 1999]

[115] Harrad et al, 1994 [100] use a coefficient of 0.25 g /metric ton of scrap recycled in estimating PCB releases during fragmentizing of electrical equipment.

emissions from fragmentizing operations in the Watershed region.

c) Askarel-type transformers currently in operation are estimated to contain **~2,000 tons of PCBs**, including 1,400 tons within units estimated to be operating at nonutility facilities (70% of total). As noted above, there is scant information about nonutility disposal practices. It is assumed that most of these transformers and capacitors will reach the end of their useful operating life within the next decade.

Emissions from fragmentizing operations

Watershed population	Coefficient	PCBs leaked
14,000,000	0.004 g/capita/yr	56 kg/yr

Source: Berdowski, 1997 [99]

3) Combustion processes

Combustion processes, such as when transformers and capacitors catch fire, may contribute to PCB releases. Although electrical equipment fires are infrequent, they have the potential to release not just PCBs but also other toxic substances. The incomplete combustion of PCBs and chlorinated benzenes during fires has been linked to the generation of polychlorinated dibenzo furans (PCDFs), and polychlorinated dibenzo dioxins (PCDDs), respectively [101]. For example, both PCDDs and PCDFs were found in soot generated during a large transformer fire accident in Binghamton, NY (see description below). This accident also provided evidence that the use of chlorobenzenes as diluents in transformer fluids leads to the formation of dioxins during combustion processes. The US EPA has determined that fires involving transformers containing PCBs in concentrations higher than 500 ppm represent a risk to human health and the environment [102].

A fire in Binghamton, NY, in 1981 involving 200 gallons of transformer oil containing 65% PCBs by weight, released ~1,300 lb of PCBs. Although it has been estimated that there are ~20 fires per year nationally, the amount of PCBs potentially released really depends on the specific conditions of each fire event [98]. Nevertheless, some reports indicate that even low concentrations of PCBs may be problematic in cases of structural fires. When the World Trade Center towers were destroyed, two electrical substations (located in 7 World Trade Center) were also destroyed. One of these substations was considered virtually PCB-free, but the older unit contained oil with trace amounts–less than 50 ppm PCBs. Runoff samples collected near the World Trade Center site on September 14th and 20th after two rain events contained ~8 to 24 ppb PCB (among other pollutants), composed mostly of high-MW PCB congeners, suggestive of Aroclor 1260 (used in PCB transformers) [103].

Actions to prevent releases:

- Replacement with non-PCB equipment: replace and properly dispose of all PCB and PCB-contaminated transformers and capacitors.
- Retrofilled transformers are brought to concentrations of less than 50 ppm. Resampling is performed 90 days after completing the retrofilling process to confirm that concentrations remain below 50 ppm. Conducting the resample test *after 6 months* would ensure that internal parts that have soaked PCB-contaminated fluid have not rereleased PCB over time and that concentrations remain <50 ppm.

Con Edison, NYSEG, ORU and Niagara Mohawk have been engaged in retrofilling transformers that are *known* to contain 50 ppm or greater PCBs, and retiring PCB capacitors. Con Edison is using mineral type transformer oil or, in some cases, silicone oil in its transformers. See box below that discusses an alternative to mineral and silicone oils.

Possible measures to prevent or minimize PCB releases associated with transformers and capacitors have been

BIO BASED TRANSFORMER OIL

In 1994, Waverly Light & Power (WL&P–Iowa) experienced a 20-gallon spill from four PCB-contaminated transformers. The cleanup cost was approximately $27,000. The costly cleanup for this small utility company encouraged industry–university collaboration, in which WL&P and the University of Northern Iowa worked together to develop soy-based transformer oil. Although the oil is more expensive than mineral oil (about $7/gallon vs. roughly $2/gallon for mineral oil), the company is finding that the soy-based oil may extend the transformer life by about four times. Therefore, the life cycle cost may be considerably lower. The oil is food-grade, easily breaks down when released to the environment, and can be reused as an industrial lubricant.

developed both for this region[116] and elsewhere. Obstacles to retiring PCB equipment, however, are numerous. For example, one barrier is the lack of deadlines to phase out remaining uses, and, therefore, there is no regulatory structure to address these sources [104]. For owners of the electrical equipment, the main obstacles are costs, manpower needs, logistical constraints, and potential service disruptions. Considering that much of the PCB electrical equipment will reach the end of its life in the present decade, that the number of reported spills has increased in the last five years, and the large quantity that may be potentially released from transformers and capacitors, it is important to develop a plan for proper maintenance and decommissioning. Regulatory agencies in the Great Lakes region are working with utilities to promote a more rapid phase-out of PCB equipment [55]. They have encouraged owners and operators of PCB transformers to take into consideration costs associated with cleaning spills and releases (due to malfunctioning equipment or fires) against the costs of phasing out this equipment. In addition, the Great Lakes initiative is considering the following incentives to encourage owners to retire PCB equipment [104]:

- Increasing the cost of keeping PCB equipment in service by increasing regulatory costs. These costs may be avoided by retiring all PCB equipment.
- Reducing regulatory and compliance costs for companies taking extra steps to phase out PCBs.
- Lowering the cost of disposal alternatives; large-scale equipment phase-out is likely to be less expensive than piecemeal efforts to retire the equipment when it fails.
- Supporting and recognizing companies that voluntarily reduce PCBs and increase public awareness of facilities that still use PCB equipment.

Summary of findings on PCB-containing electrical equipment

As is clear from the discussion above, we do not have a good handle on how much PCB-containing equipment is still in use in the Watershed; however, the calculations suggest it is considerable. We also do not have complete information on the retirement and fate of PCB transformers *and* capacitors for the entire watershed region.

In New York State, the Public Service Law, Section 66 (23) requires every gas corporation or electric corporation having equipment containing five hundred parts per million or greater of polychlorinated biphenyls (PCBs), including but not limited to, capacitors and transformers, to submit a report to the commission. The report shall contain (1) a list of such equipment that is in service, each unit's location, size and service age, (2) a list of such equipment that is retired from service after the effective date of this subdivision, the date each unit was retired from service, and the location of the facility where the unit and/or PCBs are processed or stored, (3) the date for shipment of PCBs within or out of New York state, and (4) a description of the New York state portion of the shipping route. The commission shall require the report to be updated and distributed semiannually. In addition, such corporation shall submit to each county and city located in the service territory of the corporation a report containing the information listed above for such equipment and PCBs located in or transported through the county or city receiving the report.[117]

For the purposes of this subdivision, capacitors, transformers, and equipment designed to use the PCB-free mineral oil dielectric fluids shall be presumed to contain concentrations below five hundred parts per million of PCBs, unless the unit has been serviced with fluid which contains five hundred parts per million or greater of PCBs, or there is any other reason to believe that the unit contains or was ever mixed with fluid with a concentration level of five hundred parts per million or greater or unless testing has specifically shown otherwise.[118]

This information is not required by the NJ Board of Public Utilities. There are no data on *nonutilities'* management and retirement of PCB equipment throughout the Watershed region. This suggests that the first step toward management is a complete inventory. The following recommendations are intended for all PCB-containing equipment and are meant to help determine where and how much PCBs are still in use as the first step toward safeguarding the Harbor from releases. This information will lead to better management and pollution prevention.

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[116] For example, Con Edison has been involved in retrofilling all PCB and PCB-contaminated transformers to concentrations below 50 ppm. A phase-out plan is being developed for the Great Lakes region. EPA is in the process of developing a phase-out plan as part of a national PCB program.

[117] As defined by Public Service Law, Section 66 (23); 16 NYCRR Part 730 is the New York Code of Rules and Regulations which is the regulation used to implement the law (PSL 66(23)).

[118] Ibid.

RECOMMENDATIONS for electrical equipment (excluding small capacitors)

Measures to ensure an accurate Watershed inventory:

- **To develop a regional inventory, owners of PCB electrical equipment should, report yearly (or continue to report if already reporting)[119] on:**
  - **Number of units in operation, by category (PCB-, PCB contaminated-, and non-PCB-units)**
  - **Estimate of the amount of PCBs contained in units (≥50 ppm) in operation**
  - **Number of units retired, by category**
  - **PCBs content of retired electrical equipment[120]**

Measures to ensure proper management and disposal

- **A regulatory gap (PCB concentration assumptions during use no longer apply once units are taken out of service for disposal) hinders enforcement of possible improper disposal. Therefore, it is possible that some facilities might dispose of liquid-filled transformers without determination of their actual PCB content.[121]**
  - **Close the regulatory gap that hinders deterrence of improper disposal of untested transformers.**
  - **Estimate PCB content in all unlabeled and untested transformers manufactured before July 1979 at end of life.[122]**
- **Monitor PCB concentrations in air, water, soils at dismantling, fragmentizing, storage, and disposal facilities.**
- **Assess the cumulative effect of small spills (assumed to have released <1 lb PCBs) to determine whether these spills could result in significant soils or sediment contamination. If found to be significant, reevaluate the federal and state *"de minimis"* rules for spill reporting that exempt certain oil spills (e.g., spills assumed to have released <1 lb PCBs).**

Small Capacitors

Small capacitors are defined as containing <3 lb of PCB dielectric fluids[123] and typically contain Aroclor 1242 and Aroclor 1254 [105]. PCB small capacitors were used in certain home appliances, such as lighting ballasts (found within fluorescent, mercury, neon tubes, and sodium lighting fixtures), television sets, refrigerators, microwave ovens, air conditioners, dishwashers, and circuit breakers [100,106]. Small capacitors were also used in motor start capacitors, which were installed in various electrical equipment and commercial devices with large motors, including automobiles, industrial heating units, laundry machinery, downwell water pumps, and ventilating fans [44]. Although as a general rule the production and sale of PCBs was prohibited in 1978, manufacturers were allowed to use their inventoried capacitors into new products (ballasts only) until about 1982,[124] and imported appliances might have had PCB small capacitors as late as 1989 [100]. Many of these appliances have already been retired; however, some portion of these units may still be in use or reaching their end of life [93]. In particular, fluorescent lamp ballasts containing PCB capacitors (and tar or asphalt potting compound potentially contaminated with PCBs) that were typically installed in commercial or institutional settings. It has been estimated that one third of the *global* PCB production can be traced to lighting ballasts [45]. Usually these ballasts contain ~24 grams PCBs (0.05 lb) [44].

Calculating the number of units in service today

In the US ~870 million [12] small PCB capacitors were reported to be in operation in 1977. A national estimate suggested that ~500 million small PCB capacitors remained in operation in 1982 and that the annual rate of removal is 10%, because of equipment obsolescence or failure of the capacitor [12]. Assuming a constant rate of removal since 1982, it is estimated that ~50 million small PCB capacitors may remain in operation today in the US. If a higher rate of disposal is assumed, such as 20% per year, then it is estimated that ~43 million small PCB capacitors remain in operation in the US.

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[119] We are not asking for additional reporting. If the reported data is already available at public entities, this information can be gathered from them. We have not defined who should gather the regional inventory data.

[120] When these units are sent for disposal in some cases they are assumed to be PCB equipment, disposed of as such, and are not tested. In such cases, their PCB content could be estimated and reported.

[121] TSCA PCB regulation, 40 CFR, §761.2 describes assumptions for use. However, once an untested transformer is designated as taken out of service for disposal, the assumptions no longer apply. The regulations still require proper disposal. However, enforcement against improper disposal is difficult to apply because there is no *explicit* requirement to test the transformers. Facilities engaging in improper disposal do so at their own risk and face penalties if caught.

[122] A waste generator can choose to assume that a piece of equipment contains >500 ppm PCBs, and properly dispose of it without determining its actual PCB concentration. Nevertheless, for the purposes of an inventory, it would be useful to have an estimate of its PCB content.

[123] As defined under TSCA PCB regulation, 40 CFR, §761.

[124] Fred Cornell, Environmental Director, Hugo Neu Schnitzer East, comments at the *"Meeting to Discuss Recommendations for PCB Transformers and Capacitors,"* April 14, 2004, NY Academy of Sciences.

Extrapolating from the national to the regional population in the Watershed region suggests that from **2.5 M to 2.9 M small PCB capacitors** are likely to remain in service in the Watershed today. Assuming an average PCB content of 24 grams for all units, it is estimated that these small capacitors may contain from **59 to 70 metric tons** of PCBs (see Appendix E for details about how these estimates were derived).

Estimating releases

Assuming a 10–20% annual rate of disposal for small PCB capacitors, ~250,000 to 586,000 units containing **~6 T to ~14 T PCBs**, may be retired in the US in 2004 (see Appendix E). Releases to the environment and PCB remobilization may take place when small capacitors containing PCBs are not recovered at the end of their life cycle and become part of the waste stream. Small capacitors are most likely disposed of as demolition debris, sent for metal recovery, or disposed of in residential waste. These wastes may go to special demolition landfills or residential landfills or be sent to metal recovery or waste-to-energy facilities. The fate of PCBs sent to landfills, shredders, and waste-to-energy is not known, but some possible pathways for small capacitors to the environment are:

- Emissions from municipal waste incinerators and waste-to-energy facilities
- Runoff from landfills, metal-shredding operations
- Landfill leachate/groundwater infiltration
- Volatilization
- Compaction or crushing during waste collection operations.

Because small PCB capacitors within fluorescent lamp ballasts and home appliances are not regarded as hazardous waste[125,126] they are entering the nonhazardous waste stream.[127] Therefore, it is estimated that a significant proportion of the 6 to 14 tons discarded to waste in 2004 might be available for release. Once they enter the municipal waste stream, small capacitors are sent to municipal waste landfills and incinerators. It has been estimated that approximately one third of the municipal waste in the Watershed region is sent to municipal waste combustors or waste-to-energy facilities. However, there is no information about how many small capacitors enter the municipal waste and how many are removed as part of demolition debris. Therefore, there is high uncertainty about the PCB loads to the Harbor Watershed from this pathway. The section on releases from waste management facilities (below) provides information on emissions from local landfills and municipal waste combustors for all waste sent to these facilities. It is estimated in that section that 14 kg/yr PCB are released from municipal waste combustors and 1 kg/yr from landfills.

Our research and findings from a consultative meeting on capacitors indicates that in the Watershed region:

- Small capacitors may be diverted from the waste stream if collected during household hazardous waste collection events.[128] However, it has been noted that regional recycling coordinators have limited funding for collection and advertising. Furthermore, the public is not aware of what household appliances and other items contain PCBs, and there is some indication that hazardous waste collection events are poorly advertised.[129]
- Metal recyclers from the region stated that there are standard procedures for dealing with PCBs. In general, metal dismantlers know which products contain PCBs, especially those with big motors (industrial heating units, air conditioning units, and small appliances). It was noted that refrigerators, washers, and dryers, currently being recycled are

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125. Under the Toxic Substance Control Act, nonleaking ballasts may be sent for disposal at municipal solid waste landfills. Exceptions to this rule include: small capacitors that are leaking PCBs; ballasts owned by a company that at any time in the past manufactured equipment that contained PCBs; and ballasts that contain asphalt potting or tar material with PCB in concentrations in excess of 50 ppm. Leaking ballasts must be handled as PCB waste. PCB ballasts containing contaminated potting compound in fluorescent lamp ballasts, if nonleaking, must be handled as PCB bulk product waste. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) requires notification to the National Emergency Response Center when more than 1 lb (or 16 ballasts) are disposed of within a 24-hour period [107].

126. Disposal requirements for small capacitor or equipment manufacturers are found at 40 CFR section 761.60 (b)(2)(iv), which states *"Any person who manufactures or at any time manufactured PCB Capacitors or PCB Equipment, and acquired the PCB Capacitor in the course of such manufacturing, shall place the PCB Small Capacitors in a container meeting the DOT packaging requirements at 49 CFR parts 171 through 180 and dispose of them in accordance with either: (A) Disposal in an incinerator which complies with section 761.75; or (B) Until March 1, 1981, disposal in a chemical waste landfill which complies with section 761.75." http://www.epa.gov/pcb/2003pt761.pdf*

127. David Lasher, Environmental Engineer for NYS DEC, comments at the *"Meeting to Discuss Recommendations for PCB Transformers and Capacitors,"* April 14, 2004, NY Academy of Sciences.

128. Paul Mander, Division of Solid and Hazardous Waste, NJ DEP, noted that, although household hazardous waste is exempted from regulations, there are collection days when these items may be safely disposed of. (Comments during the *"Meeting to Discuss Recommendations for PCB Transformers and Capacitors,"* April 14, 2004, New York Academy of Sciences).

129. Manna Jo Greene (Clearwater Inc., NY) remarked that hazardous collection days are not often advertised in NY. Furthermore, people are not aware that their appliances (appliances with large motors such as air conditioners and microwave ovens) may contain PCBs.

not thought to contain PCBs[130] (older units that may have contained PCBs are thought to be already retired). Most of the PCB small capacitors are associated with fluorescent lamp ballasts manufactured before 1982.[131] PCBs may also be found in the sealing tar or the asphalt potting material of ballasts.

- PCB capacitors are kept out of the shredder to the extent possible.[132] Landfills that accept "fluff" material (e.g., the soft parts from automobile shredding) have been shown to have higher concentrations of PCBs (see description below). There is anecdotal information that the recovered small capacitors are not recycled but rather sent to nonhazardous landfills.[133] The small capacitor rule was intended to apply to residential and commercial users (as well as users of equipment that contained small capacitors)–not to manufacturers of small capacitors or manufacturers of small capacitor-containing equipment. Therefore, the EPA encourages (but cannot enforce) those discarding large quantities of PCB small capacitors to treat them as regulated waste [107].

Because there is potentially a very large pool of PCBs associated with small capacitors (Appendix E), but there are almost no data available on disposal patterns for PCB small capacitors, we are recommending that research be undertaken to identify and quantify the fate of PCB-containing small capacitors from demolition activities and household disposal through combustion and land filling.

Recommendations for Small Capacitors

- **Quantify and track the fate of PCB capacitors that are entering the waste stream (e.g., disposed of at demolition sites, recycling, dismantling, and metal recovery facilities, household waste collection, and consolidation centers)**

C2b. Partially Closed or Semiopen Applications

Partially closed systems involve applications in which PCB oil is not directly exposed to the environment but may be released during typical use. Examples of partially closed applications are detailed in Table C6. These PCB applications have been discontinued, but some of the products are still in use.

Hydraulic Fluids

Hydraulic fluids containing 20–90% PCBs (Aroclors 1232, 1242, 1248, 1254, and 1260, see Table B2) were used in applications that required heat and/or fire resistance, such as machinery used by the iron, steel, and die-casting (e.g., aluminum automotive parts) industries [108], and in mining equipment [109]. It has been reported that 36,364 tons of such hydraulic fluids were sold nationwide from 1957 to 1971 [52,54]. Extrapolating from this estimate to the Watershed (by population), we estimate that **~2,100 tons** were used in the region. Nonchlorinated fire-resistant hydraulic fluids are presently available [110]. However, no information has been found about the degree of replacement already completed by the above industries, the quan-

Table C6. Partially closed applications of PCBs

Application	Typical locations
Heat transfer fluids	Organic and inorganic chemicals, plastics, and petroleum refining industries
Hydraulic fluids	Mining equipment, aluminum, copper, steel, and iron production industries
Underground compressor units blow-by and mist	Gas distribution lines

Adapted from U.N. Environment Programme, 1999 [44]. Original sources: Goodwin 1998, US EPA, 1994; Dobson and van Esch, 1993. Information on compressor units from Sowinski, 1997 [79].

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[130] Fred Cornell, Environmental Director, Hugo Neu Schnitzer East, comments at the *"Meeting to Discuss Recommendations for PCB Transformers and Capacitors,"* April 14, 2004, NY Academy of Sciences.

[131] Fluorescent lamp manufacturers were permitted to continue to use their inventory of PCB small capacitors until 1982.

[132] Fred Cornell, Environmental Director, Hugo Neu Schnitzer East, comments at the *"Meeting to Discuss Recommendations for PCB Transformers and Capacitors,"* April 14, 2004, NY Academy of Sciences.

[133] Information provided by Fred Cornell, Environmental Director, Hugo Neu Schnitzer East, during a Harbor Consortium meeting, June 24, 2004.

tities that may have been released to the environment, or the amount of PCB hydraulic fluids remaining in use today. Therefore, no estimate of releases can be developed.

Heat Exchange Fluids

Heat transfer fluids were used in industrial tools and devices used by the chemical, plastics, and petroleum refining industries, as well as equipment used for processing of food, drugs, animal feed, and veterinary products, which have now been removed [109]. The most common PCB compound used in heat exchange fluids was Aroclor 1242 (Table B2). Approximately 9,000 tons of PCBs were sold for this type of application (see Table B4). It is estimated that **~527 tons of PCBs** used for heat transfer fluids may have been commercialized in the Watershed region. No information is available about the amount of PCBs remaining in use in this type of application.

Gas Pipelines

PCB-based oils were utilized in gas transmission compressors. The compressors were used to move/push natural gas through thousands of miles of pipelines across the country [111]. PCB oil that leaked from the compressors inside the pipes then could have been distributed through the pipeline or released at condensate points. This is called "compressor blow-by." PCBs were also used to inject a fine mist of oil fog into underground metal gas pipes to slow down corrosion and lubricate the pipelines. This procedure is estimated to have contributed several tons of PCBs to underground gas pipelines that extend throughout the country. Although the practice ended in the mid-1970s PCBs remain in the gas pipeline systems until remediated. Leaks and spills around contaminated pipelines contribute to environmental releases. This is considered one of the "mystery" PCB sources that are difficult to quantify [79][134].

The major natural gas transmission system in the NY/NJ Harbor Watershed is the Transcontinental Gas Pipe Line Corporation (Transco), which extends 10,500 miles from Texas to New York. The company has been found responsible for PCB contamination in the region and in 2002 agreed to pay a $1.4 million civil penalty and to begin remediation efforts of contaminated soil and groundwater along the pipeline that traverses 12 states. The Transco pipeline system includes 53 compressor stations, and PCB contamination has been found in and around several of these stations. The University of Pennsylvania and the Gas Research Institute have investigated remediation strategies to solve this contamination problem in underground gas distribution systems [95]. There were also other companies that were fined.[135]

It seems unlikely that there is a way to quantify how much hydraulic and heat exchange fluids were used in the region. *Further research is needed to try to establish whether these fluids remain in use today (testing) and determine the fate of hydraulic and heat exchange fluids when disposed of. This should also include testing soils and groundwater at likely leakage points along gas pipelines (compressor stations, condensate collection points) and ensure cleanup of pipelines when technologies are available.*

C2c. Open Applications

Open systems are applications in which PCBs may be in direct contact with their surroundings and therefore may easily transfer to the environment [44]. At the peak of their production, from 1957 to 1970, PCBs were used to manufacture plasticizers and sealing agents (applied to rubber hoses, plastic tubing or PVC, caulking, gaskets, paints, surface coatings) and dye carriers in carbonless paper and adhesives. In addition, PCBs were used in building materials (nonslip floors [110], Galbestos [112], asphalt roof tiles,[136] wood preservatives, and paint), as well as in fluids to control dust on roads and train railyards, oils used in microscopy slide preparation, and sound-deadening felts [55]. These applications have been discontinued, except for a few permitted uses.[137] The US EPA has recognized many other open applications that may inadvertently contain PCBs, for example, agricultural chemicals, printing inks, certain plastic materials, soft soap formulations,[138] and certain soap bars.[139]

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[134] The use of PCB oils for corrosion prevention in gas pipelines could not be verified by contacting Transco.

[135] Further information on this and other settlements is available at a Department of Justice Press Release, (Feb. 2002), "US settles case with natural gas pipeline company – Transco to conduct environmental tests and cleanup along its 10,500 mile pipeline crossing 12 states." *http://www.usdoj.gov/opa/pr/2002/February/02_enrd_053.htm*

[136] PCB-contaminated oil was used in the manufacturing of asphalt roofing [113].

[137] Such as use in and servicing of nonrailroad transformers (except as prohibited); use in and servicing of railroad transformers (≤1,000 ppm); use in capacitors (except as prohibited); use in and servicing of mining equipment; use in heat transfer systems (<50 ppm), in hydraulic systems (<50 ppm), in carbonless copy paper; in and servicing of electromagnets, switches, voltage regulators, etc. (except as prohibited); in natural gas pipelines (<50 ppm); in small quantities for research and development; as a mounting medium in microscopy; certain recycled PCB uses (<50 ppm); and use in excluded products/processes (<50 ppm) [52].

[138] For example, when using recycled oil that may contain PCB for its manufacture [44].

[139] Specifically, products manufactured with different animal products that may contain PCBs may be used to manufacture candles, soaps, lipsticks, shaving creams, and other cosmetics. These animal products include tallow (rendered beef fat), animal fat, and oil [114].

Estimating PCBs used in open applications for the Watershed region

It has been reported that, of the US PCB total domestic production, ~52,273 metric tons (or 9.2% of the total) were allocated to plasticizer uses and as paint amendment. This suggests that an estimated **3,000 metric tons of PCBs**[140] may have been sold in plasticizer applications in the Watershed region, before their use was discontinued (Table B4). Table B4 also indicates that ~20,500 metric tons of PCBs (or 3.6% of the total domestic production) was used in the dye carrier compounds of carbonless paper. Extrapolating to our Watershed region[141] suggests that **~1,200 metric tons of PCBs** in carbonless paper may have been sold in this region. In addition, ~12,273 metric tons of PCBs (or 2.7% of the total) were used nationwide in miscellaneous applications, suggesting that **~700 metric tons of PCB** were used in the Watershed region in such applications. In summary, an estimated **4,900 metric tons of PCB** within *all* open applications are likely to have been sold in the Watershed region before PCB usage for open systems stopped completely in 1971.

Below are descriptions of the known open applications that commonly used PCBs.

PCBs in paints and other plasticizer applications

PCB compounds were used in plasticizer applications such as resins, synthetic rubber, surface coatings, wax, sealants, waterproofing compounds, glues, and adhesives. PCBs were also added to various types of paint. Many of these PCB-amended materials were used by the construction industry. For example, until 1970, PCBs were added as plasticizers to sealants and rubber material used for building with prefabricated materials involving concrete. These PCB-amended sealants were also utilized in the manufacture of isolation window glass, and in flooring material, such as the binder in nonslip floors. PCBs were commonly added to PVC (polyvinyl chloride) and chlorinated rubber paints, as well as lead-based paints. Galbestos, used as building siding, was an application that combined PCBs (Aroclor 1268) and asbestos (described below). PCBs were added to ship paint [110] some lead-based paint produced up to the 1970s, also contained significant amounts of PCB's (>10,000 ppm) [115]. PCB-containing paints and plastic materials have been found in ships, trains, and metal towers.

Polychlorinated biphenyls were commonly added to industrial paints from the 1940s through to the 1970s. PCBs were added directly to the paint mixture as a fungicide, to increase durability and flexibility and to improve resistance to fires and moisture. The concentration of PCBs in the paint varies from trace amounts to 7.4%. Typically, these paints were not labeled as containing PCBs. The only way to determine whether PCBs are present in paints is through laboratory testing. PCB-amended paints were used in specialty industrial/institutional applications prior to the 1970s. This includes, but is not limited to, government buildings and equipment in industrial plants, radar sites, and non-government rail cars, ships, grain bins, automobiles, and appliances [48].

The use of PCBs in marine paint has been well documented in Norway [116].[142] Using the "fingerprint method" developed by Konieczny and Mouland[143] an investigation by the Oslo Port Authority[144] was able to trace the PCBs present in Oslo Harbor directly back to the ship paint manufacturers.[145] Three manufacturers of commercial paints containing PCBs have been identified, as described in Table C7.

In Canada, a "PCBs in Paints" Working Group was formed to examine options for managing and disposing of demolition debris from the Distant Early Warning (DEW) line system. Most of the PCBs were found in paint used in buildings, wood, and pillars, painted steel, billboards, towers, and nearly every painted structure in the DEW. This group has recommended that such materials should be prevented from entering the waste

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[140] By direct extrapolation from the national to the regional population (5.2%), adjusted to reflect the level of regional economic activity (5.8%).

[141] Ibid.

[142] A 1996 assessment of a PCB phase-out campaign in the port of Oslo showed that the effort did not yield the expected results. A proposed zero-emissions abatement plan involved all known sources of PCBs to the Harbor waters, including the phase out of all transformers and capacitors with PCB concentrations above 2 ppm. However, a follow-up monitoring program found that elevated levels of PCBs along the coast were still prevalent at the end of the phase-out program. Subsequent research was able to identify the source of PCBs as shipyards around Oslo Harbor and certain paint factories. The investigation showed that PCBs had been used in additives and chlorinated rubber, the most common ship paint in the 1960s and 1970s. It was found that a normal ship painting procedure involved sandblasting of the old paint (the paint was flushed directly into the Harbor or the nearest seashore dump). In addition, it is estimated that up to 30% spillage into the environment was common when applying the new paint coating.

[143] The method has been published in Konieczny, R.M. og L. Mouland, 1997. Tolkning av PCB-profiler. Beregning av totalt PCB-innhold i marine sedimenter. SFT-rapport nr. 97:33, TA-1497/1997

[144] Advokatfirmaet Føyen & Co. ANS* in cooperation with Friends of the Earth Norway (Norwegian Society for the Conservation of Nature) (February 2001), PCB cleanup and manufacturer liability: Prestudy on a possible cause of legal action for Oslo Port Authority. (*an Oslo firm of lawyers).

[145] The Norwegian authorities have initiated legal actions to hold the manufacturers of the PCB paint responsible for the cleanup which is estimated to cost millions of pounds.

Table C7. Commercial PCB blends identified in Oslo Harbor[146]

Manufacturer	Country	Product name	Products
Bayer AG	West Germany	Clophen A60 (60% chlorine)	Additive used in paint
Kanegafuchi Chemicals Industry Co. Ltd.	Japan	Kanechlor	Marine paint oil platforms in North Sea (due to sandblasting)
Monsanto Industrial Chemicals Co. (& Solutia)	USA and UK (Belgium)	Aroclor (Blend of 1260 and 1254)	

stream, and should not be re-used or recycled. In addition, they recommend efforts to prevent flaking of the PCB-laden paints, such as repainting buildings and structure often [48].

In the late 1990s, the US Navy became aware that many of its ships had been painted with marine paints containing PCBs.[147] The Navy has sampled 28% of all retired Navy ships for contaminated materials and found that 77% contained PCBs above 50 ppm in at least one material. In addition, the Navy has sampled 50 of the 113 Navy ships ready for disposal and found PCB at levels of regulatory concern in all of these sampled ships. Thus, it has been estimated that 98% of the 358 US Navy ships presently awaiting disposal may contain some PCBs in solid materials [80]. The US Maritime Administration (MARAD) reports similar findings. Furthermore, PCBs are regularly found during dismantling and recycling of merchant ships. A recycling facility in India reports up to 800 kilograms of PCBs in the paint of merchant ships recycled in recent years [80]. This represents a major disposal problem at time of decommissioning, in part, because of the added costs of dismantling ships with contaminated materials, and, in part, because the majority of the dismantling operations are conducted overseas[148] and US regulations prohibit the export of PCB materials for recycling or otherwise [55]. In addition, during routine maintenance, PCBs may be released to the environment during painting and sandblasting of ships with PCB-amended paints [80].

Estimating Releases from paints

The environmental impact of PCB-amended paints in the NY/NJ Harbor Watershed is highly uncertain, and it is not possible to calculate how much of the estimated **~3,000 tons** of PCBs in paints and plasticizers sold in the Watershed may be found in the environment or remain in use. The limited available data suggest that PCB concentrations in, and releases from, surfaces painted with PCB-amended paints vary greatly. One document indicates that a DRMS[149]/Navy survey in California found paint scraped off from two 1945 barges contained PCBs in concentrations of 71 and 148 ppm, respectively [117]. A recent press release [118] reports that PCB concentrations as high as 22,000 ppm have been tested in paint at some Army buildings in Badger, WI. PCB concentrations in soils near painted surfaces have been found to be much lower. One report indicated that soil concentrations next to PCB-amended paint flaking off from the parts of a nuclear power plant being decommissioned in Massachusetts, exceeded 1 ppm,[150] whereas a Maine soil analysis from an area near radio towers painted with PCB-laden paints had PCB concentrations ranging from 25 to 50 ppm [120].

A NYS DEC study of sources of PCB to the Harbor has not yet been published, although preliminary information suggested that ship paint might be a source of PCBs. A recent industrial classification census[151] indicates that there are about 39 shipyards in the Port of New York and New Jersey, but only five facilities are dedicated to major

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146. Ibid. This study states that fingerprint identification on another blend remains uncertain and that “the PCB blend is unusual because its visual profile has a negative downturn of CB 138 where the others have a peak. CB 138 constitutes a long trough along with CB 118,” pp. 10 of 24.

147. Since the PCB regulations became effective, the US Navy has found PCBs in heavy electrical equipment (e.g., off-shore yard transformers), small capacitors and transformers in shipboard electronic equipment, a unique military lubricant and antifoulant used on the cables of some naval mines, as well as in various materials, including plastics, rubbers, adhesives, gaskets, and other commercial nonmetal products used in ships and facilities [80].

148. India represents 41% of the ship dismantling and recycling industry. Other countries with a considerable share of this market include Turkey, China, and the Philippines [80].

149. Defense Reutilization Marketing Services, a branch of the Defense Logistics Agency.

150. “PCB amended paint was flaking off the Vapor Container (VC), a 120-foot diameter steelball structure in the Yankee Nuclear Power Plant (MA). Soils in the vicinity of the VC exhibit PCBs at concentrations greater than 1 ppm. The volume of contaminated soil is approximately 1,900 cubic yards [119].

151. Search engine for the North American Industrial Classification System (NAICS) *http://www.naics.com/search.htm* Information was corroborated with another search engine: Tech Savvy (company directory) *http://www.techsavvy.com/*

vessels[152] and four are large marinas.[153] The port includes the New York Naval Shipyard on the Brooklyn side of the East River (but ships are not being dismantled at this site at this time). Water sampling conducted by NYS DEC found Aroclor 1260 in the vicinity of the Brooklyn Navy Yard. Although Table C7 indicates that this may be a plausible association, it is not known whether the Aroclor 1260 is related to paint (e.g., ships), coating materials (e.g., underwater pillars at docking stations), transformers found in the proximity of the Brooklyn Navy Yard, or other sources. The NYC DEP's survey of their Red Hook Wastewater Treatment facility in 1998 found elevated concentrations of PCBs in inflows to this plant. Their report [87] speculates that these PCBs may be from the ~150 transformers located at the Brooklyn Navy Yard. A survey conducted in May 2000 found 10 PCB units, 26 PCB-contaminated units, and 117 units with less than 50 ppm on this site.[154] Recent sampling of NYC's 14 wastewater treatment plants' effluents has shown that the Red Hook drainage area no longer has the highest levels of PCBs in comparison with other plants.[155] Follow up monitoring and track-down studies would be useful to determine the source(s) of PCBs *in this area.*

Carbonless copy paper

In 1954, the National Cash Register (NCR) Company of Dayton, OH, introduced carbonless copy paper (CCP) to the market as "No Carbon Required" (NCR) paper. A good example of this pressure-sensitive paper is the typical three-part business form, which contains microscopic capsules with solvents to bring out the dye components.[156] The main solvent used in the microcapsules was PCBs, in particular, Aroclor 1242. In the 1960s, Monsanto's sales of PCBs for CCP reached 16,000 tons, and, by 1970, annual worldwide production increased to 100,000 tons [122]. It has been reported that from the introduction of CCP in 1957 until the early 1970s, the amount of PCBs (mostly Aroclor 1242) used domestically in CCP increased 20% each year, from ~272 tons to ~3,000 tons in 1970. Total usage of PCBs in CCP in the US has been estimated as ~20,000 tons or ~28% of the total estimated Monsanto Co. sales for plasticizer applications [121] and 6.3% of its total domestic sales of PCBs from 1957 to 1971 [123,124]. The PCB content of CCP paper was ~3.4% by weight.[157]

Extrapolating to the Watershed region suggests that **~1,160 tons** of PCBs in CCP may have been commercialized in the Watershed region before 1971. Another calculation arrives at a similar estimate: given that ~625,000 tons *of CCP were* produced, and that the average PCB content was 3.4% by weight, it is estimated that **~1,200 tons of PCB** in CCP may have been contained in ~36,250 tons of CCP sold in the Watershed region.

No estimates are available of the current disposal rate for CCP paper containing PCBs, although an educated guess suggests that <1% CCP with PCBs remains in paper being disposed of today, which either is sent to landfills or finds its way to paper recyclers.[158] Thus, the remaining 99% is likely to have already entered the waste stream. Preventing disposal of the estimated 1% CCP remaining in use today is commonly considered a low priority, although 1% of 1,200 tons of PCB in CCP likely to have been commercialized in the Watershed amounts to more than one ton of PCBs (1.2 T). Furthermore, sampling during track-down, revealed trace amounts of PCBs possibly associated with recycled CCP paper in an area of the NY Harbor, close to the location of a paper recycling facility.[159] *Further research is recommended to understand the impact of this and other paper recycling operations and alternative technologies.*

PCBs in carbonless copy paper were replaced by solvents considered less toxic.[160] Starting in the early 1970s, manufacturers of CCP used either isopropyl biphenyls, Santosol; secondary butyl biphenyls, or di-isopropilyne naphthalenes.[161] There is evidence that paper mills that recycle paper using a chlorine wash to bleach the new

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[152] Facilities that deal with large vessels include: (1) Union Dry Dock, Hoboken, NJ; (2) Caddell Dry Dock, Staten Island, NY; (3) G. Marine Diesel, Brooklyn Navy Yard; (4) Bayonne Drydock, MOTBY, Bayonne, NJ; (5) Direktor, Mamaroneck, NY (information from Lingard Knutson, EPA, Region 2; personal communication (e-mail) October 18, 2004).

[153] Larger marina operations include: (1) Muller Boatworks, Sheepshead Bay, Brooklyn, NY; (2) Reynolds Ship Repair, Staten Island; (3) Tottenville Marina, Staten Island, NY; and, (4) NY Waterways, Edgewood, NJ (information from Lingard Knutson, EPA, Region 2; personal communication (e-mail) October 18, 2004).

[154] Lilly Lee, Bureau of Wastewater Treatment, NYC-DEP, personal communication, December 2004.

[155] Information provided by Lily Lee, NYC DEP, December, 2004.

[156] This pressure-sensitive paper works because the under surface of the top two sheets are coated with an emulsion containing a colorless dye in a solvent. This emulsion is held in microscopic capsules that are torn open when pressure is applied to the top sheet, for example, with a pen or pencil. The released dye then reacts with a reagent on the surface of the next sheet of paper, thus changing the dye to a blue, black, or violet coloration [121].

[157] Carr et al., 1977; and Paul Peterman (1983); P. Peterman, Analytical Chemist, USGS, Columbia, OH; personal communication; November 19, 2003; ppeterman@usgs.gov

[158] Paul Peterman, Analytical Chemist, USGS, Columbia, OH; personal communication; November 19, 2003 ppeterman@usgs.gov

[159] Simon Litten, NYS DEC; personal communication, November 19, 2004.

[160] However, a recent report suggests that health concerns continue regarding CCP [122].

[161] The replacement compounds were also approximately 3% by weight. Manufacturing techniques and chemical constituents were described by RE Miller and PS Philips Jr., in US Patent 3672935.

type of carbonless paper may be releasing compounds similar to PCBs. It is estimated that up to 5% (by weight) of isopropyl biphenyl could chlorinate, and this component has now been phased out in favor of secondary butyl biphenyls, or di-isopropilyne naphthalenes, which have less potential for chlorination.[162] However, recyclers of papers containing Santosol, may be releasing PCB-like compounds when using a chlorine wash to bleach the paper. Releases can be prevented by using peroxide or water-based baths. Most paper mills are already in the process of phasing out this chlorine wash to prevent dioxin releases.

Miscellaneous uses of PCB

Many building materials produced before 1971 contained PCB, including Galbestos (a combination of asbestos, PCBs [112], and polychlorinated terphenyls.)[163] This material is a galvanized metal that has been coated with asbestos-and PCB materials, which was applied as metal siding to exterior walls (e.g., in the Peregrine plant of General Motors) and other exterior building materials. It is produced by coating galvanized iron sheets with chrysotile on each side and then covering them with a coating of paint or bitumen [125]. The main PCB compound used in Galbestos was Aroclor 1268. This construction material was available in flat, corrugated, and additional profiles and was manufactured from the 1950s through to the 1970s by the H. H. Robertson Company [126]. Other building supplies containing PCBs include caulking materials to seal joints or window frames in buildings construction, roof shingles, and flooring materials.

Estimating PCB releases from “miscellaneous” open applications

No information is available to estimate releases from the estimated 700 tons of PCBs in miscellaneous applications that may have been sold in the Watershed before 1970. The section on waste management provides information on releases from municipal waste facilities, although most of this material may be managed as demolition debris.

C3. Inadvertent PCB production

Small quantities of PCBs may be generated as by-products during chemical processes or end up in products being manufactured today, without intentional addition by the manufacturer. Inadvertent production of PCBs is possible during certain chemical processes involving carbon, chlorine, and high temperatures. PCBs are also found in the processing equipment of certain manufacturing industries, and, as a result, the products may contain small amounts of PCBs (e.g., PCBs in extruded plastic and rubber products from use of PCB-contaminated oil as an extrusion lubricant). Therefore, PCBs can be found both as a functional and an accidental component of certain products [80].

In 1984, the US EPA recognized about 200 chemical processes that *potentially* may inadvertently generate PCBs. From that list, 70 processes were identified as *likely* to produce PCB. Appendix F, lists these processes, which include the production of chlorinated solvents, dyes, and pigment manufacturing (some of these are reported to contain PCBs in the order of µg/kg). EPA issued regulations under TSCA (40 CFR § 761.20) to prohibit manufacture, processing, and the commercial distribution of any product containing an annual average of 25 ppm (mg/kg) PCB (with a maximum concentration at any time set at 50 ppm) [82]. The agency also required manufacturers or importers of products and processes associated with inadvertently produced PCBs to report any PCB concentrations greater than 2 ppm[164] in such products or processes [82].

Of particular concern in the NY/NJ Harbor Watershed is the inadvertent production of PCBs during manufacturing of certain organic pigments, as well as use of the resulting products—certain yellow and red pigments used in plastics and printing. One of the congeners released during pigment manufacturing is **PCB 11** or 3,3'-dichlorobiphenyl,[165] which is a prominent congener in ambient waters in the NY/NJ Harbor, Long Island Sound, and the New York Bight [65]. PCB 11 has been found both in effluents at publicly owned treatment works (POTWs) and in the pigments themselves. The effluent of a few NY and NJ wastewater treatment facilities has been found to have high concentrations of PCB 11 (100–340 ng/L)[166] compared with other treatment facilities.

A recent survey of local industries indicates that there are several active pigment-manufacturing facilities currently

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[162] Paul Peterman, Analytical Chemist, USGS, Columbia, OH; personal communication; November 19, 2003 ppeterman@usgs.gov

[163] Information provided by Simon Litten, NYS DEC, personal communication, November 19, 2004.

[164] For any resolvable PCB gas chromatographic peak.

[165] For more information on 3,3'-dichlorobiphenyl (PCBs 11) and its inadvertent production during organic pigment manufacturing, see Litten, 2002 [67].

[166] Presentation by Dr. Simon Litten, Research Scientist, Division of Water, NYS DEC, focused on sources and pathways of PCB 11 in wastewater treatment plants' effluents, ambient water, and industrial sources in the NY/NJ Harbor Watershed. Presentation at the *Meeting on Inadvertent Production of PCBs*; organized by the NY Academy of Sciences' Harbor Project, March 31, 2004 and held at Rutgers University.

operating in the Harbor Region.[167] One facility in Staten Island has recently stopped an individual manufacturing process (pigment) that inadvertently generated PCB 11. The discovery of PCB 11 from this facility occurred during sampling as part of a contaminant track-down program (CARP).[168] NYC DEP entered into negotiations with the manufacturer, who agreed to stop this process in the spring of 2002.[169] It was reported that this company moved this process to another facility in Europe. Ongoing sampling has found that **PCB 35**, and **PCB 77** are present in samples from this facility to the local POTW (or wastewater facility).[170] EPA sampling of sludge during a survey of POTWs in 1999 reported dioxin-like PCB concentrations. This survey indicated that PCB 77 (3,3', 4,4'-TCB) represented the highest average concentrations of all the 12 dioxin-like PCB congeners sampled (42,460 ng/kg).[171] The source of the PCB 35 and 77 is not known.

PCB 11 has also been sampled in the effluent of the Passaic Valley wastewater treatment facility in NJ.[172] The drainage area of this POTW in NJ includes at least three pigment-manufacturing facilities. At a meeting on inadvertent production, representatives from the Passaic Valley Sewerage Commission (PVSC)[173] explained their efforts to track down sources of PCB 11 in the Passaic Valley wastewater treatment district, where concentrations of total PCBs of ~330 ng/L were found in one sample, with average flows of 273.7 million gallons per day. PCB 11 made up 98% of the total PCBs measured in this sample. In an effort to determine the source of the PCBs, PVSC measured samples from the pigment manufacturing facilities as well as at key junctures in the sewerage system. Using composite samples provided by the pigment manufacturing facilities as well as samples from the interceptor pipes and the wastewater treatment plant,[174] PVSC found that concentrations of PCB 11 seemed to enter the system at many points–there was no obvious pattern that pointed to the pigment facilities alone. PVSC is following up with additional sampling and is looking to a larger industrial base to include not just manufacturing facilities but also users of the pigment such as paint manufacturers and paper recycling plants, also discharging to the PVSC district. PCB 11 is more soluble [127], more volatile [31,128], and less likely to sorb to organic matter in water-borne particles [129] than heavier congeners. As a result, PCB 11 should be washed out of the estuary more rapidly than heavier congeners, suggesting that when it is detected it is likely to have been more recently generated.[175] Although NYC DEP was able to intervene to control the PCB 11 discharge to its Richmond County wastewater treatment plant, the agency has no jurisdiction to effect change in other regions or in the use of the product (pigments).

PCB 11 is estimated to represent **~5 to 20% of total PCBs** entering the NY/NJ Harbor.[176] A best management practices plan is available and may be utilized by pigment manufacturing facilities using 3'3–dichlorobenzidine to reduce the generation of PCB 11 and effluent concentrations. The plan was put together by Environment Canada and was designed for a Canadian based pigment manufacturing facility.[177]

PCB 209 is another congener inadvertently generated during titanium dioxide production, which involves high temperatures and chlorine. A by-product of titanium dioxide production is ferric chloride (iron chloride), which is contaminated with PCB 209, and is marketed as a water

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[167] http://www.naics.com/search.htm and http://industry.com For the category "Synthetic Organic Dye and Pigment Manufacturing," this search indicates that there are three such facilities on the New York side of the Watershed (one in Staten Island, one in Brooklyn, and one in Westchester). In New Jersey's Watershed region, there are 22 reported facilities (three in Bergen County, seven in Essex County, one in Hudson County, two in Middlesex, six in Passaic, and three in Union County).

[168] Litten (NYS DEC) identified very high levels of PCB 11 discharging from the Port Richmond Wastewater facility into the Harbor. He fingerprinted it as a pigment. NYC-DEP then became involved because this agency has jurisdiction over discharges to Wastewater Treatment facilities (NYS DEC has jurisdiction over discharges to Harbor waters). By monitoring influents and effluent to this POTW, NYC DEP was able to identify a pigment manufacturer within that discharge district as the source of the elevated PCBs.

[169] Philip Heckler, NYC DEP Chief, Wastewater Bureau, as recorded in the minutes from a NYC DEP Citizens Advisory Committee, November 2002). Mr. Heckler has since retired from NYC DEP.

[170] Described during a meeting of the NYC DEP Citizens Advisory Committee, 2003; Simon Litten, personal communication.

[171] US EPA. National Sewage Sludge Survey (NSSS) (Notice of Data Availability, 55 FR 47210. Nov. 9, 1990).

[172] PCB 11 is present in very low levels in Aroclors; therefore, it is not usually measured in regular PCB analysis, as described by Lisa Totten, 2004 [65].

[173] Sheldon Lipke, Superintendent of Operations at Passaic Valley Sewerage Commissioners (PVSC) at a meeting on Inadvertent Production of PCBs, March 31st, 2004, organized by the NY Academy of Sciences at Rutgers University.

[174] All samples were analyzed using the electron-capture-detection (ECD) method.

[175] Comment by Lisa Totten, Rutgers University; Department of Environmental Sciences during the meeting on Inadvertent Production of PCBs, March 31st, 2004, organized by the NY Academy of Sciences at Rutgers University.

[176] Ibid.

[177] Although we have obtained a copy of the "Model of Pollution Prevention Plan for Inadvertent Production of PCB," we are not at liberty to provide copies to others. Those interested in obtaining a copy of this plan may contact Sandy Rossi (sandy.rossi@ec.gc.ca or 416-739-4381) at Environment Canada, Environmental Protection Branch.

treatment flocculent,[178] both for drinking water and wastewater. A chemical plant in Delaware has indicated that they sell ferric chloride to POTWs in the Watershed region.[179] Elevated levels of PCB 209 were found in 1 sample from the Joint Meeting Essex and Union county POTW effluent in NJ. Levels were low in two other samples. However, this facility did not start using ferric chloride until after this sampling study.[180] NYC DEP uses ferric chloride at their POTWs that have dewatering facilities to prevent buildup of struvite in the pipes (not for "backwashing" the system). Their sampling of the POTWs effluent showed that PCB 209 concentrations are low. The mass balance indicates that homolog group 9 (which includes PCB 209) is the smallest contributor by homolog group to wastewater. *Because ferric chloride is the only source of PCB 209 that we have been able to identify, it may be useful to time the effluent sampling to coincide with the use of this product and to also measure PCB concentrations in the sludge because higher MW PCBs have a greater affinity for particles.*

The EPA has developed a certification and record-keeping procedure, with reporting requirements for facilities known to inadvertently produce PCBs. It also set up specific regulatory concentration limits for air and water releases from manufacturing process inadvertently releasing PCBs: less than 10 ppm for PCBs emitted to air, and less than 100 ppb for PCBs discharged to water [82]. The current regulatory structure regarding the inadvertent production of PCB may be summarized as follows:

Federal regulations

- Section 6(e) of the Toxic Substances Control Act (TSCA), 15 USC 2605 (e) (2) (A), prohibits the manufacture, processing, and distribution of PCBs. However, 40 CFR § 761.1(f) (1) excludes manufacturing processes that result in "inadvertent generation" of PCBs as by-products or impurities, provided that manufacturers comply with the conditions specified in the regulatory definition of "excluded manufacturing processes" specified in § 761.3.
- Companies with excluded processes must meet the following restrictions on PCB releases specified in 40 CFR §761.3, definition of excluded manufacturing process[82]:
    - PCB concentrations in the components of detergent bars are limited to 5 ppm.
    - Concentrations of PCB in all other products are limited to an annual average of less than 25 ppm, with a maximum of 50 ppm. If the 25 ppm average is exceeded, total concentrations in products must be reported.
    - PCB concentrations at the point where such PCBs are manufactured or processed and are vented to the ambient air are limited to less than 10 ppm.
    - PCB concentrations discharged from manufacturing or processing sites to water are limited to less than 0.1 ppm for any resolvable gas chromatographic peak.
    - All process waste containing PCBs at 50 ppm or greater are to be disposed of in accordance with the PCB disposal requirements of 40 CFR Part 761, subpart D.

State regulations

New York, ambient water quality standard:

- For the protection against cancer in humans eating fish: 1 pg/L (ppq)
- For the protection of aquatic and wildlife resources: 0.12 ng/L (ppt) for both freshwater and estuary or coastal waters (salt water)

New Jersey, surface water quality criteria (NJ AC7, 9B regulation)

- For human health protection against cancer: 170 pg/L
- For freshwater aquatic/chronic criteria: 14 ng/L
- For saline waters (estuary/coastal) aquatic/chronic criteria: 30 ng/L

Other

The Delaware River Basin Commission has imposed a Total Maximum Daily Load (TMDL) of 379.96 mg total PCBs per day (139 kg/yr). This is mostly allocated to nonpoint sources (322.10 mg/day) with 38.86 mg/day for point sources (including municipal and industrial discharges), and a margin of safety of 19.00 mg/day.[181] If allocation between point and nonpoint sources were applied for the NY/NJ Harbor, then point-sources of PCB 11 may provide a relatively straightforward target for reduction efforts.

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[178] Used to precipitate colloids when backwashing the system.

[179] This company represents 1/4 to 1/3 of the total market share for ferric chloride in the US.

[180] Joel Pecchioli, personal communication, December 15, 2004.

[181] Lisa Totten, Rutgers University, personal communication; Harbor Project meeting on Inadvertent Production of PCBs, March 31, 2004.

Inadvertently produced PCBs tend to be identified during POTW effluent sampling[182]*; however, the POTW is not the primary source of these PCBs. PCB inputs may be sporadic (e.g. tied to industrial processes, treatment plant activities, storms events). Therefore targeted track-down efforts that are informed by an inventory of the industrial processes and schedules, rainfall, etc. in the region could help to pinpoint specific sources. Track-downs should also include measurements of PCBs associated with suspended solids and sludge to account for the total PCB loads to the system as well as the fate of those PCBs.*

C4. Incidental Releases through Recycling and Remanufacturing of PCB-Contaminated Material

The recycling of certain materials may account for PCB mobilization in the Harbor region. Materials containing PCBs, such as oil blends or certain papers may allow for releases to the environment when reprocessed for remanufacturing or recycled. Several examples are given below, including glossy paper recycling, the use of scrap tires for fuel, and dismantling of metal products that may result in PCB discharges.

Paper Recycling

Kaofin® is a patented product, sold by a NJ paper company, and is a by-product of recycling operations. This powdery material is derived from recycling the glossy surfaces of some papers (e.g., magazine covers that were printed with inks/pigments, some of which contained PCBs). The recycling process creates a clay-like sludge, which is used to make a coproduct called "Kaofin® fiber clay." These Kaofin® granulate and fiber cake products can be used in different earth works engineering, agricultural, and industrial applications, including [130]:

- Soils and compost blending
- Retention pond liner
- Daily landfill cover
- Chemical solidification
- Mine reclamation ingredient
- Cement additive
- Animal bedding and pet litter manufacturing

Kaofin® is reported to contain ~0.4 ppm PCBs. The NJ manufacturer produces ~127,000 metric tons/yr of this material, containing **~50 kg PCBs per year**. PCB analysis indicates that the main homologue groups found in "Kao-bed," for example, are tri-, tetra-, and pentachloro congeners. It has been reported that in New Jersey some of this material is used as landfill daily cover, as feedstock for composting operations and may be used as an alternative fuel. There is an effort to use more of this material in composting, which means more would eventually be land applied.[183]

It is not known whether other paper recyclers also manufacture a similar product from the clay sludge generated when processing glossy color paper. *Although the concentrations may be low in any of the individual by-products, the overall quantities and the potential for wide distribution of these products suggests that further research is warranted to identify the specific source of these PCBs (e.g., inks/pigments), whether the source is current or historical, and their contribution to PCB loadings to the Harbor and to the nation as a whole.*[184]

Oil Recycling

The incomplete combustion of PCBs can occur when PCB contaminated oil is recycled as fuel[185] in industrial/commercial boilers and furnaces (e.g., cement kilns). In general, the industrial boilers, furnaces, and kilns that burn used oil with 2 to 49 ppm PCB are regulated by air and waste permits. Certain PCB fluid blends may contain traces of highly toxic PCDDs and PCDF (from the production process) and when heated to temperatures above 300°C to 1,000°C more dioxins and furans may be formed and possibly released [11]. Dioxins are likely generated from the incomplete combustion of the chlorinated benzenes used as solvents in transformer fluids.

The EPA protocols indicate that to ensure proper destruction, PCBs must be combusted for a minimum of 10 seconds at >1100°C (2,100°F) [79]. However, even under combustion conditions that ensure PCB and

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[182] PCBs measured in the effluent generally only represent a portion of the PCBs entering the POTW. PCBs are particle reactive and therefore are likely to end up in the sludge.

[183] Information from Michael Aucott, NJ DEP. Personal communication, September and November 2004.

[184] It has been noted that current regulations calculate acceptable concentrations for chemical contaminants in soil using a model based on Superfund sites. Such Superfund-based models, however, are appropriate only where the assumption of a relatively small land area is valid. Some pathways of exposure such as soil ingestion in children are not sensitive to land area. Runoff to waterways as a pathway of concern becomes more important as the land area at a given concentration increases. Superfund soil cleanup guidance may not be appropriate to determine acceptable levels of contaminants in soil where the land area assumption incorporated into the model is violated. For a land application product, such as Kaofin, a large landscape model and total mass of contaminant estimate is a better approach than a concentration-based risk assessment approach. Information from Bob Hazen, NJ DEP. Personal communication, November 5 and 10, 2004.

[185] Oil containing less than 50 ppm PCBs may be used for fuel blending (mixed with regular oil), and commercialized as recycled fuel. Information from Jay Specter, G & S Scrap Metal Recycling (201-998-9244, x33) March 8, 2004; and Russ Furnari, PSEG, NJ; November 3rd, 2003.

dioxins/furans destruction, dioxins and furans can be resynthesized after combustion. The main pathways are (1) precursor reactions from small aromatic and aliphatic compounds which are products of incomplete combustion; (2) *de novo* synthesis from a solid carbon source such as fly ash or soot particles [131]. Even when PCBs or dioxins/furans are not originally present in the feedstock material (e.g., tires, oil), combustion can still generate dioxins and furans. After reevaluation, the EPA determined that burning 2 to 49 ppm PCB oil in utility boilers and industrial furnaces such as cement kilns and burning <2 ppm PCB oil in any combustion device does not pose an unreasonable risk to health and the environment. Thus, current EPA rules allow such uses as fuel but prohibit dilution to meet the 2 ppm and 50 ppm criteria. Once combustion conditions are optimized, rapidly cooling the combustion gases below 250°C, and installing adequate air pollution control devices to avoid emissions of any remaining toxics in the gases and ashes can minimize dioxins/furans after combustion generation. One utility in the Watershed region has provided an estimate of how much mineral oil is recycled from reclassified electrical equipment.[186]

Dioxins and furans can form during combustion unless specific incineration practices are strictly followed. Ensure enforcement of guidelines to prevent emissions of dioxins and furans during combustion of PCB-contaminated mineral oil (PCB concentrations between 2 and 50ppm).

Scrap Tires Used as Fuel

Vehicle tires, after disposal, may be combusted for energy recovery, for example, at pulp and paper manufacturers and/or recyclers. It is estimated that ~242 million scrap tires, weighing approximately one half million metric tons, were incinerated in 1990 in the US [132]. This same year, it is estimated that 10.7% or ~25.9 million tires were burned for fuel. This percentage represented a doubling of rates in the 1980s, and it is expected that it has continued to increase. Approximately 46% of the tires burned for energy recovery in the US are used by paper and pulp manufacturers and recyclers; 23% by cement kilns, and 19% by waste-to-energy (WTE) facilities [98].

Stack tests from a single facility in California indicate that the average emission factor for the total tetra- through hepta-chlorinated congener groups is 1.2 µg/kg of tire incinerated. Extrapolating to the half million metric tons incinerated nationwide in 1990 suggests that total PCB emissions from this process were low (~0.6 kg/yr). It is not known whether this facility is representative of the combustion processes involved in the many industries noted above that use tires as fuel. It is possible but not known whether dioxin-like PCBs are formed and released from this combustion process (as noted above in the oil-recycling section).

There are many alternative uses for shredded tires that do not involve energy recovery via combustion including roadbed construction, drainage material, and insulation around building foundations. These uses could be prioritized over incineration.

Metal Recycling

Several facilities in the region dismantle discarded equipment to recover valuable components, such as metals, wood, and hard plastics. Recycling facilities may receive old equipment that contains PCB oil or that has been coated with PCB paints or plasticizers. If the products arrive uncrushed, metal recyclers can remove small PCB capacitors included in household appliances and devices with large motors, such as household and industrial heating units, air conditioners, washing and drying machines, refrigerators, microwave ovens, old TV sets, and automobiles. There are industry standards for dealing with PCB-containing metal products and metal recyclers also have inbound-scrap quality control programs that exclude PCB items from their facilities. However, the elements of such programs are not consistent across the industry, and it has been argued that the effectiveness may vary.[187] Processing and dismantling this equipment without knowledge of the potential risks can contribute to workers' exposure and PCB mobilization in the Harbor region. Polychlorinated dibenzofurans may form when cutting metals with a flame if these metals have been coated with PCB-amended paints [133]. There are several examples in the Watershed where enforcement actions have been taken because PCBs were not properly managed or disposed of [134].[188]

Very little information is available to characterize the relative contribution of the poorly quantified and poorly understood processes described in sections C2b, C2c, C3, and C4. Even when releases can be estimated, it is impossible to track their pathways to the Watershed. *Therefore it would be useful to determine the importance of these processes to the overall burden to the Harbor. Further studies are needed to deter-*

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[186] David P. Roche, Senior Scientist Con Ed, personal communication, January 6, 2005; reported that the annual volume of oil sent for recycling by Con Ed fluctuates from year to year depending on projects. The average for the last 4 years was approximately 278,000 gallons oil handled in bulk, all of which was burned for energy recovery in the region (such as by Bridgeport United Recycling in Connecticut).

[187] Fred Cornell, Environmental Director, Hugo Neu Schnitzer East, comments at the *"Meeting to Discuss Recommendations for PCB Transformers and Capacitors,"* 4/14/04, NY Academy of Sciences.

[188] Hazardous Waste Superfund Week (September 24, 2001) PCB Charge; Business Publishers, Inc. EPA Contact, Nina Habib-Spencer, US EPA Region 2.

mine releases to air, water, and soils from the reuse and remanufacture of the materials described above.

C5. PCBs in Municipal Solid Waste

This section covers waste that may be contaminated with PCBs and entering the municipal waste stream. For example, materials containing PCBs are found in buildings and may be mobilized during demolition, or renovation. Some examples of these materials are dielectric fluid in electrical equipment, such as small and large capacitors, transformers, switches, voltage regulators, and fluorescent lamp ballasts (including insulating material). PCBs may also be found in caulking compounds (e.g. in windows), flooring materials, or roofing shingles manufactured with PCB-contaminated oil, or building siding.[189] Federal and state laws regulate the proper management and disposal of materials that contain PCBs above certain concentrations.[190] However, Table C8 suggests that many other materials may enter the municipal waste stream. This table also shows different activities that may contribute to PCB remobilization.

In addition to the materials described in Table C8, PCBs may also be found in household waste, including home appliances and equipment (with small capacitors). A study in 1992 found that 10% to 25% of all US household white goods contain capacitors with PCBs [136];

Table C8. PCB-containing wastes

Activity/source	Typical locations
Fluff (upholstery, padding, insulation material) derived from the shredding of cars and appliances	Landfills
Inadvertent production by chemical plants	Industrial waste disposal sites Industrial waste water streams
Dredging (navigational)	Dredged water bodies and their sediments
Transfer spillage (PCB leakage that may take place during the transfer of PCB-containing waste from one location to another	Soil or water near landfills and industrial sites and along the roads between locations
Accidents/fires	Power distribution networks (e.g., transformers) Industrial sites Materials from burnt buildings
Vacuum pump cooling water or condensate	Water discharge sites and leakage
Floor and equipment cleanup wastes	Landfills Industrial dump sites
Waste generated during repair or decommissioning of equipment, and not properly disposed of	Repair shop grounds Waste disposal sites Equipment repair or decommissioning sites Industrial facility grounds
Building demolition	Landfills Waste disposal sites
Various recycling operations Reused oil practices	Recycled oil in equipment Industrial plants Pesticide formulations Soft soap formulations Natural gas pipelines (from compressors) Automobile service stations

Source: adapted from UN Environment Programme [44].

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[189] Information from various documents, including Öberg, 1996 [110], and New York University Environmental Services, 2002 [112]. PCB-contaminated oil was used in the manufacturing of asphalt roofing shingles [135].

[190] Information about management of PCB waste may be found in US EPA, 1997 [52].

Table C9. Quantities and allocations of MSW generated in NJ and NY per year (T)

	Population (2002)	Total MSW (T)	Recycled (T)	WTE (T)	Landfills (T)
NJ	8,590,300	18,865,390	7,168,848 (38%)	1,697,885 (9%)	9,998,657 (53%)
NY	19,157,532	24,775,000	7,432,500 (30%)	4,211,750 (17%)	13,130,750 (53%)
NY & NJ Total	27,747,832	43,640,390	14,601,348	5,909,635	23,129,407
Watershed (52%)	**14,428,873**	**22,693,003**	**7,592,701 (33%)**	**3,073,010 (14%)**	**11,668,786 (53%)**

however, it has been estimated that only 0.01% of the household hazardous waste contains PCBs. In the US this represents ~210 tons per year or 12 tons per year in the Watershed [137].[191]

An estimate of the total quantity of PCB-contaminated waste was developed in 1991. It was estimated that an average of ~382 million tons of PCB-contaminated waste (or a range of 168–597 M tons) was distributed in contaminated sites across the US. However, PCB concentrations were not specified [52].

Waste Generated in the Watershed Region

Both national and regional data indicate that solid waste is the major component of the waste stream. Approximately 18,865,390 and 24,775,000 tons of nonhazardous municipal solid waste (MSW) are generated per year in New Jersey and New York, respectively [138].This waste stream includes residential, commercial, construction, demolition, and industrial waste, and tires. In addition, New Jersey also processes agricultural waste as part of its MSW, and New York processes waste from other states. Of the total MSW generated, the state of New Jersey recycles ~38%, sends ~9% for combustion at waste to energy facilities, and sends ~53% to landfills. In New York, ~30% of the MSW is recycled, 17% is sent to Waste to Energy (WTE) facilities, and 53% is sent to landfills (see Table C9) [138]. Thus ~3 million tons are sent to MSW combustors or WTE facilities, and ~11.6 million tons are sent to landfills. Considering that construction and demolition debris enters this MSW stream, it is possible that some PCB waste from building materials (e.g., flooring, roof tiles, and painted surfaces) is being incinerated. Small capacitors containing PCBs may be sent to MSW landfills or end up in the waste sent to WTE facilities. In the section below, these numbers are used as background to the discussion on pathways of PCBs during disposal.

Estimating Releases from Waste and Waste Management Facilities

Air emissions from disposal and waste management activities

A significant portion of PCB *air emissions* reported nationwide are associated with the combustion or incineration of municipal waste (6 kg/yr in the Watershed). Table C10 describes sources of air emissions from the combustion of both MSW and regulated PCB waste. The emissions from incineration of medical and hazardous waste containing PCB is estimated as 7.6 kg/yr (combined). The total air emissions contribution from such combustion sources in the Watershed is estimated to be **~14 kg/yr**.

Other sources also contribute to PCB *air releases,* such as waste management activities at different facilities, including landfills and Treatment, Storage, and Disposal facilities (TSDFs), hazardous waste sites; steel and iron reclamation facilities (e.g., auto scrap burning); accidental releases (from PCB electrical equipment leaks and/or fires); environmental sinks of past PCB contamination [52] and especially open burning, which merits further discussion.

Open Burning

The EPA's National Emission Inventory (NEI) reports that in 1999, ~2,292 pounds (>1 ton) of PCBs (Aroclors) were emitted *to the air* in New York and New Jersey (~1,850 lb in NY and 442 lb in NJ). Nearly all of these PCBs were reported in source classification code (SCC) 2610030000, which is described as *"Waste Disposal, Treatment, and Recovery (open burning, residential, household*

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[191] Estimated by direct extrapolation from the national to the regional population (5.2%), adjusted to reflect the level of regional economic activity (5.8%). This means that the national number is multiplied by 5.8% to derive the Watershed estimate.

[192] Carol Bellizi, EPA Region 2; personal communication, November 2004; this information is available from AIRData at *http://www.epa.gov/air/data/index.html* and can be accessed by selecting "Reports and Maps;" plus "Geographical area"; and then under reports/maps, by selecting PCBs under HAP/emissions.

wastes).”[192] This type of accounting is only available for a few years in the last decade. Therefore, it is difficult to determine whether the 1999 report is indicative of a trend or an isolated occurrence. Nevertheless, this indicates that ensuring proper management of PCB waste is important, particularly because much of the remaining PCB products are approaching the end of their useful life and will enter the waste stream in the next 10 to 15 years.

In addition, it is commonly assumed that PCB releases only involve redistribution of past PCB stock. However, it has been shown that PCBs can be newly synthesized from combustion processes, even if PCBs are not originally present in the feed, as summarized in Dyke, 2002 and US EPA, 1991 [139,140]. It is hypothesized that mechanisms are similar as those resulting in dioxins and furans formation. PCBs could be present and not destroyed during combustion, or could be generated in the gas phase or on particle surface, both from small organic molecules and from *de novo* synthesis. Uncontrolled combustion, such as open burning or tire fires likely have the greatest potential to release PCBs, as well as other pollutants, including dioxins and furans and PAHs.

According to assumptions in the US EPA Dioxin Reassessment [98], 40% of rural population disposes of ~63% of their waste through open burning. Each person generates 616 kg of waste per year. Lemieux [141] estimated that between 0.97 and 2.86 mg of PCBs are released to air per kilogram of trash burned in barrels, for recyclers and nonrecyclers, respectively. Open burning is banned in New Jersey; therefore, we assume no open burning by its Watershed rural population (244,609 people). Applying these assumptions to the 1,015,401 people in New York state rural areas within the Watershed yields an estimate of 153 to 451 kg of PCBs released to air per year. Note that PCBs were also found in the residual ash on the order of 122 to 220 *u*g/kg ash [141]. The waste used in this study included paper, plastics, food waste, textiles/leather, wood, glass/ceramics, and metal (ferrous and nonferrous) waste (cans, foil, wire, pipe, batteries), but did not include household appliances or other products that may contain PCBs, and that are likely burned together with regular household waste.

A simplified calculation to estimate the importance of open burning to the Watershed is given below. Assuming the Watershed is a box, 205 km on a side and 1 km tall and the average wind speed is 4 m/s, then 153 to 451 kg/yr of PCB emissions yields a background PCB concentration of ~6 to 17 pg/m^3.[193] The regional PCB background air concentrations are ~150 to 200 pg/m^3. Therefore, according to our estimate, open burning seems to contribute less than 10% of the background air levels.[194] Open burning is also a major source of other contaminants including dioxins and PAHs. *Support efforts to ban open burning in New York State and nationally.*

Landfill leachate

The PCB mass balance (Appendix A) estimates that only **1 kg/yr** is being released as leachate in the Watershed region. This is derived from concentration data from 16 leachate samples at three landfills (ranging from 9 to 1,490 ng/L, or an average of 330 ng/L) and relatively low infiltration rates (2.6 million gallons per day) resulting in the small loadings estimate.[195] Note that these samples included only dissolved-phase PCBs, and, as noted, PCBs are generally particle reactive.

In a different sampling study, Simon Litten (NYS DEC) analyzed leachate and treated effluent at Fresh Kills and other NY and NJ landfills (using method 1668A–considered to be more sensitive) and found PCBs in concentrations ranging from 9 ng/L (9 ppt) to ~2,000 ng/L (2 ppb). However, the total volume of water leaching from the Fresh Kills landfill is small, and, therefore, the PCB load to the Arthur Kill is assumed to be small.

PCBs in Shredder Fluff

During a meeting on April 14, 2004, David Lasher (NYC DEC) summarized a NYS DEC internal report by Robert Bazarnick [7] that found PCBs in landfill leachate to be closely related to having accepted shredded fluff waste (e.g., nonmetal automobile components such as seats and plastics). PCB levels in the fluff were often >50 ppm. Typical concentrations of PCB in leachate were ~0.2 ppb, except three cases in which it was >0.5 ppb, with a maximum concentration of 1.4 ppb). The same report indicated that the control group (six landfills not receiving shredded fluff waste) had nondetectable levels of PCBs in leachate, except one landfill with concentrations ranging from 0.13 to 0.61 ppb. Although this is not enough data to draw definitive conclusions, five of eight landfills accepting fluff had measurable amounts of PCBs in leachate at some point during sampling (samples were measured using EPA method 8082, which has a lower sensitivity than currently available methods). A 1991 EPA pilot study [140] found PCBs in shredder material in

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[193] Lisa Totten, personal communication (e-mail). November 29, 2004.

[194] Ibid.

[195] Sampling data from Simon Litten, NYS DEC. A summary of these data is now available at (*http://www.dec.state.ny.us/website/dow/bwam/CARP/*).

Table C10. PCB emissions to air

Combust. source category	Number of facilities		Activity level, metric tons (T) incinerated/yr		PCB emis. factor (mg/T)	Emissions (kg/yr)		Percet contribution	
	USA	Water shed	USA	Water shed		USA	Water shed	USA	Water shed
Municipal waste	158	6*	29,030,400	2,195,424*	2.75	79.8	6.0	53.4	43.0
Medical waste	3,400	60†	1,569,456	262,181†	23.25	36.5	6.1	24.4	43.4
Other–biological	1,700	99§	106,959	ND	23.25	2.3	0.1§	1.5	0.9
Sewage sludge	174	19‡	864,743	48,097‡	5.4	4.7	0.3	3.1	1.8
Hazardous waste	150	9§	25,220	ND	1,000	25.2	1.5§	16.8	10.4
Scrap tire	18	1§	499,867	ND	1.89	1.0	0.1§	0.6	0.4
Stationary External Fuel			Barrels[a] (kg PCB burned)		(kg/10^6 kg PCB burned)				
Util.residual fuel oil	545	32§	164,203,200 (137,894)	ND	1	0.1	0.008§	0.1	0.1
Industrial Residual fuel oil	6,000	348§	59,875,200 (49,896)	ND	1	0.0	0.003§	0.0	0.0
Total						**149.6**	**14.1**		

Open burning	Activity level (kg trash burned/yr per person)	Watershed rural population	Emission factor (mg/kg of trash burned)	Emission (kg/yr)
Estimated	616 kg/yr/person	1,015,400	0.97–2.86	153–451**

Open Burning 1999 data	NEI air emissions Waste management	New York (kg/yr)	New Jersey (kg/yr)	Watershed (kg/yr)
	Category: SCC[++]2610030000	1,850 lb.	442 lb	2,292 lb or 1 T

Primary Source: US EPA, 1998 [142].

* Kiser and Zanes, 2004 [143].

ND= no data available.

† Approximate value. Sources: NYS DEC and NJ DEP, 2004 [144,145].

§ By direct extrapolation from the national to the regional population (5.2%), adjusted to reflect the level of regional economic activity (5.8%).

† Alia Roufaeal, Regional Biosolids Coordinator, Water Compliance Branch, Division of Enforcement and Compliance Assistance USEPA. Personal communication (email). August 18, 2004.

**This yields air background concentrations of ~6–17 pg/m3, which is equivalent to <10% of the background air levels in the Watershed region.

++Source Classification Code (SCC) 2610030000 refers to *Waste Disposal, Treatment, and Recovery (open burning, residential, household wastes).*

a. Barrels of residual oil contaminated with PCB. Numbers in parenthesis express the amount of PCB burned when the residual oil is combusted.

all samples from seven shredding operations. Approximately 98% of the PCBs in shredder output were associated with the fluff (as opposed to shredded metal, which contained ~0.2–0.9 ppm). PCB concentrations in fluff ranged from 0.67 to 760 ppm, with an average of 43 ppm. Overall, the highest concentrations (mean 180 ppm) were found in ”mixed fluff,” which included material from demolition sites, white goods (appliances), and automobiles. White goods had a mean of 80 ppm PCBs, whereas automobile fluff had 32 ppm. Leachate was not measured directly. Instead, fluff samples were extracted with water at 22° C and 60° C, with 0.0073 and 0.0050% of PCBs, respectively, recovered in the water extract. This was considered to be very low, and indicative that PCBs are less likely to be leached from fluff than from most soils (This study also used US EPA method 8082). Note that, although the hot water extract was regarded as a "worst-case scenario," it may not be representative of the actual processes taking place in landfills, where all kinds of wastes are disposed of, including oils and fats.[196]

Recommendation for solid waste: Identify and promote strategies to prevent PCB-contaminated products from entering the waste stream.

C6. Contaminated Sites

Contaminated sediments, water bodies, rivers, buildings, floodplains, dredge spoils, remnant deposits–including Superfund sites, brownfields, and other contaminated sites –are among the reservoirs of toxic compounds in the environment (see maps below). All of these sites are relevant to our overarching goal to prevent pollution to the Harbor because they are or have the potential to act as sources of PCB contamination to the Harbor region.

Despite intense interest and regulatory activities focused on certain sites, there is very little information available about how much PCBs are contributed to the Harbor from each of the myriad of contaminated sites in the Watershed. Given the Harbor Program's specific focus on loadings *to the Harbor*, the mass balance in this document treats all PCBs entering the Harbor above the George Washington Bridge as a single input. Thus, the Hudson River input upstream of the Bridge includes the Hudson River Superfund site, as well as NYS Superfund sites (e.g. Hastings-on-Hudson; Fort Edward; Hudson Falls), other contaminated sediments, and potential inputs from floodplains, dredge spoils and remnant deposits. The mass balance indicates that these Hudson River upstream sources account for ~50% of the total PCBs entering the Harbor at the George Washington Bridge.

However, the Consortium as a group decided at the beginning of its PCB work to focus attention on PCB sources close to the Harbor itself because they have not been under recent scrutiny. Nevertheless, because the Upper Hudson input represents half of the loads to the Harbor, remediation of this site and other PCB contaminated areas along the Hudson is important to achieve reductions in PCB inputs to the NY/NJ Harbor watershed. Therefore, the Consortium recommends a long-term monitoring program to assess the impact of upstream remediation on the Harbor watershed. There is considerable debate about the scope and how best to remediate the Upper Hudson River PCB contamination; links to further information about the Hudson River Superfund and other contaminated sites are provided in Appendix B.

One of the largest *downstream* sources of PCBs to the Harbor identified in the mass balance analysis is stormwater runoff (albeit this estimate has high uncertainty). This suggests that sites near the Harbor with high concentrations of PCBs may be significant sources during storms or they may contribute to the volatilized pool of PCBs that can be deposited on the Harbor waters.

We have mapped the PCB contaminated Superfund (Federal and State) and brownfield sites for New Jersey and the Superfund sites for New York (brownfield data were not available for NY). These maps provide a better view of the number of such sites in the Watershed, and they may suggest possible opportunities for track-down activities and future studies.

The PCB contribution of such sites to the Harbor is not known; however, in an attempt to understand their relative contribution, we employed the following approach.

The Delaware River Basin Commission (DRBC) has estimated PCB runoff inputs from contaminated sites to the Delaware River by using the Universal Soil Loss Equation (USLE). Penta-PCB inputs were estimated to be in the order of 10 kg/yr[197] [146] (~30% of all penta-PCB inputs in the Delaware River). This calculation included only 49 sites within the Delaware River Watershed,[198] and it did not take into account volatilization or leaching. For

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[196] As pointed out by Lisa Totten, personal communication. December 15 and 16, 2004.

[197] Reported as 15.89 kg of penta-PCBs released over 577 days. This estimate is currently being revised and probably will be lowered once all data have been incorporated and computation methods are made consistent.

[198] The process to define what sites would be included was complex and iterative. The initial area encompassed sites within 5 miles from the water. Some sites were purposely excluded, to avoid double counting, if they affected Delaware River tributaries that were already taken into account. At the time the report had to be completed, not all relevant sites had all necessary information available, and therefore were not included. Calculations were made by EPA regions 2 and 3 and the states of Pennsylvania, New Jersey, and Delaware separately. Not all work groups used the same equation to derive runoff inputs.

this particular input, penta-PCBs were calculated as 15% of total PCBs[199], so total PCB loads from contaminated site runoff to the Delaware River would amount to ~67 kg/yr. According to this calculation, each site would contribute ~1.3 kg/yr to the river. Applying this average to each of the ~180 Superfund sites in the NY/NJ Harbor watershed[200] gives a load of ~230 kg/yr. This contaminated sites runoff estimate is comparable to the runoff-CSOs combined estimate from the mass balance (103–280 kg/yr, see Appendix A). However, both estimates are highly uncertain. The mass balance estimate is based on a small sampling pool. The contaminated sites runoff model also has significant limitations. The model provides a crude estimate that does not take into account the specifics of each contaminated site (e.g., distance from the river/tributaries, PCB concentration in soil, surface area, slope, soil type, surface cover, etc.). Limitations notwithstanding, this suggests that contaminated sites may have a significant effect on the Harbor. *A comprehensive methodology to calculate PCB loads of runoff, volatilization, leaching, and possibly dust, from these sites is needed to better estimate their true contribution to the Harbor.*

Map 1. PCB-contaminated Superfund sites in the Watershed

There are 179 Superfund sites (Federal and State) in the Harbor Watershed area that are known to be PCB contaminated, including 115 in New Jersey and 64 in New York [147]. These Superfund sites in the Watershed region have been classified according to source of the contaminants as 27% waste storage and treatment; 26% manufacturing/industry; 23% unknown; 8% waste recycling; 6% other; 3% government; 3% affected natural areas; 3% mining and extracting activities; and 2% residential.

Map 2. PCB-contaminated brownfield sites in New Jersey[201]

New Jersey has a publicly accessible database of brownfield sites including some information about the contaminants present at these sites. It is estimated that ~550 brownfield sites in New Jersey are PCB contaminated. Similar data for New York would be useful to get a geographical view of these sites.

Map 3. PCB-contaminated landfills in New Jersey

The database from NJ DEP indicates that there are about 60 landfills in the New Jersey that are contaminated with PCBs.

Map 4. PCB-contaminated sites in New Jersey classified as "unknown/other"

There are approximately 26 other PCB-contaminated sites in Northern New Jersey, which have been classified as "other contaminated sites: unknown/other."

Remediation of PCB-contaminated sites

There is no standard way to treat PCB contamination. Each case has to be studied individually to decide the cleanup strategy. The most common method to deal with PCB-contaminated soils and dredged material is containment (land filling), particularly when large quantities of material with relatively low PCB levels are involved. Other technologies have been applied less frequently. For instance, the remediation of sediments from the Fox River (WI) involved a glass furnace technology.[202] Heavily contaminated soils with materials such as PCB oils are typically incinerated.

Based on the estimates from the Harbor mass balance, runoff is a significant source of PCBs to the Harbor. It is logical to assume that contaminated sites in the Watershed may be sources of some of the PCBs that end up in runoff. Further research on the impacts of contaminated sites in the Watershed to the loadings of PCBs to the NY/NJ Harbor may help to determine how important these sites are and lead to recommendations on how to stem or contain this flow until the sites are remediated. As a first step, this research could be modeled on the efforts of the Delaware River Basin Commission to estimate how much PCB is being added to the river from contaminated sites in close proximity to the river.

Recommendations for contaminated sites:

- **Determine the importance of contaminated sites (especially land sites) to the inputs of PCBs (as well as other contaminants) to the NY/NJ Harbor (e.g., via air emissions, runoff, groundwater, erosion).**
- **Support an ecosystem/watershed-wide sustained and long-term monitoring effort to determine whether remediation, pollution prevention, and best management practices are having an impact on the health of the Harbor.**

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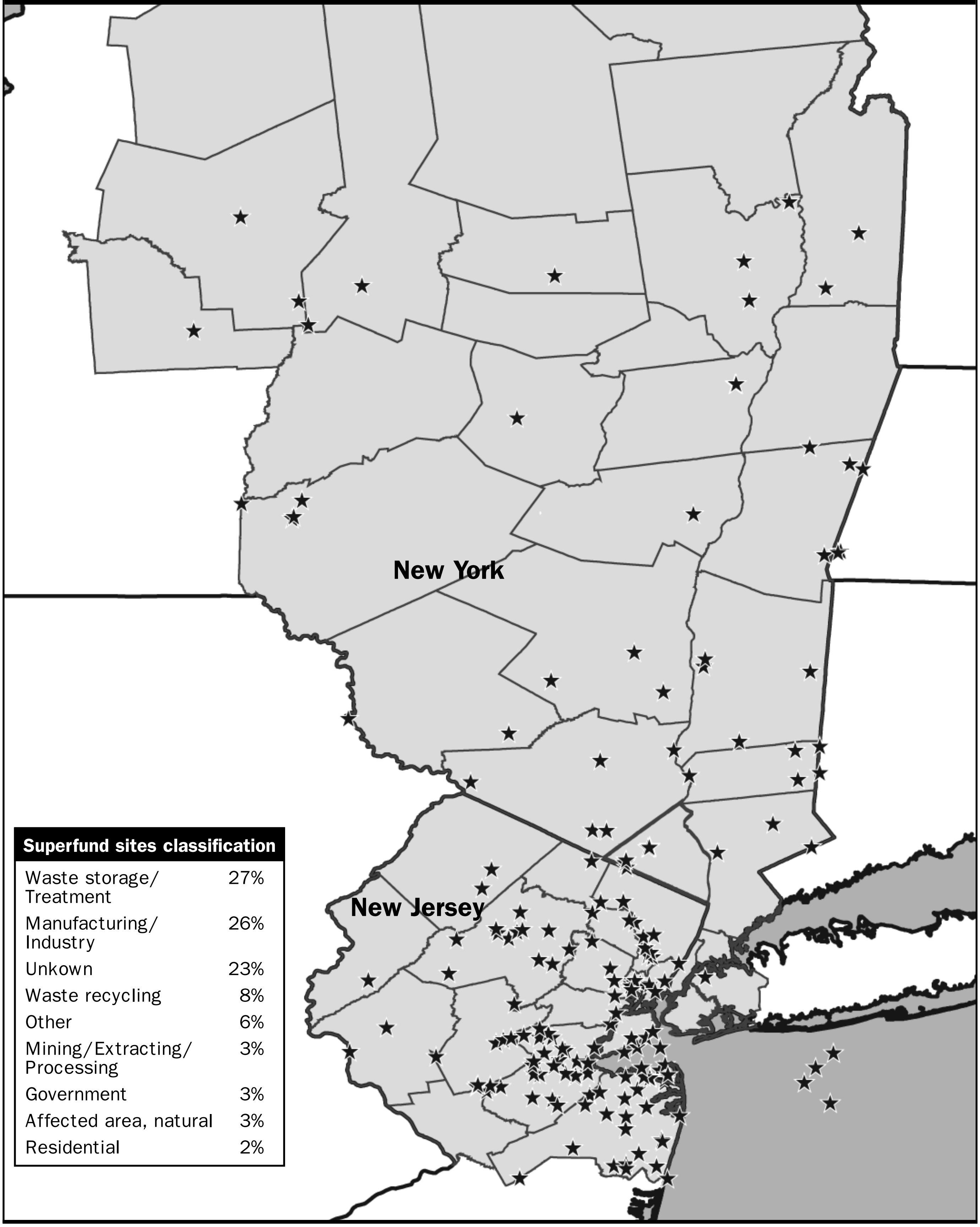
[199] Penta-PCBs were ~15% of PCB production, and it is assumed that the percentage remained unchanged for PCBs in contaminated sites.

[200] Superfund sites were used because it was the only data set consistent across New York and New Jersey. Brownfields, landfills, and other contaminated sites were excluded from this estimate because the number of these sites was not available for the NY side of the Harbor. There was no attempt to select only Superfund sites closest to the Harbor.

[201] Only the New Jersey part of the NY/NJ Harbor watershed (Northern NJ) has been considered to develop these maps.

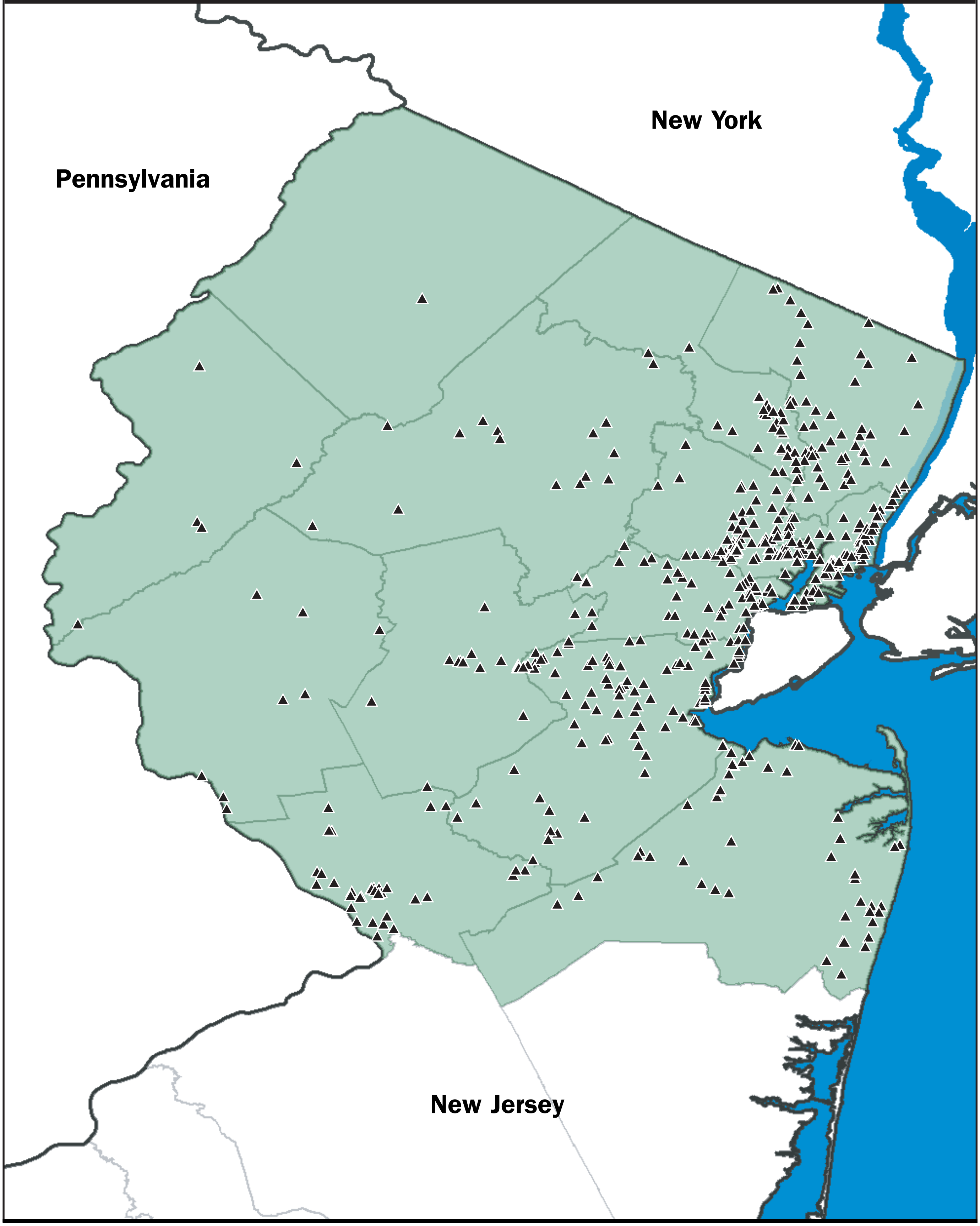
[202] *http://www.dnr.state.wi.us/org/water/wm/lowerfox/minergy/*. January 3, 2004.

Map 1. PCB-contaminated Superfund sites in the Watershed

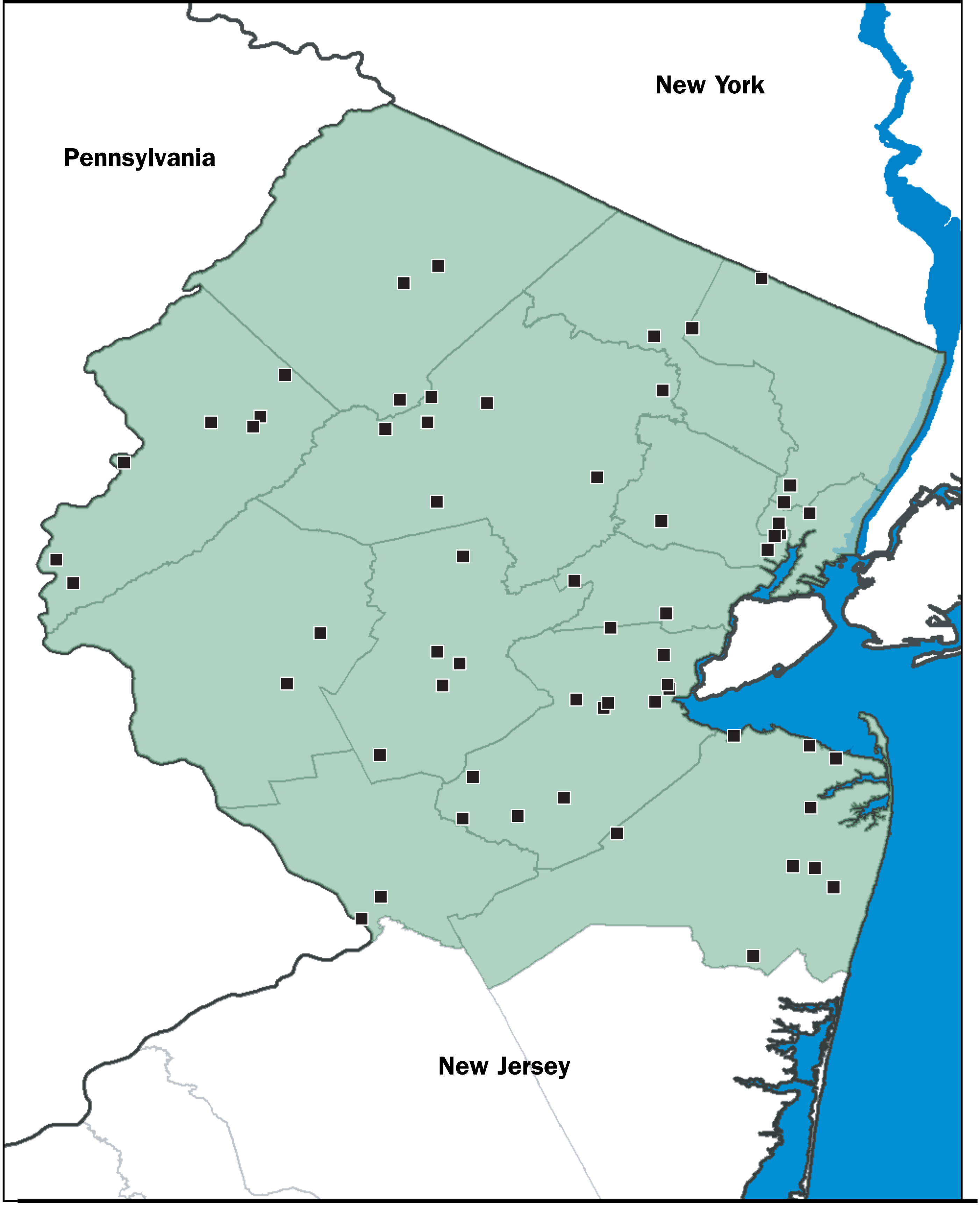


Superfund sites classification	
Waste storage/ Treatment	27%
Manufacturing/ Industry	26%
Unkown	23%
Waste recycling	8%
Other	6%
Mining/Extracting/ Processing	3%
Government	3%
Affected area, natural	3%
Residential	2%

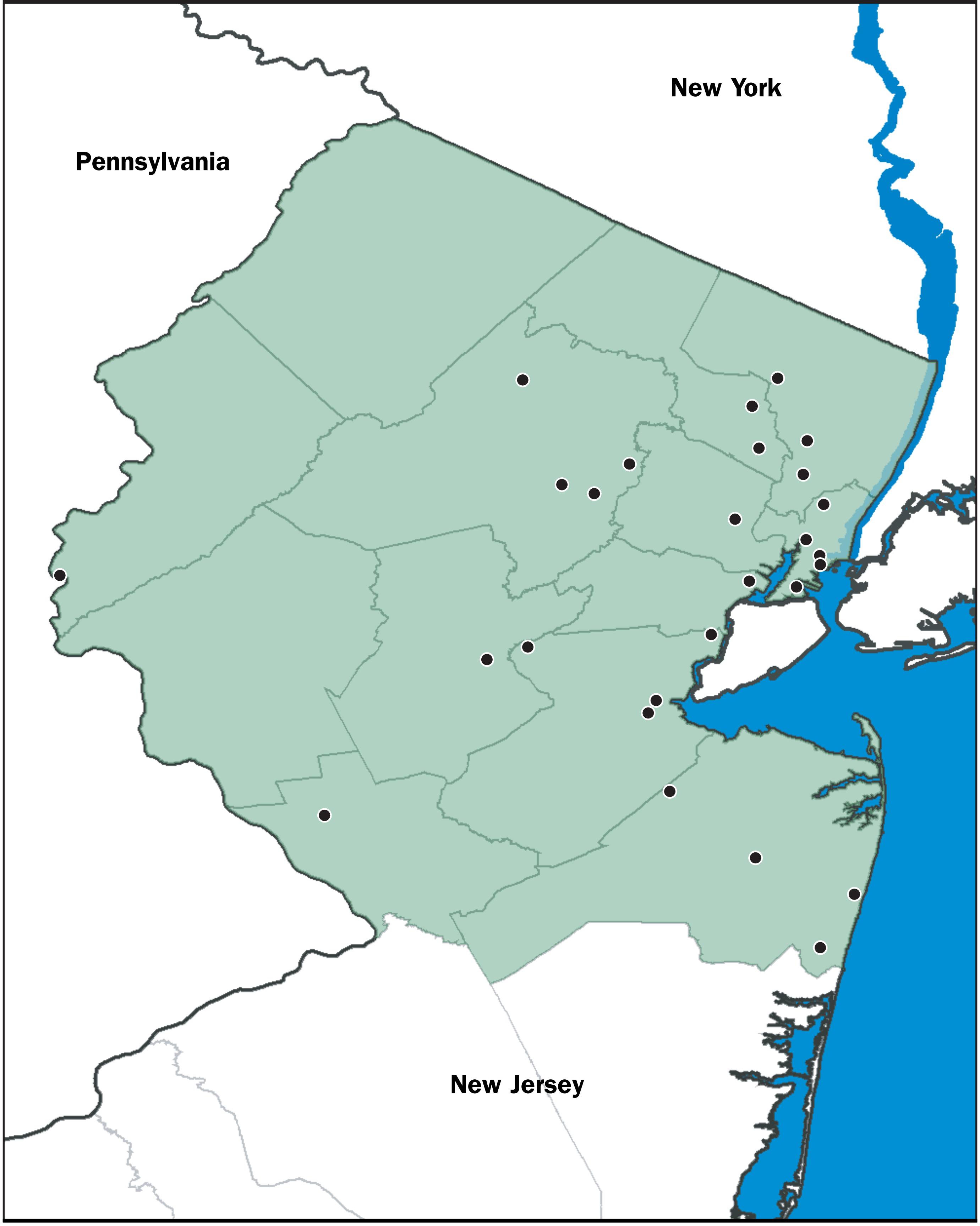
Map 2. PCB-contaminated brownfield sites in New Jersey



Map 3. PCB-contaminated landfills in New Jersey



Map 4. PCB-contaminated sites in New Jersey classified as "unknown/other"



CONCLUSIONS

PCBs are pervasive, persistent toxic chemicals found in products, soils, water, and the atmosphere across the globe. The history of this and other countries' efforts to control the release of PCBs has resulted in some progress, but there is still a very long way to go (only 5% has been permanently destroyed, see Table B5). What is perplexing about this is that we have been quite successful at reducing the releases of many other toxicants in the last 30 years but have had much less success with this chemical whose production was banned over 25 years ago. Our PCB research suggests that banning production but allowing certain uses is not enough. If the ban includes exclusions for certain uses and inadvertent production, as is the case for PCBs, then mandatory and comprehensive inventories, especially of disposal practices should be required. Furthermore, PCBs should be permanently destroyed upon disposal, to avoid reuse and recycling, which can lead to PCB remobilization and dispersal.

Table C11 summarizes the calculations described in the previous sections and provides an overview of PCB products, sources, and possible releases for the Watershed. Note that the releases column is considered the upper limit specifically for the electrical equipment because the release coefficients used to calculate these values are all considered upper limits. Furthermore, the mass balance suggests that 425 to 845 kg are released to the Harbor every year (see Table C12). When compared with the order of magnitude higher release estimates in Table C11 for electrical equipment, it suggests that releases from electrical equipment could be a significant contributor to the overall inputs but is most likely overestimated in these calculations. Further research is needed to improve the accuracy of the industrial ecology analysis and better quantify PCB release estimates.

One of the largest estimated releases in Table C11 is from small capacitors. As is the case with most PCB products, there is no actual inventory of small capacitors; however, even using high rates of disposal (20% each year over the last 20 years) results in hundreds of thousands of capacitors being disposed of in the region (see Appendix E). Each individual capacitor is small; however, when you consider the number of items being disposed of, they amount to our largest release estimate for the Watershed. Discussion about small capacitors during the November 12, 2004 Consortium meeting by the waste and recycling industry gave the impression that these items are out of circulation; however, there are no actual data to support this. Circumstantial evidence from automobile fluff suggests that small capacitors are occasionally being shredded with automobiles and the largest use of small capacitors was in fluorescent lamp ballasts, which would not be sent to recyclers or shredders at end of life. There has been no attempt to quantify ballasts during demolition or to track the fate of these items after demolition. Therefore, we have included in our recommendations a call for research to quantify the disposal rate of small capacitors and determine the fate of the PCBs associated with the capacitors.

One response to the estimates and uncertainties in PCB loadings to the Harbor summarized in Table C11 would be to make the most rigorous recommendations possible, based on the concern for the Harbor. Given the lack of any coherent data collection over the last 25 years of the PCBs ban and the inability to minimize uncertainties in various sectors, the Consortium suggested a different path: to focus our recommendations on the sources that were better quantified and to call for much more data gathering on the use, release, and pathways of PCBs to the Harbor. This document reflects that charge from the Consortium.

The consortium also called for a multi-disciplinary, ecosystem/watershed-wide, and long-term monitoring effort to determine whether remediation, pollution prevention, and best management practices are having an impact. This was based in part on the discussion of the planned dredging of the Hudson River site and determining what the outcomes and impacts of that action will be downstream. Systematic monitoring was also called for to establish benchmarks to be able to determine whether we can see any real trends in concentration decreases as sources of PCBs are dealt with. A long-term ecosystem view of the region would provide the kind of data needed to understand how PCBs are affecting our Watershed now and into the future and help understand what types of mitigation have the greatest positive impact. Members of the consortium have been active in monitoring and pollution mitigation efforts in the region and therefore, could play a key role, either individually or collectively, in developing this type of a systems view.

The November Consortium meeting also included a discussion of the impacts that a PCB TMDL (total maximum daily load) would have on the recommendations. It was noted that the Delaware River Basin Commission is using the TMDL process to enforce action on PCBs entering the river. A similar effort could be undertaken in the NY/NJ Harbor as the TMDL is being developed and promulgated by New York and New Jersey. This may be the type of unifying process that could provide the framework for an ecosystem approach mentioned in the "Summary of Findings" section at the beginning of this report.

Table C11. Summary of all PCB estimated releases for the NY/NJ Harbor Watershed

	PCB sold up to 1977 (T)	PCB in use (T)	Upper limit of releases (kg/yr)	Aroclor type used for each application
Closed applications				
Askarel transformers	~8,800	1983: ~6,500 Today: ~1,900	~550	1242, 1254, 1260
Mineral oil transformer (PCB, and PCB contaminated)	PCB not purposely sold	~18	1.5–14	
PCB large capacitors	~16,000	1983: ~2,700 Today: ~1,000	4,200	1016,1242, 1254
PCB small capacitors		1983: ~1,200 Today: ~60–70	6,000–14,000	1016, 1254
Semi-open applications				
Hydraulic fluids	~2,100	Undetermined	Undetermined	1232,1242,1248,1254,1260
Heat exchange fluids	~527	Undetermined	Undetermined	1242
Gas pipelines	Undetermined	Undetermined	Undetermined	1242, 1260
Open applications				
Plasticizer (incl. paint)	3,000	Undetermined	Undetermined	1254, 1260
Carbonless copy paper	1,200	Today: >12	Undetermined	1242
Miscellaneous application	~700			1242, 1268
Inadvertently produced PCB				
Pigment manufacturing	PCB not purposely sold	Unknown	~50 (PCB 11)	PCB 11, 35, 77
Ferric Chloride	PCB not purposely sold	Unknown	Unknown	PCB 209
Incidental releases during recycling/remanufacturing				
Paper recycling–Kaofin	N/A	50 kg/yr	Undetermined	
Tire as fuel	N/A	Unknown	0.60	
Oil recycling	N/A	8	0.01	1016, 1242, 1254, 1260
Metal recycling	N/A		56.00	1242, 1254, 1260

Table C11. Summary of all PCB estimated releases for the NY/NY Harbor Watershed (cont'd)

	Waste (T)	Emission factor (mg/T)	kg/yr released
PCB in Combusted wast in the Watershed			
MSW	2,195,424	2.75	6
Medical waste	262,181	23.25	6
Hazardous waste	1,450	1,000	1.5
Other: biological	6,200	23.25	0.01
Recycled oil (utility)	9,523,000	1	0.008
Recycled oil (industrial)	3,472,762	1	0.003
Sewage sludge	48,097	5.4	0.3
Scrap tires	29,000	1.2	0.03
PCB in solid waste sent to landfills			
MSW	~12,000,000	330 ng/L leachate	1
Contaminated sites	**Number of sites**		
Superfund sites	179*	~1.3 kg/yr per site¥	230
Brownfield sites	550+		
Contaminated landfills	60+		
Other contaminated sites	26 (NJ) + 61 (NY)		

* This does not include the Hudson River Superfund site. It is estimated that the Upper Hudson (including the Hudson River Superfund site) contributes more than 50% of the PCBs entering the NY/NJ Harbor (266 to 471 kg/yr; see Appendix A, "Riverine Inputs" section).

¥ See description of how this value was calculated in the "Contaminated Sites" section above.

Table C12. Sum of inputs & losses of ΣPCBs homologs 3–9 from the NY/NJ Harbor (kg/yr)

	Inputs		Losses	
Homolog	Low	High	Low	High
3	117	211	193	435
4	110	211	263	570
5	66	139	100	200
6	46	107	56	107
7	22	54	21	40
8	6.4	17	9.5	18
9	1.7	4.7	2.2	4.2
ΣPCBs	**425**	**845**	**746**	**1631**

Source: Totten, Lisa (2004); *Present-Day Sources and Sinks for Polychlorinated Biphenyls (PCBs) in the Lower Hudson River Estuary;* see Appendix A.

FINAL OBSERVATIONS

Our current system of tracking and valuing material goods is expressed in price and monetary flows (economic statistics). The actual physical mass and toxicity of important material flows is ignored. This severely hampers our ability to track and manage contaminants in our society. Recently, individuals from both within the federal government and outside of the federal government have begun to discuss the importance of a materials tracking data infrastructure.[203] In addition, in 2004, the Organization for Economic Cooperation and Development (OECD) also expressed the importance that member countries take steps to develop material flow accounts and assist each other in this process. These ongoing efforts should be supported up to the highest levels of government. PCBs are the perfect example of what happens when we do not keep complete records of materials from their production through intermediate use, consumption, and disposal, and which are later discovered to be harmful to human health and environment. We can observe this pattern repeatedly with other chemicals and materials that are produced, but never tracked, and the subsequent costs of dealing with these problems, through either end of pipe approaches, or environmental remediation, are and will continue to be staggering.

This study was quite exhaustive in terms of locating the available data. The dearth of information about where PCBs are in the environment (and we include humans and their infrastructure as being part of the environment) points to real gaps that our past experience suggests will come back to haunt us in the future. *The lack of a systems view approach about the total universe of PCB remaining in use may prevent appropriate management and monitoring of proper disposal.* The main take home message here is the need for much better inventories, monitoring, and research to try to stem the current flow of PCBs to the Harbor as well as protect us in the future.

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[203] In particular, the National Academy of Sciences/National Research Council released a report in 2003 entitled Materials Count: The Case for Material Flow Analysis.

APPENDIX A.
PRESENT-DAY SOURCES AND SINKS FOR POLYCHLORINATED BIPHENYLS (PCBS) IN THE LOWER HUDSON RIVER ESTUARY

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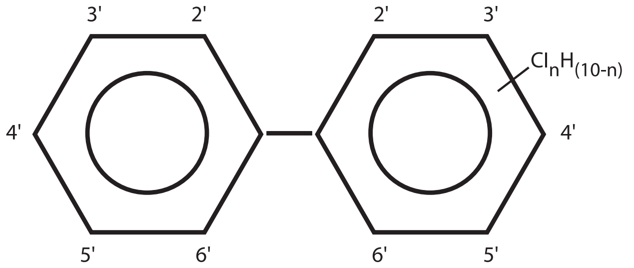
I. INTRODUCTION

Polychlorinated biphenyls (PCBs, Figure 1) are a class of compounds previously used as fluids in electrical equipment, particularly transformers and capacitors. PCBs also had a myriad of other uses and are sometimes inadvertently produced during chemical synthesis, even today *(1)*. PCBs are classified as probable human carcinogens and have been shown to cause a range of serious noncancer health effects in animals *(2)*. The manufacture, processing, and distribution in commerce of PCBs were banned in 1977 because of concerns over their toxicity and persistence in the environment *(3)*. PCBs are of particular interest in the Hudson River ecosystem because for about 30 years, ending in 1977, General Electric discharged as much as 1,330,000 lbs of PCBs in to the Upper Hudson from plants at Fort Edward and Hudson Falls *(3)*. A large portion of the Hudson River (from New York City nearly 200 miles upstream to Hudson Falls) has been designated as a Superfund site because of this contamination, and GE has entered into an agreement with the US EPA to dredge portions of the Upper Hudson at an estimated cost of $460 million *(3)*. The Upper Hudson therefore has long been recognized as a source of PCBs to the Lower Hudson River Estuary (NY/NJ Harbor). Until recently, little information was available about sources of PCBs to the NY/NJ Harbor other than the Upper Hudson. In particular, almost nothing was known about the loadings of PCBs to the estuary from tributaries other than the Hudson, specifically the Raritan, Hackensack, and Passaic Rivers and the Long Island Sound. Recent measurements of PCBs in these tributaries and new measurements of PCBs in the air and water of the estuary permit a better assessment of the sources and sinks for PCBs in the NY/NJ Harbor. Much of these data arise from the CARP project (Contaminant Assessment and Reduction Program), which is administered by the New Jersey Department of Environmental Protection (NJ DEP), the New York State Department of Environmental Conservation (NYS DEC), the US Environmental Protection Agency (EPA), and the Hudson River Foundation (HRF). The individuals involved in this effort have kindly provided preliminary data from this project. This report aims to construct a mass balance of PCBs and, to the extent possible, PCB homologs, in the NY/NJ Harbor. Similar (but more comprehensive) efforts have been conducted by Mueller et al. *(4)* in 1982, Thomann et al. *(5)* in 1989, and Farley et al. *(6)* in 1999, but these reports were hampered by the lack of information about tributary inputs and concentrations of PCBs within the Raritan Bay and in the coastal Atlantic.

Figure 1. Structure of Polychlorinated Biphenyl (PCB) Molecule

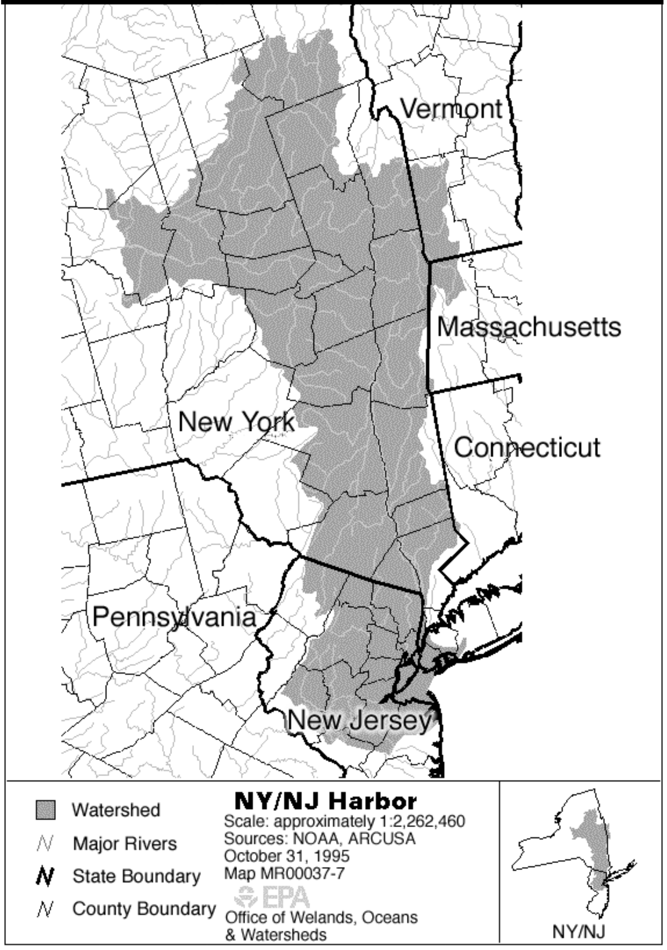


II. PCB CYCLING IN THE HUDSON RIVER

The biphenyl backbone of a PCB may contain 1 to 10 chlorines, producing 209 possible congeners. A group of congeners having the same number of chlorines is referred to as a homolog group. PCBs range in MW from 189 to 499 grams per mole. Much of the PCBs used in the United States were sold as mixtures of many different congeners under the trade name "Aroclor" and given numbers which identified the Aroclor mixtures by their percentage of chlorine content. For example, Aroclor 1242 contained 42% chlorine. Thus, for example, Aroclor 1248, which contained 48% chlorine, generally comprised congeners with higher MW than the congeners present in the 1242 mixture.

Physical properties of PCBs vary over a wide range. Vapor pressures of PCBs range from 1 to 10^{-3} Pa *(7)*. These values put them in the class of chemicals considered "semivolatile," meaning that they exist in the atmosphere in measurable quantities in both the gas and aerosol phases (although ~90% of their total atmospheric concentration is typically found in the gas phase). In those phases they are subject to deposition to water bodies (and other surfaces) via dry particle deposition, wet deposition, and absorption into water from the gas phase ("gross gas absorption"). Their low water solubilities, ranging from about 10^{-2} to 10^{-8} g/L *(8)*, make them amenable to volatilization from the dissolved phase in water to the gas phase (the opposite of gas absorption). PCBs are hydrophobic and prefer to associate with organic matter in solid phases such as sediment and suspended sediment rather than remaining in the dissolved phase in water. In general, the lower the molecular weight of a PCB congener, the higher its vapor pressure, and the less pronounced its preference for organic matter. Because of the strength of their association with sediment, a comprehensive assessment of PCB fate in an aquatic system such as the NY/NJ Harbor thus requires that a mass balance be developed on the solids (sediment) in the system. Such mass balances have been constructed previously, most recently by Farley et al. *(6)*. Transport of PCBs with sediment will be addressed in this report by using "whole-water" PCB concentrations (the sum of PCBs in the dissolved phase plus those associated with suspended particulate matter in the water column) to develop tributary loadings and tidal exchange losses to the New York Bight. The balance between the inputs and outputs of PCBs from the NY/NJ Harbor is assumed to represent either storage in, or removal from, the system. This storage presumably consists of storage (deposition) of PCB-laden sediments within the NY/NJ Harbor. Net removal would likely consist of removal of PCBs bound to sediments that were deposited in the NY/NJ Harbor in previous years.

Figure 2. New York/New Jersey Harbor Drainage Basins



III. APPROACH

The New York/New Jersey Harbor drainage system covers an area of 42,128 km^2 (16,456 square miles) (Figure 2). The water surface encompasses ~811 km^2. These mass balance calculations are based on the general three-box model used to examine cadmium distributions in the estuary *(9, 10)*. This model has been used in past to construct mass balances on mercury *(11)* and cadmium *(12)* in the estuary. The model includes three boxes: *Hudson River, Estuary* and *New York Bight*. The River box includes all freshwater bodies (i.e., combined riverine inputs from the Hudson, Hackensack, Passaic, Raritan, Elizabeth, Rahway, and East Rivers). The River box is separated from the estuary by the zero salinity point. Note that the geographical location of this point depends on the water discharge; at low discharge the tidal tongue pushes the river upstream, whereas at high discharge, typically in March and April *(6)*, the freshwater body extends further downstream. The Estuarine box extends from zero salinity seaward (for area calculation we designate the Newburgh Bridge as the northern extension of the estuary; Table 1) and includes the Upper and Lower Harbor. The line connecting Sandy Hook with Long Island separates the Harbor from the New York Bight.

Sources of PCBs to the NY/NJ Harbor considered in this report include:

- Tributaries
- Atmospheric deposition via wet and dry particle deposition and gross gas absorption
- Wastewater treatment plant discharges
- Combined sewer overflows

- Leachate from landfills
- Runoff

This report will attempt to quantify the above processes. Other processes could be important sources of PCBs to the NY/NJ Harbor, but the data necessary to evaluate their importance are unavailable. These include (a) ship paint *(13–15)*, (b) unidentified point sources (e.g., pigment manufacturing processes *(1)*), (c) runoff of PCB-laden soils and dust from contaminated sites (e.g., Superfund sites, rail yards), and (d) leaching from PCB-containing transformers and capacitors that are still in use. All of these processes are partially accounted for in the tributary inputs. Process 3 is partially addressed by considering inputs from runoff. Leaching of PCBs in groundwater into the NY/NJ Harbor is thought to be unimportant, because most of the PCBs are expected to remain associated with the large amount of solids in the aquifer rather than remain in the dissolved phase and leach into the estuary.

Processes considered in this report which remove PCBs from the water column of the NY/NJ Harbor include:

- Advection of dissolved or suspended sediment-bound PCBs out of the NY/NJ Harbor into the coastal Atlantic Ocean
- Volatilization of dissolved PCBs into the atmosphere
- Removal of sediment-bound PCBs via disposal of dredged sediments outside the NY/NJ Harbor
- Accumulation or burial of sediment-bound PCBs with sediment in the NY/NJ Harbor

Although accumulation of sediment-bound PCBs in the bottom sediments of the estuary removes them from the water column, it does not remove them from the estuary itself and therefore is not truly a loss process. In accord with previous studies, biological dechlorination of PCBs is assumed to be unimportant in the NY/NJ Harbor *(6)*.

App A Table 1. Total water surface area used in this study *(16)*

Subbasin	Area km^2	Percentage of area
Lower Harbor	318	39%
Upper Harbor	104	13%
Jamaica Bay	47	5.8%
Newark Bay	32	3.9%
Battery to Newburgh Bridge	310	38%
Total water surface area	811	100%

IV SOURCES AND SINKS

A. Riverine Inputs

River flow data from Fitzgerald and O'Connor *(11)* were used to assess tributary inputs to the NY/NJ Harbor. To estimate loadings of PCBs from these tributaries, it is necessary to determine an average concentration of PCBs in each river above the head of tide, to ensure that tidal mixing of PCBs already present in estuary does not affect the measured concentration (and therefore the loading). For the Hudson River this is difficult, because the boundary of the Estuary for this report is taken to be the Newburgh Bridge, which is within the tidal portion of the Estuary, and not the Troy Dam, which is the head of tide for the Hudson. Thus, PCB measurements within the tidal reach will be used to construct loadings estimates, because of the presence of PCB sources below the head of tide, such as the wastewater treatment plant at Poughkeepsie. NYS DEC conducted several sampling campaigns from November 1998 to April 2000 in which ambient PCB concentrations in the Hudson were measured. These data have been kindly provided by Simon Litten (NYS DEC) via personal communication. NYS DEC collected four composited samples in each of three reaches of the River: between Kingston and Poughkeepsie, between the Tappan Zee and Bear Mountain Bridges, and between the Tappan Zee Bridge and the Harlem River. ΣPCBs concentrations ranges were 13–23, 12–34, and 16–65 ng/L in these three reaches, respectively. These recently measured concentrations are similar to a measurement reported by the US EPA of 24.7 ng/L ΣPCBs in the Hudson in a sample taken near Yonkers in 1992 *(17)*. The measurements from Kingston to Poughkeepsie best represent the condition of the river near the Newburgh Bridge and will be used to calculate the PCB load to the NY/NJ Harbor. Because no clear relationship between river flow and PCB concentration is evident in this data set, the ΣPCB concentrations measured are assumed to apply to all flow regimens. Thus, the loading of PCBs from the Hudson to the NY/NJ Harbor is 13–23 ng/L multiplied by the flow of 650 m^3/s, or between 266 and 471 kg/y. This load is apportioned by homolog using the NYS DEC data. Because this load is based on measurements of PCBs taken below the head of tide, it may be an overestimate due to incursions of PCBs from downstream. However, because PCB levels remain fairly constant from the Troy Dam south to the Harlem River, these PCBs may be fairly assumed to arise from the Hudson River above the Newburgh Bridge. In addition, our Hudson River loading is in good agreement with that of Farley et al. *(6)*, who estimated that in 1997 ~250 kg PCBs per year entered the Lower Hudson River over the Troy Dam and ~60 kg/yr entered from the Mohawk River.

Waters from Long Island Sound enter the NY/NJ Harbor through the East River at a flow rate of ~355 m^3/s *(11)*. NYS DEC conducted four cruises from November 1998 to October 1999 in Long Island Sound in which composited water samples were collected between Port Jefferson, NY, and Bridgeport, CT. ΣPCB concentrations ranged from 0.4 to 0.6 ng/L. This translates into a load of about 6 kg/yr into the NY/NJ Harbor from the Long Island Sound.

The US Geological Survey is in the process of constructing head-of-tide loading estimates for PCBs based on the complete hydrograph of water and sediment flow in the Raritan, Hackensack, Passaic, Elizabeth, and Rahway Rivers. These estimates should be available in early 2005. In the absence of these data, the loads of PCBs from these tributaries at their heads of tide are assumed to be negligible.

B. Atmospheric Inputs

Since October of 1997, Steve Eisenreich and researchers at Rutgers University have operated the New Jersey Atmospheric Deposition Network (NJADN). This network has consisted of as many as nine sites scattered throughout the state where PCBs and other semivolatile organic compounds (SOCs) are measured in air, aerosol, and rain. The NJADN included three sites within the NY/NJ Harbor Watershed at Sandy Hook, Jersey City (at the Liberty Science Center), and New Brunswick (at Rutgers Gardens). The results demonstrate that concentrations of PCBs in the atmosphere of the urbanized area surrounding the NY/NJ Harbor are elevated above those measured in more remote parts of New Jersey. The average ΣPCB concentrations in the gas phase at Jersey City and Sandy Hook were 1,000 and 420 pg m^{-3}, respectively, in measurements taken from October 1998 to January 2001 *(18)*. In contrast, the average concentration of ΣPCBs in the gas phase at a more remote site in New Jersey (Chester) was 140 pg m^{-3} during this time period.

Higher atmospheric concentrations of PCBs contribute to larger deposition fluxes to the estuary via wet and dry particle deposition, and gross gas absorption. These three deposition modes combined yield a total atmospheric deposition flux of ΣPCBs of 140 and 44 ng m^{-2} d^{-1} at Jersey City and Sandy Hook, respectively *(18)*. To translate these fluxes into a loading to the NY/NJ Harbor, it is necessary to make some judgment about the concentrations of PCBs likely to be present in the atmosphere over the waters of the estuary. Totten et al. *(19)* and Yan *(20)* report PCB concentrations in the atmosphere at a location in the middle of Raritan Bay that were generally higher than those measured at Sandy Hook and lower than those measured at Jersey City. Thus, the deposition fluxes calculated at Jersey City and Sandy Hook are assumed to represent the maximum and minimum fluxes, respectively, likely to prevail in the estuary. Multiplied by the surface area of the NY/NJ Harbor [811 km^2 from ref *(10)*], this translates to 13 to 41 kg of PCBs deposited to the estuary from the atmosphere each year. The homolog distribution of these PCBs is shown in Table 5.

C. Wastewater Loadings

The NY/NJ Harbor receives effluent from 26 water pollution control plants (WPCPs). Based on the average flow of these plants, the NY/NJ Harbor receives more than 2,000 million gallons of treated effluent each day *(21)*. This translates into a flow of 94 cubic meters per second. In comparison, flow of the Hudson River past Manhattan is ~430 cubic meters per second for most of the year *(6)*. Based on analysis of effluent samples collected in 1994 and 1995, Durell and Lizotte *(21)* estimate that 88 kg of PCBs are discharged to the NY/NJ Harbor each year from these 26 WPCPs and the combined sewer overflows (CSOs) associated with them. Based on this information, the Interstate Environmental Commission has undertaken a track-down study to identify the sources of PCBs in WPCP influent. A portion of these data has been provided by Simon Litten of NYS DEC. NYS DEC sampled 20 WPCPs in New York and New Jersey from September 1998 to May 2001. Three to five samples were collected at most plants, where average concentrations of ΣPCBs ranged from 2 to 12 ng/L. Two plants exhibited extremely high concentrations of ΣPCBs in their effluent: Passaic Valley (NJ) and Port Richmond (on Staten Island). Concentrations of ΣPCBs averaged 130 ng/L at Port Richmond, but because the average flow at this plant is about 35 million gallons per day *(22)*, this effluent is less of a concern than that of the Passaic Valley plant, where ΣPCBs were 330 ng/L in a single sample, and the average flow is 273.7 million gallons per day *(22)*. At both of these plants, a single PCB congener (PCB 11 or 3, 3 -dichlorobiphenyl) accounted for between 65 and 98% of the total. Excluding this congener, ΣPCB concentrations at these plants were similar to those measured at the other WPCPs. This congener is present in very low levels (<1%) in Aroclors and for this reason is typically not measured during PCB analysis. Thus, other data sets used in this report did not attempt to quantify this congener. **Therefore, this congener is excluded from the mass balance on the estuary.** If the single sample collected at Passaic Valley accurately represents the effluent of this plant, the loading of this congener into the estuary is estimated to be on the order of 100 kg/y. PCB 11 is produced inadvertently during pigment manufacture *(1)*. Because of its low MW, it will not bind strongly to sediments but will remain in the dissolved phase, where it will be subject to volatilization.

The NYS DEC PCB concentration data were multiplied by the average 2001 flow for each WPCP to estimate loadings to the estuary. (WPCP flow data are available for 2002, but these data were not used because flows were generally lower than in previous years, assumedly because of the extensive drought of 2002.) The 18 plants sampled by NYS DEC that discharge ~1,700 million gallons per day of effluent to the estuary contribute about 22 kg of PCBs per year. This estimate does not include another eight plants in New Jersey which discharge about 230 million gallons per day of treated effluent to the estuary. The effluents of these plants were sampled by New Jersey DEP staff and sent for analysis to a different contract laboratory than was used for the NY plants. The average ΣPCB concentration in the NJ samples was 31 ng/L, more than twice the average at the New York plants. It is not clear whether the NJ WPCPs do in fact contain higher levels of PCBs in their effluent or if this is an artifact of the different contract laboratories or sampling methods used for these samples. At an average effluent concentration of 31 ng/L, the NJ WPCPs contribute an additional 10 kg of PCBs to the estuary per year. Thus, the load of PCBs to the estuary from all WPCPs is estimated to be ~32 kg/yr, excluding PCB 11. The homolog distribution of this effluent is estimated by using the average homolog distribution of all plants reported by NYS DEC except Passaic Valley and Port Richmond.

The loading estimated here from data collected during 1998–2001 is about one third the load previously estimated by Durell and Lizotte *(21)* based on data collected in 1994 and 1995.

D. Combined Sewer Overflows

The total flow from combined sewer overflows (CSOs) to the Harbor is ~424 cfs (23). NYS DEC and Simon Litten collected 16 samples of wet-weather influents to represent NYC CSOs and observed concentrations of ΣPCBs ranging from 10 to 3,500 ng/L. The highest concentration was associated with a former industrial area at the 26th Ward and shows a congener pattern very similar to Aroclor 1260. The CSO load is estimated by multiplying the average PCB concentration by the total CSO flow. In determining this average, the data from the 26th Ward were excluded, as was the contribution of PCB 11 in the Port Richmond WPCP influent, to yield a mean PCB concentration of 282 ng/L. The standard error of the mean is 106 ng/L, or 37%. This translates into a load of 107 kg/yr from the CSOs. If the uncertainty in this load is assumed to be equal to the standard error, then the load is 67–143 kg/yr. This load is apportioned by homologs by using the average homolog profile of 14 CSO samples (excluding Port Richmond and the 26th Ward).

E. Landfill Leachate

NYS DEC collected nine samples of leachate from three landfills. Although concentrations of ΣPCBs were sometimes very high (ranging from 9 to 1,490 ng/L) the volume of leachate generated each year is estimated to be small. Simon Litten estimates that at a yearly rainfall of 1.1 meters and an infiltration rate (proportion of rainfall that becomes part of the groundwater) of 1, the estimated leachate production is only 2.6 million gallons per day. This results in a PCB load to the estuary of much less than 1 kg per year. Loadings from landfill leachate therefore are ignored in this report.

F. Runoff

The flow of stormwater into the NY/NJ Harbor Estuary is highly uncertain. The EPA used a flow of 1,000 cubic feet per second (893 million cubic meters per year) in a report from 1997 *(24)*. Robin Miller (personal communication, 2004) from HydroQual kindly provided estimates of stormwater flows to the “Harbor Core Area,” which is essentially the same as the Estuary as defined in this report except that in it, the Hudson River begins at Piermont Marsh as opposed to Newburgh Bridge. These estimates are based on the detailed hydrodynamic model of the Hudson River and its Estuary developed by HydroQual over the last ~25 years. Stormwater flows were calculated based on the rain that actually fell and the groundcover type in the drainage area on an hourly basis for six different water years: 1988–1989, 1994–1995, 1998–1999, 1999–2000, 2000–2001, and 2001–2002. (A water year runs from October through September.) The estimated stormwater flows range from 462 to 1,062 million cubic meters per year and average 710 million cubic meters per year. The 95% confidence level on the mean is ±30%.

A PCB loading assessment for the US EPA in 1997 *(24)* used a PCB concentration in the stormwater of between 50 and 200 ng/L to estimate that the stormwater PCB load to the NY/NJ Harbor was between 0.25 and 0.5 kg/day (~90–180 kg/yr). The Delaware River Basin Commission, in establishing a TMDL (total maximum daily load) for PCBs to the tidal Delaware River, has used an event mean concentration (EMC) of ΣPCBs of 62 ng/L *(25)*. (The EMC is defined as the total mass load of PCBs yielded from a site during a storm divided by the total runoff water volume discharged during the event.) These values are in good agreement with the two stormwater samples from Jamaica Bay analyzed by Simon Litten and the NYS DEC, which were found to contain 48 and 70 ng/L ΣPCBs. Thus, the concentration of PCBs in the stormwater is associated with a much larger degree of uncertainty that the magnitude of the flow of stormwater into the estuary. The uncertainty in the flow therefore is ignored, and the load is calculated as 50–200 ng/L ΣPCBs multiplied by the flow of 710 million cubic meters per year, or 36 to 142 kg/yr. This load is apportioned into homologs using average homolog distribution observed in the stormwater sampled by Simon Litten and the NYS DEC.

Runoff may represent a significant source of PCBs to the NY/NJ Harbor Estuary, but the size of the load is highly uncertain. Very few measurements of PCB concentrations in runoff in the Estuary exist. The sources of PCBs in runoff are also uncertain but could include indirect atmospheric deposition (dry and wet deposition of PCBs to land surfaces which is then collected in the runoff) or erosion of PCB-contaminated soils. Indirect atmospheric deposition alone probably cannot account for the entire PCB runoff load.

G. Tidal Exchange

To evaluate the effect of tidal exchange on the PCB budget in the NY/NJ Harbor, the estimates of tidal exchange of Rosenthal and Perron-Cashman were used *(12)*. They report the flow of water from the Estuary to the Bight to be 1,971 m^3/s, and the flow of ocean water into the Estuary to be 726 m^3/s. Yan *(20)* recently measured PCBs in the dissolved and suspended sediment phases in the Raritan Bay and the coastal Atlantic Ocean. During five cruises on Raritan Bay in all four seasons during 1999–2001, the mean concentration of ΣPCBs in the water column (dissolved plus particle phases) was 2.7 ng/L in 20 measurements, with a standard error of 0.3 ng/L. Yan *(20)* also found an average of 1.0 ng/L ΣPCBs in three surface water measurements at a site in the coastal Atlantic just off of Sandy Hook in April 2001. Simon Litten and the NYSDEC measured concentrations averaging 2.8 and 0.1 ng/L in Raritan Bay and the New York Bight, respectively. If the average concentrations of PCBs in the waters flowing in to and out of the estuary are 0.1–1.0 and 2.7 ± 0.3 ng/L respectively, then between 132 and 192 kg of PCBs flow out of the NY/NJ Harbor to the northern Atlantic each year. The homolog distribution of these PCBs is shown in Table 6.

H. Dredging

Dredging to maintain the shipping channels of the NY/NJ Harbor is conducted by the US Army Corps of Engineers in conjunction with the Port Authority of New York and New Jersey. The estimates of the volume of sediments dredged each year are taken from Farley et al. *(6)*, who estimate that 656,000 metric tons of dry sediment are removed from the NY/NJ Harbor annually. The source of this material by subbasin in the Estuary is shown in Table 2 *(6)*. To estimate the amount of PCBs removed because of this dredging, a PCB concentration in the surface sediment was assigned to each portion of the Estuary, based on the REMAP data of Adams et al. *(16)*. The 90% confidence limits on these PCB concentrations were used to generate the high and low estimates of the PCBs removed from each subbasin. The REMAP sediment PCB concentrations are in accord with a 1998 survey of sediments in the NY/NJ Harbor, in which Feng et al. *(26)* observed concentrations of PCBs ranging from 0.08 to 1.4 ppm in 14 sediment samples. Yan *(20)* likewise measured 0.14 to 0.72 ppm PCBs in 34 suspended sediment samples in Raritan Bay. This suspended sediment should be representative of the sediments that have been recently deposited in the navigation channel. Raritan Bay also receives sediment inputs from all of the subbasins of the Estuary, so that the homolog pattern of the Raritan Bay suspended sediment can be used to estimate the homolog distribution of the PCBs removed from the Estuary via dredging (Table 6).

IV Volatilization

Estimation of the volatilization flux of PCBs for any aquatic ecosystem is fraught with a great deal of uncertainty. The approach used here is to take the truly dissolved concentration of PCBs ($C \bullet f_{diss}$) times the mass transfer coefficient (K_{OL}) times the surface area of the system *(A)*:

$$\text{Volatilization Loss} = C \bullet f_{diss} \bullet K_{OL} \bullet A \bullet 365 \text{ days}$$

PCBs are measured in natural waters by passing the water through a filter, to collect particle-bound PCBs, and then through a resin column. PCBs measured in the resin column may have been truly dissolved or may have been associated with small particles (colloids) passing through the filter. Only the truly dissolved PCBs can volatilize. The amount of colloids present can be estimated from the dissolved organic carbon (DOC) concentration, and the fraction of PCBs that are truly dissolved may then be estimated by assuming that the binding constant for PCBs to the DOC (K_{DOC}) is 10% of the binding constant for organic carbon (K_{OC}). This approach was used by Farley et al. *(6)* and appears to work well in the Lower Harbor *(19)*.

App A Table 2. PCBs removed from the Estuary via dredging

Sub-basin	Sediment removed % of total Ref *(6)*	PCBs in sediment ppb[a] Ref *(16)*	PCBs removed (kg/y) Low	PCBs removed (kg/y) High
Battery to Newburgh Bridge	20%	224 ± 42	24	35
Newark Bay	20%	756 ± 270	64	136
Lower Harbor	23%	120 ± 44	11	25
Upper Harbor	21%	429 ± 125	42	77
W. Long Island Sound	13%	86 ± 22	5	9
Other	3%	224 ± 42	3	5
Total	**656,000 Metric tons (dry)**		**151**	**287**

a. Confidence limits ±90%.

The calculated f_{diss} at a DOC concentration of 3 mg/L (as assumed for Haverstraw Bay; see below) is listed in Table 3. Obviously f_{diss} introduces only a small uncertainty into the flux calculation for the lightest congeners, because they are nearly 100% dissolved. For the heavier congeners, the uncertainty in f_{diss} is more important.

Of the parameters in the above equation, only A is reasonably certain. C, f_{diss}, and K_{OL} all change with both time and space in the Estuary. In addition, the procedure for estimating K_{OL} is complex [see refs *(19, 27)* for details], and the resulting values are thought to be associated with an uncertainty ranging from 40% to 200% *(27, 28)*. In this report, a yearly average K_{OL} value will be used (Table 3) to estimate a yearly volatilization flux. The greatest error in the estimation of K_{OL} occurs at low wind speeds, where the different models for estimation the mass transfer coefficient across the stagnant water boundary layer diverge significantly. At the yearly average wind speeds used here (about 5 m/s), the uncertainty in K_{OL} is thought to be less than 200%. Herein, the uncertainty in K_{OL} will be assumed to be 40%, in accord with the recommendations of other researchers *(27, 28)*. A *conservative* estimate of the uncertainty in the flux may be obtained by assuming that uncertainty introduced by the calculation of f_{diss} is negligible and the uncertainty in the measurement of C is 20%. The propagated error in the volatilization flux is then ~47%. Because of this high degree of uncertainty, this report will estimate volatilization only in the Lower Harbor and the area from the Battery to the Newburgh Bridge. Volatilization from the remainder of the Estuary (~33% of the surface area) is assumed to be negligible, because PCB concentrations in these areas are lower than in the Battery to Newburgh Bridge area. Thus, this exclusion is estimated to lower the calculated flux by perhaps 15%, or well within the range of uncertainty. In addition, volatilization of congeners with seven or more chlorines is assumed to be negligible, in accordance with the findings of Totten et al. *(19)*.

Estimates of the volatilization of PCBs out of the Lower Harbor have less uncertainty that those in other parts of the Estuary as shown by the careful study of Yan (20), who measured DOC and PCBs in the operationally defined dissolved phase during five cruises on the Lower Harbor in all four season during 1999–2001. This reduces the uncertainty in C and f_{diss}. Yan *(20)* estimates an average yearly volatilization flux of 120 µg per square meter per year. This flux, multiplied by the surface area of the Lower Harbor (318 km^2), translates into a loss of 27 kg of PCB per year. The uncertainty in this estimation is assumed to be 47%, as calculated above.

Concentrations of PCBs in the operationally defined dissolved phase measured by Simon Litten (NYS DEC) in Haverstraw Bay range from 6.2 to 12 ng/L and average 9.8 ng/L in three samples collected during 1998–2000. The Haverstraw Bay area encompasses the largest portion of the surface area of the Battery to Newburgh Bridge subbasin, and therefore these concentrations will be applied to this region. PCB concentrations are more uncertain in this region than in the Lower Harbor because they are based on fewer measurements. Also, DOC was not measured at the time that the PCBs were measured, so an average DOC concentration of 3 mg/L *(6)* was used, resulting in the f_{diss} values in Table 3. Thus, the volatilization flux calculated from the parameters in Table 3 and using the average PCB concentration is 504 kg/y. The uncertainty in C, which is assumed to be about

60%, dominates the uncertainty in the volatilization loss from the Battery to the Newburgh Bridge.

The volatilization loss from the Estuary thus is estimated to range from 317 to 846 kg/y. This range is based on conservative estimates of uncertainty. The homolog distribution of this loss is shown in Table 6.

App A Table 3. Parameters used to estimate volatilization of PCBs

Homolog	f_{diss}	K_{OL} (m/d)
1	100%	0.60
2	97%	0.59
3	92%	0.60
4	83%	0.69
5	64%	0.67
6	42%	0.60

J. Storage in Sediments

To estimate storage of PCBs in the sediments deposited to the estuary, it is necessary to estimate both a sediment PCB concentration and a sedimentation rate. Woodruff et al. *(29)* estimate that an annual sedimentation rate of 2–3 mm/yr over the entire Estuary is required to keep a constant river depth with respect to current sea-level increase. Assuming the same sediment surface area as for the water (i.e., 811 km^2; Table 1) and a solids concentration of 500 g/L, 2–3 mm/yr equals 0.8–1.2 x 10^9 kg/yr. The median sedimentation estimate therefore is taken to be 1 x 10^9 kg/yr, and the uncertainty in the sedimentation rate is assumed to be 20%. Assuming that sedimentation is uniform over the entire surface of the Estuary, the amount of PCBs stored in the various subbasins may be estimated by applying the appropriate sediment PCB concentration from Adams et al. *(16)* (Table 4). The homolog distribution of this material is again estimated from the homolog distribution of PCBs in the suspended sediment from Yan *(20)*. The uncertainty in the storage estimate is propagated from the uncertainties in the sediment PCB concentrations and the sedimentation rate. Much of the PCBs stored in the sediments remain available for resuspension and transport out of the estuary. A portion of the deposited sediments will become permanently buried in the deep sediments.

K. PCB Annual Budget

Tables 5, 6, and 7 present the annual budget for PCBs in the NY/NJ Harbor based on the information given above. Storage in the sediments is presented in Table 6 as a loss process, but it must be remembered that storage does not represent a loss of PCBs from the system, but rather an accumulation of PCBs within the estuary. The loadings and losses are associated with varying degrees of uncertainty. In general, loadings and losses are calculated by multiplying a concentration by a flow rate. In most cases, the concentration term is associated with the largest uncertainty because a limited number of measurements can never capture the natural variability in a system as large and dynamic as the NY/NJ Harbor Estuary. The Hudson River load is known with more certainty because of the decades of measurements conducted in that portion of the Estuary. The other loads, most of which were calculated from CARP data, are less certain because they rely on fewer data points and are based on data that are not currently publicly available. More measurements can always reduce uncertainty, but it should be recognized that the NY/NJ Harbor Estuary is

App A Table 4. Calculation of PCB storage in the sediments of the NY/NJ Harbor Estuary

Subbasin	Percentage of area	PCBs in sediment Ref (16) ppb[a]	PCBs stored (kg/y) low	PCBs stored (kg/y) high
Lower Harbor	39%	120 ± 44	28	67
Upper Harbor	13%	429 ± 125	37	77
Jamaica Bay	5.8%	112 ± 68	2	11
Newark Bay	3.9%	756 ± 270	18	42
Battery to Newburgh Bridge	38%	224 ± 42	63	110
Total			**147**	**307**

a. Confidence limits ±90%.

perhaps the most studied system in the world with respect to PCB contamination, and that CARP has vastly expanded the amount of data available on PCB concentrations within the Estuary. Thus, there are few areas where an additional 10 or 20 PCB measurements will greatly reduce uncertainty in the PCB mass balance for the Estuary. The notable exception is stormwater, which may represent the second largest loading and for which very few measurements are available. In contrast, flow rates are much less uncertain than PCB concentrations for most processes. This report has attempted to deal with the question of uncertainty by generating high and low estimates of loadings and losses.

Loadings of ΣPCBs to the NY/NJ Harbor are dominated by inputs from the Hudson River at the Newburgh Bridge, which compose ~56% of the total. Farley et al. *(6)* estimate that the Upper Hudson River (i.e., at the Troy Dam) is responsible for slightly less than half of the total PCB load to the Estuary, with the Mohawk River contributing another 5–10%. The load from the Hudson River at the Newburgh Bridge would include the Hudson at Troy Dam and Mohawk River loads as well as potential loads from sources in the Lower Hudson River. The current estimate is in good agreement with that of Farley et al. *(6)*, suggesting that PCB sources south of the Troy Dam which have an impact on the load calculated at the Newburgh Bridge are comparatively small. This conclusion is also similar to the findings of a 1997 US EPA report *(24)* which estimated that 54% of the PCB load in the Estuary was derived from the Upper Hudson (at Troy Dam). CSOs and runoff from the urban area surrounding the estuary are the second most important sources of PCBs to the estuary, each contributing ~17% of the total ΣPCB load. Wastewater and atmospheric deposition are of roughly equal importance, each making up ~5% of the total ΣPCB load. Approximately half of all the ΣPCB losses from the NY/NJ Harbor are caused by volatilization. Storage in the sediments and removal via dredging each account for ~20% of the ΣPCB losses in the system. Tidal exchange with the Atlantic Ocean accounts for ~14% of the ΣPCB losses. All these calculations are based on the assumption that the loads from the minor tributaries are negligible. Although we believe this is a reasonable assumption, it must be recognized that the relative contribution from the other sources would be different if the loads from the minor tributaries were significant.

The inputs of PCBs to the NY/NJ Harbor are estimated to be 425–845 kg/yr. Losses from the NY/NJ Harbor are estimated to be 746–1,631 kg/yr. Possible interpretations of these loading and losses are:

1. Loadings of PCBs in the Estuary equal losses (i.e., the mass balance is closed), suggesting that the true inputs to the system are near the upper end of the estimates and/or the true losses to the system are near the lower end of the estimates.
2. The true loadings and losses of PCBs in the Estuary are closer to the median estimates, suggesting that PCBs previously stored in the estuary are now being lost from the system.

To gain a better understanding of the system, it is important to examine the loads and losses by homolog. Tables 5–7 suggest that although the mass balance may not be closed for the sum of PCBs, it is essentially closed for homologs 6–9. Losses appear to exceed inputs only for homologs 3, 4, and perhaps 5. These are precisely the homologs most susceptible to volatilization. They are also the homologs most prevalent in the Hudson River load. In other words, both the sources and losses are very different for the low-MW PCBs versus the high-MW PCBs. Approximately 83% of trichlorobiphenyls (homolog 3) and 68% of the tetrachlorobiphenyls (homolog 4) in the Estuary come from the Upper Hudson. About half of all the losses of these two homologs are caused by volatilization. For these homologs, the mass balance is probably not closed. The median estimates would suggest that perhaps 400 kg/yr of tri- and tetrachlorobiphenyls, which were previously stored in the sediments, are being lost to the atmosphere each year. This process is primarily occurring in the area surrounding the Tappan Zee Bridge (Tappan Zee and Haverstraw Bay), where high concentrations of low-MW PCBs from the Hudson River and a large surface area combine to produce huge PCB volatilization losses. Farley et al. *(6)* reached a similar conclusion. Their model results indicated a net loss of PCBs from the estuary of ~250 kg in 1997. This study defined the area of the estuary more broadly, such that the surface area of the model segments totaled about 18,500 km^2 and included large portions of the Bight. Their study nonetheless corroborates the finding of this report, that the estuary experiencing a net loss of hundreds of kilograms of low-MW PCBs each year.

For the high-MW PCBs, the picture is very different. CSOs and runoff account for ~60-80% of the inputs of homologs 7, 8, and 9 into the estuary. Volatilization of these homologs is negligible, and their fate is largely determined by their association with sediments. About 80% of the mass of these homologs that enters the Estuary is either stored there in the sediments or removed via dredging. The sedimentation estimates from Table 6 therefore suggest that high-MW PCBs are accumulating in the sediments of the Estuary at a rate of ~10–25 kg/y.

Although there is a great deal of uncertainty about the size of the runoff and CSO loads, several lines of evidence suggest that significant sources of higher MW PCBs exist in NY/NJ Harbor Estuary. First, an analysis of PCB congener patterns in water and sediment samples in the Hudson River system for the US EPA *(30)* suggested that higher MW PCBs were more prevalent in the southern areas of the estuary, leading the authors of the report to conclude that a source of higher MW PCBs existed in the estuary near River Mile 10. These authors also concluded, however, that this source was small in comparison with the Hudson River (at Troy Dam) source. Second, Simon Litten of NYS DEC has carefully examined the data from the CARP project and has noted that (a) the average MW of the PCB mixture in samples throughout the Hudson River systematically increases in samples collected further downriver, and (b) congeners which are markers for heavier PCB formulations (Aroclor 1248 and higher numbers) are likewise present in higher concentrations in downriver samples. Because the GE plants in the Upper Hudson released primarily Aroclor 1242 *(31)*, the shift in congener patterns in the southern portions of the estuary strongly suggests a source of higher MW PCBs in the southern portion of the estuary. Also, Gigliotti *(32)* conducted a statistical analysis on congener patterns from water samples collected in Raritan Bay and concluded that more than half of the variability in PCB congener concentrations was caused by a source with a congener profile similar to Aroclor 1248. In the statistical analysis, this source could be clearly differentiated from PCB sources from the Hudson River at Troy Dam. This analysis again suggests the presence of a source of higher MW PCB formulations in the southern portion of the estuary. These three lines of evidence suggest that this source (or sources) is large enough to significantly shift the congener patterns in the lower portion of the estuary, suggesting that it must contribute a mass of PCBs to the estuary each year which is similar to the loading from the Upper Hudson, that is, on the order of several hundred kilograms of PCBs per year. Thus, it is seems plausible that this source is CSO flows and runoff from the urban zone surrounding the estuary, which here are estimated to contribute 103–288 kg of PCBs to the estuary each year, and which contain a PCB mixture having a higher average MW than the Hudson River (at Newburgh Bridge) PCBs. It is also possible that other, significant sources of PCBs exist in the estuary,which have not been identified in this report.

The main findings of this report are:

1. Despite the uncertainty in the loadings estimates, the results of this mass balance demonstrate that the Upper Hudson River remains the largest source of PCBs to the NY/NJ Harbor.
2. The load of PCBs from stormwater runoff is the process in the Estuary that is associated with the greatest uncertainty. To reduce this uncertainty, additional measurements of PCBs in runoff are needed.
3. Volatilization is the most important loss process for low-MW PCBs in the NY/NJ Harbor. Estimates of volatilization are highly uncertain because of the uncertainty associated with the mass transfer coefficient, K_{OL}. Better estimates of K_{OL} would greatly aid efforts to understand the ultimate fate of PCBs in the NY/NJ Harbor estuary (and in virtually all aquatic systems).
4. The NY/NJ Harbor Estuary is probably releasing at least several hundred kilograms of historically sediment-bound low-MW PCBs to the water column and thence to the regional atmosphere each year. These sediments have served as a reservoir for a substantial fraction of the PCBs from the Hudson River, and are now releasing part of this PCB burden back to the water column, where much of it volatilizes. This process is occurring primarily in the Tappan Zee and Haverstraw Bay.
5. High-MW PCBs (homologs 7–9) enter the estuary primarily via runoff and CSOs. More than 80% of the mass of these homologs that enters the Estuary is either stored there in the sediments or removed via dredging. The mass balance for these PCBs is closed; that is, it is reasonably certain that no major loadings or losses of these PCBs exist which were not addressed in this report.
6. Loadings from all of the other tributaries, wastewater treatment plants, and atmospheric deposition are relatively small. Combined they make up ~10% of the total ΣPCB loads to the Estuary.
7. Little is known about the possible inputs of PCBs to the NY/NJ Harbor from sources such as PCB-containing transformers and capacitors still in use, ship paint, runoff from contaminated sites, and indirect atmospheric deposition. Runoff of contaminated soil from rail yards was recently identified as a possible source of PCBs to the Delaware River. These sources should be characterized by measuring PCBs levels in urban runoff and in shipyards.
8. The recent discovery of PCBs produced during pigment manufacture *(1)* raises concerns about the existence of additional unrecognized sources of PCBs to the Harbor. More sampling to identify all 209 PCB congeners is needed to identify such sources.

App A Table 5. Loadings of ∑PCBs and homologs 3-9 to the NY/NJ Harbor in kg/yr

	Rivers			Atmosphere Deposition						
	Hudson		East			Wastewater[a]	CSOs		Runoff	
Homolog	**Low**	**High**		**Low**	**High**		**Low**	**High**	**Low**	**High**
3	98	174	0.85	2.2	6.1	6.9	5.5	12	2.6	11
4	79	139	1.4	6.8	19	7.4	11	23	5.3	21
5	26	46	1.2	5.4	11	7.1	17	38	9.0	36
6	10	17	0.89	2.0	4.9	5.0	18	39	10	40
7	2.7	4.7	0.36	0.98	3.7	2.3	10	21	5.6	22
8	0.85	1.5	0.13	0.40	1.8	0.53	2.9	6.2	1.6	6.4
9	0.31	0.56	0.037	0.21	1.2	0.096	0.66	1.4	0.34	1.3
∑PCBs	**266**	**471**	**6**	**18**	**48**	**32**	**67**	**146**	**36**	**142**

a. Does not include loadings of PCB 11.

App A Table 6. Losses of ∑PCBs and homologs 3-9 from the NY/NJ Harbor in kg/yr

	Tidal exchange		Dredging		Volatilization		Storage in Sediments	
Homolog	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
3	32	47	31	59	99	266	30	64
4	53	77	52	99	108	289	51	106
5	23	34	30	56	19	50	29	60
6	13	19	20	39	2.9	7.8	20	41
7	5.0	7.2	8.3	16	0	0	8.1	17
8	2.1	3.1	3.7	7.1	0	0	3.6	7.6
9	0.49	0.71	0.89	1.7	0	0	0.87	1.8
∑PCBs	**132**	**192**	**151**	**287**	**317**	**846**	**147**	**307**

App A Table 7. Sum of inputs & losses of ∑PCBs and homologs 3–9 from the NY/NJ Harbor (kg/yr)

	Inputs		Losses	
Homolog	**Low**	**High**	**Low**	**High**
3	117	211	193	435
4	110	211	263	570
5	66	139	100	200
6	46	107	56	107
7	22	54	21	40
8	6.4	17	9.5	18
9	1.7	4.7	2.2	4.2
∑PCBs	**425**	**845**	**746**	**1631**

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APPENDIX B.
HUDSON RIVER PCBs WEBSITES

There is considerable discussion about the history of the Hudson River PCBs Superfund site, what actions should be taken, who is responsible for cleanup, the extent of the remediation needed, and many other issues. There are also numerous other sites contaminated with PCBs in the Watershed (see Maps above) including NYS Superfund sites (e.g. Hastings; Fort Edward; Hudson Falls) other contaminated sediments, and potential inputs from floodplains, dredge spoils and remnant deposits. The links below give an overview of some of the discussion, actions, regulation and points of view surrounding the ongoing and proposed cleanup of these contaminated areas. These websites were chosen because members of these organizations are part of the Harbor Project Consortium.

EPA's general description of the Hudson River PCB Superfund Site: *http://www.epa.gov/hudson*

EPA's Record of Decision (ROD) for the Hudson River PCB Superfund Site:
http://www.epa.gov/hudson/RecordofDecision-text.pdf

EPA's progress reports for the remedial design are available at: *http://www.epa.gov/hudson/progress_reports.htm*

Hudson River Sloop Clearwater's website on Hudson River PCBs: *http://www.clearwater.org/pcbs/*

Scenic Hudson's website on Hudson River PCB Cleanup:
http://www.scenichudson.org/pcbs/overview.htm

Joint statement by Hudson River Sloop Clearwater and Scenic Hudson:
http://www.clearwater.org/pdf/011805_cw_pcb_statement.pdf

Riverkeeper's description of Hudson River PCBs site:
http://riverkeeper.org/campaign.php/ge_pcbs

General Electric website on Hudson River PCBs:
http://www.ge.com/en/commitment/ehs/hudson/index.htm

http://www.hudsoninformation.com

NYS Department of Environmental Conservation's link to Hudson River --then use search tools for PCBs.
http://www.dec.state.ny.us/website/hudson

APPENDIX C.
PCB TRANSFORMERS REGISTERED WITH THE EPA

App C Table 1. PCB transformers registered with EPA

Facility type	National total	Region II	Watershed
Utility	9,137	593	80
Federal	2,025	40	11
State	100	32	26
Steel	1,719	4	—
Metal	1,416	21	5
Auto	1,300	65	—
Paper	372	45	2
Mining	240	—	—
Commercial	168	87	8
Consumer goods; general manufacturing	1,700	7 9	10
Rubber production	352	14	—
Glass; plastics	164	28 15	1
Chemicals: i.e., elements, compounds, adhesives, lubricants, polymers, coatings	356	50	3
Cement	269	9	1
Cardboard containers/lumber	253	—	—
Electronics	162	2	—
Transportation	130	22	7
Natural gas pipeline	99	2	—
Food/feed and fertilizer	149	—	—
Water treatment	12	—	2
Miscellaneous	492	2	2
TOTAL	**20,742**	**1,045**	**158**

Source: EPA registry for PCB transformers. Data query: *http://www.epa.gov/pcb/data.html.*

APPENDIX D.
INVENTORY OF TRANSFORMERS IN THE NYC AREA

The table below was developed by the NYC DEP and shows quantities of PCBs that remain in transformers in the New York City area. The last column in this table (pounds of PCBs remaining in use) was calculated by NYC DEP personnel, from data obtained by this agency and published in aggregate form for all units in each location (e.g., Manhattan). Notice that the PCB concentrations are shown in terms of average parts per million (ppm) for all units and do not indicate how many are PCB contaminated and how many are not. Averaging the concentrations over the total range of mineral oil transformers (with and without PCBs) does not allow to estimate how many units may be PCB contaminated. Nevertheless, the reported PCB quantities (in pounds) indicate how much PCB remained in transformers located in the New York City area.

App D Table 1. Inventory of NYC Utility Transformers*

Transformer owner	Location	Units	Average PCB (ppm) **	PCBs (lb)
Con Edison	Manhattan	8,588	28.8	1,547.0
	Staten Island	10,817	1.0	4.6
	Bronx	5,522	8.8	236.4
	Brooklyn	13,104	12.4	799.2
	Queens	9,968	13.7	676.0
Metering transformers	NYC	2,000	Untested	
Con Edison TOTAL	NYC	~50,000	12.6	3,263.2
Keyspan (NYC only)	Rockaway	2,072	50.0	20.2
Total utility- owned transformers in NYC		**52,072**	**31.3**	**3,284**†
† 3,284 lb = 1.5 metric tons (T) of PCBs				1.5 T

* Information from presentation by Lily Lee, NYC DEP, Bureau of Wastewater Treatment, to the NYC DEP Citizens Advisory Committee on Pollution Prevention, May 14, 2003. Table was developed in 1999.

**Because the data has been averaged, we cannot determine how many units may be above 50 ppm.

The following table provides a partial account of transformers privately owned by the nonutility sector in New York City. These units are connected to the Con Edison grid.

App D Table 2. Privately owned transformers (high-voltage users)**

Transformer type	No. of transformers	Percentage of total number
Non-PCB (0–50 ppm)	2,148	83.9%
PCB contaminated (50–499 ppm)	239	9.3%
PCB (≥500 ppm)	35	1.4%
Unknown Concentration, assumed PCBs	47	1.8%
Old (built before 1979), assumed PCBs	27	1.1%
Askarel* (>600,000 ppm or 60%)	64	2.5%
Grand total	**2,560**	**100.0%**

Information provided by Lily Lee, NYC DEP.

* Askarel transformers mostly from two major transportation organizations.

** Transformer data submitted by 119 out of 131 known high-voltage users (as of March 19, 2001)

APPENDIX E.

ESTIMATION OF SMALL CAPACITORS IN USE AND RETIRED PER YEAR SINCE 1977

App E Table 1. Estimation of small capacitors in use and retired per year since 1977

	Yearly number of small capacitors remaining in use in the US (1977 to 2004), assuming three different annual disposal rates		
Year	**10% retirement rate**	**15% retirement rate**	**20% retirement rate**
1977	870,000,000	870,000,000	870,000,000
1978	783,000,000	739,500,000	696,000,000
1979	704,700,000	665,550,000	591,600,000
1980	634,230,000	598,995,000	532,440,000
1981	570,807,000	539,095,500	479,196,000
1982	513,726,300	485,185,950	431,276,400
1983	462,353,670	436,667,355	388,148,760
1984	416,118,303	393,000,620	349,333,884
1985	374,506,473	353,700,558	314,400,496
1986	337,055,825	318,330,502	282,960,446
1987	303,350,243	286,497,452	254,664,401
1988	273,015,219	257,847,706	229,197,961
1989	245,713,697	232,062,936	206,278,165
1990	221,142,327	208,856,642	185,650,349
1991	199,028,094	187,970,978	167,085,314
1992	179,125,285	169,173,880	150,376,782
1993	161,212,756	152,256,492	135,339,104
1994	145,091,481	137,030,843	121,805,194
1995	130,582,333	123,327,759	109,624,674
1996	117,524,099	110,994,983	98,662,207
1997	105,771,689	99,895,485	88,795,986
1998	95,194,521	89,905,936	79,916,388
1999	85,675,068	80,915,342	71,924,749
2000	77,107,562	72,823,808	64,732,274
2001	69,396,805	65,541,427	58,259,047
2002	62,457,125	58,987,285	52,433,142
2003	56,211,412	53,088,556	47,189,828
2004	50,590,271	47,779,701	42,470,845
Small capacitors remaining in use in the Watershed in 2004[204]			
Units in Watershed	2,934,236	2,771,223	2,463,309
PCB content, T[205]	70.42	66.5	59.1
Small capacitors retired in the Watershed (in 2004)			
Rate of disposal: 10%	293,424	277,122	246,331
Rate of disposal: 20%	586,847	554,245	492,662
PCB content, (metric tons) in small capacitors discarded (in 2004)			
Rate of disposal: 10%	6.4	6.0	5.4
Rate of disposal: 20%	12.8	12.1	10.7

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[204] Extrapolating from the national estimates, by regional level of economic activity (the Watershed region represents 5.8% of the national economy).

[205] Each unit is estimated to contain ~0.05lb or ~24 grams.

APPENDIX F. CHEMICAL PROCESSES THAT HAVE THE POTENTIAL TO GENERATE PCBS

List of chemical processes that have the potential to generate inadvertently produced PCBs [148].

Allyl alcohol
Allyl amines
Aluminum chloride
Aminoethylethanolamine
Benzene phosphorus dichloride
Benzophenone
Benzotrichloride
Benzoyl peroxide
Carbon tetrabromide
Carbon tetrafluoride
Chlorendic acid / anhydride esters
Chlorinated acetophenones

Chlorinated benzenes:
    Dichlorobenzenes
    Hexachlorobenzene
    Monochlorobenzene
    Pentachlorobenzene
    1,2,4,5-Tetrachlorobenzene
    Trichlorobenzenes

Chlorinated benzotrichlorides
Chlorinated benzotrifluorides
Chlorinated, brominated methanes

Chlorinated ethanes:
    1,1-Dichloroethane
    1,2- Dichloroethane
    Hexachloroethane
    Monochloroethane
1,1,2,2- Tetrachloroethane
    1,1,1-Trichloroethane
    1,1,2-Trichloroethane

Chlorinated Ethylenes:
    1,1-Dichloroethylene
    1,2-Dichloroethylene
    Monochloroethylene
    Tetrachloroethylene
    Trichloroethylene

Chlorinated, fluorinated ethanes
Chlorinated, fluorinated ethylenes
Chlorinated, fluorinated methanes

Chlorinated methanes:
    Carbon tetrachloride
    Chloroform
    Methyl chloride
    Methylene chloride

Chlorinated naphthalenes
Chlorinated pesticides
Chlorinated pigments / dyes
Chlorinated propanediols

Chlorinated propanols:
    Dichlorohydrin
    Propylene chlorohydrin

Chlorinated propylenes
Chlorinated, unsaturated paraffins
Chlorobenzaldehyde
Chlorobenzoic acid / esters
Chlorobenzoyl peroxide
bis(2-Chloroisopropyl) ether
Dimethoxy benzophenone
Dimethyl benzophenone
Diphenyl oxide
Epichlorohydrin
Ethylene diamine
Glycerol
Hexachlorobutadiene
Hexachlorocyclohexane
Hexachlorocyclopentadiene
Linear alkyl benzenes
Methallyl chlorides
Pentachloronitrobenzene
Phenylchlorosilanes
o-Phenylphenol
Phosgene
Propylene oxide
Tetramethylethylene diamine
Trichlorophenoxy acetic acid

In the early 1980s 49 companies requested an exemption from EPA to manufacture, process, or distribute products contaminated with ≥50 ppm PCBs, including companies in the aluminum, chemical, paper, plastic, printing and soap manufacturing industries. Ten of these companies were located within the Harbor Watershed [149].

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