POLLUTION PREVENTION AND MANAGEMENT STRATEGIES FOR POLYCYCLIC AROMATIC HYDROCARBONS IN THE NEW YORK/NEW JERSEY HARBOR

September 2007

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PREFACE

What is new about this report on reducing the burden of polycyclic aromatic hydrocarbons (PAHs) to the New York/New Jersey Harbor—this fifth major report of the Harbor Consortium? Much of the format is the same. But both the technical complexities and the process leading to a consensus agreement to issue this report presented unprecedented challenges.

The Consortium Process. Let's quickly review the Consortium process to date. Selecting the first four contaminants (mercury, cadmium, polychlorinated biphenyls [PCBs], and dioxins) to be addressed by the New York Academy of Sciences' Harbor Consortium had been a relatively relaxed process. The overall purpose of the selection was to be the same each time: to determine how the contemporary introduction of a contaminant into the Harbor could best be prevented. We would examine established criteria to identify substances or compounds that were in some way a significant threat to the Harbor's health. Through mass balances and other environmental measurement techniques, we would explore both historical and contemporary loadings of those contaminants to the Harbor (entering directly or through waterways leading to it). Then, using techniques pioneered or improved through industrial ecology methods, we would track down the sources of those contaminants to the loadings and determine how they could be prevented, slowed, or diverted from entering the Harbor.

These basic steps were to be the technical or scientific mode of operation for the new Harbor Consortium. But, in addition, a fundamentally new process would accompany these steps. It was this: representatives from the diverse bi-state institutions (public, private, nonprofit, quasigovernmental) listed in this report would observe and/or participate in the technical process—and then be in a position to recommend (by consensus, we hoped) who should do what to achieve the pollution prevention purposes.

As the four major Harbor Consortium reports preceding this one attest, both the technical process for evaluating what is coming into the Harbor and the social process of recommending by consensus how best to slow and/or prevent Harbor contamination have worked far better than anyone could have expected.

PAHs—a distinctive challenge. But the fifth contaminant (PAHs) has, in many ways, been the toughest test. First, the Consortium had to select which would be the last of five toxicants to go through its process. Because it was to be the last, and because it had become clear that key players in the bi-state region really were paying attention to the work of the Consortium (its recommendations were being implemented in a wide variety of ways), there really was something at stake in this selection. To help decide, a paper was written for the Consortium to explore possible choices. Additionally, several newly emerging toxicants of concern were advocated for study by some Consortium members. The Consortium had always handled this selection process by a vote; in the end, PAHs were selected by an exceedingly close margin. The technical experts associated with the Consortium knew at once that the analysis of PAHs would, at the least, pose new technical challenges.

Why? First, PAHs make up a collection of more than 100 different chemicals. These chemicals as a class are believed to be carcinogenic and to have other harmful effects on human health, as well as having adverse ecological effects. But the toxicity of the various chemicals clearly varies significantly. PAHs break down in soil and water at quite different rates that are affected by temperature and other environmental factors; this made tracking and evaluating them even more difficult. PAHs are ubiquitous and have both natural and anthropogenic sources, primarily combustion activities. They are produced or formed during incomplete combustion, not just in coal, oil, and gas in stationary and mobile sources, but also in combustion of garbage and diverse other organic substances. However, their distribution is not limited to emissions to the air that are deposited in the Harbor, since they, like other substances with which the Consortium has worked, may be deposited on land and move to the Harbor by means that are both diverse and contested.

Further, as the Consortium was soon to learn, some of the major sources of PAHs that proved to be of greatest concern for the Harbor had nothing to do with local combustion processes, but were found, for example, in manufactured goods such as coal tar, creosote, and motor oil. To what extent would PAHs found in these materials reach the Harbor from their diverse applications in products such as treated wood and driveway sealants?

It certainly was not clear at the outset that a coherent and persuasive account of the burden to the Harbor from PAH's could be developed. With the active support of some of the better academic and public sector environmental scholars in the bi-state region and beyond, the Harbor Consortium staff went to work to bring the same discipline to this highly complicated technical challenge as they had brought to what now seemed the far easier task of tracking mercury or cadmium, the subjects of the initial two Consortium reports. The report on PAHs you are about to read demonstrates again that "our" staff is just very good. It has always been made up of Academy employees, and has been headed for the past three years by Marta Panero, Ph.D. In this report's case, the lead staff effort is the excellent work of Sandra Valle. Their two university-based consultants, professors Leslie Shor and Lisa Rodenburg, helped carry out this work. You will find a much more sophisticated account of the fate and transport process by which PAHs from various sources reach the Harbor than we had been able to develop for the contaminants in the earlier reports. In fact, it is likely that the Academy team have developed methods and data that belong in the peer-reviewed literature, as well as in this report. But I encourage the reader to take time to read this quite extraordinary account, because the weaving of this technical fabric into a quite clear picture of which PAHs reach the Harbor and how they potentially affect the Harbor's general health is, in my view, a significant achievement.

The technical account is just the half of it. As indicated above, the goal of the Consortium is not just to know what reaches the Harbor, but to know it well enough to recommend what we, who live and work in this complex watershed, ought to be doing to protect it. If the initial presumption of many Consortium members had been right and the major sources of PAHs reaching the Harbor had been combustion sources, then it is likely that the recommendations in this report would largely be a repeat of those we made on "poor combustion" processes when examining dioxins, to which we would add recommendations on the better-regulated sources (mobile and stationary). But the analysis clearly suggested that our focus should turn to the use of two key manufactured product types that have been of concern to environmental regulators for some time: coal tar sealants (such as those found on driveways and parking lots) and creosote-treated woods in diverse applications (including marine ones). Both product types slowly emerged as very important sources of PAH contamination to the Harbor.

Consequently, as the recommendations for pollution prevention began to focus on these two product types, those associated with their manufacture became regular attendees at a series of Consortium workshops and meetings. In one sense, there was nothing new in the Consortium being asked to examine—and to enter into a dialogue with producers and even recyclers of—products that contained worrisome substances that might reach the Harbor. Indeed, the Consortium had found it useful numerous times in the past six years to draw those associated with either the production or use of such products into the Consortium discussion, so that it could decide on the most effective recommendations for protecting the Harbor. The Consortium had found quite effective ways earlier to conduct its inquiries and to make its decisions when addressing the consequences of production and use, even when there were active public processes involved (including remedial design, litigation under CERCLA, etc.). But in this case, the Consortium found itself host to players who were actively involved in the full range of both technical and political struggles concerning the future use of creosote and coal tar. In one case, the products had been prohibited from use in one local city, and other jurisdictions were considering similar action. In another case, the state legislatures in both New York and New Jersey were in the midst of a several-year legislative process to control the use of the product, even as the Consortium process continued.

Achieving consensus again. The challenge to the Consortium was to keep focused on its technical base, to evaluate the challenges to its analyses that these players from several sides were making, and to continue on a path to the soundest recommendations it could make. In the midst of that kind of controversy, the Consortium members could still find consensus. It took an extra and, in my view, extraordinarily careful Consortium meeting in June of this year to allow the diverse Consortium participants, in a very open discussion, to understand the staff conclusions and to hear the views of those affected parties who differed with the staff on a variety of technical issues and, of course, on the recommendations. In the end, the story that unfolds in this report is the one developed by the staff, and the Consortium again reached a consensus on the entire technical report and the resulting recommendations. The report here provides the reader with an opportunity to review key elements of that debate.

What is still missing. As always, there were important lessons in this effort that may not be reflected fully in the report itself. The most important to me, as the Chair of the Consortium, was to recognize how far we, as a society, are from having the institutional means to help our citizenry sort out what a commitment to being a "green" consumer actually means. As we struggled hard with the issues of what is involved in creating and maintaining something as simple as a driveway or parking lot, the diverse claims of those who wanted to limit use of sealant products and those who wanted to use or market the product proved exceedingly hard to evaluate. The staff did limited research to evaluate the claims and counterclaims—and ended up with recommendations on limiting use of certain PAH products that it viewed as a threat to the Harbor. But the development of broad criteria or the arraying of data that would enable the clear recommendation of one product to replace another lay beyond the scope of our work. The same was true for creosote-treated wood in marine environments, where work to test alternative products is under way. The claims and counterclaims of those advocating or criticizing the alternatives are not fully resolvable by a Consortium with the limited resources and scope of this one. Yet it is patently clear that credible independent institutions capable of making such evaluations are needed. As a Consortium we could responsibly say, "limit or divert this contaminant from getting to the Harbor where it may/will cause harm, and to do so, we unanimously recommend limiting Z use of X to do task Y." What we could not do, in many or even most cases, was to say persuasively that we are confident that "task Y can best be done by using/doing W." In discussions with diverse Consortium members and many others, I conclude that the establishment of an institution or institutions capable of doing that work is the sine qua non of greening as an effective societal goal.

What we have achieved. I want to conclude this preface by reviewing the goals of the Consortium and what this fifth report does to complete the project. In doing so, I do not want to provide a synthesis of our work. A final report with the goal of doing that should be ready for review by the Consortium by the end of the year. Still, I do want to catch the significance of the fact that this fifth Consortium report will be issued exactly 10 years after the formation of the Consortium was recommended at a well-attended workshop I chaired in September 1997. The first sentence of the final paragraph (headed Outcomes) of the report of that workshop, published by the New York Academy Sciences in February 1998, said the following:

> The ultimate objective of the Consortium process is to develop the industrial ecology analyses that will frame and inform long-term solutions to the flows of five critical contaminants into the New York Harbor and communication of those solutions such that a broad commitment to their implementation is realized. (*Industrial Ecology and the Environment: Applications to the New York Harbor,* p. 40)

That precise work, and much more, has been done. I want to thank those who have supported this Consortium process financially, donated Consortium member time and talent, and provided the Consortium with an institutional home. Finally, and especially, I want to thank our talented and persistent staff. It has been an unprecedented process.

Charles W. Powers
Chair

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The ongoing contributions of our Harbor Consortium, led by its Chair, Charles W. Powers, merit special mention. The Consortium has been at the center of this project, playing a key role in overseeing the research and the pollution prevention deliberation process. We are grateful for the guidance of all its members, their continued involvement in the project, and their generous sharing of time and expertise.

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AFUE	Annual fuel utilization efficiency
APCD	Air pollution control device
BAP	Benzo[a]pyrene
BMP	Best Management Practices
BOF	Basic oxygen furnace
BTU	British thermal unit
BUR	Built-up roof
CAFE	Corporate Average Fuel Economy
CARP	Contaminant Assessment and Reduction Project
CDD	Chlorinated dibenzo-para-dioxin
CDF	Chlorinated dibenzofuran
CDT	Clean diesel technology
CHE	Cargo handling equipment
CHP	Combined heat and power
cm	Centimeter
CO	Carbon monoxide
CSF	Cancer slope factor
CSO	Combined sewer overflow
DIFM	Do-it-for-me
DIY	Do-it-yourself
DOC	Dissolved organic carbon
DOC	Diesel oxidation catalyst
DOD	Department of Defense
DPF	Diesel particulate filters
EGR	Exhaust gas recirculation
EIA	Energy Information Administration
ESP	Electrostatic precipitator
EU	European Union
FAA	Federal Aviation Administration
FB	Fluidized bed
FF	Fabric filter
ft	Feet
FUDS	Formerly used defense sites
FWPCA	Federal Water Pollution Control Act
GLBTS	Great Lakes Binational Toxics Strategy
HW	Hazardous waste
IRIS	Integrated Risk Information System
kg	Kilogram
Kow	Octanol–water partition coefficient
lb	Pound
LTO	Landing and take off
MES	Mild extract solvents
mg	Milligram
MHF	Multiple hearth furnace
Mi	Mile
MISLE	Marine Information for Safety and Law Enforcement
MS4	Municipal Separate Storm Sewer System
MSW	Municipal solid waste
MW	Molecular weight
NEI	National Emissions Inventory
NJ	New Jersey
NJADN	New Jersey Atmospheric Deposition Network
NOAA	National Oceanic & Atmospheric Administration
NOEL	No observed effects level
NOx	Nitrogen oxide
NRC	National Response Center
NY	New York
OWB	Outdoor wood boilers
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyls
PCD	Port Commerce Department
p-DCB	Para-dichlorobenzene
PM	Particulate matter
ppm	Parts per million
R-EMAP	Regional Environmental Monitoring and Assessment Program
Rfd	Reference dose
RMW	Regulated medical waste
RTA	Railway Tie Association

LIST OF ACRONYMS (CONT'D)

SCR	Selective catalytic reduction
SOx	Sulfur oxides
SPCC	Spill prevention control and countermeasure
SPDES	State Pollutant Discharge Elimination System
SSI	Sewage sludge incinerators
TDAE	Treated Distillate Aromatic Extracts
TEF	Toxicity equivalency factor
TRI	Toxics Release Inventory
U.S. DOT	United States Department of Transportation
U.S. EPA	United States Environmental Protection Agency
USCG	United States Coast Guard
VOC	Volatile organic compounds
WTE	Waste-to-energy
WWPI	Western Wood Preservers Institute
yr	Year

EXECUTIVE SUMMARY

Overarching P2 Recommendations for Major Sources of PAHs in the Watershed Region

A wide spectrum of sources contributes to total polycyclic aromatic hydrocarbon (PAH) releases in the New York/New Jersey Harbor Watershed, ranging from vehicle use, to fuel combustion, to leaking and dumping of petroleum products, as well as industrial and commercial activity. However, of the numerous PAH sources evaluated in this report, 11 major sources are estimated to contribute individually more than 2% to the total emissions released to each primary medium of release (air, water, and land) (Fig. 1).[1]

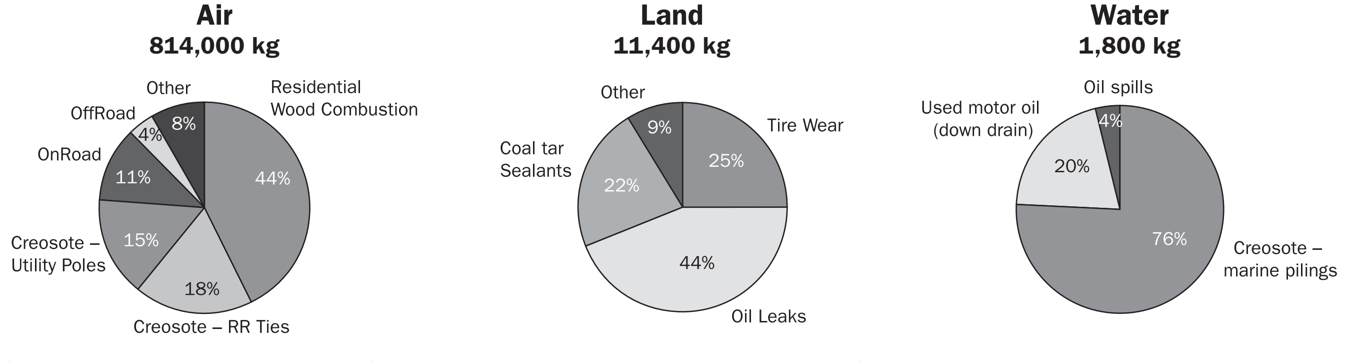
While these major emission sources differ in definition, some share fundamental characteristics. For example, many of these sources share a similar mechanism of release. PAHs released from vehicle exhaust and residential wood heating, as well as several of the minor sources, are all the result of combustion processes, many of which include the combustion of fossil fuel. Furthermore, although vehicle exhaust, tire wear, used motor oil disposal, and oil leaks differ with respect to medium and mechanism of release (i.e., petrogenic vs. pyrogenic), they are all associated with transportation-related activities (Table 1). Thus, by systematically grouping sources of PAHs based on common characteristics, overarching pollution prevention recommendations can be made that address multiple sources of PAHs.

In general, PAH emission reductions can be addressed at several points prior to the contaminant reaching the endpoint or environment of concern (in our case the Harbor); these points include the following:

1. at the supply side (e.g., reducing the use of materials containing PAHs in the manufacturing processes, thus generating products with no, or low PAHs);
2. at the demand side (e.g., reducing the demand for fossil fuel consumption through alternative design and material substitution);
3. at the point of release (e.g., increasing the efficiency of the combustion device or implementing BMPs to prevent leakage); and
4. after the PAHs have been released but prior to their reaching the environment of concern (e.g., through stormwater management measures).

Implementation of various measures at all of these points is critical for a comprehensive abatement strategy, which may include pollution prevention (P2) as well as best management practices (BMPs). Below is a summary of overarching P2 and BMP alternatives that address the reduction of PAH releases from combustion, transportation, and material-related PAH sources. For more details on these recommendations, see the specific sector sections presented in the technical section of this report.

Figure 1. Relative releases of PAHs by primary medium of release (air, water, and land)



"Other" air and land releases refer to sources that individually contribute 2% or less to total releases to the respective medium. These include industrial sources, residential and commercial fossil fuel combustion, open burning of household waste and tires, other transportation-related sources (e.g., vessel and personal boats, locomotive, airplane), and PAHs in ash residue that is sequestered in a landfill.

*Average of the estimated range of releases.

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[1] For some sources, such as creosote-treated railway ties, it is believed that PAHs are released to both air and land; however, air is considered the primary medium of release for creosote-treated railway ties and poles because it is to this medium that releases are more likely to impact the Harbor. Similarly, coal tar sealants release PAHs to land and air; however, we were able to estimate releases only to land.

Table 1. Categorization of major sources of PAHs in the Watershed region.

Combustion	Transportation	Materials containing PAHs
Mobile Vehicle exhaust Nonroad engine exhaust	**Mobile** Vehicle exhaust Nonroad engine exhaust Tire wear Used motor oil (down storm drains, leaking)	**Mobile** Tire wear Used motor oil (down drain, leaking)
Stationary Wood combustion Other, minor sources	**Infrastructure** Coal tar parking lot sealants Creosote railroad ties Creosote marine pilings	**Infrastructure** Coal tar parking lot sealants Creosote railroad ties Creosote utility poles Creosote marine pilings
Other Minor sources	**Other** Minor sources	**Other** Minor sources

Overarching Pollution Prevention (P2) and Best Management Practice (BMP) Recommendations:

Combustion-Related Recommendations

1. Reduce supply-side combustion activities.
   - Promote the generation of power from renewable sources of energy (that do not release PAHs).
2. Reduce demand for combustion activities.
   - Promote energy conservation by means that include increasing the energy efficiency of buildings and homes (e.g., through improved insulation and windows), strengthening building energy standards, improving efficiency standards for heating and cooling units, and the use of energy efficient appliances. Consider implementing these measures through voluntary and educational measures as well as revised energy codes.
   - Promote energy efficient manufacturing operations, services, and products. Identify and encourage consumption of products that are less energy intensive to manufacture, such as products that contain recycled material.
   - (Recommendations for reducing emissions from vehicle fuel combustion are included under recommendations, below.)
3. Reduce PAH emissions from combustion activities.
   - Optimize combustion conditions (e.g., high temperatures, adequate oxygen supply) through the adoption of best management practices.
   - Promote utilization of the best available pollution control devices to capture and minimize the release of PAHs, such as technologies that capture particulate bound PAHs (e.g., filters, electrostatic precipitators) and atmospheric PAHs (e.g., carbon beds).

Transportation-Related P2 Recommendations

1. Reduce vehicular use and the development of related infrastructure that can release PAHs.
   - Increase infrastructure capacity of public transportation, while establishing incentives for responsible vehicle use (such as taxes, congestion pricing, or incentives for public transport).
   - Enhance the diversity of transportation options by improving public access to mass transit, thus reducing vehicle traffic, congestion, and paved impervious parking areas.
   - Prioritize pedestrian and biking areas when developing or redeveloping communities. Plan communities that connect via pedestrian and bike pathways, and via public transportation.
   - Prioritize construction projects that fill in areas in already developed urban centers (possibly through policy and permitting

practices). Couple this with programs that encourage the settlement in, and development of, urban centers, possibly by providing incentives for urban dwellers and those that choose to live close to towns. Support informational and educational campaigns about the benefits of living in urban centers.

2. Reduce PAH releases from transportation-related activities and infrastructure.
   - Increase the efficiency of combustion engines in vehicles and nonroad equipment while increasing the market share of vehicles and equipment that are not powered by the combustion of fuels that release PAHs. This could be done by aggressively raising the federal efficiency standards for vehicles bought or sold in the U.S.
   - Encourage the use of engines that produce fewer PAHs through incentives such as variable registration fees (i.e., lower registration fees for engines that are likely to release fewer PAHs).
   - Reduce unnecessary emissions and releases of PAHs through proper maintenance practices, such as regularly checking equipment for malfunctions and leaks, and through the enforcement of anti-idling regulations; consider extending anti-idling regulations to all nonroad equipment.

NOTE ON ALTERNATIVE PRODUCTS AND MATERIALS

The purpose of this report is to identify sources releasing PAHs in the region and propose recommendations that will reduce the overall quantity of PAHs in use or released within the NY/NJ Harbor Watershed and thus reduce the amount of PAHs that may eventually reach the Harbor. While for some sectors we identify alternative materials and/or practices that could potentially be implemented and/or used to reduce the quantity of PAHs released in the Watershed, the relative environmental impacts of these alternatives, outside of PAHs, are often undetermined and demand further investigation. Some of the analytical tools that can be used to make a comparison between products and policies are life-cycle assessment and material-flows analysis (specifically burden shifting). A comparative analysis would be optimal, although it goes beyond the scope of our current research. Therefore, we are not in a position to recommend any particular alternative materials or products.

Materials-Related P2 Recommendations

1. Decrease the supply of, and demand for, materials containing PAHs.
   - Explore the potential costs and benefits of using alternative materials that do not contain PAHs. Costs may include price of purchase, time required to implement change or use of materials, and an inferior product, while benefits might include a superior product, healthier work environment, less harm to the environment, and fewer regulations. Educate industry and consumers on the results of these assessments.
   - Investigate the development of substitutes for PAH-containing materials, as well as product and structural designs that eliminate the need for materials containing PAHs. This may be pursued through industry and federally supported studies.
2. Reduce PAH releases from the use of materials that contain PAHs.
   - When feasible, avoid the use of products that contain and release PAHs.
   - Promote the use of best management practices to reduce PAH releases throughout the manufacturing stage and use of products and materials. This could be done through education and outreach.
   - Educate people on the proper disposal of materials containing PAHs, while increasing opportunities to recycle or properly dispose of the materials (e.g., recycling facilities, pick-up services, collection locations at retail establishments).

Stormwater Management Recommendations

The last point at which P2 and BMP recommendations can be made is after PAHs have been released but before they reach the Harbor. These types of recommendations are relevant to most sources releasing to land (and to the atmosphere if PAHs deposit onto land). For PAH sources that release directly to the Harbor there are no further opportunities to curb loadings.[2]

The quantity of PAHs reaching the Harbor via stormwater runoff may be reduced by several means:

- Increase the area of pervious surfaces (green infrastructure) that can potentially filter contaminants out of stormwater (e.g., increase vegetated medians, sidewalks, and green roofs; restore abandoned developments into green spaces; use pervious surface material). Consider implementing these measures through education and outreach as well as policy and sustainable-development initiatives.
- Implement and enforce stormwater management policies for already developed, redeveloped, and newly developed areas statewide. For example, for large development projects that will increase overall impervious surface area, consider requiring on-site stormwater treatment measures, such as stormwater filtration, retention systems, or stormwater capture and reuse. Consider retrofitting existing sites with similar stormwater treatment measures.
- Educate the public on the importance of keeping stormwater clean and how they can help (e.g., not dumping contaminants down the stormwater drains, reducing the impervious surface area of their property).
- Conduct further stormwater sampling to confirm the importance of stormwater to total loadings of PAHs to the Harbor.

Data Gap Recommendations

While efforts were made to use the best available emission factors and source activity information when calculating releases of PAHs, some data were incomplete and/or outdated, and/or there were uncertainties with the data ultimately impacting the uncertainty of the emission estimate. The following recommendations address the need for ongoing improvement of PAH emission factors and data collection. Recommendations addressing specific sectors where data gaps have been identified are included in the technical section of this report.

- Invest in the update/improvement of PAH emission factors, ensuring that, when possible, all 16 U.S. EPA priority PAHs are evaluated. Improved emission factors for sources that have been identified as potentially significant should be developed first.
- Develop emission factors for sources of PAHs that have been identified but for which data that allow release estimates to be calculated are not available.
- For activities that have been identified as potentially significant sources of PAHs, collect more accurate and detailed activity data. These data potentially will provide clarity on the nuances of emission rates as they relate spatially and temporally in a region.

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2. More information on stormwater best management strategies and related policies will be available in a forthcoming Harbor Project report on how to prevent the mobilization of suspended solids before they reach waterways.

SUMMARY OF FINDINGS

The goal of this report is to use an industrial ecology approach to evaluate all potential sources releasing polycyclic aromatic hydrocarbons (PAHs) in the New York/New Jersey Watershed region and to evaluate their potential to reach the Harbor. We have estimated primary releases of PAHs from each source by compound, county, and medium of release (i.e., to air, land, or water). We also estimate the likelihood of each of these emissions to reach the Harbor via fate and transport modeling. Finally, we compare our estimated inputs to the Harbor from this exhaustive industrial ecology approach with an independent mass balance that computed PAH inputs based on environmental monitoring data. Our ability to demonstrate broad consistency between the two approaches helps validate the accuracy of our findings, despite the inherent difficulty of the task.

This section provides the following:

A. Summary findings of the major sources of PAHs in the Harbor watershed region (including classification by medium of release and source category). Sources are considered major if their emissions individually comprise more than 2% of releases from all sectors evaluated in this report that release to air, water, or land (Fig. 1). Sources that are considered minor to this particular region are discussed in Section 4 of this report; they may be considered major sources of PAHs in other regions;

B. An explanation of the likelihood of releases to reach the harbor (based on the fate and transport model) and a comparison of our estimates of loadings to the Harbor to the independently developed mass balance assessment; and

C. A summary of related P2 recommendations to curb releases from the major sources affecting the NY/NJ Harbor.

A. Major Sources of PAHs in the Watershed

PAHs can be found naturally in petroleum deposits and are produced naturally through biogenic processes[3]; they are also the products of the incomplete combustion of organic material. Some PAHs are manufactured for use in dyes, insecticides, and solvents. Historically, anthropogenic point sources were the major source of PAHs; however, due partly to pollution control devices, nonpoint sources have become the dominant source of PAHs. Consequently, the major sources currently releasing PAHs in the Watershed area may be classified into three general categories:

- Combustion processes, mobile and stationary (e.g., wood, fossil fuel)
- Petroleum spills/dumping
- Releases from products made with petroleum or coal (e.g., creosote, coal tar).

Specific sources that fall under these general categories include residential wood combustion, vehicle exhaust, creosote-treated wood, refined coal tar sealants, and petroleum leaks and dumping (Table 2).

Releases by Medium

Our estimates of primary releases of PAHs indicate that atmospheric releases are the dominant source of PAHs in the Watershed (Fig. 2). This is partially due to the pervasiveness of combustion activities throughout the Watershed, particularly the combustion of wood in residential heating units and vehicle activity, and partially due to PAH volatilization from creosote-treated wood (Fig. 1).

Releases by Source Category

Several major sources of PAHs in the Watershed fall into the transportation sector, and include vehicle exhaust, motor oil leaks and improper disposal, nonroad engine exhaust, and surfaces sealed with refined coal tar sealants. These comprise approximately 15% of total releases to all media in the Watershed.[4] Wood combustion comprises more than one-third of total releases from major sources; however, the dominant source of PAH releases is creosote-treated wood (including uses in water and on land) (Fig. 3).

B. Potential for PAH Emissions to Reach the Harbor

Not all PAHs that are released into the environment will ultimately reach the Harbor. The potential for

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[3] PAHs may be synthesized by biochemical processes in both terrestrial and marine organisms, and released into the environment by metabolic activity or decomposition. Given the urbanization of the Watershed area, it is likely that this is a relatively small source.

[4] Creosote-treated railway ties and marine pilings could also be considered under the PAH release category Transportation (increasing the percentage of emissions from this group closer to 50%); however, given their collectively large release of PAHs, we chose to present creosote-treated wood emissions in a separate category.

Table 2. Summary of major sources of PAHs within the Watershed

	PAH release in the Watershed			Emission factor/ratios applied		Level of regional activity
Source	Quantity released (kg/yr)	Medium of release	PAH loadings to the Harbor[a] (kg/yr)	Particle-bound or gaseous	Uncertainty[b]	Uncertainty[c]
Residential fuel combustion						
Residential wood stoves and fireplaces	341,200	A	500	P&G	E	II
Materials containing PAHs						
Creosote, utility poles	122,200	A	300	G	D	II
Creosote, railway ties	291,600	A, L	500	G	D	I
Creosote, marine pilings	1600	A, W	800	G/P	D	III
Refined coal tar sealant	900–5800[d]	L	900[e]	P	C	I
Transportation						
Vehicle exhaust	91,500	A	300	P&G	D	II
Tire wear	2800	L	1400	P	B	II
Oil leaks	5000	L	2600	P	D	IV
Improper disposal of used motor oil (down drain)	400	W	200	P	B	IV
Nonroad internal combustion	32,500	A	100	P&G	D	II
Oil spills and dumping						
Oil spills[f]	70	W	70	P	D	IV

A= atmosphere, W= water, L=land, P= particle bound, G= gaseous

[a] Loadings to the Harbor represent the calculated loadings described in The Potential for PAHs to Reach the Harbor found later in this report.

[b] The U.S. EPA gives a rating to emission factors in their AP-42 database of air pollutant emission factors, ranging from A to E, with A being the best. The rating is a general indication of the reliability or robustness of the factor. When emission factors were not rated by the U.S. EPA or another source, the same metrics used by the U.S. EPA to assign a rating were applied. See Appendix D for a description of rating metrics.

[c] A rating system similar to that used by the U.S. EPA was created to represent the uncertainty of activity levels used to estimate emissions. See Appendix D for a description of rating.

[d] This estimate is based on a particulate PAH yield published in Mahler et al. [1] and reflects the range of area that is sealed per gallon of sealant (60–80 square feet) and the length of time between resealings of a surface. (Surfaces may be sealed every 1 to 5 years; therefore, the total area of sealed surface may be proportional to 5 times the annual quantity of sealant consumed.) An unpublished study by the City of Austin estimates an average annual rate at which the sealant is worn away. When this rate is used and it is assumed that the area of sealed surface is equal to 5 times the annual consumption rate, it is estimated that up to 40,000 kg/yr of PAHs are released (to land and air combined) in the Watershed region.

[e] This estimate is based on yields published in Mahler et al. [1] and the average area sealed per gallon of sealant and resealing rate. When the unpublished City of Austin wear rate is used, and the fate and transport factors are applied, it is estimated that approximately 1600 kg/yr of particulate PAHs are reaching the Harbor.

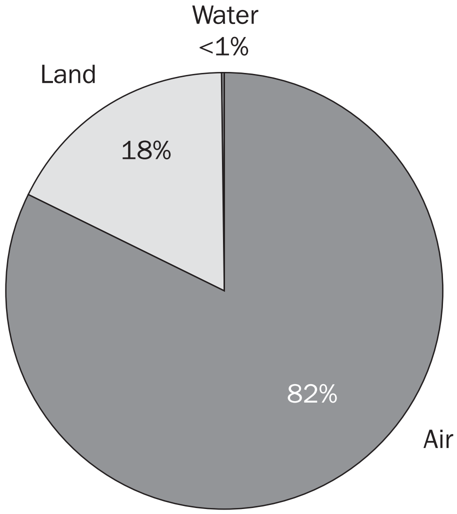
[f] It should be noted that the quantity of oil spilled varies greatly from year to year. The value presented here is an average of spills that reached the water in the Harbor area reported in 2001–2004.

PAHs to reach the Harbor depends on the characteristics of the particular PAH compounds and the medium of release. It also depends on several factors regarding the point of release, including the proximity of the point of release to the Harbor; the distribution of pervious versus impervious land surfaces; and the hydrodynamics of stormwater, sewers, and surface water features, among many other factors. In an attempt to understand the potential for different PAH emissions (by source, compound, and location) to reach the Harbor, a simple fate and transport model was constructed to estimate transmission of each PAH compound from major emission sources in each county in the region.

A large number of simplifying assumptions were required to make this task tractable, and the selection of "typical" fate and transport parameters is necessarily somewhat arbitrary. These assumptions will influence the calculated transmission efficiency of each PAH from each source to each medium from each county, and, thereby, the resultant prioritization of PAH emission sources most impacting the Harbor. For a more detailed discussion of the fate and transport analysis, see Appendix C of this report.

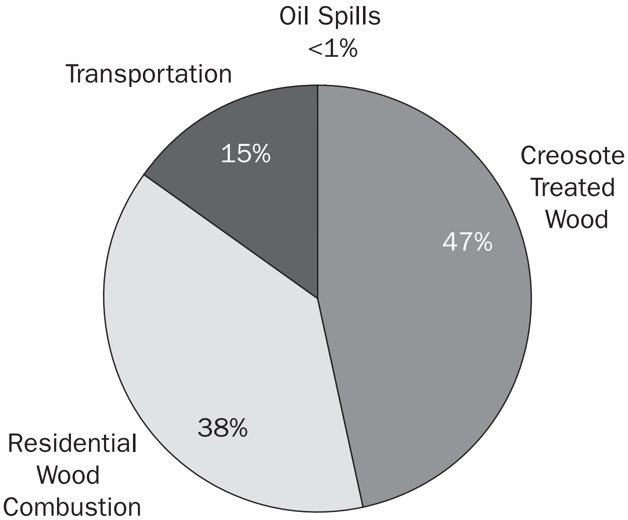
The largest primary PAH emission sources in the region are very different from the sources that con-

Figure 2. Estimated relative PAH emissions from the major sources of PAHs in the Watershed to air, water, and land



Land releases include releases from creosote-treated railway ties, and the average estimated release from coal tar sealed surfaces using yields from Mahler et al. [1].

Figure 3. Estimated relative contribution to total releases from the major PAH sources in the Watershed



Releases from creosote-treated railway ties to land are included, as well as the average estimated release from coal tar sealed surfaces using yields from Mahler et al. [1].

tribute most to PAH loadings to the Harbor waters [5] (Fig. 4). Recall that the dominant sources of primary PAH emissions are atmospheric sources, including wood combustion, volatilization from creosote-treated wood, and vehicle exhaust. Even accounting for wet and dry deposition of particles, gross gas absorption of PAHs by surface water, and runoff of atmospheric fallout in stormwater into streams and sewers, only a very small percentage of primary atmospheric emissions ever reach Harbor waters. By contrast, sources involving emission of PAHs directly onto impervious land surfaces in counties nearest the Harbor are readily transported to harbor waters, and dominate PAH loadings to the Harbor. These sources include oil leaks, tire wear, and the use of coal tar sealants.[6]

Our estimates indicate that transportation-related activity (i.e., on-road and off-road engine exhaust, tire wear, and motor oil disposal and leakage) is the source category contributing most greatly to total loadings of PAHs (Fig. 5). Releases from coal tar sealed surfaces could also be categorized under transportation, in which case, transportation-related activity would be responsible for over 70% of estimated PAH loadings to the Harbor.

B.1 Comparison of Estimated PAH Loadings with Mass Balance

Our industrial ecology and modeling approach allows us to follow primary releases across environmental compartments throughout the region and to prioritize primary PAH sources by their ultimate contribution to PAHs in Harbor waters. In this section, we demonstrate the consistency of our estimated loadings using this approach with results of an independent analysis calculating loadings from environmental monitoring data, referred to as the PAH mass balance. While consistency between the two independent approaches by no means guarantees the accuracy of either, it does provide some reassurance that the analysis is likely to be on (or near) target.

The mass balance for 14 of the U.S. EPA's priority PAHs was developed using data primarily from the Contaminant Assessment and Reduction Project (CARP) [2], the Regional Environmental Monitoring and Assessment Program (R-EMAP) [3], and the New Jersey Atmospheric Deposition Network (NJADN) [4].[7] The goal of the mass balance was to understand the flux of PAHs entering and leaving the Harbor

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[5] Our focus is on PAH pollution sources reaching Harbor waters. Other emission sources may still impact other geographic locations or environmental compartments.

[6] The average estimate of loadings from surfaces sealed with refined coal tar–based sealants is presented in Figure 4. The upper end of the estimated coal tar–sealant loadings is approximately 2000 kg/yr.

[7] The PAHs included in the mass balance are naphthalene, acenapthene, fluorene, phenanthrene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[a] pyrene, perylene, benzo[b+k] fluoranthene, benzo[ghi]perylene, indeno[1,2,3-cd]perylene, and dibenz[ah]anthracene.

Figure 4. Estimated releases (kg/yr) of the major sources of PAHs in the Watershed (white) compared with estimated loadings (black)

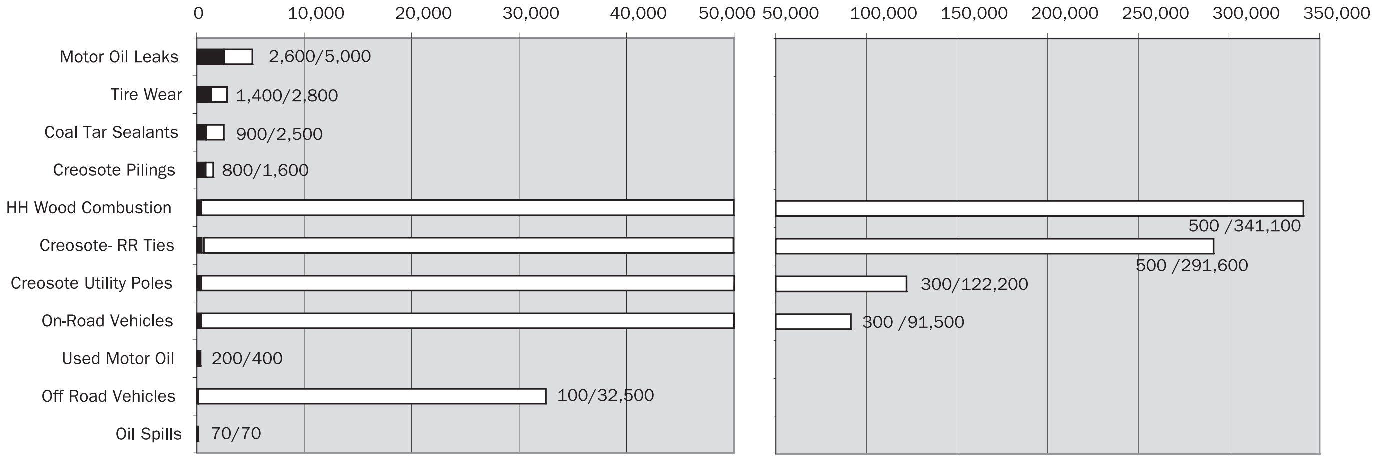
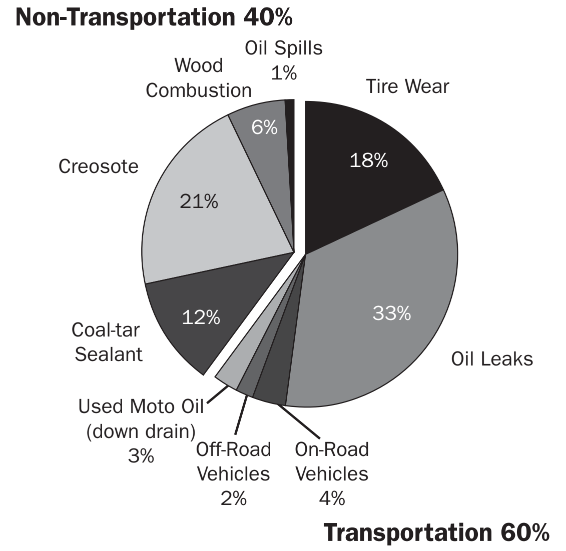


Figure 5. Estimated relative loadings of PAHs to the Harbor from major PAH sectors in the Watershed



through various transport mechanisms. This mass balance considers inputs of PAHs from tributaries, atmospheric deposition, wastewater treatment plant discharges, combined sewer overflows (CSOs), stormwater runoff, and oil spills. It also considers outputs of PAHs via advection of dissolved or suspended sediment-bound PAHs into the coastal Atlantic Ocean or Long Island Sound, volatilization of dissolved PAHs into the atmosphere, and removal of sediment-bound PAHs via disposal of dredged sediments outside the NY/NJ Harbor. A summary of the mass balance can be found in APPENDIX B. Additional details are expected to be available in a future publication. Information can now be obtained from Lisa Rodenburg.[8]

Although the PAH mass balance for the Harbor identified six loading mechanisms, most of the loadings are due to stormwater/CSO (53%) and tributaries (23%). We therefore compare our loadings, by loading mechanism (as described in the POTENTIAL FOR PAHS TO REACH THE HARBOR section of this report), with the loadings from stormwater, CSOs, and tributaries presented in the PAHs mass balance. A range of loading values is given by the mass balance to account for variability in the monitoring data and in estimation of flowrates.

Loadings were estimated by applying fate and transport factors to estimated primary releases of PAHs to air, land, and water for each of the 16 priority PAHs for each county in the region.

Our estimated loadings from stormwater and tributaries are consistent with the range of inputs calculated in the mass balance (FIG. 6). Our total estimated loadings via stormwater are in the middle of the range of inputs presented in the mass balance. We have not estimated Harbor loadings via wastewater, including the wastewater contribution to CSO outflows, which are included in the mass balance CSO loading estimate. Estimated loadings from the tributaries are also consistent with the mass balance, although the industrial ecology–transmission approach estimate is at or near the bottom of the range for the mass balance inputs.

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[8] Lisa Rodenburg, Rutgers, The State University of New Jersey, totten@envsci.rutgers.edu.

Estimated loadings to stormwater, CSOs, and surface water are dominated by transportation-related activity and releases from surfaces sealed with coal tar sealants (Fig 7). Loadings from transportation-related activity are dominated by tire wear and oil leaks. These sources are relatively low in total emissions, especially relative to atmospheric emissions, but have high transmission efficiency, since they all involve direct emissions to an impervious surface, allowing high stormwater transport potential. The releases directly to the Harbor are similar in quantity to estimated loading from the tributaries; however, these loadings are dominated by emissions from creosote-treated pilings.

Figure 6. Estimated PAH loadings (solid bars) vs. range of PAH loadings estimated in the mass balance (hollow bars)

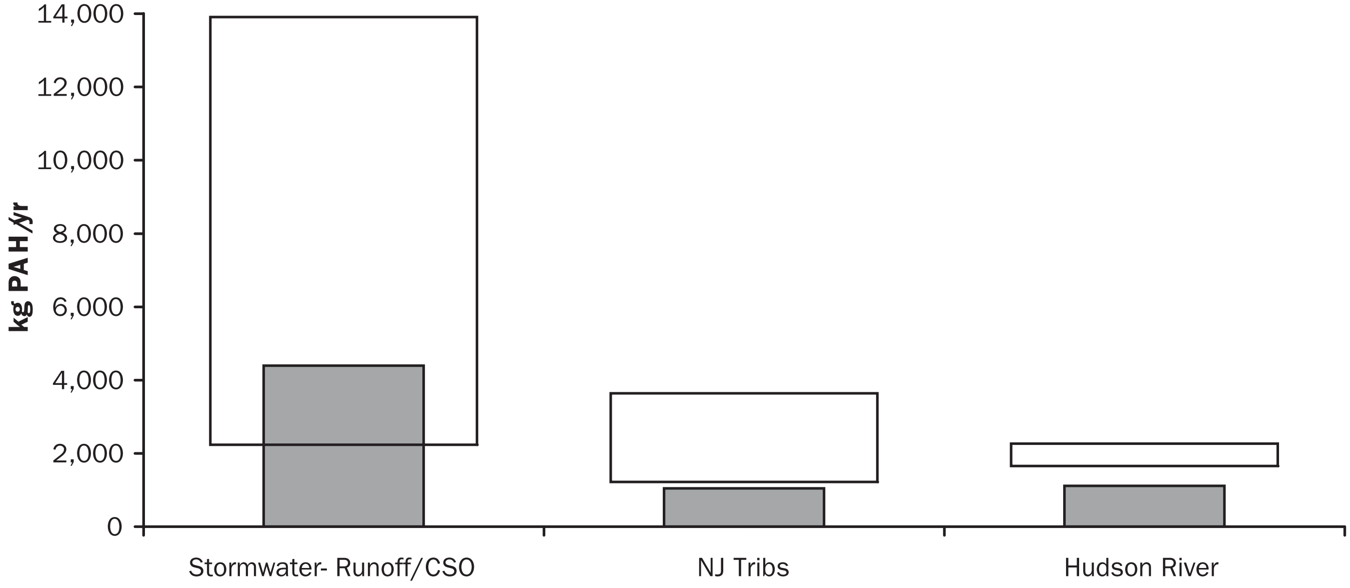
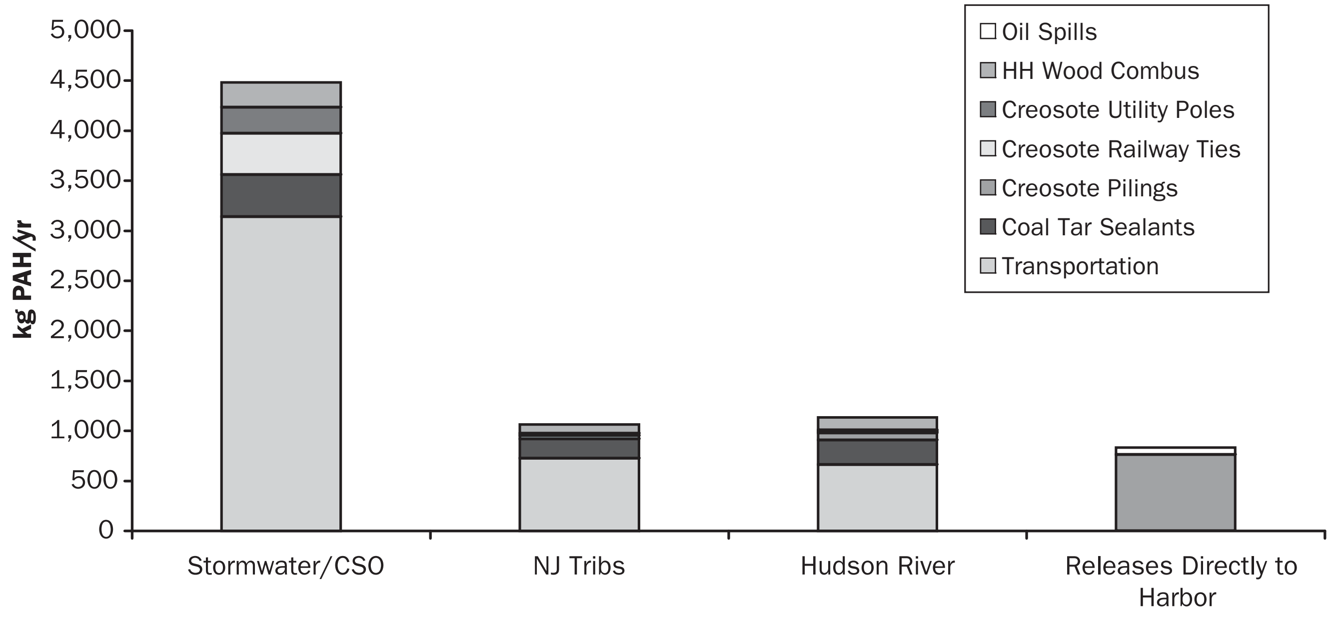


Figure 7. Estimated loadings of PAHs from sources contributing PAH stormwater, tributaries, and directly to the Harbor



Note on Major Sources of Benzo[a]pyrene

Many PAH compounds have been found to cause adverse effects on humans and ecosystems. However, benzo[a]pyrene (BAP), along with a few other PAHs such as naphthalene, are considered possible or likely human carcinogens, and have been targeted as priority compounds for which releases should be reduced. BAP does not break down easily in the environment, and, like many hydrophobic organic contaminants, can accumulate up the food chain in fatty tissues. BAP is included in the U.S. EPA's Persistent Bioaccumulative and Toxic (PBT) initiative.[9] Some regions have taken direct action to reduce releases of BAP, such as the Great Lakes Binational Toxics Strategy: Canada–United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes (GLBTS). The GLBTS is an ongoing program seeking to reduce releases of persistent toxic substances including BAP.

Our analysis indicates that major primary BAP emission sources in the Harbor region are household wood combustion and the use of coal tar sealants. Taking fate and transport factors into account, the three largest sources of BAP loadings to Harbor waters are the use of coal tar sealants, tire wear, and household wood combustion (Fig. 8).

C. Summary of Findings and Recommendations for Sectors Affecting the Harbor

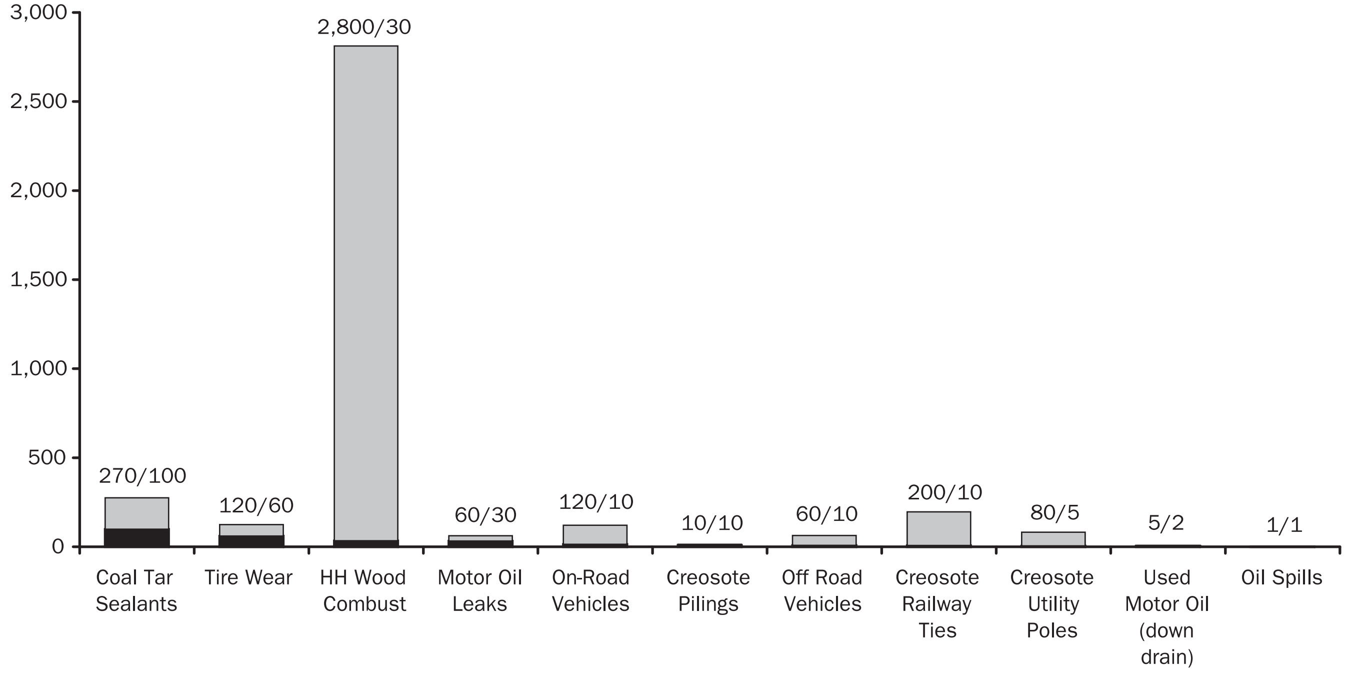
Below is a summary of our findings for the major sources of PAHs in the Watershed region, listed in order of total quantity of PAHs released per year, and specific P2 and BMP recommendations to curb releases from these sources.

C.1. Combustion Sources

Residential Wood Combustion

The major residential heating fuels in the U.S. are natural gas, fuel oil, electricity, coal, wood, and kerosene. In 2001, the Energy Information Administration reported that residential wood combustion was approximated only 6% of total energy consumed for heating. However, in the Watershed, releases of PAHs from residential wood combustion are almost 30 times larger than releases of PAHs from residential gas, oil, and coal combustion combined. Wood is typically combusted in a fireplace, wood stove, or outdoor wood boiler (OWB). While fireplaces and woodstoves may have pollution control devices, OWBs are not regulated.

Figure 8. Estimated releases of BAP (kg/yr) from the major sources of PAHs in the Watershed (gray) compared with estimated loadings (black)



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[9] For more information on PBTs, visit the EPA web site at http://www.epa.gov/pbt/.

In the Watershed, the percentage of homes using wood combustion as their primary heating source is less than 1%. However, PAH emissions from this source contribute to over one-third of the total releases from the major sources of PAHs in the Watershed. We estimate that approximately 341,200 kg of PAHs are released every year by the combustion of wood in fireplaces and wood stoves, most of which occurs in conventional wood stoves that do not utilize pollution controls. An emission factor for PAHs released from OWBs was not available at the time of this report. It is probable that releases of PAHs from OWBs are a significant source of PAHs in the Watershed region.

Summary of Recommendations for Residential Wood Combustion

- Reduce the consumption of heating fuel (wood) by properly sizing the heating unit for the heated space; by implementing residential energy efficiency measures such as increased insulation, sealing cracks, and passive solar design; and by the use of non-PAH-releasing heating fuel. Consider using outreach as well as regulations to promote these measures.
- Optimize combustion conditions by educating the community on the proper use and maintenance of wood combustion units.
- Consider increasing emission standards for wood burning units to reflect the best available control technology. Promote the penetration of these units in the market through changeout and incentive programs.
- It is likely that outdoor wood boilers release a significant amount of PAHs, given that they are typically larger, combust more material, and are not regulated. Research should be conducted on the quantity of PAHs emitted from combusting wood in outdoor wood boilers.

C.2. Materials Containing PAHs

Creosote-Treated Wood

Creosote, a distillate of coal tar, is a probable human carcinogen and is commonly used to waterproof and preserve wood. The only U.S. EPA registered use of creosote-treated wood is in commercial applications. Approximately half of creosote-treated wood manufactured in the U.S. is used for railroad ties, while 30% is used for utility poles, and only a small fraction is used for marine pilings (0.17%) [5]. Creosote is approximately 80% PAHs by weight (and approximately 20% priority PAHs, as defined by the U.S. EPA). PAHs are released from creosote-treated wood through leaching and volatilization.

Railroad Ties: In the Watershed region, most of the PAHs released from creosote-treated wood are released from on-land applications, railway ties in particular (as opposed to in-water applications, such as marine pilings). Reportedly 95% of ties in use are treated with creosote, with only a small proportion of track segments using concrete ties. We estimate that approximately 291,600 kg of PAHs are released from railway ties in the Watershed per year. The exact proportion of PAHs released to air and land from railway ties is largely unknown. Given the aqueous solubility of individual PAHs, the quantity of precipitation typical for our region, and the geometry and installation of railroad ties, we assumed that 50% of PAH emissions are volatilized to the atmosphere and 50% are leached to pervious land surfaces.

Utility Poles: An estimated 13% of the utility poles in service nationwide are treated with creosote. However, in two New York counties, approximately 40% of the poles in service are treated with creosote. Given the typical geometry and installation of utility poles, and the relatively low water infiltration and air exchange rates expected in densely packed soil versus coarse granular railroad ballast, we have assumed PAHs are lost only from the fraction of a pole's length that extends above the ground surface, and have attributed 100% of those emissions to the atmosphere. Based on these assumptions, we estimate that approximately 122,200 kg of PAHs are released to the air every year as volatile emissions from creosote-treated poles.

An informal phone survey of electric distributors in the Watershed, conducted by the Harbor project staff, revealed that approximately 9% of distributors are replacing retired utility poles with creosote-treated poles. Most distributors are replacing poles with pentachlorophenol-treated poles; pentachlorophenol is a compound associated with dioxins. Most retired phone poles and railway ties are combusted in a cogeneration facility. However, some are donated or given to the public where they cannot be traced and managed.

Marine Pilings: These pilings are exposed to land, water, and air, and the rate at which PAHs are released is influenced by each of these media. The quantity of pilings in the Watershed is difficult to estimate, given the many types and sizes of aquatic facilities (e.g., private, public, commercial marinas). Based on the best available information, it is estimated that approximately 1600 kg of PAHs are released from marine pilings to air and water every year in the Watershed.

Summary of Recommendations for Creosote-Treated Wood

While this report was under development, New York and New Jersey passed legislation banning the sale and use of creosote-treated wood state wide, with exemptions for creosote-treated wood used in railway and power pole/utility applications. The laws also ban the combustion and disposal in an unlined landfill[10] of all creosote-treated products.[11] The recommendations presented below reflect the conclusions of the Harbor Consortium that were reached based on the data presented in this report, and are separate from the legislation described above. They may also be applicable to other marine environments.

Because our focus is on the reduction of all PAHs reaching the Harbor, we make the following recommendations:

- Where feasible (in terms of cost, availability, and performance), avoid the use of creosote-treated wood. As noted earlier, we are not in a position to recommend alternatives, although further research comparing alternatives, such as a life-cycle assessment, would be optimal.[12]
- If creosote-treated wood is used for aquatic applications, use wood that has been treated, transported, and installed according to the Best Management Practices (BMPs) for the use of treated wood in aquatic and other sensitive environments developed by the Western Wood Preservers Institute (WWPI), Wood Preservation Canada, the Southern Pressure Treaters Association, and the Timber Piling Council.
- Consider using BMPs (similar to those referenced above) if creosote-treated wood is used for land applications (railway ties and utility poles). (The WWPI BMPs for creosote-treated wood were developed specifically for wood used in aquatic and other sensitive environments. It is likely, however, that these BMPs are also appropriate for wood used in terrestrial applications.)
- Do not distribute retired treated wood to the general public.
- Educate the public and, particularly, utility and railway employees who may distribute wood to the public on why it is recommended that wood not be distributed to the public (i.e., hazards associated with burning treated wood in uncontrolled combustion units, and potential exposure of humans and animals to the treated material).
- Evaluate the costs and benefits of removing dilapidated structures constructed with creosote-treated wood. In addition to removing material containing and releasing PAHs, removing dilapidated wood from waterways may improve navigational routes.

Refined Coal Tar Parking Lot Sealants

Many parking lots and driveways are made of asphalt pavement and may be sealed with either asphalt or refined coal tar sealants. Although there is no statistical or quantifiable evidence that pavement sealers extend the life of the pavement, they typically are applied to asphalt substrates every one to five years to protect the pavement from degradation caused by weather, motor oil spills, and traffic. These dark black sealants are also applied for aesthetic purposes. Refined coal tar sealants containing up to 20% total PAHs[13] are primarily used in the eastern U.S. PAHs may be released from the sealed surface primarily through volatilization (especially the lower molecular weight PAHs) and through abrasion of the sealant from vehicular traffic. Asphalt sealants contain up to 0.66% total PAHs and are used in the western U.S. Pavement sealers, refined coal tar sealers particularly, have only recently been identified as a potentially significant source of PAHs; however, the sale and use of refined coal tar sealants has already been banned in Austin, Texas, and Dane County, Wisconsin. In addition to regional regulations, home improvement retailers such as Lowe's and

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[10] Such as a landfill that is not properly lined to prevent groundwater contamination.

[11] The New York legislation also prohibits the manufacture of products containing creosote and has an exception for wood burned in a permitted facility.

[12] The Creosote Council, a participant in the development of this report, did not agree with all of the report's recommendations (see footnote to recommendations on creosote-treated wood in the Technical Report). Nevertheless, all the members of the Consortium approved the recommendations by consensus.

[13] Total PAH refers to the following compounds: naphthalene, 2-methylnaphthalene, acenaphthylene, acenapthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[a]pyrene, and dibenz[ah]anthracene.

Home Depot have discontinued the sale of this type of sealant at their stores nationwide.

Based on the estimated volume of refined coal tar–based sealant sold in the region, and the quantity of sealant typically applied to a square meter of surface area, we estimate that between 7.8 and 10.4 million square meters are sealed every year. However, a given area may be resealed as seldom as once every five years, so it is possible that regional sales correspond with an area of sealed surface of up to 50 million square meters, or approximately 0.1% of the harbor drainage basin land surface area. Based on the yields calculated in a peer-reviewed study by Mahler et al. [1] and the estimated range of sealed surface area in the Watershed, we estimate that between 900 and 5800 kg of particulate-bound PAHs are released per year from surfaces sealed with coal tar sealants in the Watershed. Using a wear rate provided by the City of Austin (unpublished), we estimate that between 8000 and 40,000 kg of PAHs are released per year (to land and air, combined) from surfaces sealed with coal tar sealant in the Watershed. Because the City of Austin study was not published at the time of this report's publication, throughout our report we use only estimates that are based on the published yield rates.

PAHs from coal tar sealants are released directly onto impervious surfaces, making the transmission of PAHs to the Harbor much more efficient.

Summary of Recommendations for Refined Coal Tar Sealants

- Implement urban-form measures or policies that reduce the need for parking lot areas, such as increasing mass transit services, increasing pedestrian and biking areas, and providing incentives for current and future drivers that reduce or eliminate miles driven.
- Advise architects, developers, homeowners, and decision makers to avoid the use of sealants containing PAHs and to consider alternative designs and paving materials for certain surfaces.
  - Residential driveways. Alternatives include no- or low-PAH sealants, gravel, or pervious concrete. These efforts should be focused on suburban areas that typically have more driveways and parking lots.
  - Commercial parking lots. Alternatives include no- or low-PAH sealants, concrete, pervious concrete, placing parking lots beneath structures where they will not be exposed to stormwater transport, and reducing the overall paved area of the project.
- Determine through scientific studies whether pavement sealants extend the life of the asphalt parking lot/driveway and other surfaces onto which sealants are applied. Research the benefits and environmental impact of using alternative products such as concrete driveways, no- or low-PAH sealants, or asphalt-based sealants versus using no sealants.
- Promote the development of a specification for the manufacture of asphalt-based sealants that results in a consistently lower concentration of PAHs **AND** a minimum level of performance (e.g. a lifetime of at least five years).

C.3 Transportation-Related Releases

PAHs are released by transportation-related activities through combustion of fossil fuels and from the materials that are used during the operation of the vehicle. Refined coal tar sealed parking lots could also be considered under this category of sources, although for this discussion we have chosen to include sealants in the "Materials Containing PAHs" category.

Approximately seven million passenger vehicles are registered in the Watershed. In New York alone, vehicle miles driven are expected to increase by 14% from 2002 to 2010. As a group, transportation-related releases are the third largest source of PAHs in the Watershed region, with most of the releases due to vehicle exhaust (Fig. 9).

Summary of Transportation Recommendations (Overall)

The Watershed region, like many other areas, relies on the efficient transport of goods and people from place to place for a vibrant economy and quality of life. This mobility, however, is not without environmental consequence. Reducing PAH releases from this source will require pollution prevention measures for transportation demand as well as for PAH point of release (e.g., fuel combustion). The following are general P2 recommendations aimed at reducing vehicular transportation:

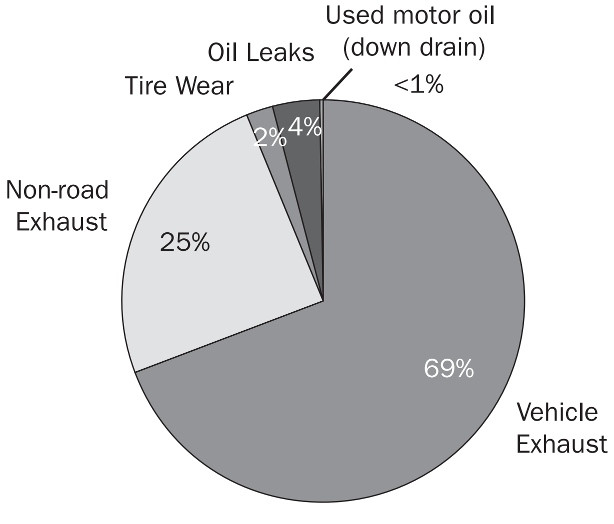
- In dense urban communities, increase infrastructure capacity of public transportation, while establishing measures that deter vehicle use and generate revenue for improved mass transit options, such as pollution taxes or congestion pricing. Promote the development or redevelopment of communities that provide pedestrian access to surrounding communities via pedestrian and bike pathways.

- In rural and suburban areas, design communities that foster public transportation, bicycling, and walking, possibly through the development of smaller economic centers in tandem with incentives to live close to the center of town.
- In urban and rural communities, prioritize infill projects that capitalize on existing municipal infrastructure and do not require the development of undeveloped land.

Vehicle exhaust: PAH emissions from vehicle exhaust are the result of the incomplete combustion of gasoline or diesel. The quantity of PAHs released depends on the fuel combusted, vehicle class (e.g., light duty, heavy duty, or motorcycle), and the mode in which the vehicle travels. For example, a recent study (Shah et al. [6]) indicates that the average PAH emission rate for diesel vehicles driving in congestion is approximately an order of magnitude higher than for diesel vehicles cruising.

We estimate that approximately 91,500 kg of PAHs are released in the Watershed every year from vehicular exhaust. Although vehicles travel all over the Watershed, approximately one-third of the activity takes place in the Watershed counties directly bordering the Harbor. Given the population density of this area, vehicles are often traveling in stop-and-go traffic, potentially releasing more PAHs than if the miles were traveled on uncongested highways. Our emission estimates indicate that gasoline vehicles are the vehicle class contributing the most PAHs from this source category

Figure 9. Estimated contribution of PAH emissions from transportation-related activity in the Watershed



Summary of Recommendations for Vehicle Exhaust

1. Reduce fuel combustion by establishing higher fuel efficiency standards for vehicles; transforming the fleet of vehicles in the Watershed (public and private) to more fuel efficient and/or hybrid models through a combination of legislation, incentives (e.g., free parking for hybrids, tax breaks for the purchase of fuel efficient vehicles), and education; enforcing current anti-idling laws; and educating the community on the environmental burdens associated with vehicle exhaust.
2. Improve vehicle performance by promoting and investing in innovative vehicle design, such as reduced drag aerodynamic designs and lightweight materials, and by promoting clean diesel technology research.

Tire wear: Vehicles release PAHs through particulate matter that is worn away from tires as the vehicle is driven.[14] PAHs in tires can be attributed to naphthenic and aromatic extender oils that are added to improve stress resistance, and that contribute to tire tread grip, wear, and endurance qualities. Tire tread can contain 17 to 357 mg PAHs per kg of tire tread, or approximately 160 to 500 mg of PAHs per tire. The quantity and size of particles released depend on vehicle type, terrain over which the vehicle travels, how the vehicle is driven, and tire qualities. Tire wear rates can range from 96 mg of tire particulate per mile traveled (for motorcycles) to 656 mg of tire particulate per mile traveled (for heavy-duty vehicles). It is also possible for PAHs to volatilize from the tire, especially when the tire comes in contact with high temperature surfaces. So far, however, only low levels of gaseous PAHs have been observed [7] (as cited in [8]).

We estimate that approximately 2800 kg of PAHs from tire wear are released to the land surface of the Watershed every year. Because the miles driven are

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[14] Brake dust is also a source of PAHs; however, an emission factor was not available.

expected to increase, it is likely that releases from this source will also increase. The European Commission has decided to restrict the PAH content in tires; starting in 2010, they will require extender oils used to manufacture tires to have a maximum concentration of 10 mg PAHs[15] per kg or approximately 5 to 7 mg PAHs per tire. Companies manufacturing tires both in the EU and in the U.S. will likely play a role in the market penetration of lower-PAH tires in the U.S. once the appropriate extender oil alternatives have been established in the EU.

Summary of Recommendations for Tire Wear

Research substitutes for high-PAH extender oils that are currently used in tires (potentially capitalizing on the research that has begun in the European Union) while continuing to meet tire safety standards.

- Reduce tire wear rates by educating the driving community on proper tire maintenance, including proper tire inflation, vehicle alignment, and the importance of allowing adequate time to brake. Support the investigation of advanced tire designs that reduce tire wear rate.

Motor oil leaks: Motor oil leakage from vehicles is typically released onto pavement, and although some of the motor oil released may be absorbed into the pavement, some of it will be transported readily across impervious surfaces. There is limited information on the number of vehicles leaking motor oil in the U.S; therefore, there is uncertainty in our estimated releases. The American Petroleum Institute estimates that approximately 70% of motor oil consumed results in used motor oil. The remaining 30% is either leaked or lost to combustion (another source of PAHs, although not quantified in this report). One source reports that 46% of vehicles leak hazardous fluids, including motor oil [9].

We estimate that approximately 5000 kg of PAHs are released per year to the region's land surface from leaking passenger vehicles in the Watershed. Leaks from commercial trucks and vehicles are not included in this estimate and likely contribute to releases of PAHs from this source as well.

Summary of Recommendations for Motor Oil Leaks

- Reduce undetected oil leaks through education and outreach to the driving community on how to check for oil leaks; incorporate oil leak testing and remediation into the standard vehicle emissions testing currently required by the state.
- Reduce the need for motor oil through innovative vehicle design that requires less lubrication.

Improper disposal of used motor oil: In 2004, the U.S. demand for motor oil was approximately one billion gallons. Of this, approximately 70% results in used motor oil (see above). Motor oil that has been used in a gasoline engine dramatically increases in PAH content (up to 4% to 8% polyaromatic plus 2% to 5% diaromatic). Survey data indicate that approximately 16% of the population who change the oil in their own cars (do-it-yourselfers) do not dispose of used motor oil properly. Improper disposal includes dumping it on the ground, down sewer or sink drains, or placing it in the garbage where it will end up in landfill.

We estimate that the following quantities of PAHs are released in the Watershed every year from improper disposal of used motor oil: 1800 kg to landfill, 400 kg to the ground, and 400 kg down drains. Overall, our estimates indicate that approximately 8% of the used motor oil generated in the Watershed is disposed of improperly.

Summary of Recommendations for Used Motor Oil

- Increase collection of used motor oil by elevating awareness of existing used motor oil collection services through outreach and education campaigns that target vehicle and nonroad equipment users as well as educational institutions. Materials to be distributed should include information on local collection facilities (e.g., vehicle service centers, municipal collection sites, and municipal collection days), and about the hazards of improper disposal. Solicit the support of industry and government to implement these initiatives.
- Increase collection of used motor oil by providing incentives, such as a deposit or coupon program for motor oil that is returned to a collection facility.
- Facilitate access to used motor oil collection services by increasing the number of retail stores collecting used motor oil through industry sponsored partnerships.

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[15] The PAH concentration maximum refers to the following PAHs: benzo(a)pyrene, benzo(e)pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(j)fluoranthene, and dibenz(a,h)anthracene. A maximum PAH concentration in tire extender oils of 1 mg/kg has also been established for benzo(a)pyrene.

- Increase the end-use market for used motor oil by promoting the use of re-refined motor oil through government and corporate procurement programs and outreach initiatives.
- Reduce consumption of motor oil through proper vehicle maintenance and changing oil only when needed. Consider the use of synthetic motor oil that has a longer change interval than traditional motor oil.

Nonroad engine exhaust: Nonroad emissions include exhaust released from any class of two- or four-stroke gasoline or diesel engine, such as recreational, lawn and garden, construction, industrial, commercial, logging, airport maintenance, and agricultural equipment. Two-stroke engines have been found to release more PAHs than four-stroke engines, likely due to the lack of valves or emissions controls.

Nonroad equipment also generates used motor oil, specifically equipment with a four-stroke engine, and tire wear. The quantity of PAHs released from these sources is unknown, and it is possible that these are noteworthy sources of PAHs.

We estimate that approximately 32,500 kg of PAHs are released per year from engines in nonroad equipment within the Watershed region, mostly from lawn and garden equipment. Commercial and construction equipment, such as pressure washers, generators, and cranes, also release a large fraction of PAHs in this source category. The relative contribution of PAHs from the different equipment types varies within the Watershed region. For example, in rural communities most nonroad PAH emissions are from agricultural equipment, whereas in urban centers construction and industrial equipment predominate.

Summary of Recommendations for Nonroad Exhaust

While several types of nonroad equipment utilize internal combustion engines, lawn care, construction, and commercial equipment are estimated to contribute the most PAHs from this source category. Furthermore, construction and commercial activity are highest in the counties directly surrounding the Harbor. Therefore, our P2 recommendations focus on these two categories.

Lawn Care Equipment

- Promote the use of best available equipment through voluntary or legislative measures. For example, consider the implementation of a voluntary changeout program that would facilitate the exchange of older, less efficient equipment for newer, more efficient engines, such as those utilizing a catalytic converter or an electric motor.
- Reduce the need for lawn equipment by providing incentives for low-emissions landscape design and maintenance such as a program that recognizes landscapers who reduce their emissions through design (e.g., by growing land cover that does not need to be mowed) and maintenance (e.g., by using no- or low-emission equipment). Homeowners should also be informed about emissions associated with yard care and about alternative landscape designs that demand little or no equipment for maintenance.

Construction and Commercial Equipment

- Consider the implementation of statewide emissions control programs that retrofit older equipment with pollution reduction technologies.
- Educate equipment owners on the importance of proper equipment maintenance and how to maintain equipment properly to ensure maximum fuel combustion performance. Consider addressing the following maintenance issues: restricted air filters, improper engine timing, malfunctioning fuel injectors, defective air fuel controllers, and poor fuel quality.
- Reduce unnecessary idling of equipment by extending idling restrictions to nonroad engines and through the promotion of idling reduction technologies such as automatic shut-off devices.

C.4 Petroleum Spills

The PAH content of crude oil can vary dramatically depending on the source rock (i.e., marine- or terrestrial-derived organic deposits) and the thermal environment prevailing during oil formation. Crudes with the highest PAH content tend to come from marine deposits that are found in the Middle East.

It is difficult to quantify the total amount of oil released in a given year. While larger spills are well documented, smaller spills often go unreported. It is estimated that approximately eight million gallons of crude oil (or approximately 14 tons of PAHs) are released to waters nationwide every year.

It is estimated that on average 70 kg of PAHs per year are released in the Harbor by petroleum spills.

This estimate is based on data in the U.S. Coast Guard Marine Information Safety and Law Enforcement (MISLE) database, and is likely incomplete, given that only "closed" cases are reported. Of the spills reported, most have been due to equipment failure. In addition to the spills reported in the MISLE database, several recent, relatively large petroleum spills in the Arthur Kill, Passaic River, and Rahway River, may have contributed another 192 kg of PAHs to the Harbor.

Very large hydrocarbon spills may become partially trapped in soil or sediment, and slowly release PAHs to the Harbor over many years. Quantifying the annual inputs of PAHs from individual historically contaminated sites was not possible. However, PAH inputs from this source are likely to be an important contributor of PAHs to the Harbor, given the number of contaminated sites in the region and the magnitude of contamination at certain individual sites.

Summary of Recommendations for Petroleum Spills

The available data indicate that most spills are the result of equipment failure. Therefore, our recommendations focus on improving preventive maintenance at the facility level.

- Consider strengthening the equipment failure and maintenance sections of the Spill Prevention Control and Countermeasures Plan federally required for owners or operators of facilities who drill, produce, gather, store, process, refine, transfer, distribute, use, or consume oil and oil products.
- Increase employee spill prevention knowledge through training and continuing education efforts.
- Support an expeditious and thorough cleanup of the historical petroleum spill along Newtown Creek (a tributary of the East River) that continues to seep into the creek.

Approach Used to Calculate Releases and Loadings and Cautions on Estimate Use

For most sources, emission estimates were calculated by applying emission factors for each source and medium of release to area-specific activity levels. The emission factors that we used allow for a quantitative, compound-specific measure of PAH releases per unit of activity (i.e., mg pyrene released per kg hardwood burned or vehicle mile traveled). We emphasized using emission factors from peer-reviewed publications whenever possible. In some cases, when emission factors were not available, emission values reported to the U.S. EPA's Toxics Release Inventory (TRI) were used.[16] For example, emission factors for petroleum refineries were not available; therefore, emissions from refining facilities in the Watershed reported to the TRI are presented in this report.

Activity (i.e., kg wood burned or vehicle miles traveled per county per year) was quantified from regional activity data whenever possible. However, when necessary, we extrapolated from state or national activity data based on Watershed county population or a reported correlated activity expected to represent desired activity. For example, train track miles for New York and New Jersey were available; therefore, the miles of train track in the Watershed was extrapolated based on reported locomotive PM_{10} emissions. Although not all counties are 100% in the Watershed, emissions calculated for difuse/nonpoint sources were typically made for all counties that are entirely or partially in the Watershed.

The relevant region for releases to water and land is the New York/New Jersey Harbor Watershed; however, with regard to atmospheric sources, emissions both from inside and outside the Watershed (New York and New Jersey only) are estimated. Experts consulted concluded that considering atmospheric sources within the entire states of New York and New Jersey would likely capture most of the atmospheric emissions capable of reaching the Harbor.[17]

PAH releases are reported in kilograms per year. Release estimates represent order of magnitude estimates of releases for a given year and are not necessarily representative of the most recent year. All ton units are reported as metric tons (1000 kg).

Although efforts were made to use the best available data when calculating PAH releases and loadings, caution should be used when viewing these estimates. Three of the primary uncertainties with this report are 1) omission of potentially major sources of PAHs

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[16] The TRI is a publicly available U.S. EPA database that contains information on toxic chemical releases and other waste management activities reported annually by certain covered industry groups as well as federal facilities. Reporting to the TRI is triggered by how much of the chemical is manufactured, processed, or otherwise used during the year.

[17] On August 4, 2005 we held a consultative meeting with experts on the issue of long-range transport of PAHs and other toxics. For a detailed discussion on this meeting, see page 40 of the report *Pollution Prevention and Management Strategies for Dioxins in the New York/New Jersey Harbor,* New York Academy of Sciences (2006).

to the Harbor; 2) lack of robustness of emission factors and activity estimates; and 3) limitations inherent in the simplifying assumptions included in the fate and transport modeling. Specific sources known or suspected to emit PAHs in the region but not included in this report include historically contaminated sites, brake dust, and outdoor boilers (see Section 3.6 SOURCES FOR WHICH EMISSION FACTORS ARE NOT AVAILABLE). PAH emission factors are available for many sources; however, they do not always characterize emissions of all 16 EPA priority PAHs and/or have associated uncertainties that transcend and impact calculated emissions. For example, the quantity of PAHs released in a combustion process is a function of oxygen concentration, temperature, and characteristics of the materials being combusted. Neither this degree of detail in emission factors, nor the corresponding detail in activity factors for each type of combustion conditions in a given location in a given year, are generally available. The limitations of the fate and transport modeling are discussed in APPENDIX C. But in spite of all these limitations, this report provides an assessment of PAH sources to the Harbor that is truly unprecedented in scope, and serves as a model for better understanding the key sources and transmission vectors of nonpoint source persistent and bioaccumulative toxins in modern, urban settings.

TECHNICAL REPORT

INTRODUCTION

The fifth class of contaminants chosen to be investigated by The Harbor Consortium was polycyclic aromatic hydrocarbons, a class of contaminant with both pyrogenic and petrogenic sources. PAHs elicit concern for several reasons: they are directly toxic to marine animals; they are harmful to humans; and PAH metabolites are potent animal and human carcinogens. Recent trends indicate an increase in PAH contamination in U.S. waterways in or near urban areas [10] [11]. In the New York/New Jersey Harbor region specifically, high concentration of PAHs in aquatic sediments have been documented [12] [13]. In addition, elevated concentrations of several PAHs have been detected in aquatic organisms found in the Watershed, including blue crab, perch, oysters, and mussels [14] [15].

The objective of this report is to identify the primary sources of PAH releases within the New York/New Jersey Harbor estuary, understand how these releases might reach the Harbor, and make recommendations aimed at stemming PAH loadings to the Harbor. An industrial ecology approach was used to identify sources and to estimate total emissions of PAHs from all known sources throughout the Harbor region. Subsequently, a semiqualitative analysis of the fate and transport of PAHs from the primary sources to the Harbor was conducted and a comparison with the PAH mass balance was made as a means of constraining our estimated values. It should be noted that this report does not attempt to estimate PAH availability to biota or environmental impact associated with each of the individual sources.

In the following sections we attempt to provide a comprehensive discussion on PAHs and their properties, emission sources (both national and regional), major sources of PAH releases within the Harbor watershed, and the fate and transport characteristics within the Harbor complex used to estimate loadings of PAHs to the Harbor.

1. GENERAL BACKGROUND ON PAHS

1.1. Physical and Chemical Characteristics

Polycyclic (or polynuclear) aromatic hydrocarbons, or PAHs, are a class of compounds characterized by two or more fused aromatic rings composed of carbon and hydrogen [16]. PAHs are found naturally in petroleum deposits and are the product of the incomplete combustion of organic matter. Elevated PAH concentrations can be found in urban air, in soil and groundwater adjacent to certain industrial operations, and, especially, in sediments underlying industrialized ports and waterways. While hundreds of different PAHs exist, 16 compounds were designated as "priority pollutants" by the 1977 Clean Water Act because of their toxicity and status as known or possible human carcinogens [17].[18]

The PAHs selected for investigation in this report, along with their chemical formulas and molecular weights, are listed in Table 1.1. These 17 compounds include the 16 U.S. EPA-designated priority PAHs as well as perylene.[19] They represent a wide range of molecular weights, which are closely related to the physical properties of the compounds. These PAHs (except naphthalene and acenaphthene) were measured in all three of the datasets used to construct the mass balance (see Appendix B). Naphthalene is frequently the most abundant PAH in the dissolved phase, and it is designated by the U.S. EPA as a possible human carcinogen [19].

The physical-chemical properties of PAHs cause them to behave in the environment like other hydrophobic organic contaminants, including polychlorinated biphenyls (PCBs) and dioxins [16]. PAHs can bioaccumulate in fatty tissues, and one compound, benzo[a]pyrene, is on the U.S. EPA's list of Priority Persistent and Bioaccumulative Toxins (PBT) [20].[20] These types of organic contaminants tend to accumu-

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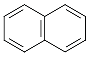
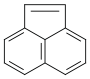
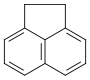
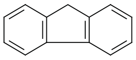
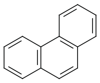
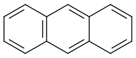
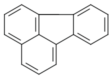
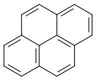
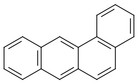
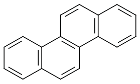
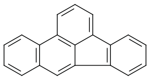
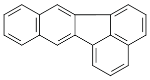
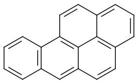
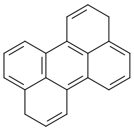
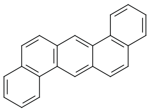
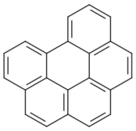
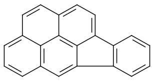
[18] The 16 U.S. EPA priority PAHs are naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a] anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[a,h]anthracene, benzo[g,h,i]perylene, and indeno[1,2,3-CD] perylene.

[19] Oxygenated and methylated PAHs have the potential to be more toxic than their parent PAHs [18]. It is our assumption that presence of the parent PAHs addressed in this report indicates the presence of these metabolites.

[20] Persistent, bioaccumulative, and toxic (PBT) chemicals do not break down readily in the environment, are not easily metabolized, may accumulate in human or ecological food chains through consumption or uptake, and may be hazardous to human health or the environment.

Table 1.1. Chemical formula, molecular weight (MW), and structure for selected PAHs

PAH	Chemical formula	Molecular weight (g mol⁻¹)	Structure
Naphthalene	$C_{10}H_8$	128	
Acenaphthylene	$C_{12}H_8$	152	
Acenaphthene	$C_{12}H_8$	152	
Fluorene	$C_{13}H_{10}$	166	
Phenanthrene	$C_{14}H_{10}$	178	
Anthracene	$C_{14}H_{10}$	178	
Fluoranthene	$C_{16}H_{10}$	202	
Pyrene	$C_{16}H_{10}$	202	
Benz[a]anthracene	$C_{18}H_{12}$	228	
Chrysene	$C_{18}H_{12}$	228	
Benzo[b]fluoranthene	$C_{20}H_{12}$	252	
Benzo[k]fluoranthene	$C_{20}H_{12}$	252	
Benzo[a]pyrene	$C_{20}H_{12}$	252	
Perylene	$C_{20}H_{12}$	252	
Dibenz[a,h]anthracene	$C_{22}H_{14}$	278	
Benzo[g,h,i]perylene	$C_{22}H_{12}$	276	
Indeno[1,2,3-CD]pyrene	$C_{22}H_{12}$	276	

Source: Mackay et al. [16].

late preferentially in hydrophobic compartments of the environment, including organic matter–rich soil and sediment, suspended particles in air and water, and the lipid fractions of biota, owing to the high PAH absorption capacity of these phases. As a result, very little of the total hydrophobic pollutants in the environment are found freely dissolved in water, and one might expect adverse effects to the ecosystem to arise primarily from contact with PAH-contaminated particles.

Hydrophobicity can be measured by determining the distribution of a given compound between octanol and water phases. This parameter is called the octanol–water partition coefficient (K_{ow}) and is often reported as log K_{ow}. The higher the K_{ow} is, the greater the affinity for hydrophobic phases. Many PAHs also have very low vapor pressure, and only the lightest (e.g., naphthalene) are likely to be found in substantial quantities as free PAH in the atmosphere. Based on characteristic differences in physical and chemical properties, the first eight compounds are sometimes referred to as the "low molecular weight" PAHs, while the last eight (plus perylene) are "high molecular weight" PAHs. The aqueous solubility, octanol–water partition coefficient, and vapor pressure for the 16 priority PAHs and perylene are given in Table 1.2.

In general, PAHs become more hydrophobic and less volatile with increasing molecular weight (Fig. 1.1).

1.2. Toxicology and Human Health Effects

PAHs can cause a variety of adverse human health effects, including liver, kidney, and hematologic effects; cataracts; and cancer [19]. Several noncarcinogenic reference doses (RfDs) have been established by the U.S. EPA for chronic exposure to various PAHs via oral and inhalation routes (Table 1.3). An RfD is the concentration to which humans (including sensitive subgroups) can be exposed on a daily basis over a lifetime without expecting adverse health effects [21]. The RfD for a given compound and exposure route is calculated from the "no observed adverse effects level" (NOAEL)[21] from a human or animal study, according to Equation 1:

Table 1.2. Physical-chemical properties of selected PAHs including aqueous solubility, log octanol–water partition coefficient, and vapor pressure

	PAH	Aqueous solubility (mg L^{-1})	Log K_{ow}	Vapor pressure (Pa)
Low molecular weight	Naphthalene	34.4	3.37	10.8
	Acenaphthylene	3.93	4.07	0.89
	Acenaphthene	3.88	4.03	0.30
	Fluorene	1.90	4.18	0.09
	Phenanthrene	1.29	4.57	2.27E-02
	Anthracene	0.073	4.54	3.60E-03
	Fluoranthene	0.26	5.22	8.61E-03
	Pyrene	0.14	5.18	3.39E-03
High molecular weight	Benz[a]anthracene	0.014	5.91	2.20E-05
	Chrysene	0.0020	5.91	5.70E-07
	Benzo[b]fluoranthene	0.0015	6.50	5.00E-07
	Benzo[k]fluoranthene	0.00081	6.84	5.20E-08
	Benzo[a]pyrene	0.00380	6.50	7.32E-07
	Perylene	0.00040	6.50	5.31E-09
	Dibenz[a,h]anthracene	0.00050	7.19	1.33E-08
	Benzo[g,h,i]perylene	0.00026	6.85	1.39E-08
	Indeno[1,2,3-CD]pyrene	0.00019	7.66	NA

Log K_{ow} = log octanol–water partition coefficient
Source: Mackay et al. [16].

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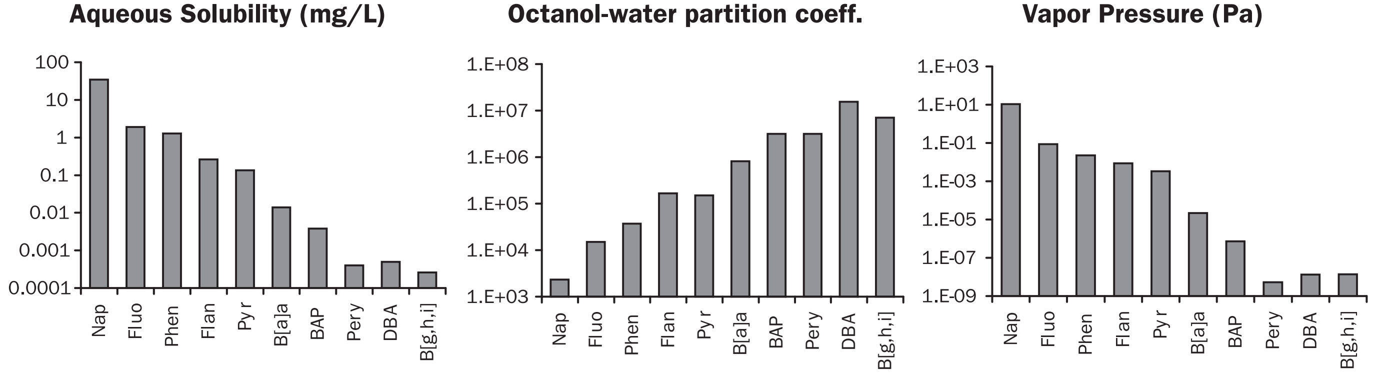
[21] "No observed adverse effects level" (NOAEL) is the highest tested dose of a substance that has been reported to have no harmful (adverse) health effects to humans or animals. In the case of NOAEL, the adverse health effect is known prior to testing.

Figure 1.1. Aqueous solubility, octanol–water partition coefficient, and vapor pressure for selected PAHs



The vertical line separates the low molecular weight PAHs from the high molecular weight PAHs. (From Mackay et al. [16].) Naphthalene (nap), fluorine (fluo), phenanthrene (phen), pyrene (pyr), benz[a]anthracene (b[a]a), benzo[a] pyrene (BAP), perylene (pery), dibenz[a,h]anthracene (DBA), and benzo[g,h,i]perylene (B[ghi]).

Equation 1. The RfD for a given compound and exposure route is calculated from the "no observed adverse effects level" (NOAEL) from a human or animal study

$$RfD = \frac{NOAEL}{UF\ MF}$$

UF and MF represent, respectively, the associated uncertainty factors and modifying factors for the study.

In each case, confidence in the parameter is low (or "low-medium" in the case of the naphthalene inhalation reference dose). No RfD values are available for exposure to acenaphthylene, phenanthrene, or any of the high molecular weight PAHs.

Seven priority PAHs including BAP have been designated level B2, for "probable human carcinogen," and naphthalene is designated level C, for "possible human carcinogen." Other priority PAHs are designated cancer classification D (not classifiable as to human carcinogenicity; Table 1.4) [19]).[22] Risk from exposure to carcinogenic compounds is defined as excess cancer risk, or the number of additional cancers that would result from a lifetime of exposure to that contaminant [23]. Excess cancer risk is computed by multiplying the total quantity of contaminant to which an individual would be exposed over a lifetime, given various exposure scenario-specific exposure factors, by a measure of the carcinogenic potency of the compound, called the cancer slope factor (CsF). Data to define a CsF are sufficient for only one PAH, benzo[a]pyrene (BAP) [19]. Excess cancer risk for exposure to other PAHs is computed by multiplying the total exposed dose by the toxic equivalency factor (TEF, also sometimes termed potency equivalency factor or PEF) for that compound, and then applying the CsF for BAP to the resulting BAP-equivalent dose. TEF values reported by Nisbet and LaGoy [24] and provisional guidance to the U.S. EPA [25] (Table 1.4) continue to be used and cited widely [26] [27], and are consistent with other PAH toxic equivalency studies [28]. According to both the U.S. EPA and the Nisbet and LaGoy values, the most carcinogenic PAHs besides BAP are dibenz[a,h] anthracene, indeno[1,2,3-cd]pyrene, benzo[b]fluoran-

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[22] The following information defining cancer classes is available on the U.S. EPA web site, http://www.epa.gov/iris/. The cancer class system was used from 1986 to 1996. However, until the system can be replaced with a better approach, U.S. EPA still reports cancer classifications in the Integrated Risk Information System (IRIS) database for all PAHs:

GROUP A–HUMAN CARCINOGEN: used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer.

GROUP B–PROBABLE HUMAN CARCINOGEN: includes agents for which the weight of evidence of human carcinogenicity based on epidemiologic studies is limited and also includes agents for which the weight of evidence of carcinogenicity based on animal studies is sufficient. The group is divided into two subgroups. Group B1 is reserved for agents for which there is limited evidence of carcinogenicity from epidemiologic studies. Group B2 is used for agents for which there is sufficient evidence from animal studies and for which there is inadequate evidence or no data from epidemiologic studies.

GROUP C–POSSIBLE HUMAN CARCINOGEN: used for agents with limited evidence of carcinogenicity in animals in the absence of human data.

GROUP D–NOT CLASSIFIABLE AS TO HUMAN CARCINOGENICITY: generally used for agents with inadequate human and animal evidence of carcinogenicity or for which no data are available.

GROUP E-EVIDENCE OF NONCARCINOGENICITY FOR HUMANS: used for agents that show no evidence for carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies [22].

thene, and benz[a]anthracene. Both sources consider dibenz[a,h]anthracene to be at least as carcinogenic as BAP; Nisbet and LaGoy [24] consider dibenz[a,h]anthracene to be five times more carcinogenic than BAP, but data are still insufficient to compute a cancer slope factor for this compound [19].

While direct human exposure to contaminated sediment is unlikely to cause adverse health effects (for example, from exposure of recreational swimmers and boaters to contaminated sediment [27]), the human and ecological toxicity of PAHs in sediment triggers restrictions on available options for dredged sediment disposal and thereby constitutes a high financial burden to the region. In addition, some human exposure risks may not be negligible, such as health risks to area fishermen who ignore posted warnings and consume

Table 1.3. All available reference doses for chronic noncarcinogenic adverse health effects from exposure to PAHs via oral and inhalation routes

PAH	Critical effect (oral)	RfD[a] (mg/kg-day)	Critical effect (inhalation)	RfC[b] (mg/m^3)	Other effects
Naphthalene	Decreased mean terminal body weight (male rats)	0.02	Respiratory hyperplasia and olfactory metaplasia	0.003	Hemolytic anemia (oral, inhalation); cataract formation (inhalation)
Acenaphthene	Hepatotoxicity	0.06	NA		
Fluorene	Decreased RBC & hemoglobin	0.04	NA		
Anthracene	No observed effects	0.3	NA		
Fluoranthene	Kidney, liver, and blood effects	0.04	NA		
Pyrene	Kidney effects	0.03	NA		

NA = not assessed

Source: U.S. EPA [19].

[a] For oral ingestion, RfD= noncarcinogenic endpoint reference dose, defined as the concentration to which humans (including sensitive sub-groups) can be exposed on a daily basis over a lifetime without expecting adverse health effects.

[b] For inhalation, RfC= carcinogenic endpoint reference dose.

Table 1.4. Cancer class and relative carcinogenic potency expressed as toxicity equivalency factors (TEF) for selected PAHs

PAH	Cancer class	TEF (U.S. EPA)	TEF (Nisbet & LaGoy)
Naphthalene	C		
Acenaphthylene	D		
Acenaphthene	N/A		
Fluorene	D		
Phenanthrene	D		0.001
Anthracene	D		0.01
Fluoranthene	D		0.001
Pyrene	D		0.001
Benz(a)anthracene	B2	0.1	0.1
Chrysene	B2	0.001	0.01
Benzo(b)fluoranthene	B2	0.1	0.1
Benzo(k)fluoranthene	B2	0.01	0.1
Benzo(a)pyrene	B2	1 (index)	1 (index)
Perylene			
Dibenz(a,h)anthracene	B2	1	5
Benzo(g,h,i)perylene	D		0.01
Indeno(1,2,3-CD)pyrene	B2	0.1	0.1

TEF= toxic equivalency factor

Sources: Nisbet and LaGoy [24]; U.S. EPA. [25]

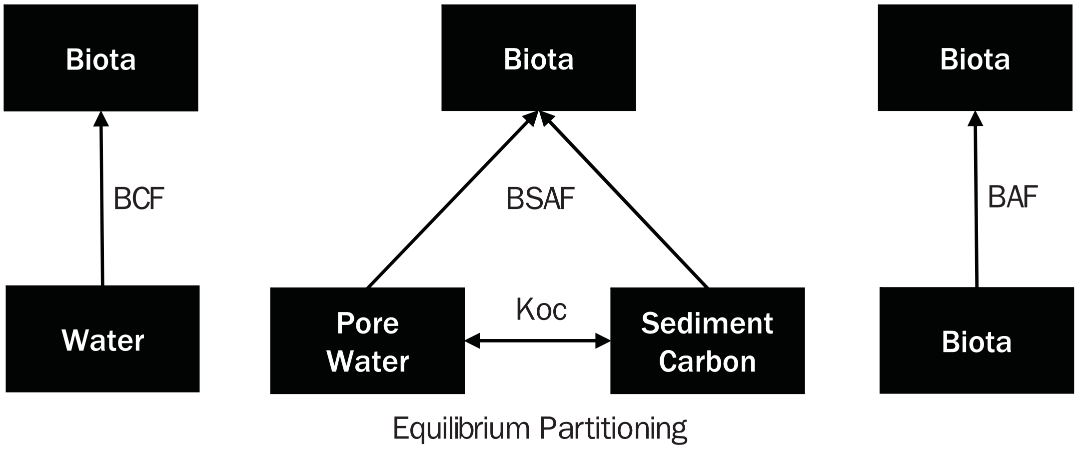
fish caught in contaminated areas (Shor, unpublished data). While these involuntary risks are likely to be far lower than various voluntary PAH exposure risks (e.g., cigarette smoking, indoor pollution from fireplaces, consuming grilled meats [29]), the purpose of this document is to quantify the major sources of PAH pollution to the Harbor. This document provides the necessary background information for the Harbor Consortium to deliberate on recommendations to curb loadings of PAHs to the Harbor. The ensuing policy recommendations are expected to be consistent with the regional goals of ensuring the economic and ecological vitality of the Harbor.

1.3. Ecological Impacts

PAHs are commonly detected in U.S. surface waters [30], in sediments underlying U.S. ports, and in other industrialized waterways [31] [32]. PAH contamination is known to adversely affect the viability of benthic species and the diversity of aquatic, estuarine, and marine ecosystems [33, 34]. Given the importance of estuaries in the life cycle of many marine species, including commercially important fish populations [35-39], the adverse impact to the NY/NJ Harbor caused by PAH contamination extends far beyond its geographic boundaries to include various species and humans.

As with other hydrophobic organic contaminants, PAHs can become concentrated in the lipid-rich tissues of animals and accumulate along the food chain [16]. Three different bioaccumulation parameters are defined according to the route of exposure: 1) bioconcentration factors (BCF) are for exposure from water; 2) biota–sediment accumulation factors (BSAF) are from exposure to sediment; and 3) biomagnification factors (BMF) are for exposure through trophic levels [40] (Fig. 1.2). Species that live in sediment are exposed to PAHs by contact with and ingestion of PAH-contaminated sediment and pore waters, and ingestion of PAH-contaminated biota. Species that live in the water column are exposed to PAHs by direct exposure to PAH-contaminated water, as well as via trophic transfer. In general, biomagnification is not as pronounced for PAHs as it is for some other persistent and bioaccumulative compounds (e.g., PCBs, dioxins), because many animals have the ability to metabolize and eliminate PAHs from their bodies [41]. In some instances, trophic dilution is observed in predatory organisms as a result of metabolic transformation within organisms and their prey species [42]. However, many studies measure only the parent compound and not PAH metabolites. For example, one study with polychaete worms found some cases where parent compounds represented less than 10% of the total burden of parent compound plus metabolites [43]. Since the mechanism of benzo[a]pyrene (BAP) carcinogenicity to humans begins with sequential oxidation to BAP-7,8-oxide, BAP-7,8-diol, and, ultimately, BAP-diol-epoxide [44], ideally, the concentration of metabolites would also be measured to estimate their potential impact more accurately.

Figure 1.2. Diagram showing different ways biota concentrations are estimated from other types of data, including water, pore water, and biota concentrations via a bioconcentration factor (BCF), a biota-sediment accumulation factor (BSAF), and a biomagnification factor (BMF), respectively



Modified from DiToro et al. [45].

BSAF [dimensionless] is computed by dividing the lipid-normalized PAH concentration in biota [mg PAH/kg dry weigh] by the organic carbon content –normalized sediment concentration [mg PAH/kg dry weight], as below:

Equation 2. Biota-sediment Accumulation Factor

$$BSAF = \frac{\left(\frac{C_{biota}}{\%\ lipid}\right)}{\left(\frac{C_{sed}}{\%\ org\ C}\right)}$$

For well-defined systems in thermodynamic equilibrium, ecologically protective sediment quality criteria can be computed readily via equilibrium partitioning theory from readily measured parameters, including sediment organic carbon content and toxic effects thresholds for target species [45]. For example, DiToro et al. [46] [47] use equilibrium partitioning theory to generate "final chronic value" (FCV) sediment quality guidelines. An important feature of their narcotic toxicity approach is harmful effects from PAHs, which are assumed to be additive, so the FCV given for individual PAHs (acenaphthene, phenanthrene, pyrene, and fluoranthene) are nearly equal to each other and to the FCV for total PAHs [47].

Equilibrium partitioning is a unified and useful approach, but deviations from equilibrium behavior have often been noted in measured sediment–water–biota partitioning. Factors that lead to nonideal partitioning include selective feeding, biotransformation, and bioturbation by biota [40]; various sediment-related factors such as reduced bioavailability with contaminant aging [48] and differing organic matter properties [49] [50]; and factors related to variability in the PAH-binding ability of dissolved organic carbon (DOC) [51]. In realty, measured BSAF values vary broadly, even within the same region. For example, Baumard et al. [52] reported a range of BAF for mussels (*Mytilus* sp.) in the Baltic Sea of 0.02–52, depending on sampling date, PAH concentration, carbon content of sediment, and lipid content of the organism. Another study reported BSAFs for eight locations in Hoffman Marsh (San Francisco Bay) for several species of benthic invertebrates, including Asian clam (*Potamocorbula amurensis*), Japanese littleneck clam (*Tapes japonica*), and polychaetes [50]. Total PAH concentrations in sediment at the study sites varied from 10 to 150 mg/kg; however, BSAF values ranged nearly three orders of magnitude (0.0069–5.4), with reduced PAH bioavailability in sediments with a high soot content (from urban runoff) as a determining factor. Given the variability in BSAF values, bioavailability assays [53] [40] or biomarker approaches [54, 55] are probably necessary to generate criteria that account for site-specific differences in contaminant availability. The U.S. EPA has evaluated the status and needs of bioaccumulation information for sediment quality assessment, and lists improving test methods, developing more BSAF values, and better understanding of bioavailability, food chain multipliers, and mixture effects as high priority research areas [56].

Given the difficulty in establishing universal sediment concentration limits, several agencies have established sediment criteria guidelines to identify potential impacts of sediment contamination on coastal resources and habitats. The National Oceanic and Atmospheric Association (NOAA) developed a set of sediment screening concentrations for inorganic and organic contaminants. NOAA reports a sediment screening concentration for total PAHs in freshwater of 12,000 ppm dry weight for upper effects level and in marine waters of 44,792 ppm dry weight for median effects range.[23] The New York State Department of Environmental Conservation, Division of Fish and Wildlife and the Division of Marine Resources, has also established sediment criteria for several PAHs (Table 1.5) [57]. These criteria do not necessarily represent the final concentrations that must be achieved through sediment remediation and comprehensive sediment testing. Risk management is necessary to establish when remediation is needed.

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[23] For more information, visit the NOAA web site at http://response.restoration.noaa.gov/book_shelf/122_squirt_cards.pdf.

Table 1.5. New York State Department of Environmental Conservation PAH sediment criteria

PAH	Human health		Benthic aquatic life, acute toxicity		Benthic aquatic life, chronic toxicity[a]	
	FW	SW	FW	SW	FW	SW
	µg/g Organic carbon					
Acenaphthene					140(E)	140(E)
Benzo(a)pyrene	1.3	0.7				
Fluoranthene					1020 (E)	1340 (E)
Phenanthrene					120 (E)	160 (E)
Anthracene			986		107	
Benz(a)anthracene	1.3	0.7	94		12	
Fluorene			73	348	8	38
Benzo(b)fluoranthene	1.3	0.7				
Benzo(k)fluoranthene	1.3	0.7				
Chrysene	1.3	0.7				
Indeno(1,2,3-cd)pyrene	1.3	0.7				
Naphthalene			258	328	30	38
Pyrene			8775		961	

FW= freshwater; SW= saltwater

Source: New York State Department of Environmental Conservation [57].

Criteria marked (E) extracted from U.S. EPA [58]

2. PAH EMISSIONS SOURCES

In years past, literature reports have identified certain industries, including energy and metal production, as the main culprits releasing large quantities of PAHs to the atmosphere. However, modern atmospheric emissions controls have dramatically reduced the emission of PAHs from these processes.[24] Similarly, catastrophic releases of petroleum to land and water have become less common nationwide as a result of improved engineering controls, although the cumulative impact of smaller petroleum spills is still of concern.

Today, a general consensus of literature reports two major national and global sources of PAHs in the environment: 1) incomplete combustion of organic matter, especially common, nonpoint activities that utilize modern emissions controls (e.g., cars) or less common activities with no emissions control (e.g., tire fires); and 2) releases of petroleum, including oil spills and illegal dumping. Major sources include forest fires, motor vehicle emissions, open burning, domestic fireplaces, and spills and dumping of petroleum products. In the sections that follow, what is known about releases of PAHs from natural and anthropogenic sources in the Watershed to air, water, and land will be quantified.

2.1. General Anthropogenic Sources

Anthropogenic emissions of PAHs to the environment are predominantly incidental, including combustion byproducts from motor vehicles and various industrial processes. Unlike many other environmental contaminants of concern in the NY/NJ Harbor, very few PAHs are intentionally manufactured. The only PAH that is produced industrially in large quantities and has direct commercial uses is the bicyclic compound naphthalene [59]. The total annual consumption of naphthalene in the United States in 2000 was approximately 109,000 metric tons [60]. Major uses for naphthalene include mothballs, paint thinner, and solvent for metal surface prep [61]. Naphthalene is also used as a chemical intermediary in pharmaceutical and photographic industries, and, to a limited extent, in the production of soaps, pigments and dyes, insecticides, fungicides, plastics, and processing of certain foods [62]. In addition, naphthalene is used for the production of phthalic anhydride, an intermediate for polyvinyl chloride (PVC) plasticizers [59].

Other PAHs, including acenaphthene, anthracene, phenanthrene, fluorene, and pyrene, have some limited industrial uses. Acenaphthene is used for production of naphthalic anhydride, an intermediate for pigments [59]. Anthracene is used as a chemical intermediary for dyes, as a dilutant for wood preservatives [62], and as a scintillant for the detection of high-energy radiation [59]. Fluorene is used for the production of fluorenone, a mild oxidizing agent [59]. Phenanthrene's primary use is for production of phenanthrenequinone, an intermediate for pesticides, and for diphenic acid, an intermediate for resins, while pyrene's main use is to make dyes [59]. Annual national production data for PAHs other than naphthalene are not available, but emissions from manufactured PAHs are not expected to be a major emission source locally. As described below, 1999 U.S. EPA's National Emissions Inventory (NEI) reported that national annual atmospheric emissions of total PAHs (where the total is the sum of the 16 priority PAH compounds) from all chemical and pharmaceutical sources combined were less than 1000 kg/yr, a small fraction of the greater than 5000 metric tons/yr released from all atmospheric sources.

2.1.1 General Sources of PAHs Released to the Atmosphere

Data from the U.S. EPA National Emissions Inventory (NEI) suggest that mobile sources are an important source of atmospheric PAH emissions (approximately 90% of total atmospheric emissions in 1999, excluding forest fires [63]; Table 2.1).[25]

Although the NEI database is a very convenient repository for national chemical emissions, these data

Table 2.1. U.S. annual atmospheric emissions of total PAHs (defined as the U.S. EPA 16 priority PAHs) for all sources except forest fires

PAH source	PAH (tons/yr)	Percent total PAHs
Motor vehicles	4474	90
Nonpoint sources[a]	489	10
Point sources[b]	13	<1
Total PAHs	4977	100

Source: U.S. EPA National Emissions Inventory, 1999 [63].
a For examples of nonpoint sources, see Table 2.3.
b For examples of point sources, see Table 2.4.

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[24] See Section 4.5.4. Incineration for a description of typical emissions control devices utilized by industry today.

[25] Forest fires are excluded because the typical incidence of forest fires nationwide is not similar to the incidence in the New York City metropolitan area. Further, if transboundary sources of PAHs including western U.S. forest fires were a dominant source of PAHs on the East Coast, then we would expect to find uniform PAH concentrations in urban and rural areas, which plainly is not the case.

should be used with some caution. The data are voluntarily reported by various regional authorities, and in some cases are not reported consistently across all states or regions. Data verification or monitoring is not expected to be part of this effort. However, as a general accounting of the major sources of PAH emissions to the atmosphere, it is a useful resource.

These NEI data indicate that, nationwide, mobile sources release nearly 90% of total atmospheric emissions (again, excluding forest fires) of total PAHs. When these sources are broken down further by category, it is apparent that on-road traffic of cars and trucks is responsible for more than 99% of mobile source emissions of total PAHs to the atmosphere (Table 2.2). According to the NEI data, national emissions of total PAHs from motorcycles is only 0.7% of emissions from all mobile sources, and national emissions of total PAHs from all other nonroad sources, including aircraft, trains, all-terrain vehicles, recreational marine vessels, tractors, and lawnmowers, is only 0.1% of the total.

Table 2.2. U.S. annual atmospheric emissions of total PAHs (defined as the U.S. EPA 16 priority PAHs) from all mobile sources according to NEI data

Mobile source	PAHs (tons/yr)	Percent total PAHs
Light-duty vehicles	1966	44
Light-duty trucks	1411	32
Heavy-duty vehicles	1065	24
Motorcycles	29	<1
Nonroad	3	<1
Mobile source total	4474	100

Source: U.S. EPA National Emissions Inventory, 1999 [63].

A breakdown by fuel type shows that 95% of the total mobile emissions of total PAHs nationwide comes from gasoline-powered vehicles and the remaining 5% comes from diesel [63].[26]

The second largest (<10%) category for national atmospheric emissions of total PAHs according to the NEI is from nonpoint sources. The three largest major sources within this category are consumer and commercial product use, open burning, and fireplaces (Table 2.3). These three sources constitute 80% of the nonpoint source total. Other sources include gasoline distribution and cement manufacturing.

Table 2.3. U.S. annual atmospheric emissions of PAHs (defined as the U.S. EPA 16 priority PAHs) from all nonpoint sources

Nonpoint source	PAHs (tons/yr)	Percent total PAHs
Consumer and commercial product use[a]	133	27
Open burning	130	27
Fireplaces	126	26
Gasoline distribution	53	11
Concrete manufacturing	39	8
Other	9	2
Nonpoint source total	489	100

Source: U.S. EPA National Emissions Inventory, 1999 [63].

[a] Includes powders, polishes, soaps, hair care products, coal tar and asphalt coatings, and pesticides. For a full list of activities included under this and other source categories see the U.S. EPA National Emissions Inventory, http://www.epa.gov/ttn/chief/net/index.html.

The third main emission category of the NEI is point sources (<1%). These sources are various industrial facilities. The major contributors to PAH emissions fall into the categories of transportation equipment; fabricated metal products; and electric, gas, and sanitary services (Table 2.4). As can be seen in the following sections, national trends do not necessarily hold true for regional trends.

Emission trends for total PAHs can be quite different from emissions trends for individual compounds.

Table 2.4. U.S. annual atmospheric emissions of PAHs (defined as the U.S. EPA 16 priority PAHs) from all point sources

Point source	PAHs (tons/yr)	Percent total PAHs
Transportation equipment[a,b]	9.1	69
Fabricated metal products	1.3	10
Electric, gas, and sanitary services	1.1	9
Chemicals and pharmaceuticals	0.7	5
Stone, clay, and glass products	0.6	5
Other	0.3	2
Point source total	13.1	100

Source: U.S. EPA National Emissions Inventory, 1999 [63].

[a] Includes manufacturing and repairing vehicle, marine, and air equipment. For a full list contact the U.S. EPA Clearing House for Inventories and Emissions Factors.

[b] These emissions are the result of reporting by one motor company in Kentucky.

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[26] Vehicle emissions reported by the NEI are calculated using the emission fractions described in Section 3.3.1. Vehicle Exhaust and may not accurately reflect emissions of the current vehicle fleet.

For example, in many of these categories, naphthalene accounts for more than 50% of the total PAH emissions. When the NEI data are examined for the emissions signature of another compound, a totally different set of major sources is found. For example, let us consider emissions of the five-ring PAH benzo[a] pyrene (BAP). This compound receives a lot of attention because of its relatively high carcinogenicity and because it is included in the EPA's list of Priority Persistent and Bioaccumulative Toxins (PBT). BAP emissions are dominated by several nonpoint sources, not by mobile sources (as is the case for total PAHs) [64]. Major emissions sources nationwide for BAP are open burning, fireplaces, and a few industrial processes that include metal production, petroleum refining, and incineration (Fig. 2.1).

2.1.2. General Sources of PAHs Released to Land

While a substantial amount of PAHs reach land surfaces via dry and wet deposition of atmospheric particles, other emission sources release PAHs directly to land. Major sources of PAH emissions to land are spills and dumping, especially improper disposal of used motor oil; mobile sources, including leaking oil from cars, tire wear, and brake dust; and use of PAH-containing products such as creosote wood preservatives and coal tar–based asphalt sealants. A catalog of national sources of PAH emissions to land was unavailable.

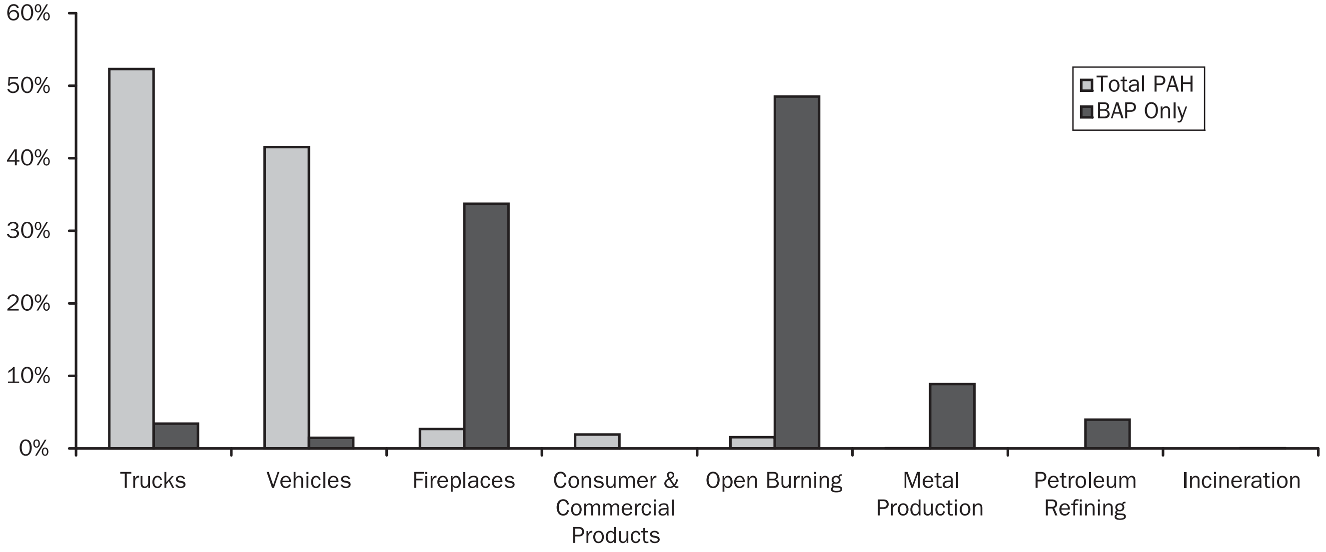
2.1.3. General Sources of PAHs Released to Water

PAHs may be released to water by several routes, including from oil spills onto water or land, stormwater runoff, wastewater treatment effluent, and creosote-treated wood use [59]. Very few data are available on typical PAH loadings in wastewater from specific industrial processes. However, some reports have indicated that important national sources of PAH releases to water are oil spills, dumping of used motor oil, stormwater runoff, and release of PAHs from products such as creosote and coal tar sealant.

2.2. General Natural Sources

PAHs have been present in the environment since long before anthropogenic activity. Naturally occurring forest fires, volcanic activity, and fossil fuel deposits are all examples of sources of PAHs in the environment.

Figure 2.1. Comparison of the breakdown by category of total PAH emissions to the breakdown by category for BAP emissions, according to the U.S. EPA 1999 National Emissions Inventory [63] [64]



3. MAJOR REGIONAL SOURCES OF PAHS

We have identified over 30 different sources of PAHs in the Watershed; however, 11 major sources each contribute more than 2% to the total PAHs released to their primary media of release (see SUMMARY OF FINDINGS). These sources include residential wood combustion, creosote-treated wood, surfaces sealed with refined coal tar–based sealants, vehicle exhaust, tire wear, leaking motor oil, improper disposal of used motor oil, and petroleum spills. Contaminated sites are also considered a major source of PAHs. While we have not estimated releases from these sites, given their pervasiveness in the region and proximity to the Harbor, they are potentially a significant source of PAHs.

The following sections of this report provide technical detail on the major sources of PAHs in the Watershed, including PAH release estimates, relevant policy, and pollution prevention recommendations.

3.1. Residential Fuel Combustion

3.1.1 Wood Combustion (Wood Stoves and Fireplaces)

Wood Stoves and Fireplaces: National Trends and Emission Factors

Nationwide there are approximately 37 million residential wood combustion devices, of which 72% are estimated to be fireplaces, 25% wood stoves, and the remaining 2% are appliances such as pellet stoves and outdoor wood boilers (OWBs) [65]. Wood stoves and fireplaces release PAHs through the incomplete combustion of wood. While a suite of PAHs are released during this process, wood combustion has been identified by several sources (including the NEI and the Great Lakes Binational Toxic Strategy) as a dominant source of benzo(a)pyrene, one of the more toxic PAHs [66, 67].

Emissions factors for PAHs from domestic wood combustion devices are highly variable and depend on many factors, including type of fuel (e.g., species of wood, and the aging process), wood moisture content, and design of the combustion device. The U.S. EPA provides emission factors for conventional, noncatalytic,[27] and catalytic[28] wood stoves (TABLE A.1) [68]. However, the report cautions that the available data used to generate the emission factors were sparse and/or had a high degree of variability, and should therefore be used with caution. Of the three wood stove types, emission factors for conventional stoves are the highest, likely because they lack emissions control devices.

Currently, regulations require all wood stoves manufactured after 1992 to pass U.S. EPA emissions certification, Phase II classification, in which noncatalytic and catalytic stoves have a smoke emission limit of 7.5 and 4.1 grams of smoke per hour, respectively [69]. Woodstoves have a relatively long life span, and it is estimated that only 11% of woodstoves currently in use are U.S. EPA certified [65].

A recent report provides PAH emissions factors for the domestic burning of seasoned hardwood in a fireplace (TABLE A.1) [70]. Unlike wood stoves, fireplace emission standards are regulated at the state and local level [71]. The U.S. EPA has, however, certified fireplace inserts that adhere to the same emission limits as woodstoves [72].[29]

Little information is available on the release of PAHs from outdoor wood boilers (OWBs).[30] However, a study by the New York State Attorney General's Office states that on average wood boilers emit 0.97 grams of PAHs per hour and 71 grams of particulate matter per hour [73]. A recent report by the U.S. EPA compared PAH emissions from OWB and certified wood stoves (catalytic and noncatalytic) and found wood stove emissions to be 1.5 times greater. OWBs are not currently subject to any Federal regulations, likely because of their low popularity during the 1980s, when wood stove standards were initially established by the U.S. EPA. Recently, however, OWBs have increased in popularity [73]. In fact, U.S. OWB sales in 2005 doubled from the previous year, reaching approximately 67,500 units [74].

Pellet stoves are another device used to combust wood. Pellet stoves consume wood and biomass that have been compressed into pellets. While some pel-

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[27] Noncatalytic stoves increase the potential for complete combustion by utilizing large baffles to create a longer and hotter gas flow path, as well as by introducing preheated combustion air.

[28] Catalytic stoves are equipped with a noble metal–coated combustor that ignites and burns the combustible components in the effluent.

[29] Fireplace inserts are structured similar to free-standing woodstoves and are designed to fit into an existing fireplace opening. Fireplace inserts reduce the amount of heat that is typically lost up a chimney [72].

[30] OWBs are freestanding combustion units resembling a shed with a low-standing chimney and are located outside of the home. The combustion exhaust is used to heat a water reservoir, which is then piped into the structure to be heated. A thermostat adjusts heat by controlling the amount of air that is supplied to the burn box. While restricting the air to the burn box results in lower temperatures, it also creates a lower quality combustion environment, generating PAHs.

let stoves are subject to the 1988 New Source Performance Standards, others are exempt, because of their high air-to-fuel ratio of 35:1[68]. Available emission factors are incomplete for pellet stoves.

Wood Stoves and Fireplaces: Regional Releases

The New York and New Jersey residential sector consumed over 4.5 million tons of cordwood in 2001 [75].[31] Watershed consumption of cordwood was estimated by extrapolating from state data based on the percentage of homes in the Watershed that reported using wood as their primary heating source to the U.S. Census—40% and 44% in the New York and New Jersey Watershed, respectively (or 2 million tons of cordwood) [77]. While it is unknown what type of combustion unit the wood is burned in, it is assumed that more wood is consumed in wood stoves (72%), because wood stoves are used as a primary heating source, whereas fireplaces are typically used as a supplementary heating source or for aesthetic value [65]. It is not know how much wood is consumed in OWBs. However, OWB sales in New York have increased by almost 70% over the past five years, and it is likely that some of the wood consumed by the Watershed residential sector is combusted in these units [73].

It was unknown whether any of the emission factors for the catalytic and noncatalytic wood stoves are calculated based on emissions from U.S. EPA–certified units (stoves that are likely to have lower PAH emissions than conventional models). Therefore, it was assumed that 11% of the wood consumed in wood stoves is combusted in a noncatalytic wood stove, the model with the overall lower PAH emission factor, and that the remaining 89% of the wood is consumed equally between the conventional and catalytic wood stoves.[32]

Releases to the Atmosphere. Estimated PAH emissions from residential wood combustion were calculated by applying the emission factors presented in Table A.1 to the estimated wood consumption in the Watershed (Table 3.1). Over half of the estimated PAH emissions from this source come from the combustion of wood in conventional wood stoves, followed by those stoves with catalytic converters. It appears that more PAHs are released from combustion devices outside of the Watershed.

There is some uncertainty with this estimate. The emission factors are based on laboratory testing of wood combustion devices, not actual use. Stove maintenance, type of wood combusted, and operating procedures will impact the efficiency of the combustion device and, in turn, PAH emissions.

Measures to Reduce Releases of PAHs from Residential Wood Combustion

Currently, there are no residential wood burning guidelines in New York and New Jersey other than those established by the U.S. EPA [79] [80]. U.S. EPA–certified noncatalytic wood stoves have been demonstrated to emit less particulate matter, volatile organic compounds, and PAHs (85% less) than noncertified

Table 3.1. Estimated residential wood combustion activity and associated PAH emissions in New York and New Jersey[a]

	Estimated wood consumption (tons/yr)	PAH emissions (kg/yr)			
		Fireplace	Conventional	Catalytic	Noncatalytic
Watershed					
New York	1,634,400	16,800	170,600	96,200	23,100
New Jersey	184,000	1900	19,200	10,800	2600
Total	**1,818,400**	**18,700**	**189,800**	**107,000**	**25,700**
Outside Watershed					
New York	2,487,700	25,600	259,700	146,400	35,100
New Jersey	235,600	2400	24,600	13,900	3300
Total	**2,723,300**	**28,000**	**284,300**	**160,300**	**38,400**

Source: Total Wood Consumed by Residential Sector, http://www.eia.doe.gov/emeu/states/sep_use/total/pdf/use_nj.pdf.

a PAH emission estimates are based on emission factors presented in Table A.1. For estimated PAH emissions by compound, see Tab A.2.

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[31] Wood consumption data are an estimate of wood that is purchased and harvested by end users. Data were collected through surveys by the Energy Information Administration (EIA). It is assumed that the consumption of manufactured wood, such as wax/sawdust fire logs, is not represented in the data. Wax wood has been shown to emit fewer total PAHs than cordwood [76].

[32] In a cooperative study between Environment Canada and the Hearth Products Association of Canada, U.S. EPA–certified stoves were found to emit, on average, 66% fewer PAHs than conventional models [78]. Based on emissions calculated using U.S. EPA emission factors, noncatalytic woodstoves were found to emit 86% less PAHs than conventional stoves.

conventional stoves [81].[33] As previously mentioned, all wood stoves manufactured after 1992 must meet the U.S. EPA Phase II guidelines; however, their penetration into the market has been slowed by the long life span of wood burning stoves. Some communities have combated this issue by sponsoring changeout programs that offer incentives or rebates when older stoves are exchanged for newer, more efficient models, or when fireplace inserts are purchased. For example, a community in Libby, Montana participated in the U.S. EPA's Woodstove Changeout Campaign, in which residents owning stoves that are older than eight years and who qualify for public assistance are eligible for a wood stove replacement [82].[34] A similar program was conducted in the Great Lakes region from February to April of 2001, and encompassed Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, New York, Ohio, South Dakota, Wisconsin, and the Georgian Bay region of Canada. This program facilitated the replacement of over 1200 older stoves with newer, less polluting stoves [83].

The U.S. EPA emission standards at this time do not reflect best available technology. Washington state, for example, has a limit of 4.5 g/hr for noncatalytic woodstove and 2.5 g/hr for catalytic stoves (almost half the U.S. EPA's limit) for all stoves sold in the state. Based on an evaluation of industry data that indicate approximately 75% of new EPA-certified woodstoves meet the more stringent Washington state standards, the U.S. EPA has chosen to focus on facilitating the exchange of older stoves, rather than implementing stricter emission standards [84].

WOOD HEATING BEST MANAGEMENT PRACTICES

Firewood

- Using seasoned wood (wood with less than 20% water) produces more heat and makes less smoke.
- Wood is ready to burn when it has cracks in the end grain, does not hiss or sizzle in the fire, is lighter to carry than when it was cut, and has darkened to brown or gray.
- Don't burn household garbage (especially plastics), treated wood, particle board, or saltwater driftwood.
- Never use gasoline or oil to start a fire.

Fireplace or Wood Store

- When purchasing a wood stove make sure it is EPA certified, or when purchasing a fireplace buy an EPA certified insert.
- Before adding wood, rake coals to the front near the air inlet.
- When starting a fire, add seasoned wood, close door, and open the air control fully and/or crack the door to get the wood flaming quickly.
- Once the fire is going, close and latch the door and adjust the air inlet.
- Wood burns best when there are several logs burning at a time; less smoke means a more efficient fire.

Maintenance

- Make sure door closes properly (check hinges, door latch, and gaskets).
- Replace any cracked or damaged firebrick.
- Inspect the chimney regularly, cleaning as needed to avoid creosote buildup

Source: Summarized from *Burn it Smart! Wood Heating Guide to: Burn Less Wood, Make Less Smoke, Be More Comfortable*. Government of Canada.

Some communities have directed their air pollution reduction efforts towards exchanging wood stoves for cleaner fuel-burning devices such as gas-powered stoves. For instance, in 2003 Santa Clara County, California started a switchout campaign in

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[33] This is consistent with our estimate in which noncatalytic stoves emit approximately 86% less total PAHs than do conventional stoves.

[34] From 2005 through 2006, the U.S. EPA sponsored two to three changeout programs, targeting particulate matter, 2.5 nonattainment areas, and communities that have community-based air toxics programs. For more information visit http://www.epa.gov/airprogm/oar/woodstoves/changeout.html.

which residents received a $300 or $500 rebate, depending on age and combustion device, for switching from an old wood burning device to a natural gas system.

In addition to promoting the use of more efficient combustion units, PAH emissions from wood combustion can be addressed through energy efficiency measures and reduced fuel combustion. Various government and nonprofit groups have established energy efficiency programs for residential construction. One example is the Energy Efficiency Construction Code of New York State, which requires minimum standards of energy efficiency in new residential and commercial buildings. Another example is New Jersey's Clean Energy Program, which offers incentives for the installation of energy efficient measures in homes, specifically those that are income eligible. The Federal government supports energy efficiency through the Energy Star program, in which homes that are verified to be at least 30% more energy efficient than homes built to the 1993 national Model Energy Code or 15% more efficient than the state energy code, whichever is more rigorous, are certified. In addition to government sponsored energy efficiency programs, The U.S. Green Building Council, a nonprofit organization that promotes environmentally responsible and profitable buildings, is in the pilot stage of developing a Leadership in Energy and Environmental Design (LEED) certification for homes.[35]

Three approaches have been identified to reduce PAH emissions from residential wood combustion: reduce fuel consumption, improve combustion conditions and reduce releases of PAHs, and substitute combustion technology.

The following are pollution prevention recommendations to reduce release of PAHs from residential wood combustion activity in the Watershed:

- Reduce fuel consumption.
  - Educate retailers and consumers on how to choose a heating unit that is properly sized for the desired heating area. An oversized stove may need to be damped down regularly, creating a less ideal combustion environment.
  - Educate designers and local government officials on sustainable/green design and passive solar design elements that will contribute to a reduction in heating demands, such as increased insulation, elimination of thermal bridges,[36] optimum value engineering,[37] and properly installed and sealed windows.
  - Increase incentives for homes that are heated by non-PAH-releasing energy.
  - Adopt energy efficiency measures as code, such as those recommended by Energy Star program.
- Reduce the quantity of PAHs released.
  - Establish an ongoing state or municipal program that promotes the use of fireplace inserts and the exchange of older, less efficient stoves for new, less polluting stoves, possibly modeled after the U.S. EPA's changeout program that has been implemented in several states.
  - Educate the community on the environmental impact of combusting contaminated materials in their wood burning units, such as treated wood and household waste, as well as good maintenance practices, such as regularly checking the condition of the baffle or catalyst; cleaning the catalyst; burning only seasoned wood; and removing excess ashes.
  - Promote the sale and use of wood stoves that utilize the best available control technologies, such as those sold in Washington State.
- Consider substituting wood combustion units with heating devices that combust cleaner burning fuel, possibly through incentives.
- Data gaps.
  - As previously indicated little data are available on the prevalence of OWB use and associated PAH emissions. Given the design of these units and the lack

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[35] The USGBC currently provides LEED certification for commercial projects.

[36] An example of where a structural thermal bridge may occur is at the point where projecting beams and slabs pass through the building envelope between the cold and warm side of a building. This may allow the transfer of heat to the cold side of the structure.

[37] Optimum Value Engineering (OVE) framing optimizes the amount of lumber used to frame homes, creating more space for the insulation of exterior walls. Examples of OVE strategies include utilizing two-stud corner framing with inexpensive drywall clips; increasing floor joist and rafter spacing to 24 inches; eliminating headers in nonloadbearing walls; increasing stud spacing from 16 inches to 24 inches; and using single top plates with in-line framing to transfer loads directly.

of regulation, it is possible that this is a significant source of PAHs. Emission factors and activity level data should be developed for this source.[38]

3.2. Materials Containing PAHs

3.2.1. Creosote-Treated Wood Production and Use

Creosote-Treated Wood Production and Use: National Trends and Emission Factors

Creosote, a distillate of coal tar,[39] is an insecticide, fungicide, miticide and sporicide commonly used to waterproof and preserve wood. In the U.S., creosote-treated wood is used for railway ties (50%), utility poles (30%), and fence posts (14%), with a small fraction used in marine pilings (0.17%) [5].[40] Creosote has been designated as a probable human carcinogen by the U.S. EPA [89], and it is not available for consumer purchase.[41] Furthermore, pressure treatment of wood with creosote is the only wood treatment method used and creosote can only be used by applicators that have completed a U.S. EPA approved training program [91].

In 2004, approximately 28 million cubic feet of creosote-treated wood were produced in the U.S. from 87 million gallons of creosote [5]. The manufacture of creosote-treated wood appears to be on a downward trend. The USDA reported that 97 million cubic feet of creosote-treated wood were produced in 1999, approximately 13% of all treated wood for that year, and a 27% reduction from 1983 [92]. In the 1950s, two other wood preservatives began to replace creosote in some applications: pentachlorophenol (PCP)[42] and chromated copper arsenate (CCA), the most common preservative used to treat wood [93].[43,44]

WOOD TREATMENT TECHNIQUES

There are generally three techniques for introducing preservatives into wood: pressure, hot-cold, and superficial. Pressure treatment, by which the vast majority of wood is treated and the only method used with creosote, involves placing wood and preservative in a chamber and forcing the preservative into the wood under extreme pressure, thus impregnating the wood with the preservative [85]. Hot-cold treatment, only used when treating red cedar with copper napthenate or pentachlorophenal, involves placing the wood in a hot bath of preservative and then quickly flooding the tank with cold preservative, causing the heated air to contract and pull in the preservative. Superficial treatments (a method no longer permitted for creosote) include brushing, spraying, and dipping wood in the preservative [86]. The quantity of preservative used depends on the deterioration zone of the region in which the wood will be used (as defined by the American Wood-Preservers' Association). For example, some southern states fall within a severe zone, while northern states, including New York and New Jersey, fall within a less severe zone, requiring lower quantities of preservative to treat wood for an average product lifetime of 35-40 years [87].

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[38] A concern with OWBs has surfaced in the New York/New Jersey region as a result of increasing complaints from OWB neighbors. The New York State Attorney General's Office recently sent a petition to the U.S. EPA requesting that OWB standards of performance be promulgated under 42 U.S.C. § 7411(b)(1)(B). Several states have also signed the petition, including Connecticut, Maryland, Massachusetts, Michigan, Vermont, and New Jersey [79]. The North East States for Clean Air Future, with participation from the U.S. EPA Office of Air Quality and Standards, are composing model rules for state adoption and developing an incentivized voluntary program for outdoor wood boiler manufacturers. Issues to be addressed in the model rule are emission limitations, zoning, stack height, and operations and maintenance [80].

[39] Coal tar is a byproduct of coal coking. In 1992, 0.7 million tons (1.5 billion lbs) of crude coal tar were produced [88].

[40] Estimates assume treatment with the following volumes (cubic feet) of creosote per piece produced: railway tie, 3.54; utility pole, 60; fence post, 1.5. Marine piling estimates were provided in cubic feet [5].

[41] EPA is currently reassessing creosote under its four-phase process as part of its ongoing re-registration program for older pesticides (see http://www.epa.gov/oppsrrd1/public_summaries.htm - 4phase for more information on the process). Federal law directs U.S. EPA to periodically reevaluate older pesticides to ensure that they continue to meet current safety standards. A decision is scheduled to be made by winter of 2007 [90].

[42] Materials treated with PCP are associated with dioxin release. For more information see *Pollution Prevention and Management Strategies for Dioxins in the New York/New Jersey Harbor,* G. Muñoz et al., page 175.

[43] A representative of the Creosote Council indicated that PCP and CCA were less expensive, and the replacement of creosote with these preservatives can be partially attributed to this economic factor [87]. Utilities also changed from creosote-treated wood to PCP-treated wood because of performance, environmental, and safety issues—wood treated with PCP is stronger, and creosote is known to seep from wood and rub off on utility pole climbers (which does not happen with PCP- or CCA-treated wood) [94].

[44] Due to concerns with the chromium and arsenic found in this preservative, the U.S. EPA established a voluntary phase-out of CCA-treated wood used for residential construction by the end of 2003. Several alternatives to CAA have been developed, including ammoniacal copper quat (ACQ) and copper azole. ACQ is a water-based wood preservative that combines copper with an ammonium compound. Copper azole contains copper and boron. Copper can be harmful to aquatic systems.

Creosote is approximately 80% PAHs by weight (and approximately 20% U.S. EPA 16 priority PAHs), although concentrations vary depending on the distillation process. The environmental hazards associated with creosote may take place at different points throughout the life of the product, including production, application, use of treated products, and disposal. Emissions during creosote production result from fugitive emissions from vent and valves, as well as wastewater generated from the oil and water separation process.[45]

Creosote-treated products may be installed in the environment on land, such as railway ties and utility poles, or in water, such as marine pilings. PAHs migrate from creosote-treated wood into the environment by two primary mechanisms: volatilization into the atmosphere; and leaching into rainwater, groundwater, or surface water. Minor release mechanisms may include physical degradation and dispersal of the treated wood product itself, and flow of creosote down the surface of or inside the pole. Factors that influence the rate of volatilization or leaching of PAHs from treated wood include the physical properties of the individual PAH; ambient temperatures; time; characteristics of the wood, including geometry, variety, seasoning, and age of the wood; the creosote formulation, pressure impregnation conditions, and resulting creosote retention rate; any post-treatment aging or processing; conditions of the installation, including orientation and exposure with respect to wind, sun, and rain; and the characteristics of the leachate, including salinity and dissolved organic carbon content.

Creosote-Treated Wood Production and Use: Regional Sources

Creosote-Treated Wood Production

In 2005, the U.S. EPA's Toxics Release Inventory (TRI) reported one creosote wood–treating facility in New Jersey, outside of the Watershed (none in New York).

Railway Ties

Several assessments, including laboratory and field studies, have been conducted to measure or characterize the release of creosote from treated railway ties.

A study of desorption rates of PAHs from creosote-treated wood estimated that approximately 100 tons of PAH are released annually in the United Kingdom from creosote-treated wood, with larger quantities desorbing in warmer temperatures by a factor of 2 to 14 [96]. In a recent report by the United States Department of Agriculture, Brooks [97] investigated leaching of PAHs from new, creosote-treated railway ties into ballast rock and surrounding wetland soil over an 18-month period in an artificial mesocosm system.[46] The study found a pulse of PAHs moving away from the ties into the ballast to a distance of approximately 60 cm during the first summer. These PAHs disappeared by evaporation or microbial degradation to levels below detection over the course of the following year. However, this study did not measure compound-specific PAH release rates, releases to air, or environmental degradation rates.

Perhaps the best available information for quantifying releases of PAHs from creosote-treated railway ties under environmental conditions over long periods of time is from a recent study by Kohler et al. [98]. The authors report the quantity of creosote and PAHs released over the life span of a beechwood railway tie by comparing the original quantity of PAHs in the tie (estimated)[47] with quantity remaining at several points in time (calculated) along a cross-section through the tie.[48] The results show that approximately 5 kg of creosote and 0.5 kg of total PAHs[49] are released over the 32-year life span of a single railway tie. However, we know that not all PAHs are released at the same rate, and the paper does not report emissions for all 16 priority PAHs.

To allocate releases among all priority PAH compounds, a first-order model was fit to the estimated PAH release data at 1 year, 6 years, and 32 years. The resulting set of rate constants were regressed against the octanol–water partition coefficient, aqueous solu-

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[45] Releases during creosote application occur during and after treatment, via the opening and closing of vents, and during the storage of the freshly treated wood, when PAHs with higher vapor pressure have the opportunity to volatilize. Wastewater, another medium to which PAHs are released, may be generated during the conditioning (also known as treating) process. Process wastewater effluent discharges from wood-preserving facilities that use arsenical/chromates, creosote, and/or pentachlorophenol are regulated under the Clean Water Act (CWA). Solid waste is often generated as a result of creosote/water emulsions created during the treatment of unseasoned wood. Most of the solid waste generated is recycled back into the process or disposed of as hazardous waste [95].

[46] A mesocosm is an experimental apparatus or enclosure designed to approximate natural conditions, and in which environmental factors can be manipulated.

[47] A comparison of new and used ties indicated that there was no change in the composition of PAHs at the tie center. Original concentrations of PAHs in railway ties were estimated by assuming that the used tie's core PAH composition represents the composition of the original creosote and by applying a standard concentration profile.

[48] The beechwood ties were treated with creosote specified by the Western European Institute for Wood Preservation (WEI)-A.

[49] Emissions estimates were made for the following PAH compounds: naphthalene, acenaphthylene, acenaphthene, anthracene, fluorene, and phenanthrene. Emission estimates for the 4–6 ring PAHs could not be estimated by applying this method, given the increase in the concentration of the larger molecular weight PAHs in the outer layers of the tie.

bility, and vapor pressure of each compound. Vapor pressure was found to be the best predictor of PAH release rate ($R^2 = 0.9997$), and the resulting relation was used to calculate estimated release rates for the other priority PAHs. Finally, all release estimates were scaled to a total emission of 0.5 kg of PAHs in the 30-year life of one tie (Table 3.2).

The releases of PAHs from creosote-treated railway ties measured by Kohler et al. are from a combination of two mechanisms: volatilization to the atmosphere and leaching into rainwater. To better understand how to allocate emissions from this source to air and land, the total mass of PAHs evolved from one tie were divided by the total volume of water a typical railway tie would be exposed to over its entire service lifetime (assuming 1.08 m/yr precipitation typical for New York City and an exposed surface area of 0.5 m^2), and then this quotient was compared with the solubility limit of each PAH in water. From this exercise, it is apparent that only a tiny percentage of PAHs could possibly dissolve into all the precipitation ever available to a tie in 30 years. As a result, volatilization to the atmosphere is assumed to be the predominant mechanism for removal of PAHs from creosote-treated products in on-land applications. Leaching by rainwater is still expected to occur to some extent, and most likely contributes to the pulse of PAHs seen moving away from the railway tie mesocosm in the Brooks study. Kohler and Kunniger (2003) [99] estimated that two-thirds of the PAH releases from railway ties would be to soil, while one-third would be to the atmosphere. In this report, given the aqueous solubility of individual PAHs, the quantity of precipitation typical for our region, and the geometry and installation of railroad ties, we assumed that 50% of the PAH emissions are volatilized to the atmosphere and 50% are leached to pervious land surfaces.

The importance of volatilization as a release mechanism of PAHs may come as a surprise to those not used to thinking of PAHs as volatile compounds. Indeed, PAHs are at best semivolatile compounds; nevertheless, even the heaviest priority PAHs have been measured at various concentrations in the gaseous state in regional air monitoring programs [4]. As support for the volatilization theory for PAH emissions from creosote-treated wood, recall that the PAH property most predictive of release from ties is vapor pressure, not water solubility or hydrophobicity. Further, the findings of Mackay et al. [16], who performed multiphase equilibrium distribution calculations for PAHs in expansive environmental compartments (air, land, and water) similar in size to those of the Greater NY/

Table 3.2. Estimated releases of PAHs by compound per tie after 30 yrs

PAH	Creosote content (WEI-A) (mg/kg)	Initial PAHs per tie (g)	PAHs lost in 30 yrs (g)	PAHs lost in 30 yrs (%)
Naphthalene	9500	152.4	69.6	46
Acenaphthylene	7	0.1	0.0	32
Acenaphthene	9500	152.4	40.0	26
Fluorene	19,000	304.7	61.8	20
Phenanthrene	68,000	1090.6	163.1	15
Anthracene	9000	144.3	13.8	9.6
Fluoranthene	55,000	882.1	104.6	12
Pyrene	31,000	497.2	46.8	9.4
Benz[a]anthracene	380	6.1	0.2	2.5
Chrysene	340	5.5	0.1	0.9
Benzo[b]fluoranthene	96	1.5	0.0	0.9
Benzo[k]fluoranthene	67	1.1	0.0	0.5
Benzo[a]pyrene	160	2.6	0.0	1.0
Perylene	NA	NA	NA	NA
Dibenz[a,h]anthracene	16	0.3	0.0	0.3
Benzo[g,h,i]perylene	45	0.7	0.0	0.3
Indeno[1,2,3-CD]pyrene	40	0.6	0.0	0.3
TOTAL	**192,651**	**3242**	**500**	**15**[a]

[a] Calculated by dividing total PAHs lost in 30 years (500 g) by total initial PAHs (3242 g).

NJ Harbor area, are also supportive. Those authors found that low molecular weight compounds such as naphthalene and phenanthrene are found predominantly in the atmospheric compartment, despite their relatively low vapor pressures, due to their similarly low aqueous solubilities and the much larger size of the atmospheric compartment as compared with surface water, topsoil, or surface sediment.

Releases to the Atmosphere. The Railway Tie Association (RTA) reports that there are 3695 miles of railway track in New York and 919 miles in New Jersey [100]. The RTA also reports that there are approximately 3200 ties per mile of track, with an average annual tie replacement rate of 2.3%, and that generally 94% of all ties are treated with creosote. The number of ties in the Watershed was estimated by assuming that reported rail PM_{10} emissions are proportional to the number of ties in the Watershed (approximately 8.6 million ties).

Releases of PAHs from railway ties were estimated by applying the release rates described above to the number of ties in the Watershed. It was assumed that ties contain approximately 160 kg of creosote per cubic meter, and that the creosote used in the ties is manufactured to the AWPA Standard type P1 (see Tables A.1 and 3.3).

Table 3.3. Estimated number of railway ties treated with creosote and associated releases of PAHs[a]

State	Railways ties treated with creosote	PAHs released (kg/yr)[b]
Watershed		
New York	5,557,280	194,300
New Jersey	2,487,917	97,300
Total	**8,045,197**	**291,600**
Outside Watershed		
New York	5,557,280	247,300
New Jersey	276,435	12,600

[a] Calculations based on PAH concentrations presented in Table A.1. For emission estimates by compound, see Table A.2.

[b] It is assumed that 50% of releases are to the atmosphere and 50% are to pervious land surfaces.

Utility poles

The larger diameter of utility poles compared with railway ties may tend to reduce the fraction of PAHs that can be released in a given service lifetime (assuming similar leaching conditions, types of wood, creosote formulations, and treatment conditions). However, the geometry and orientation of utility poles brings them into contact with more direct sunlight and higher winds (though less rainwater) than railway ties, which may tend to enhance releases. Unfortunately, no peer-reviewed studies available specifically provide long-term release information for creosote-treated utility poles, nor do any studies compare releases from railway ties with those from utility poles. Without any alternative, the same release rates computed for railway ties were employed for utility poles, but with respect for differences in installation orientation, 100% of emissions from pole feet installed on land above the land surface were allocated to the atmosphere. Finally, given the relatively low water infiltration and air exchange rates expected in the densely packed soil surrounding a utility pole versus the very coarse granular material of railway ballast, we have assumed PAHs are lost only from the fraction of a pole's length that extends above the ground surface. Releases from buried sections of poles may still occur, and may impact local environments, but have a low potential to reach the Harbor (see Appendix B Fate and Transport for more information).

Releases to the Atmosphere. Prior to 1975, only creosote-treated wood was used for utility poles in the New York Watershed region; however, starting in 1975 replacement poles were typically treated with PCP and with CCA starting in 1996. A reason provided by a representative of Con Edison for this switch was the leaching potential of creosote treated poles and the need for a longer pole life [94].

The number of utility poles in the Watershed treated with creosote was not available. Therefore, the number of utility poles in the Watershed was calculated by assuming that there are 28.5 poles per distribution mile [101], and by applying this rate to the above-ground distribution pole miles (approximately 133,000) as reported in Platts 2005 Directory of Electric Power Producers and Distributors [102].[50] It is estimated that 13% of poles are treated with creosote nationally [94, 101]; however, in two counties in the New York Watershed it was reported that 42% of in-service poles are treated with creosote (approximately 78,000 poles) [94].[51] We therefore estimate the num-

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[50] Data were reported by total pole miles in all of the counties managed by a distribution company. In cases where distribution companies serviced counties that are located both in and out of the Watershed, distribution miles were apportioned evenly to all counties within the distribution company's jurisdiction.

[51] Information on treated poles from the two counties (Orange and Rockland) only, from D. Roche (pers. comm.) [94].

ber of in-service creosote-treated poles in the Watershed by assuming that for most counties 13% of their utility poles are treated with creosote, except for the two New York counties for which we have a reported number of creosote poles in service. The same release rates used to estimate PAH releases from railway ties were used to estimate releases of PAHs from creosote-treated poles by applying the rates to the fraction of pole above ground (~80% [94]; Table 3.4).

The replacement rate of poles varies with climate, demand, and wood type. The U.S. Department of Agriculture estimates that the average service life span of a utility pole is 35 years [103], while a report by the nonprofit Beyond Pesticides estimates a life span closer to 40 years. A survey conducted by Morrell [104] reports that on average 5% of poles in service are replaced every year, or in the Watershed approximately 190,000 poles are retired per year. An informal, non-scientific phone survey of electric distributors in the Watershed, conducted by the NYAS staff, revealed that approximately 57% of electricity distributors replace their poles with PCP-treated poles, and only 9% of distributors (or 21% of the poles in service) replace with creosote-treated poles.[52] Because more creosote-treated poles in the Watershed are coming out of service than are coming in, disposal of retired poles deserves some attention.

Marine Pilings

Creosote-treated wood comes in direct contact with water when used to construct marine pilings, docks, and bulkheads. It is estimated that in 2004 approximately 210,000 cubic feet of creosote-treated wood was produced in the U.S. for marine pilings [5], containing approximately 326,000 kg of PAHs.

Marine pilings have been identified as a source of PAHs to surface waters. The U.S. Navy recognized PAHs as a contaminant of concern in San Diego Bay, and identified creosote-treated pilings as the major source, with minor contributions from diesel products [105]. Removal and replacement of those pilings coincided with a significant decrease of PAH contamination in the Bay [106]. A report prepared for the National Oceanic and Atmospheric Administration provided a review of studies and models that address PAH leaching from treated wood. Although a conclusion was not reached on a universal leaching rate, several factors impacting release rates were identified, including how recently the wood had been treated, whether the wood had been treated according to the Western Wood Preservers Institute (WWPI) Best Management Practices,[53] and whether the wood was used in freshwater or saltwater [107].[54]

Table 3.4. Estimated number of utility poles treated with creosote and associated releases of PAHs[a]

	Poles treated with creosote (×1000)[b]	PAHs released to air (kg/yr)
Watershed		
New York	484,000	102,600
New Jersey	93,100	19,600
Watershed	**577,100**	**122,200**

a Calculations based on PAH concentrations presented in Table A.1. For releases by compound, see Table A.2.

b Calculations are based on the number of reported poles miles in the Watershed, assuming that there are 28.5 poles per mile. The quantity of creosote-treated poles was calculated by using the national average of creosote-treated poles in service (13%), except for two New York counties for which the number of creosote poles in service was available.

After reviewing the existing information on leaching of PAHs from creosote-treated marine pilings, two studies were identified as having the most comprehensive PAH leaching information. Bestari et al. [108] measured loss of PAHs from creosote-treated marine pilings immersed in large freshwater mesocosms over approximately two months, arriving at a loss rate of 273 mg/piling/day. The loss rate was calculated by comparing the initial concentration of PAHs in the first 0.0–1 mm and 1–2 mm of treated wood samples with the concentration of PAHs in comparable sections of treated wood after 68 days of exposure to water. The total loss of PAHs within the outermost 1-mm section was 14%, while the loss from the 1–2-mm samples was negligible.

Ingram et al. [109] measured leaching of several PAH compounds (including eight priority PAHs) from creosote-treated pilings into water. Their study quantified the concentration of PAHs in water after three days in contact with relatively small portions of a creosote-treated piling under different experimental conditions,

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[52] Telephone poles are another use of treated wood. Utilities sometimes share poles, making it difficult to get an accurate count of telephone poles. We contacted telephone companies servicing the Watershed but were unable to obtain information on the type of telephone poles used.

[53] WWPI BMPs for creosote are detailed and are different for each tree species and creosote mixture; therefore, they are not described in this report. For more information, see the WWPI BMPs for the Use of Treated Wood in Aquatic Environments, http://www.wwpinstitute.org/pdffiles/bmpsinaquatic2.pdf.

[54] The PAH leaching rate is greater in freshwater than in seawater; at high water temperatures; at high flow rates; from less dense wood; from freshly treated wood than from wood that has either been stored after treatment or been exposed to water; at higher wood surface-to-volume ratios; and from wood that has not been treated according to the WWPI BMPs [107].

including freshwater versus saltwater, and different temperatures (20°C, 30°C, and 40°C). They also compared leaching of fresh pilings with leaching from pilings that had been installed in a marine setting for 15 years. They estimated annual PAH releases of about 77 to 144 g/yr, in close agreement with the estimate by Bestari et al. [108] of 273 mg/piling/day, or about 100 g/yr. Several other reports, including work by Brooks [110], rely on release rates from the Ingram study [109].[55]

The Ingram [109] and Bestari [108] studies are the most complete sources of information on release of PAHs from creosote-treated wood into water; however, neither study reports losses of PAHs over long periods. Several different approaches were used to estimate total releases of PAHs from creosote-treated marine pilings over the entire 30-year life of a piling pole. Long-term releases were modeled using a first-order decay model, in which PAH emissions decline exponentially over time, or using a diffusion-based model. In each case, leaching data from either Ingram et al. [109] or Bestari et al. [108] were used to fit parameters to the models. These results are summarized in Table 3.5.

To summarize, the first approach (Table 3.5, first column, "Bestari 15-yr flux") was to compute a first-order rate constant consistent with the decline in three-day leaching results for 15-year aged and unaged pilings. The resulting first-order rate constant was used to compute total releases over 30 years. Clearly, these data reflect dramatic losses in 30 years—the pilings used were aged in Key West, Florida, where warm water temperatures are likely to cause overestimates in the potential for leaching in the New York area. However, these data do provide a useful upper bound on release potential over long periods.

Next, both datasets were modeled as diffusive processes, assuming a lower bound of diffusive mass transfer potential can be computed by approximating desorption of PAHs from within a creosote-treated cylindrical pole as diffusion through a semi-infinite slab. Here, a three-dimensional process is mapped into one-dimensional space by assuming diffusion is slow enough that even after the 30-year lifetime of the pole the concentration of PAHs far inside the pole has not changed very much, either because the slab is large enough or diffusion is slow enough. We also assumed a uniform initial concentration within the slab, and a surface concentration of zero in the liquid outside the slab. Under these assumptions, an equation describing the total mass released over time is as follows:

Equation 3. Analytical solution to Fick's Second Law in cylindrical coordinates assuming semi-infinite domain behavior

$$M_t = 2C_o\left(\frac{D_{obs}t}{\Pi}\right)^{\frac{1}{2}}$$

Here, M_t [g/cm^2] is the flux in time t [sec], C_o [g/cm^3] is the initial concentration in the slab, and D_{obs}, [cm^2 s^{-1}] is the observed diffusion coefficient. Using the reported flux at time from the data given in the Bestari [108] and Ingram [109] studies, and the corresponding initial PAH concentrations, surface areas, and time intervals, we can solve for diffusion coefficients, then use those diffusion coefficients to extrapolate the total percentage of each PAH lost in 30 years. Those data are given in Table 3.5, under the "semi-∞" headings, for each data source.

Finally, the 68-day desorption data from Bestari et al. [108] were modeled as a simple first-order diffusion process, and the resulting first-order parameter was used to compute total release over 30 years. The results of that work are given in Table 3.5 under "Bestari Exp."

Taking what we know about the physical-chemical properties of the individual compounds into account, and recognizing the high degree of uncertainty in assuming a governing equation and extrapolating leaching far beyond the domain of the available experimental error, we have opted to select rounded values of release over time for PAH groupings (Table 3.5). Depending on the PAH composition of the creosote, these values correspond with total releases of about 20% to 25% of PAHs in creosote-treated wood over the 30-year lifetime of the product.

Releases to Water. A wide spectrum of public and private organizations builds and manages marine structures in freshwater and saltwater environments, making it difficult to obtain a comprehensive inventory of treated wood structures that come in contact with water. However,

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[55] Dr. Kenneth Brooks has conducted several biological studies for the Creosote Council, U.S. Western Wood Preservers Institute, Department of Agriculture, and other institutions that evaluate the organismal, population, and community effects associated with the use of creosote-treated wood. While his body of work does not provide compound-specific release data, precluding its use in this report to estimate releases of PAHs, we used a study by Ingram et al., provided by Dr. Brooks and referenced in several of his papers, to develop a PAH release rate.

Table 3.5. Comparison of PAH releases calculated from each different method described in this section, the average, and the value selected for calculated emissions estimates in this report

#	Compound	Ingram 15-yr flux	Ingram Semi-∞	Bestari Exp	Bestari Semi-∞	Avg.	Selected value used in report
				PAH releases (%)			
1	Naphthalene	29	2	16	3	13	15
2	Acenaphthylene	84	2	na	na	43	
3	Acenaphthene	59	12	11	2	21	
4	Fluorene	59	12	4	1	19	20
5	Phenanthrene	84	20	26	6	34	
6	Anthracene	84	3	18	4	27	
7	Fluoranthene	84	1	31	7	31	
8	Pyrene	84	1	17	4	26	30
9	Benz[a]anthracene	na	1	17	4	10	
10	Chrysene	na	na	24	5	15	15
11	Benzo[b]fluoranthene	na	na	37	3	20	
12	Benzo[k]fluoranthene	na	na	32	3	17	
13	Benzo[a]pyrene	na	na	40	3	21	15
14	Dibenzo[ah]anthracene	na	na	4	1	3	
15	Benzo[ghi]perylene	na	na	4	1	3	
16	Indeno[123cd]pyrene	na	na	4	1	3	3
	Total PAHs	**61**	**3**	**21**	**4**	**24**	**23**

na=not available

an estimate was made by assuming that all the estimated creosote-treated marine pilings produced in the U.S. are consumed in the U.S.[56] and by extrapolating for the Watershed based on the number of marinas reported in the U.S. Census [5].[57]

Marine pilings may be exposed to air, water, and land, and the rate at which PAHs are released will differ for each of these environments. On average, 62% of a pole is exposed to water, 8% is exposed to air, and the remaining 30% is buried below sediment. Therefore, PAH releases to water, the main focus of this report, were estimated by applying the release rates described to the fraction of the pole that is exposed to water, and releases to air were estimated by applying the release rates described above to the fraction of pole that is exposed to air (Table 3.6). We assumed PAH concentrations similar to creosote specified in the American Wood-Preservers' Association Standard P1 (see Table A.1) to calculate the initial PAH concentrations of the pilings.

The actual conditions (e.g., water flow, salinity) in which treated pilings are used will impact the rate of release and potential for transport within the water body [111] [107].

Measures to Reduce Releases of PAHs from Creosote

Wood is a renewable material and when treated is relatively durable. However, creosote, a material sometimes used to treat wood, contains and releases PAHs to the environment. There are several alternatives to treated wood that each has its own benefits and drawbacks (Table 3.7). Some of the perceived advantages of treated wood are reliability, affordability,[58] and versatility [112]. Utility poles made of nonwood materials, for example, may be difficult to climb, may pose a risk of electrocution, and may collapse more readily during vehicular accidents. At the same time, alternative materials may provide an opportunity to prolong the life of the product and reduce contaminant releases, while maintaining or increasing durability.

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[56] It is estimated that ~2% of treated wood produced in the U.S. is exported; therefore, it is assumed that all creosote-treated pilings produced in the U.S. are consumed in the U.S. [5].

[57] In addition to in-water structures, creosote-treated wood used to construct over-water structures are a potential source of PAH contamination to water bodies.

[58] Costs associated with alternative products include worker training and premium due to low availability.

Table 3.6. Creosote-treated marine pilings in the Watershed and associated release of PAHs[a]

State	Pilings consumed[b] (ft³/yr)	PAHs released to water[c] (kg/yr)	PAHs released to air[c] (kg/yr)
Watershed			
New York	4269	900	100
New Jersey	2159	500	100
Total	**6428**	**1400**	**200**

[a] PAH emission estimates are based on concentration values presented in Table A.1. For estimated releases by compound, see Table A.2.

[b] Extrapolated from estimated U.S. production based on the number of marinas reported to the 2004 Census. It is assumed that all of the pilings produced in the U.S. are consumed in the U.S.

[c] It is assumed that there has been no overall growth in the number of pilings in use in the Harbor, that all poles have a life span of 30 years, and that the total number of pilings in the Watershed is equal to the annual consumption rate multiplied by 30.

Table 3.7. Alternatives materials to treated wood

Material	Description	Advantages	Disadvantages
Composites	Made of various discarded materials, including wood fibers, plastics, rubber, steel.	Does not warp, split, chip, or rot; available in a variety of colors; does not require sealing; low maintenance; moisture resistant.	More expensive; not yet rated for structural use; susceptible to mildew, mold, and stains; color fades in sunlight.
Virgin vinyl	A hollow building material; a molecularly bonded blend of 100% virgin, hi-polymer resin	Does not warp, split, chip, or rot; available in a variety of colors; does not require sealing.	More expensive; not yet rated for structural use.
Redwood	Examples include cedar and cypress.	Resistant to decay and insects; dimensional stability; does not require sealing; easy to saw and nail.	Expensive; soft surfaces susceptible to denting; susceptible to moisture.
Exotic hardwood	Examples include mahogany and a variety of Ironwoods.	Durable; resistant to decay and insects; does not require sealing.	More expensive; difficult workability; depleting supplies.
High density polyethylene (HDPE)	Thermoplastic.	Weather resistant; easy to cut or drill; no grain to split or chip.	Susceptible to stress cracking; high mould shrinkage; poor UV resistance; not rated for structural use.
Rubber lumber	Composed of 50% plastic and 50% old tires	Durable; impervious to water; resistant to insects; uses recycled materials.	Not rated for structural use.
Steel	Can be made from discarded materials.	Durable; can be recycled; reduced risk of fire.	More expensive; air pollution and energy use concerns associated with steel production.
Concrete	Concrete.	Durable; reduced risk of fire.	More expensive; made with cement, which is energy intensive.
Fiberglass	Fiberglass reinforced composite.	Low maintenance.	More expensive; subject to damage.

Source: Summarized from Feldman and Shistar [101]; U.S. EPA [113]; and Smith [114].

Some organizations have already begun to utilize alternative materials. For example, Amtrak is in the process of converting from wood ties to concrete, specifically along their Northeast corridor. Concrete ties are more durable and allow for faster train travel, which is needed for trains such as the high-speed Acela. Con Edison and PSE&G, two Watershed utilities, are participating in a nationwide study evaluating the performance of utility poles made from exotic (untreated) wood. Con Edison has received 130 of an ordered 1000 poles [94]. The Port Authority of New York and New Jersey (PANYNJ) has switched from creosote-treated wood marine pilings to steel for certain new piling installations because of steel's proven structural resiliency under some circumstances [115]. The Port Authority has found that steel lasts longer than treated wood, reducing maintenance costs.

Retired wood can continue to release PAHs, depending on the way in which it is disposed. Although we estimate a useful lifetime for creosote marine pilings to be around 30 years, pilings may remain in the water for longer periods, continuing their usefulness to marine infrastructure or becoming dilapidated, potentially releasing PAHs all the while. The PANYNJ tests retired creosote-treated wood after it has been removed for replacement and prior to its disposal; up to this point, none has been classified as hazardous.[59]

Most creosote-treated wood (40%) is combusted in cogeneration facilities [87].[60] Conrail, a freight service that operates approximately 200 miles of rail line in northern New Jersey, estimates that they use almost 100% creosote-treated ties, except for 50 concrete ties on one track, and that approximately 100% of their retired ties are sent to a cogeneration facility in Pennsylvania [116]. Creosote, a derivative of coal, exhibits combustion characteristics similar to those of coal, and facilities that are equipped with proper air pollution control devices will minimize PAH releases. Combustion of creosote in settings not equipped with adequate air pollution control devices (i.e., backyard burning, woodstoves, outdoor wood boilers) can result in relatively large releases of PAHs.

Although best management practices specify that, for liability reasons, treated materials should not be donated to employees or the general public, this practice continues. During the formulation of this report a representative of Metro-North Railway, a commuter rail line with over 775 miles of track spanning from Duchess County New York to New Haven, Connecticut, was contacted and estimated that approximately 1,000 ties per year are donated to employees while the remaining (amount unknown) is sent to Pennsylvania for incineration [117]. Public uses of spent creosote wood include landscaping, fences, and outdoor structures. It is possible that people are burning this wood in uncontrolled combustion devices that release PAHs to the atmosphere.

While this report was under development, New York and New Jersey passed legislation banning the sale and use of creosote-treated wood statewide, with exemptions for creosote-treated wood used in railway and power pole/utility applications. The laws also ban the combustion and disposal in an unlined landfill[61] of all creosote-treated products.[62] The recommendations presented below reflect the conclusions of the Harbor Consortium that were reached based on the data presented in this report, and are separate from the recent legislation described. These recommendations may also be applicable to other marine environments.

Because our focus is on the reduction of all PAHs reaching the Harbor, we make the following recommendations:

- Where feasible (in terms of cost, availability, and performance), avoid the use of creosote-treated wood. As noted earlier, we are not in a position to recommend alternatives, although further research comparing alternatives, such as a life-cycle assessment, would be optimal.[63]

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59. It is estimated that 80% to 90% of the wood is disposed in landfills [115]. A wood reuse program is being considered under the PANYNJ Environmental Management System, in which approximately 20% to 25% of wood removed from service would be recycled.
60. It is estimated that 25% of spent ties are reused in tangent or yard track, 20% are sold as landscape material, and 15% go to a landfill [87].
61. Such as a landfill that is not properly lined to prevent groundwater contamination.
62. The New York legislation also prohibits the manufacture of products containing creosote and has an exception for wood burned in a permitted facility.
63. The Creosote Council, which represents creosote producers and users, has objected strongly to the recommendation that, where feasible (in terms of cost, availability, and performance), the use of creosote-treated wood should be avoided. The Council contends that the recommendation is misleading because it erroneously implies that NYAS has conducted a risk assessment of creosote-treated wood, which the Council notes has long been an integral component of the New York Harbor region's critical infrastructure. Further, the Council contends that the Harbor Project staff has not taken into account much of the information that the Council has submitted, such as the studies conducted by Dr. Kenneth Brooks, regarding the environmental behavior of creosote-treated wood in aquatic environments. Moreover, the Council notes that it has submitted a document prepared by Waterborne Environmental, Inc., which discusses data gaps and uncertainties in the information upon which the Harbor Project staff has relied regarding PAH releases into the water and air from creosote-treated wood products. As an alternative to the report's recommendation, the Council proposed recommending that because creosote-treated wood may not be appropriate for all projects, a site-specific risk assessment should be conducted under certain circumstances, such as for projects involving more than 100 pilings, projects in industrial areas where there may be high background levels of metals or PAHs, or projects in close proximity to other projects involving more than 20 pilings that are treated with creosote or another preservative.

- If creosote-treated wood is used for aquatic applications, use wood that has been treated, transported, and installed according to the Best Management Practices (BMPs) for the use of treated wood in aquatic and other sensitive environments developed by the Western Wood Preservers Institute (WWPI), Wood Preservation Canada, the Southern Pressure Treaters Association, and the Timber Piling Council.
- Consider using BMPs (similar to those referenced above) if creosote-treated wood is used for land applications (railway ties and utility poles). (The WWPI BMPs for creosote-treated wood were developed specifically for wood used in aquatic and other sensitive environments. It is likely, however, that these BMPs are also appropriate for wood used in terrestrial applications.)
- Do not distribute retired treated wood to the general public.
- Educate the public and, particularly, utility and railway employees who may distribute wood to the public on why it is recommended that wood not be distributed to the public (i.e., hazards associated with burning treated wood in uncontrolled combustion units, and potential exposure of humans and animals to the treated material).
- Evaluate the costs and benefits of removing dilapidated structures constructed with creosote-treated wood. In addition to removing material containing and releasing PAHs, removing dilapidated wood from waterways may also improve navigational routes for boats.
- Address data gaps.
  - Conduct a survey targeting recipients of retired treated wood to evaluate their compliance with recommended uses of creosote-treated wood.
  - Compile a better (or actual) inventory of creosote-treated wood used for water applications.
  - Improve our scientific understanding of the alternatives to creosote-treated wood and their potential impacts on the environment.
  - Compile a list of waste management companies that can properly dispose of creosote-treated wood, for distribution to facility managers.

3.2.2. Refined Coal Tar Sealants

Refined Coal Tar–Based Sealants: National Trends and Emission Factors

Pavement sealers are typically applied to asphalt substrates to protect and beautify the surface. Asphalt surfaces, typical of parking lots and driveways, consist of a mixture of chemicals that are predominantly chain (aliphatic) structures and have a considerable degree of unsaturation in their molecular structure. As a result of its molecular properties, asphalt is vulnerable to degradation from weather, motor oil spills, and traffic [118]. Coal tar, composed primarily of ring (aromatic) structures, is thought to provide protection from degradation.

Generally, two types of parking lot sealants are used nationwide: refined coal tar–based and asphalt-based emulsions. Refined coal tar sealants are commonly used in the East because of the greater availability of coal tar [119]. Commercially available coal tar sealants can contain 3.4% to 20% PAH dry weight, compared with asphalt-based sealants that can contain 0.03% to 0.66% PAH dry weight [1].[64] Over time, sealants abrade from the surfaces to which they have been applied. It is often recommended that coal tar sealants be reapplied every one to five years, and asphalt-based sealants be replaced every two years.

Coal tar, a byproduct of coal coke and manufactured gas production (see Section 3.5 of this report, CONTAMINATED SITES), is composed of hydrocarbons;

Response: The Harbor Consortium deliberated on the alternative recommendations (see above), which were presented by the Creosote Council at the Harbor Consortium meeting on June 7th, 2007. After extensive discussion, the Harbor Consortium did not endorse the Council's recommendations, and the recommendations included in the text of this report were approved unanimously by Consortium members.

Among the considerations taken into account by the the Consortium members were the objectives of the Harbor Project and its Consortium. These objectives are to determine loadings of PAHs to the Harbor and identify ways to reduce these loadings to the New York/New Jersey Harbor in order to reduce concentrations of PAHs in sediments as well as management costs when these dredged sediments are contaminated. To meet these objectives, we used data that allowed a compound by compound estimate of the quantity of PAHs released annually and the amount reaching the Harbor.

The Creosote Council provided several reports, most authored by Dr. Kenneth Brooks, a consultant to the Creosote Council. However, several problems with these reports limited their usefulness, including the fact that most of this work has not been published in peer-reviewed literature, the reports do not provide sufficient quantitative data to estimate annual releases of PAHs from creosote treated wood, and they fail to measure or estimate volatilization of PAHs from creosote exposed to air (this report has identified volatilization as a major pathway for PAHs's entry into the environment). Nevertheless, every attempt was made to extract information from these reports (for example Igram et al [109], provided by Dr. Brooks).

[64] There is not a specification for asphalt sealants, potentially contributing to the wide range of PAH concentrations from product to product.

phenols; and heterocyclic oxygen, sulfur, and nitrogen compounds [60]. The PAH content in coal tar is highly dependent on the temperature of distillation. For example, coal tar formed at lower temperatures (approximately 700° C) contains fewer aromatic hydrocarbons—approximately 40% to 50% by weight—than do those formed at higher temperatures [60]. Coal tar is refined further, separating out distillate, chemical oil, and refined coal tar pitch.[65] On average, 50% of the coal tar produced is refined into coal tar pitch, which is used in the aluminum industry, for commercial carbon, built-up roofing, or pavement sealers [120].

Refined coal tar–based sealants are available for both commercial and retail applications. Commercial products are generally distributed in a concentrated form and are later diluted by a contractor with water and aggregate (such as sand and clay). A typical concentrate dilution is 100 gallons of concentrate to 35 gallons of water. Almost all coal tar sealer concentrate distributed for commercial application is designed according to ASTM[66] standard D 5727, which specifies that coal tar sealant concentrate be a minimum of 47% solids, of which approximately two-thirds is refined coal tar.[67] Consequently, commercial sealer concentrate is approximately 30% refined coal tar by weight [121]. The PAH concentration in typical coal tar sealant concentrate can be found in Table A.1.[68]

Parking lots have been identified as a source of PAHs to stormwater loadings. A study conducted in Marquette, Michigan [122] analyzed the concentrations and loadings of PAHs, as well as several other contaminants, in stormwater runoff from eight major source areas: high, medium, and low traffic streets; commercial parking lots; residential driveways; residential rooftops; commercial rooftops; and grass areas. The study found that parking lots produced the highest concentrations for all individual PAHs, and that 64% of stormwater loadings of PAH from the major source areas were from parking lots.

Recently, coal tar sealants have been identified as a source of PAHs from parking lots. A study conducted by Mahler et al. [1] compared PAH particulate in runoff from unsealed parking lots with PAH particulate in runoff from lots sealed with refined coal tar sealants and those sealed with asphalt-based sealants. The authors found that concentrations of particulate PAH in runoff from refined coal tar sealed lots was, on average, 65 times higher than particulate PAH in runoff from unsealed parking lots, while runoff from asphalt sealed lots was 10 times higher. Runoff from a parking lot is likely to include other PAH-containing materials, such as motor oil and tire wear; however, these conditions are common to all of the lots that were compared, and, given the difference in PAH concentrations between the three lot types, coal tar sealants appear to be a major contributor to the PAH concentration of parking lot surface runoff.

In addition, Mahler et al. calculated yields (or releases) based on their findings. On average, coal tar–based sealants released 890 μg of PAHs per meter squared of sealed surface during a given rain event, while asphalt-based sealed lots released 416 μg of PAHs per meter squared of sealed surface for a rain event (although the difference between the two yields was not statistically significant). It should be noted that yield data were based on a simulated precipitation event where 100 liters of water was gently sprinkled over a 50-m^2 area, simulating a light rain. Other types of rain events and regional variances in climate, such as snow and ice, may result in higher or lower surface runoff of PAHs. The study did not indicate how yields would change over time and following wet weather events.

Subsequent to the Mahler et al. paper, several other studies addressing coal tar sealed surfaces were conducted. The City of Austin [123] conducted a photographic study in which sealant wear rates were estimated for commercial parking lots in Austin, Texas. However, this study is not published at this time and is used only to provide general reassurance that our estimates are in a reasonable range.

An unpublished study by Environ, an environmental consulting company, compared PAH concentrations in sediment samples taken from creeks and streams in the Austin, Texas area in the fall of 2005 and characterized the levels of PAHs found [124]. The purpose of the study was to compare PAH inputs from various sources and to assess the hypothesized dominance of coal tar–derived pavement sealer products as a source of PAHs to the Austin stream sediments.

Coal tar is a known human carcinogen [60].[69] The City of Austin conducted three biological studies, all

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[65] Coal tar distillate is used as a wood preservative, see Section 3.2.1. Creosote-Treated Wood Production and Use. Creosote and coal tar are both carcinogenic.

[66] ASTM International is a voluntary standards developing organization.

[67] The density of the concentrate is typically 10 lbs per gallon and is broken down as follows: 3.0 lbs ASTM D 490, RT-12 grade refined coal tar; 1.7 lbs clay and fillers; <0.2 lbs emulsifiers and additives; and 5.2 lbs water [121].

[68] Currently, there is not an ASTM standard for asphalt-based sealants.

[69] Studies have found that occupational exposure to coal tars is associated with skin cancer, including scrotal cancer [60].

of which indicated some level of toxicity or ecological degradation associated with exposure to coal tar sealant.[70]

Coal Tar Sealant: Regional Sources

The quantity of coal tar sealant consumed in the U.S. is not published; however, based on sales data provided by the American Coal and Coke Chemicals Institute, it is estimated that approximately 1.4 million gallons of commercial and residential coal tar sealant are sold in the Watershed region yearly, with 50,000 gallons sold in New York City (~4% of total Watershed consumption) [120]. In general, one gallon of sealant is applied to every 60 to 80 square feet, resulting in approximately 7.8 to 10.4 million meters squared of asphalt surfaces sealed every year in the Watershed.

Releases to Land. The release of PAHs from coal tar sealed surfaces was estimated by applying the yields calculated in Mahler et al. to the estimated sealed surface area and assuming a constant release rate for all annual storm events (Table 3.8). This is likely a low estimate, given that certain weather conditions, not captured in the estimated yields, will induce degradation of the sealant, and that volatilization of PAHs is not captured by this approach. The following are conditions that are likely to induce abrasion and transport of sealant and were not captured in the Mahler et al study: heavy rains, shoveling and plowing of snow, and driving over salted surfaces.

Given that surfaces are resealed every one to five years, the annual consumption rate potentially represents only one-fifth of the sealed surfaces. Therefore, actual releases could range between one and five times estimated releases based on annual sealant consumption (Table 3.8).[71]

Based on our estimates (constant release rate per annual storm event), approximately only 1% of the PAHs applied to a parking lot surface are released over the life of the sealant (3–5 years). It is likely that a larger fraction of the sealant applied is released before a new coat is applied. One factor contributing to our potentially low release estimate is that we are unable to estimate the quantity of lower molecular PAHs volatilizing off the sealed surface over the life of the sealant. In addition, the Mahler et al.

Table 3.8. Estimated PAH release from surfaces sealed with coal tar sealants in the Watershed[a]

	Coal tar sealant consumed (gallons/yr)	Total PAHs consumed[b] (kg/yr)	Annual PAH releases[c,d] (kg/yr): Assuming one rain event (877 µg/m^2 of sealed surface)	Annual PAH releases[c,d] (kg/yr): Assuming constant yield for each rain event[e] (877 µg/m^2 of sealed surface)
Watershed	1,400,000	316,000	7–45	900–5800
New York City	50,000	11,000	0.22	31–206

[a] When the sealant wear rate reported by the City of Austin (unpublished) is applied to the dried volume of coal tar sealant in the Watershed (estimated) and the PAH concentrations reported for coal tar sealant scrapings from Mahler et al. are used, we estimate particulate PAH releases that are within range of the releases estimated by Mahler et al. (1600–7800 kg/yr of particulate PAH).

[b] PAH concentrations in coal tar sealant concentrate are based on the average of nine samples of concentrate (wet) taken by the City of Austin, 2003–2005 (Table A.1). For estimated PAH emissions by compound, see Table A.2.

[c] Estimates assume annual sealant consumption represents between 20% to 100% of the actual sealed areas, and therefore annual release rates may be up to five times estimated releases based on annual consumption.

[d] Estimates based on yields calculated in Mahler et al. [1]. To account for vehicular and depositional sources of PAHs on parking lots, yields from nonsealed lots were subtracted from yields from coal tar sealed lots. The range also takes into account that a gallon of coal tar sealant concentrate can cover between 60 and 80 feet square of surface.

[e] There has been an average of 127 days with >0.01 inches of rain in New York City for the past five years *(http://www.weather.gov/climate/index.php?wfo=okx)*. The rainfall simulated in Mahler et al. was approximately 0.08 inches.

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[70] The following is a summary of the three biological studies conducted by the City of Austin: 1) A laboratory toxicity study in which sediments were spiked with equal amounts of dried coal tar and asphalt-based sealant at low, medium, and high treatment levels. All three coal tar treatments showed significant toxicity, while none of the asphalt treatments were toxic. (Organisms in coal tar contaminated sediments had a significantly lower percentage of survival than those in asphalt contaminated sediments). UV light greatly increased toxicity in both coal tar and asphalt contaminated sediments. 2) A controlled community study in which microcosms were spiked with coal tar at low, medium, and high treatment levels. The medium level treatment (total PAH concentration near the probable effects concentration of 22.8 mg/kg) showed small but significant losses of sensitive organisms, while the high level treatment (300 mg/kg) showed dramatic community degradation. 3) A field community study, which compared biological communities and sediment chemistry upstream and downstream of coal tar sealed lots. At selected sites, PAH stream sediment concentrations increased downstream of sealed lots. Significant community degradation was demonstrated at the downstream sites, including lower abundances, lower number of taxa, and loss of sensitive species. (Chironomidae showed a negative response to PAHs and are apparently sensitive to them, while oligochaetes, which are generally very tolerant, showed a positive response. It is common in degraded communities to see tolerant organisms take over available resources as other, more sensitive taxa are pushed out.) (Journal of North American Benthological Society, in press)

[71] It is possible that some surfaces may be sealed only once, while others may be sealed every year.

yield rates do not account for releases over the lifetime of the sealant. Climate conditions specific to the Northeast, such as snow, salting, and sleet, as well as the use of plows or shovels over the sealed surface, may affect the rate at which the sealants abrade. In 2006, it was reported that there were 12 days of snow.[72] The available data do not account for differences in residential and commercial wear rates. In addition, it is not known whether the old coat of sealant is contained by the new coat or whether the layering of sealants impacts PAH release.

Although some of the abraded material containing PAHs may be transported via wind or adhesion to tires or shoes, most of the material will likely be transported by stormwater. Some of the parking lot runoff, from both commercial and residential surfaces, is captured by the municipal sewer system and treated prior to release. However, given the prevalence of separate sewer systems in New Jersey and in New York, it is likely that during any given storm event much of the abraded sealant is transported directly to Harbor tributaries.[73]

Measures to Reduce PAH Releases from Coal Tar Sealants

Currently, coal tar sealants are not regulated at the federal or state level. Coke product residues, including coal tar, are not classified as hazardous wastes if they are recycled. Under the Resource Conservation and Recovery Act, coal tar sealants are products that contain recycled coal tar. It is estimated that 50% of crude coke oven tar distillation is coal tar pitch that is used (recycled) in the production of aluminum (95%), commercial carbon, built-up roofing, and pavement sealer [125]. The aluminum sector uses coal tar pitch as an ingredient in the manufacture of anode blocks used to conduct electricity in the aluminum smelting process. Because the sealant industry consumes less than 5% of the coal tar pitch produced, it is likely that if coal tar sealants were no longer used the excess coal tar pitch would be absorbed by one of the other industries that use the material.

New York and New Jersey currently have no regulations on the application of coal tar sealants. Austin, Texas recently became the first city in the U.S. to ban the use of coal tar sealants. The ban on the sale and use of this type of sealant took effect in January 2006; it was passed after coal tar sealants were identified as a significant source of PAHs from parking lots. It is estimated that 660,000 gallons of coal tar sealant were consumed in the City of Austin in 2004 [1].[74] The ban in Austin was challenged by a sealant company and upheld by the Texas Commission for Environmental Quality. Subsequently, Dane County, Wisconsin passed a ban on the sale and use of coal tar sealants [126]. Home Depot and Lowe's have both discontinued the sale of refined coal tar sealants in their stores, limiting availability of sealant to do-it-yourself home owners in this region [127] [128].

The release of PAHs from refined coal tar– and asphalt-based sealants can be controlled by addressing land use issues, more specifically, impervious surfaces. Parking lots and driveways are, in part, a consequence of the way in which homes and cities are designed. Homes and cities that depend on the vehicular transport of its residents only encourage the construction of impervious surfaces (e.g., parking facilities) to service the vehicles and their drivers. With diminished need for parking facilities, less sealant will be consumed. In addition, paved and sealed surfaces provide a smooth surface for easy transport (and in some cases increased transport) of particles during rain and wind events, while pervious vegetated surfaces provide natural filtration for stormwater.

Another approach to control PAH releases from coal tar sealants is to utilize materials that are not typically sealed, such as concrete, or to use sealants that contain lower concentrations of PAHs, such as asphalt or concrete-based sealants. Not using sealants on asphalt surfaces may also be an option. At this point there are no quantifiable data available that show whether sealants actually prolong the life of the surface to which they are applied.

The following are pollution prevention recommendations to reduce the release of PAHs from coal tar sealed surfaces:

- Implement urban-form measures or policies that reduce the need for parking lot areas, such as increasing mass transit services, increasing pedestrian and biking areas, and providing incentives for current and future drivers that reduce or eliminate miles driven. (See also recommendations in Section 3.3.1 VEHICLE EXHAUST in this report).

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[72] Source: National Weather Service, http://www.epa.gov/oppsrrd1/public_summaries.htm - 4phase.

[73] Based on Municipal Separate Storm Sewer System (MS4) permit data, approximately 99% of the Watershed area is serviced by separate stormwater sewer systems. Communities in the Watershed that are serviced by combined sewer systems include New York City (although approximately 23% of the area is serviced by separate stormwater systems), Newark, and several municipalities in Hudson County, New Jersey.

[74] Approximately twice as much coal tar sealant concentrate is consumed in the NY/NJ Watershed.

- Advise architects, developers, homeowners, and decision makers to use no- or low-PAH sealants and to consider alternative designs and paving materials for certain surfaces.
  - Residential driveways. Alternatives include use of no- or low-PAH sealants, gravel, or pervious concrete. Efforts to promote the use of these materials should be focused on suburban areas that typically have more driveways and parking lots.
  - Commercial parking lots. Alternatives include use of no- or low-PAH sealants, concrete, or pervious concrete; placing parking lots beneath structures where they will not be exposed to stormwater transport; and reducing the overall paved area of projects.
- Determine through scientific studies whether refined coal tar sealants extend the life of the asphalt parking lot/driveway and other surfaces to which they are applied. Research the benefits and environmental impact of using alternative products such as concrete driveways, no- or low-PAH sealants, or asphalt-based sealants versus using no sealants.
- Promote the development of a specification for the manufacture of asphalt-based sealants that results in a consistently lower concentration of PAHs **AND** a minimum level of performance (e.g., a lifetime of at least five years).
- Further research.
- Although there is a consensus that sealants wear off from the surface to which they are applied, the exact quantity and rate of removal are not entirely clear. However, the need for further research should not inhibit the identification and implementation of pollution prevention measures.
  - Conduct initial research to determine whether sealants extend the life of a parking lot and by how much.
  - Conduct further research to confirm initial findings about PAH losses (volatilization and abraded material), including release, and the change in pavement thickness over time.
  - Conduct research that seeks to identify relative loadings from various sources contributing PAHs from parking lot surfaces (e.g., motor oil, atmospheric deposition). This may include an improved approach to fingerprinting PAH sources in sediments.

3.3. Transportation

3.3.1. Vehicle Exhaust

Vehicle Exhaust: National Trends and Emission Factors

Historically, PAH emissions have been associated with point source activities (i.e., industrial sources). However, sediment data indicate that today sources of PAHs to the environment are dominated by nonpoint sources, such as vehicle exhaust emissions, and urban and suburban runoff [11][75] [129][76]. Urban and suburban runoff include PAHs from motor oil, brake dust, and asphalt sealant (all of which are a result of vehicle transportation).

PAH emissions from vehicle exhaust consist of gasoline and diesel combustion exhaust released from any class of on-road vehicle, including cars, trucks, buses, and motorcycles. Fuel type, vehicle class, and driving mode influence the quantity of PAHs released. For example, a recent study shows that the average PAH emission rate for diesel vehicles driving in congestion is approximately an order of magnitude higher than for diesel vehicles cruising [6]. Gasoline- and diesel-powered engines also exhibit differences in PAH formation. For instance, the particulate PAHs found in diesel exhaust are attributed to the PAHs in the fuel, and the pyrogenic formation of PAHs (formation from the combustion of fuel) is thought to contribute only a small fraction of the total PAH emissions [130]. The aromatic content of diesel fuel has not remained constant, slowly increasing from the 1960s to the early 1990s, and then leveling off.[77] Current regulations limit the aromaticity of fuel to 35%, although Califor-

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[75] Ten long-term monitoring stations throughout Puget Sound, Washington, monitored, among other things, over 180 priority pollutant metal and organic contaminants, including PAHs, PCBs, pesticides, and other compounds. A 12-year trend analysis was conducted and found an overall decrease in metal concentrations and an increase in PAHs. This suggests a shift from industrial point source emissions to anthropogenic nonpoint sources such as vehicle exhaust and urban and suburban runoff.

[76] PAH ratios found in a core sample from Central Park, New York City, indicate a shift in 1920 from wood and coal combustion to petroleum combustion. Petroleum combustion (mainly from vehicle exhaust in Manhattan) was shown to be the primary PAH input after 1940.

[77] The increase in aromaticity of diesel fuel may be due to the growing demand for diesel fuel that is met by increased use of light-cycle oil from catalytic cracking, California Code of Regulations, Title 13, Section 2281-2285.

nia requires an aromatic maximum of 10% by volume with a few exceptions.[78]

For the purpose of this study, vehicles have been grouped into classes, defined in TABLE 3.9.

The U.S. EPA's Office of Transportation and Air Quality provide emission fractions used in their MOBILE6 vehicle emissions modeling system (TABLE A.1) [131].[79] The emission fractions are based on research conducted by Norbeck et al. [132] and by the Northern Front Range Air Quality Study [133], in which emissions from gasoline and diesel vehicles from 1965 to 1997 were tested for PAHs.[80] The emission fractions used to determine PAH emissions are expressed as grams PAH per gram of particulate matter dust sized 10 μm in diameter (PM_{10}) [134].[81] The Norbeck et al. [132] emission fractions were derived from a group of vehicles typical of two or three decades ago and may overestimate current emissions from light-duty vehicles; these emission fractions should be used with caution [133].

Vehicle Exhaust: Regional Releases

On average, over 50% of the miles driven in New York and New Jersey take place in the Watershed region (approximately 100 billion mi/yr), of which most are driven by gasoline and diesel cars [135] [136]. In New York alone, the quantity of vehicle miles traveled is projected to increase by 14% from 2002 to 2010 [135].

Releases to the Atmosphere. PAH emissions from vehicle activity in the Watershed were calculated by applying the emission fractions in TABLE A.1 to the 2002 PM_{10} vehicle emissions provided by the New York State Department of Environmental Conservation (NYSDEC) and New Jersey Department of Environmental Protection (NJDEP) (TABLE 3.10).[82] While emission estimates for 14 PAHs were calculated, naphthalene constitutes approximately 80% of the total PAH emissions.

Noteworthy is the contribution of PAH emissions from LDGVs (cars), a vehicle class that also constitutes the largest number of miles driven (FIG. 3.1). Although diesel engines are notorious for emitting large quantities of particulate matter (FIG. 3.2, *top*), based on New York emission data, more total PAHs are emitted from HDGVs (trucks and buses) and motorcycles per mile traveled than from diesel vehicles (FIG. 3.2, *bottom*). This is most likely driven by naphthalene, which has been found to be emitted in higher relative concentrations from gasoline vehicles than from diesel vehicles.[83] The U.S. EPA's National Emissions Inventory 2002 data present similar relative emissions, with

Table 3.9. Definition of vehicle class

Class name	Vehicles
Light-duty gasoline vehicle (LDGV)	Cars
Light-duty gasoline truck (LDGT)	Smaller trucks and sport utility vehicles (SUVs)
Heavy-duty gasoline vehicle (HDGV)	Large trucks and buses
Motorcycle (MC)	Motorcycle
Light-duty diesel vehicle (LDDV)	Cars
Light-duty diesel truck (LDDT)	Smaller trucks and sports utility vehicles (SUVs)
Heavy-duty diesel vehicle (HDDV)	Large trucks and buses

Table 3.10. PAH emissions due to vehicle exhaust in New York and New Jersey[a]

	Watershed		Outside Watershed	
	New York	New Jersey	New York	New Jersey
Total PAH emissions (kg/yr)	48,400	43,100	117,200	21,100

[a] PAH emission estimates are based on emission fractions presented in Table A.1. For estimated PAH emissions by compound, see Table A.2.

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[78] Small refiners and alternative formulations may have an aromatic content greater that 10% if they can demonstrate equivalent emission standards.

[79] On- and off-road vehicle emission estimates generated by the Office of Transportation and Air Quality are reported in the National Emissions Inventory (NEI), http//www.epa.gov/ttn/chief/net/1999inventory.html.

[80] The emission fractions assume that all gasoline-powered vehicles share the same PAH emission fractions and that LDDTs and LDDVs also share the same emission fractions. A separate study was used to determine HDDV emission fractions [133].

[81] With the exception of gas-phase PAHs from heavy-duty diesel engines, there is a reasonable correlation between PAH and total carbon emissions [133]. Carbon serves as the primary nucleus for the formation of particulate matter.

[82] As part of their three-year inventory cycle, the NYSDEC and NJDEP estimated PM10 mobile source emissions. The New Jersey draft data provided were for the entire state; therefore, Watershed PM10 emissions were extrapolated based on the percentage of miles traveled within the region. New York data were available by county.

[83] The difference in emissions from gasoline vehicles and diesel vehicles is also driven by methyl-naphthalene [132], a compound not included in our study.

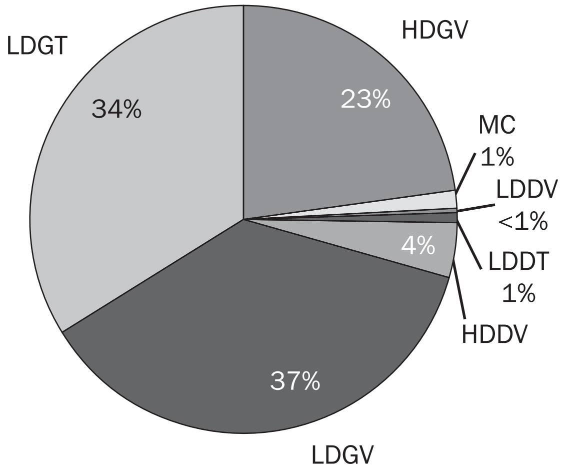
HDGVs and MCs emitting the most PAHs per vehicle mile traveled.

There is some uncertainty in this emissions estimate. The emission fractions used may be outdated, given the improvements in vehicle engine technology over the past several years. Furthermore, it is likely that diesel engines currently emit more PAHs per mile driven than do gasoline engines; however, this is not reflected in our estimates [137]. Another area of uncertainty is the way in which vehicles are driven, (i.e., in congestion or in cruise mode). As previously mentioned, emissions can increase greatly when cars are in stop-and-go traffic (also known as "creep" mode), as opposed to cruising at a constant speed. No data are available on the number of miles that are driven in each of these modes. It is expected, however, that in cities and urban centers (such as those counties contiguous to the Harbor), more vehicle travel time is spent in creep mode than in cruise mode.

Measures to Reduce Releases of PAHs from On-Road Vehicle Exhaust

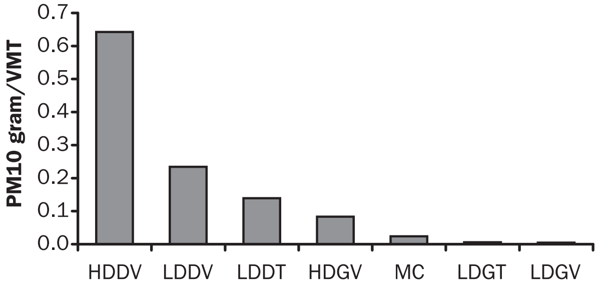
Federal and state legislative measures have been taken to reduce or manage vehicle emissions. For example, under the Environmental Policy Act the Federal government establishes national fuel efficiency standards for vehicles sold in the U.S. One of the Federal standards is the Corporate Average Fuel Economy (CAFE). The CAFE standards are a sales-weighted average fuel economy standard, expressed in miles per gallon (mpg), of a manufacturer's fleet of passenger cars or light trucks. CAFE standards for light trucks and SUVs were updated recently, mandating an average mileage for new light trucks of 24 mpg by the 2011 model year—an improvement of less than 2 mpg over the 2007 standard. There have been efforts to increase the CAFE standard more dramatically, but at this point those efforts have failed. Separate from the CAFE standards, the U.S. EPA is adopting standards that require nonmethane hydrocarbon exhaust from small and large vehicles to be no more than 0.3 g/mi and 0.5 g/mi, respectively, in cold temperatures (below 75° F) [138].

Figure 3.1. Estimated relative contribution, by vehicle class, of PAH vehicle exhaust emissions in the Watershed

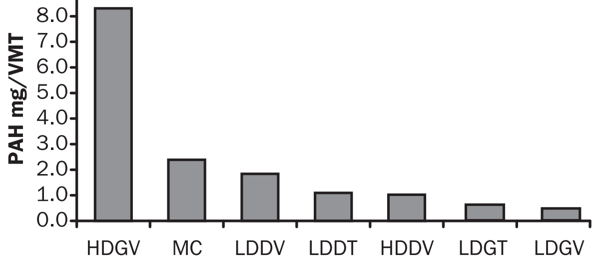


New York and New Jersey have adopted the California Low Emission Vehicle (LEV II) standards for all light- and medium-duty motor vehicles. LEV II standards are stricter than the Federal emission standards and apply to car model years 2004 and 2009 for New York and New Jersey, respectively [139].[84] LEV II requires 90% of all new passenger cars, light-duty trucks, and sport utility vehicles between 8500 and 14,000 pounds offered for sale to meet strict new tailpipe and evaporative emission standards. The standards restrict emissions from cars and light-duty vehicles less than 8500 pounds to 0.001g PM per mile, and emissions from vehicles weighing be-

Figure 3.2. Estimated New York Watershed PM10 emissions per vehicle mile traveled



Estimated New York Watershed PAH emissions per vehicle mile traveled



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[84] Starting in 2005, LEV II standards will apply to all heavy-duty vehicles in New York. This is a revision to the original California LEV program adopted in 1992, in which emission standards were placed on passenger cars and light-duty trucks up to 6000 pounds [140].

tween 8500 and 14,000 pounds to between 0.06 and 0.12 PM per mile, depending on vehicle certification [141]. In addition, the LEV II standards require manufacturers to offer 10% of their sales fleet as zero emission vehicles starting in model year 2003. Currently, however, estimated PAH emissions from vehicle activity is one of the largest atmospheric PAH emissions sources in the Watershed.

In addition to private vehicles, taxis often constitute a relatively large fraction of the vehicle fleet on the road in urban centers. The nature of taxi service (short distances in city centers) dictates that trips are made in stop-and-go traffic, a mode that is known to increase PAH emissions from vehicles. In an effort to reduce atmospheric emissions from taxis, New York City recently took steps to increase the number hybrid taxi vehicles on their city streets. The New York City Taxi and Limousine Commission (TLC) amended their vehicle dimension requirements to allow the use of hybrid sports utility vehicles as taxis. This amendment was initiated last year when, per Local Law 51, the TLC accepted bids for 19 "clean air" medallions from cab drivers interested in acquiring and using alternative fuel vehicles (instead of the conventional Ford Crown Victoria). However, at that time, medallion owners were unable to find a hybrid vehicle that had the legroom required by the TLC. To further promote the use of hybrid taxis, Council Member David Yasky introduced the "Alternative-Fuel Taxis Passenger Queue Priority Act" (Intro 158), which would allow any alternative-fuel cab to cut to the head of the line at airport passenger pick-up points.

Regulating traffic is one way to reduce PAH emissions from vehicle exhaust, particularly in congested areas. One example of a regulatory and economic approach to addressing traffic is congestion pricing. Congestion pricing entails charging a daily fee for vehicles entering a designated central business district (CBD).[85] London recently implemented such a program, and charges all private vehicles traveling into central London £8 ($14 USD) on weekdays between 7 a.m. and 6:30 p.m.[86] A pilot congestion pricing program was proposed for Manhattan as part of the PLANYC 2030, and theoretically would apply to vehicles entering Manhattan below 86th Street during the business day from 6 a.m. to 6 p.m. Cars entering this designated area would pay a daily fee of $8.00 and trucks $21.00, with exemptions for emergency vehicles, taxis, and handicapped drivers. All revenue from this project would go to fund expansion and improvement of the mass transit system.[87] Opponents to this program state that congestion pricing would result in fewer trips to the CBD, leading to a reduction in spending at local retail establishments, and that lower-income drivers would be disproportionately burdened by this tax. A report released in 2006 by the Queens Chamber of Commerce estimated that if a pricing program similar to London's were implemented in Manhattan, approximately 286,500 fewer people would enter the CBD each day, leading to an annual loss of $1.8 billion to the local economy [142]. In contrast, a report published by the New York City organization Transportation Alternatives states that there has been minimal-to-no impact on the economic vitality of the London CBD, and that congestion pricing is likely to have a similar impact in Manhattan. The report also concludes that most people driving into the CBD do so as a matter of choice (i.e., have alternative transportation available) and that one-third of drivers entering the CBD are traveling to non-CBD destinations [143]. At this point, legislation on the congestion pricing pilot has not been passed; however, a congestion pricing study has been approved by New York lawmakers, and results will be reported in the spring.

Tolls and taxes to enter or use a roadway are not novel concepts, and are currently enforced on some of the major transportation arteries in the Watershed. Similar to opponents of congestion pricing, opponents of road tolls refer to them as regressive taxes by which the poor are penalized, paying a higher percentage of their income than the wealthy. However, taxes and tolls can be structured to avoid penalizing a group based on income. For example, placing a tax based on vehicle size is one way to discourage the use of vehicles that emit more PAHs; replacing traditional taxes with taxes on pollution is another.[88]

While one approach to reducing vehicle emissions is through regulation, as described above, another approach is through implementation of

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[85] More PAH emissions are released during the creep mode (or stop-and-go traffic), which typically occurs in congested central business districts (i.e., New York, Queens, and Kings Counties) where large quantities of goods are distributed and sold in a concentrated area.

[86] Exemptions are made for buses, motorcycles, taxis, vehicles used by disabled persons, some alternative fuel vehicles, and emergency vehicles.

[87] For more information, see http://www.nyc.gov/html/planyc2030/downloads/pdf/report_transportation.pdf.

[88] For example, eliminating payroll taxes—taxes that fund social security and worker's compensation—and replacing them with taxes on emissions could, if structured correctly, be a revenue-neutral tax swap that would remove a tax that discourages companies from hiring employees while discouraging them from polluting.

voluntary programs and technological innovations such as those implemented by the U.S. EPA. The U.S. EPA has very limited authority to mandate retrofits of existing equipment, and the durability of diesel technology does not lend itself to rapid fleet turnover. In response, the U.S. EPA began the Voluntary Diesel Retrofit Program in 2000 to consider broad initiatives for modernizing and upgrading (i.e., retrofitting) current engines with newer ones. As part of this program, efforts were made to create partnerships, foster innovative technologies, and provide grants to accelerate the introduction of clean diesel technologies. In conjunction with state and local governments, public interest groups, and industry partners, the U.S. EPA set a goal of reducing emissions from the more than 11 million diesel engines in the existing fleet by 2014. The U.S. EPA determined that there are general sectors that provide the best opportunity to obtain significant reductions, including school buses, ports, construction, freight, and agriculture. Each program provides technical and financial assistance to stakeholders interested in reducing their fleets' emissions effectively and efficiently.

Increasing combustion efficiency of engines requires investment in the advancement in vehicle technology. One example of advancement is in clean diesel technology (CDT). Historically, diesel fuel combustion has been associated with smoke and with significant particulate and nitrous oxide releases. However, as a result of their fuel efficiency and higher levels of power, diesel engines have maintained their popularity throughout the world. CDT has evolved to address the pollution releases associated with diesel engines. For example, the U.S. EPA is refining existing CDTs into a unique engine design that is simultaneously clean, efficient, cost effective, and can be scaled for use in light-duty and heavy-duty vehicles. One of the technologies is a particulate matter after-treatment that reduces exhaust smoke, unburned hydrocarbons, and carbon monoxide. These technologies, coupled with the availability of low-sulfur diesel fuel, will reduce the releases associated with diesel vehicle engines.

The following are pollution prevention recommendations to reduce releases of PAHs from vehicle activity in urban and rural communities in the Watershed:

- Reduce fuel combustion.
    - Promote the purchase and use of fuel efficient vehicles while encouraging manufacturers to offer no- or low-emission vehicles.
    - Increase vehicle efficiency by educating drivers on proper maintenance and operating procedures (e.g., following manufacturers' standards on motor oil use, tire pressure, air filter maintenance, and oxygen sensors; reduced idling practices; and use of overdrive gear and cruise control), and by promoting policy that increases Federal fuel efficiency standards.
    - Improve vehicle design by promoting clean diesel technology research, low drag vehicle design, and use of lightweight durable materials such as carbon fiber composites.[89]
    - Improve compliance with and monitoring of anti-idling regulations, while increasing outreach to truck drivers on the environmental impact of idling and their legal obligations.[90,91]
    - Implement policy that promotes the penetration of alternative fueled vehicles into the Watershed fleet,[92] particularly for vehicles that typically travel in stop-and-go traffic, such as taxis, local delivery trucks, and waste haulers.[93]
    - Develop a tax structure that encourages public transportation, while improving public transportation infrastructure.
- Consider reducing the aromatic content of diesel fuel through further research and policy.

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89. The Hypercar, Inc. concept (created by the Rocky Mountain Institute) employs ultralighting and whole platform integration to reduce fuel consumption, possibly up to fivefold. The ultralighting process can be described as the use of lightweight materials—such as carbon fibers, plastics, and composites—to construct the vehicle body. A lighter body requires lighter chassis components and a smaller powertrain, all of which reduce vehicle mass [144].
90. In response to trucking industry concerns with the inconsistent patchwork of state and local idling laws, the U.S. EPA has released a model for state anti-idling law.
91. The New York State Department of Environmental Protection prohibits the idling of heavy-duty diesel vehicles for more that five minutes. The New Jersey Department of Environmental Protection prohibits idling for more than three minutes.
92. An example of a city that has taken measures to promote the use of hybrids is New Haven, Connecticut where regulations were passed allowing hybrid vehicles registered in New Haven to park for free at metered spots within the city.
93. Autocar LLC has developed a trash truck that utilizes a hybrid drive system that captures and stores energy used while braking. The stored energy is then used to get the truck moving again. As of 2006, the truck was not in production, and efforts were being made to keep the truck weight neutral [145].

Urban and rural communities will each require unique transportation solutions, given their differences in landscape and design (and in some cases, lack thereof). Urban centers are compact, with significantly more vertical growth than in rural communities, which typically have more horizontal growth. Urban communities are conducive to public and pedestrian transportation, given the high population density and the relative proximity of amenities and services. In contrast, public transportation expenses can be economically prohibitive in rural communities, given the low population density and often long distances between destinations. Therefore, some recommendations have been identified as particular to rural or urban environments.

Recommendations specific to urban communities

- Improve and expand public transportation into and out of city centers.
- Reduce congestion through measures such as congestion pricing or scheduled daily closures of parts of the city to vehicular traffic. Consider potential economic impact when developing such measures.

Recommendations specific to rural communities

- Design communities that foster public transportation, bicycling, and walking. Include the fostering of smaller economic centers, while providing incentives for residents who live in the center of town.

3.3.2. Vehicle Tire Wear and Motor Oil Leaks

Vehicle Tire Wear and Motor Oil Leaks: National Trends and Emission Factors

In addition to exhaust, vehicles also release PAHs through oil leaks, brake dust, road particles, and tire wear. Of the later three, it is tire wear that has the highest concentration of PAHs per gram of particle released [146] (Table A.1). PAHs in tires can be attributed to the aromatic and naphthenic extender oils used as a substitute for some of the more costly rubber materials. High aromatic extender oils improve the viscoelasticity of the rubber compound and contribute to the tread rubber compound grip, wear, and endurance qualities of tires.[94] Tire tread can contain up to 28% extender oil with a concentration of 17 to 357 mg/kg total PAHs [8]. The quantity and size of particles released varies with vehicle type and driving conditions. The U.S. EPA, for example, reports that tire particles are released from vehicle tires at the following rates: passenger vehicles, 192 mg/mi; light-duty vehicles, 336 mg/mi; heavy-duty vehicles, 656 mg/mi; and motorcycles, 96 mg/mi [8]. Nonroad vehicles also release PAHs via tire particulate; however, there is not enough information to estimate releases from this source.

It has been reported that, in addition to tire wear, tires in contact with roads that have relatively high surface temperatures may release vapor emissions of PAHs. So far, however, only low levels of gaseous PAHs have been observed [7] (as cited in [8]).

Motor oil leaks, another vehicular source of PAHs, are readily apparent from blackened areas on roadways, parking lots, and driveways. The rate of oil leakage is generally unknown, making it difficult to estimate emissions from this source. It is likely, given improvements in vehicle technology that oil leaks have decreased over the years. One source estimates that 46% of vehicles on the road leak hazardous fluids, including motor oil [9].

Vehicle Tire Wear and Motor Oil Leaks: Regional Releases

Releases to Land. The quantity of tire particles released in the Watershed was estimated by first determining tire wear particles generated, and second applying the PAH emission fraction to the estimated particle generation (Table 3.11).[95] Due to lack of available data, PAH releases from brake linings cannot be estimated at this time.

Releases of PAHs from motor oil leaks were estimated by assuming that 46% of vehicles on the road in the Watershed leak motor oil and that 15% of the motor oil used in those vehicles is leaked.[96]

Measures to Reduce Releases of PAHs from Vehicle Tire Wear and Motor Oil Leaks

One way to address releases of PAHs from tire wear is to reduce the overall miles traveled by a vehicle (see Section 3.3.1 Vehicle Exhaust for more discussion).

Another approach is to reduce the rate at which a tire wears or the quantity of particulate generated by tire use. The rate at which tires wear is related to factors such as fuel economy (referred to as tire roll resis-

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[94] Viscoelasticity refers to the viscosity (resistance of a fluid to deform under shear stress) and the elasticity of a material.

[95] Tire wear particle generation was estimated by applying vehicle miles traveled to the respective particle generation rate (i.e., particle generation rates for passenger car, light-duty vehicle, heavy-duty vehicle, and motorcycle).

[96] It is estimated that 70% of motor oil used in a vehicle results in used motor oil, and that 30% is either combusted in the engine or leaks from the vehicle [147]. The exact quantity leaked is not known; therefore, it is assumed that half of the oil that does not result in used motor oil is leaked from vehicles. The quantity of oil consumed in a car is estimated to be 2.1 gallons per year [148].

Table 3.11. Estimated PAHs released by tire wear and motor oil leaks in the New York and New Jersey Watershed[a]

	Vehicle miles traveled per year (×1,000,000)	PAHs released by tire wear (kg/yr)	PAHs released by motor oil leaks[b] (kg/yr)
New York	50,000	1600	2600
New Jersey	64,000	1200	2400
TOTAL	**114,000**	**2800**	**5000**

Sources: Wolfgang et al. [146]; American Petroleum Institute [147]

a PAH emission estimates are based on PAH emission factors presented in Table A.1. For estimated PAH emissions by compound, see Table A.2.

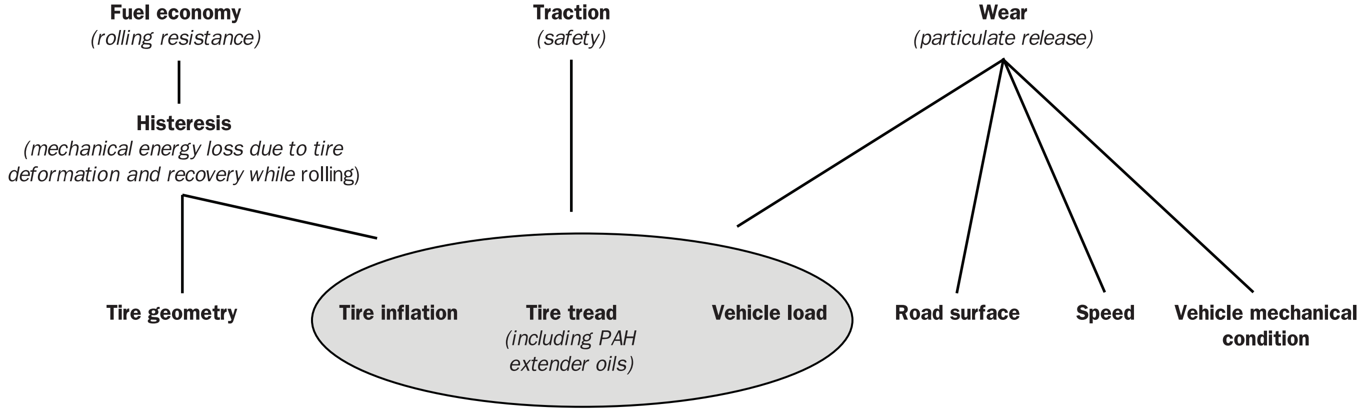
b Estimates assume that 46% of vehicles in the Watershed leak oil, and that 15% of the oil consumed in those vehicles is leaked.

tance) and traction; improving one factor can impact the other two.[97] Figure 3.3 provides a simplified description of how these factors are related. In general, traction and rolling resistance have an inverse relationship, and traction and tire wear have a direct relationship. For example, reducing traction may lead to a decrease in tire wear but an increase in fuel economy. However, this is not always the case, and other factors such as tire inflation and vehicle load can confound these results.[98]

PAHs associated with tire wear can also be reduced by eliminating the high aromatic content extender oils primarily used in the tire tread. Currently, there are approximately 160 to 500 mg of PAHs per tire.[99] Some regions have already started to regulate the PAH content in tires. For example, the European Commission has decided that in 2010 they will restrict the concentration of PAHs in extender oils used to manufacture tires to 10 mg PAHs per kg [149],[100] or approximately 5 to 7 mg PAHs per tire. Aromatic extender oils are thought to contribute to the grip, wear, and endurance qualities of the tire, and finding substitutes has been difficult for European tire manufacturers. Some of the low-PAH alternative extender oils under investigation are mild extract solvents (MES) and treated distillate aromatic extracts (TDAE). MES and TDAE are both mineral oils and generally have 20 to 50 times fewer PAHs than typical high aromatic extender oils. The availability of MES and TDAE, and potential safety issues, demand more research before tires sold in the EU can meet PAH concentration requirements.

There is little evidence that the U.S. is moving to-

Figure 3.3. Summary of the relationships between tire fuel economy, traction, and wear rates



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97. It is estimated that a 10% decrease in rolling resistance can yield a 1% to 2% increase in fuel economy (all other factors held constant). Underinflated tires specifically can yield a 1% increase in fuel consumption for every 5% that the tire is underinflated.

98. The following are general relationships between tire factors that can change based on the interactive relationship of the factors: tire geometry—reducing the height relative to the width decreases roll resistance; tire inflation—proper tire inflation reduces roll resistance and tire wear, and increases traction; tire tread—tread contains much of the hysteretic material in the tire that reduces tire wear, but increases roll resistance and traction; vehicle load—a heavier vehicle load increases roll resistance, traction, and tire wear; road surface—rougher roads increase tire wear; vehicle speed—increased speed increases tire wear; and vehicle mechanical condition–improper alignment and loose steering and suspension parts increase tire wear.

99. This estimate was calculated based on the following assumptions: vehicle tire is 9 kg, 6% to 8% of tire is aromatic extender oil, and extender oil is 300 to 700 mg total PAH/kg [8]. Concentrations vary between extender oils and tire manufacturers.

100. The maximum PAH concentration refers to the following PAHs: benzo(a)pyrene, benzo(e)pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(j)fluoranthene, dibenzo(a,h)anthracene. A maximum PAH concentration in tire extender oils has also been established for benzo(a)pyrene, specifically, 1 mg/kg.

wards restricting PAH content in tires; however, some companies that manufacture tires for multiple countries have implied that once they have established the appropriate extender oil alternatives for EU tires, they may bring lower-PAH tires into the U.S. market as well.

The following are pollution prevention recommendations to reduce the release of PAHs associated with tire wear in the Watershed:

- Research the development of a substitute for high PAH extender oils, while continuing to meet tire safety standards, and potentially capitalizing on research that has already begun in the EU.
- Reduce tire wear rates through research and development of advanced materials and tire design; much of this information is proprietary, placing the onus on the industry to improve tire design.
- Educate the driving community on proper vehicle and tire care, such as correct tire inflation, vehicle alignment, and allowing adequate time to brake.
- Reduce vehicle drive time through congestion control and driving route maximization strategies (see VEHICLE EXHAUST P2 recommendations presented earlier in this report).

Currently, vehicles leaking motor oil are not regulated. Efforts to reduce leaky vehicles has centered on outreach and education to drivers.

In addition to vehicles, nonroad equipment may also leak motor oil, although release rates are even more unclear.

The following are pollution prevention recommendations to reduce the release of PAHs associated with motor oil leaks in the Watershed:

- Reduce undetected oil leaks by educating drivers on how to check their vehicle for oil leaks (e.g., placing cardboard below parked vehicle, visually checking engine for oil cleanliness, and checking oil to determine if it is constantly low), and incorporating oil leak testing and repairing requirements into the standard vehicle emissions testing required by the state.
- Further research.
  - Survey the current vehicle fleet to determine the quantity of motor oil leaked.
  - Determine the PAH content of synthetic motor oil and how its properties change after use.

3.3.3. Improper Disposal of Used Motor Oil

Improper Disposal of Used Motor Oil: National Trends and Emission Factors

In 2004, motor oil demand in the U.S. was approximately 1.04 billion gallons [150]. Although the number of vehicles has increased over the years, the demand for motor oil has remained relatively constant, given the increase in time between oil changes.[101]Motor oil contains PAHs, although the PAH content does not remain constant. For example, using motor oil in a gasoline-powered engine increases PAH content dramatically [59], leading to a PAH concentration in used motor oil of as much as 4% to 8% polyaromatic (plus 2% to 5% diaromatic) [152]. TABLE A.1 provides the concentration of PAHs in used motor. These data are based on 40 samples of motor oil used in gasoline vehicles taken from the crankcase and storage tanks [153]. The concentration of PAHs in used motor oil varies depending on vehicle type and use.

Over time, motor oil becomes dirty and needs to be changed. The way in which used motor oil is disposed of varies. A 1974 study on used motor oil disposal revealed that 142 to 185 million gallons, or about 25% of the total, was released into the environment (TABLE 3.12).[102] A more recent estimate (2002) of used motor oil disposal indicates that 3% of the population over the age of 18 is disposing of used motor oil improperly—approximately 25 million gallons per year [151].[103] Disposal practices that release used motor oil to the environment include pouring it onto the ground, down storm drains, or directly into bodies of water, or dumping it into municipal garbage collection where it ends up in landfill. Historically, some rural communities spread used motor oil over dirt roads to keep dust

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[101] Synthetic lubrication oils typically have a longer change interval and are more energy intensive to produce. The demand for synthetic lubrication oils is forecast to grow by as much as 20% annually [151]. Synthetic lubrication oils are highly refined, oil-based stocks, and include poly-alpha olefins, hydrocracking, and gas-to-liquids–based oils.

[102] It is estimated that France and Germany collect 78% and 94% of used oil in their markets, respectively [150]. Germany's high recovery may be attributed to consumer interest in recycling, treatment of used oils as hazardous waste, requiring oil marketers to provide a collection facility near retail establishments, and retailers paying for used oil pickup.

[103] This estimate assumes that each oil change generates one gallon of used oil and that, on average, oil is changed 3.6 times per year [148]. It is estimated that those who change oil themselves do so at a greater frequency than those who have their oil changed by others [151].

levels down; however, this practice has been banned by Federal regulation 40 CFR 279.82.

Improper Disposal of Used Motor Oil: Regional Releases

At the time of this report, information on the disposal of used motor oil in the Watershed was not available; therefore, national data provided by the U.S. Department of Transportation (USDOT) were used to estimate regional disposal of used motor oil.[104] Data from the 2002 USDOT Household Survey indicate that, on average, approximately 21% of the population over the age of 18 are "do-it-yourselfers" (DIYs) who change their own motor oil, and that of the DIY population, 16% dispose of the oil improperly [151]. Improper oil disposal practices in the survey included placing it in the garbage, and pouring it down the drain, on the ground, or in bodies of water.[105,106] The survey data also reveal that, on average, those changing their own oil do so on average 3.6 times per year.

Table 3.12. Breakdown of used motor oil disposal nationwide in 1974

	Gallons (millions)	Percent of total
Supplemental fuel	195–308	31.6–50
Road oiling	143	23.20
Incorporated into asphalt	67–103	11–16.7
Re-refined	20–57	3.3–9.2
Released to environment	142–185	23.0–30.0

Source: U.S. Dept. of Health and Human Services [152].

The quantity of improperly disposed used motor oil in the Watershed was estimated by applying the above statistics to the Watershed population that is 18 years and older, as reported in the 2000 Census, and accounting for the difference between national vehicle ownership and Watershed vehicle ownership (TABLE 3.13).[107,108] It is assumed that used motor oil generated by "do-it-for-me's" (DIFMs), those who have their oil changed at a service station, is disposed of properly.[109]

Used motor oil is also generated by nonroad equipment such as marine, lawn and garden, and commercial equipment. It is likely that nonroad used oil generation has not received enough attention, given that most oil changes are done by the equipment owner and not at a service station. There are no data available at this time on the generation and disposal of oil from these sources.

Releases to Land and Water. The estimated quantity of PAHs released to the environment via improper disposal of used motor oil is presented in TABLE 3.14. Next to the category "other," disposal of used motor oil into the garbage is the largest. Although containers holding used motor oil may rupture during transport from household garbage to landfills, it is likely that most of the spilled oil does not reach the Harbor. Oil released to water (i.e., poured down indoor drains and sewer drains) is more likely to reach the Harbor, because most of the Watershed is serviced by separate

Table 3.13. Estimated generation and disposal of used motor oil in the Watershed

	New York	New Jersey	Total Watershed
Used motor oil generated (gal/yr)[a]	11,234,537	6,802,457	18,036,994
Used motor oil generated by DIYs (gal/yr)	5,636,879	3,413,103	9,049,982
Used motor oil improperly disposed by DIYs (gal/yr)	901,901	546,096	1,447,997

a To estimate total used motor oil generated in the Watershed, oil change rates were applied to vehicles registered to DIYs and DIFMs in the Watershed and it was assumed that the number of DIFM vehicles was equal to total registered vehicles less DIYs (see above for a description of DIY estimates). It was assumed that DIYs change their oil 3.6 times per year and DIFMs change their oil 2.1 times per year.

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104. In New York and New Jersey used motor oil collection data are available only for facilities permitted to collect used motor oil. Service stations and retail facilities are not required to keep records of motor oil collected from DIYs [154] [155].

105. Although disposing of used motor oil in the garbage is not considered a proper disposal method, it is unlikely that used motor oil disposed of in this manner will reach the Harbor.

106. It was assumed that DIY survey participants who answered "other" in regards to disposal practices were not recycling the oil and were therefore disposing of the material improperly.

107. The USDOT Household Survey is a national survey, whereas average U.S. vehicle ownership is likely different from vehicle ownership in the Watershed. To account for this difference, a ratio of regional and national private vehicles per person was applied to the Watershed population over age 18. National vehicle ownership was available as a total of commercial and private vehicle ownership; therefore, it was assumed that 10% of vehicles were commercial. This assumption was based on the calculated New York Watershed commercial vehicle ownership that 10% of private and commercial vehicles are commercial [156].

108. The legal driving age in New York and New Jersey is 16 and 17 years, respectively. Both states implement a multistage driver's license program.

109. In 1997, it was estimated that 66% of used motor oil generated in DIFM operations was recycled; however, currently it is estimated that virtually all DIFM used motor oil is recycled [150].

Table 3.14. Estimated releases of PAHs from improper disposal of used motor oil in the Watershed[a]

	Water	Garbage/landfill	Ground	Other[a]
Percent of improperly disposed oil	5	24	5	66
Total PAH to Watershed (kg)	400	1800	400	4900

Source: U.S. Dept. of Transportation [151]

a PAH emission estimates are based on PAH concentrations presented in Table A.1. For estimated PAH emissions by compound, see Table A.2.

b The disposal practices in this category are unknown; however, several participants in the USDOT survey indicated that the used motor oil was consumed for fuel.

stormwater systems that transport stormwater directly to an outfall without being treated.

Releases to the Atmosphere. In New York and New Jersey, used motor oil must be recycled unless consumed on site in combustion system that meets specifications such as correct burner size and ventilation.[110,111] In a 1996 American Petroleum Institute study, it was estimated that approximately 20% of used motor oil collected in New York was disposed of in on-site space heaters [147].[112] The atmospheric emissions from this type of combustion activity are unknown.

Measures to prevent used motor oil releases. All service stations in New York and New Jersey that sell new oil and perform vehicle services must accept from the public at no charge 5 to 10 gallons of used oil per person per day [154] [160].[113,114] Retail establishments in New York that sell at least 1000 gallons per year of new oil must also accept used oil from the public, or contract to have another service or retail establishment accept it on their behalf. New York and New Jersey also have permitted drop-off facilities supported by local government or by independent recycling organizations. In addition, some municipalities have organized regional collection days.

RECYCLING USED OIL

Recycled oil is re-refined, reconditioned or reprocessed. When oil is re-refined, it is cleaned of contaminants such as dirt, water, fuel, and additives, and mixed with fresh additives. Oil can be re-refined multiple times without compromising the product's quality. The reconditioning of oil consists of passing oil through a filtration system. The original quality of the oil is not attained through this process; however, the life of the oil can be extended. Reprocessing removes water and particles from the oil [157], producing a product acceptable for use in asphalt, industrial boilers, steel mills, cement kilns, commercial boilers, and pulp and paper mills [158].

Market Barriers. Today, the sale of re-refined oil, a product that meets the same automotive standards established for virgin oil, is gaining market share. This trend is more prominent within the Federal fleets. For example, the U.S. Postal Service is following Federal procurement guidelines and purchasing re-refined motor oil for their fleet [159]. The private fleet, on the other hand, is a consumer group that is often brand loyal, causing slower penetration of recycled motor oil into the market. Another market barrier is the cost of re-refined oil (driven mostly by collection costs), which was previously high compared with virgin oil. However, as virgin oil prices continue to rise, re-refined oil may become more price competitive [148].

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110. In New Jersey, motor oil may not be disposed in landfills like other solid wastes (NJAC7:26-2A.4). Therefore, generators may overclassify their oil as hazardous waste and comply with the associated regulations, or they may recycle the oil (NJAC 7:26G). All motor oil that is recycled or in route to a recycling facility is regulated by the less stringent provisions of NJAC 7:26A-6. New York State Environmental Conservation Law Section 23-2308 states that no person shall engage in the improper disposal of used oil, and that used oil shall only be deposited in an available used oil retention facility or disposed of as otherwise authorized or permitted by the commissioner.

111. On-site space heaters must be designed to have a maximum capacity of no more than 0.5 million BTU/hr and combustion gases from the heater must be vented to ambient air.

112. It is possible that the combustion of used motor oil in space heaters is increasing. State laws requiring the free collection of used motor oil and a provision allowing the combustion of the material in a space heater create economic incentives to collect and combust used motor oil.

113. In New York, only those auto service stations that sell at least 500 gallons per year of new oil (~500 oil changes) are regulated by this rule [160].

114. In an attempt to simplify the process and increase recycling rates, service facilities are not required to obtain recycling permits or keep records of quantities of oil recycled

Once oil is collected at a collection facility, it is retrieved by oil recycling companies and is re-refined, reconditioned, or reprocessed.[115] Re-refined oil is growing in the national market as it becomes more price-competitive and available through procurement programs. For example, the U.S. EPA established procurement guidelines in which procuring agencies are required to purchase certain products that have been manufactured with recovered materials, including re-refined oil [161].[116,117] New York and New Jersey have also established state procurement programs that require state agencies to purchase motor oil that contains at least 40% re-refined oil [162] [163].

There are no re-refining facilities in the Northeast, with the closest facility located in Illinois. There are, however, several reprocessing facilities in New York and New Jersey (Table 3.15).

Based on our calculations approximately 8% of used motor oil generated is still being disposed of improperly. Three parties that have the opportunity to increase oil recycling have been identified: DIYs, oil producers, and government agencies. These groups will need to work together to effectively reduce the quantity of used motor oil that is disposed of improperly.

Table 3.15. Used oil reprocessing facilities in the Watershed

State	County	Capacity (gal/day)	# of facilities
NY	Queens	30,000 pp	1
	Brooklyn	25,000 pp	1
	Richmond	uk pp	1
	Orange	72,000	2
	Westchester	445,000	2
	Albany	uk	1
	Oneida	43,000	2
NJ	Middlesex	uk	1

pp = permit planned/pending, uk = Unknown
Sources: O'Brien (pers. comm.) [155]; New Jersey Dept. of Environmental Protection [79].

The following are pollution prevention recommendations to reduce releases of PAHs associated with improper disposal of used motor oil:

- Educate the community, including schools and vocational institutions, on the location of local oil disposal facilities (such as service stations and retail stores) and on the dates of municipal collection days. Also provide information on correct oil change intervals and on the hazards of improper used motor oil disposal.[118]
- Reduce improper disposal of used motor oil by increasing access to collection services and by establishing additional collection facilities (e.g., retail stores, municipal collection facilities).
- Consider establishing incentive programs, such as offering a deposit on returned motor oil or coupons when oil is returned to a collection facility.
- Increase the end-use market for used motor oil by promoting the purchase of re-refined oil through government and commercial procurement programs and by educating consumers on the quality and availability of re-refined motor oil.
- Reduce motor oil consumption by increasing the interval between oil changes (as indicated by the manufacturer); this may include working with car manufacturers to indicate proper oil change intervals in the vehicle owner's manual,[119] and promoting the use of synthetic motor oils.[120]
- Reduce vehicular travel (see Section 3.3.1 Vehicle Exhaust for more detailed recommendations to reduce vehicle use).

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[115] A report by the U.S. Department of Energy found that re-refining used oils saves 8.1% of the energy content of the used oil compared with combusting the oil for heating purposes. The report also found that transforming all used oil that is currently combusted into lubrication oil products could save 63 million gallons of fuel oil equivalent per year [150]. This value is likely to increase as more energy intensive synthetic lubrication oils enter the market.

[116] A procuring agency is any Federal agency, or any state agency or agency of a political subdivision of a state, that is using appropriated Federal funds for procurement.

[117] Designated products that must contain recovered materials when using Federal procurement funds fall under the following categories: construction products, landscaping, nonpaper office products, paper and paper products, park and recreation products, transportation products, vehicular products, and miscellaneous products. For a complete listing of products, see the U.S. EPA's Comprehensive Procurement Guidelines, http://www.epa.gov/cpg/products.htm.

[118] DIYs are estimated to change their oil 3.6 times per year on average [151]. This is greater than the 2.2 average for all Americans [148].

[119] Reducing the production of used motor oil may appear contradictory to the recommendation for increasing the end-use market. However, given that relatively large quantities of used motor oil are still not being recovered, this may not be a concern at this time. For example, it is estimated that 80% of used motor oil generated by DIY activities nationwide is not being recovered.

[120] While synthetic motor oils do not need to be changed as often as standard motor oils, they are more energy intensive to refine, and the recovery and recycling of this material will become more economically and environmentally important as their use continues to grow.

- Address data gaps.
  - More information is needed on recycling rates and improper disposal rates. Available data are national and may not reflect local activities. Obtaining this information may require conducting a local survey. Motor oil disposal data could also be collected through better record-keeping requirements by collection facilities or recyclers, including information on the quantity of collected oil combusted in on-site space heaters.

The following are pollution prevention recommendations to reduce the release of PAHs associated with improper disposal of used motor oil from nonroad vehicles and equipment used in the Watershed:

- Establish used motor oil collection opportunities at locations visited by nonroad equipment users, including the following locations: marinas, dirt bike events, lawn and garden shows, and stores.
- Collect data on improper disposal of motor oil from nonroad equipment.

3.3.4. Nonroad Engine Exhaust

Nonroad Engine Exhaust: National Trends and Emission Factors

Sources of PAHs from nonroad engine exhaust include releases from any class of two- or four-stroke gasoline and diesel engines (stationary or mobile) that fall within any of the following engine use categories: recreational, lawn and garden, construction, industrial, commercial, logging, airport maintenance, and agricultural (nonroad watercraft emissions are addressed in the MINOR SOURCES section of this report). Although two- and four-stroke engines can often be used to perform similar tasks, in some cases one variety lends itself to specific equipment types. For example, a two-stroke engine, unlike a four-stroke engine, does not have any valves or emissions controls and is much lighter, which is why it is often used in smaller machinery such as chainsaws [80].

The emission fractions we used to calculate PAH releases are the same as those used in the MOBILE6 model described in the VEHICLE EXHAUST section of this report (TABLE A.1.).[121] Leaking, uncombusted motor oil is another source of PAH release [164]; however, only exhaust emissions are estimated at this time, due to the lack of motor oil release rates from nonroad equipment.

Nonroad Engine Exhaust: Regional Releases

Releases to the Atmosphere. Emissions from nonroad land activity were calculated by applying the emission fraction in TABLE A.1 to the 2002 PM_{10} data provided by the NYSDEC and the NJDEP (TABLE 3.16).

Based on our emission estimates, most of the PAH emissions from this source category are from four-stroke engines, gasoline-powered specifically (FIG. 3.4). The engine use categories that constitute these overall releases vary with location. For example, in rural communities most nonroad PAH emissions are from agricultural equipment, while in urban centers construction and industrial equipment dominate most other source categories. In the Watershed region overall, however, most nonroad emissions are from lawn and garden equipment, followed by commercial equipment, and construction and mining (FIG. 3.5). The remaining 12% of PAH emissions to the Watershed are derived from recreational, industrial, agricultural, logging and airport activities.

One of the uncertainties of these estimates is the emission fractions applied. The fractions were established based on minimal test results, and emission fractions used to estimate releases from two-stroke engines were based on the testing of just two engines that do not represent the entire inventory of two-stroke engine use types [133].

Table 3.16. Estimated releases of PAHs from nonroad (land) engine exhaust in New York and New Jersey[a]

	On-land activities			
	Watershed		Outside Watershed	
	New York	New Jersey	New York	New Jersey
Total (kg/yr)	17,600	14,900	15,400	5,400

a PAH emission estimates are based on emission fractions presented in Table A.1. For estimated PAH emissions by compound, see Table A.2.

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[121] Nonroad four-stroke gasoline and diesel emission fractions were calculated based on on-road emission fractions. Emission fractions for two-stroke gasoline engines were calculated based on emissions testing of two snowmobile engines [133].

Figure 3.4. Estimated relative PAH emissions from nonroad engines in the Watershed, by engine type

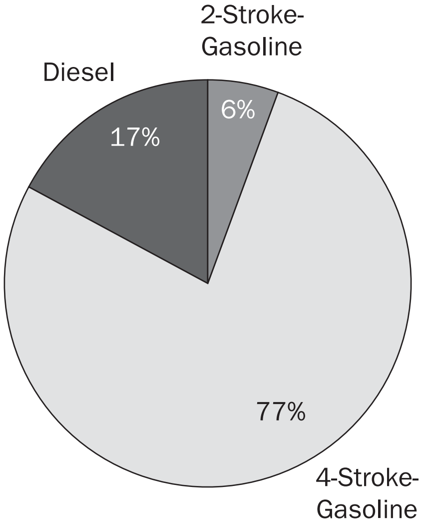
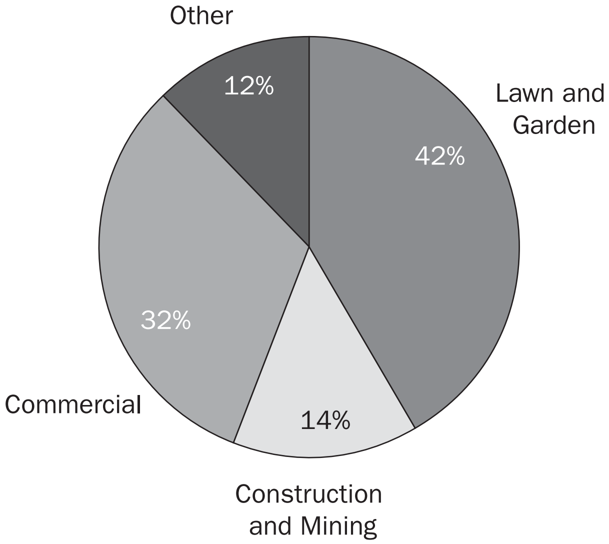


Figure 3.5. Estimated relative PAH emissions from nonroad engines in the Watershed, by engine use category



Measures to Reduce Releases of PAHs from Nonroad Engine Exhaust

Nonroad emissions are regulated by the Federal government under regulation 40 CFR Parts 9, 69, which establish standards for the manufacture of new off-road engines. For instance, the U.S. EPA has recently proposed and adopted new engine standards for nonroad diesel engines (enacted in 2004 to take effect in 2008).[122] However, these rules do not apply to existing engines; given the longevity of some equipment, older engines may be a significant source of pollution.

New York and New Jersey have not established state-level manufacturing regulations, although equipment requirements (such as the use of best available control technologies) have been developed for some areas within the Watershed. New Jersey is preempted by Federal statute from setting state-specific emissions standards for new and most in-use off-road equipment; however, standards are set on the opacity of smoke emitted by combustion [165]. At this point, New York State does not have any nonroad emission regulations superseding those established at the Federal level [166]; however, some nonroad activities are managed through regional equipment requirements. For example, New York City passed Local Law 77 requiring all city-owned or leased nonroad equipment and any equipment used in a public works project to use ultra-low sulfur diesel fuel and best available control technologies, including retrofits for older equipment (see Table 3.17. for examples of retrofit technologies).[123] Similarly, the New York State Assembly passed a law requiring New York State construction projects in lower Manhattan to use ultra-low sulfur diesel fuel in nonroad vehicles, and to retrofit existing equipment or use new equipment with emissions control technologies.

Unlike diesel engines used in construction and commercial projects, individually owned nonroad equipment, such as lawnmowers, weed-whackers, and chainsaws, historically have not received much attention in regard to exhaust emissions. However, these sources, which are dispersed throughout the residential landscape, have recently been identified as potentially significant contributors to air pollution. For example, the California Air Resources Board recently passed a bill requiring a reduction in air emissions from nonroad spark ignition engines with less than 50 HP (e.g., lawnmowers and yard care equipment), and prohibits the sale and purchase of equipment that does not meet new emissions standards. Emissions standards will most likely be met through the use of catalytic converters, a technology of which Industry has voiced safety and fire concerns, given the close proximity of the engine to flammable material. However, the U.S. EPA released a study conclud-

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[122] In addition, the allowable level of sulfur in nonroad, locomotive, and marine vessel diesel fuel has been lowered.

[123] Ultra-low sulfur diesel fuel allows proper functioning of advanced emissions control technology and produces less particulate matter than low sulfur diesel fuel when combusted.

Table 3.17. Nonroad construction equipment retrofit technologies

Technology reduction strategy	Description	Pollutants reduced
Diesel particulate filters (DPF)[a]	DPFs are honeycomb or mesh devices placed within the exhaust stream, trapping and oxidize PM.	HC, CO, PM (90% or more reduction)
Diesel oxidation catalysts	DOCs oxidize pollutants in the exhaust stream.	PM (10-50%), HC (50% or more) and CO (50% or more)
Selective catalytic reduction (SCR)	SCRs inject urea (or some form of ammonia) into the exhaust stream, reacting over a catalyst to reduce NOx emissions.	PM (about a 25% reduction) and NOx (80% reduction)
Exhaust gas recirculation (EGR)	EGRs recirculate a portion of engine exhaust back into the engine to cool pe ak combustion temperatures and thus, reduce NOx.	NOx (40-50%) , PM if paired with a DPF

Source: Summarized from U.S. EPA, http://www.epa.gov/cleandiesel/construction/technologies.htm
a Must be paired with low-sulfur fuel.

ing that more stringent, catalyst-based emission standards would not increase the risk of fire and burn to consumers during engine use [167].

In addition to lawn equipment with improved combustion efficiency, several noncombustion lawnmowers, such as electric- and solar-powered mowers, have entered the market. Electric-powered mowers are designed with a cord or without, and release fewer pollutants than traditional gasoline-powered engines; however, they have been shown to have less power in some cases. Solar-powered lawnmowers release no emissions during use; however, they are more expensive than conventional mowers.

There are many nonroad activities to consider, and providing concise pollution prevention strategies that address all of them would be lengthy; therefore, our pollution prevention recommendations will focus on lawn and garden equipment (the category with the largest overall PAH emissions in the Watershed), and construction and commercial equipment (the category with the highest activity level in counties directly adjacent to the Harbor).

The following are pollution prevention recommendations to reduce releases of PAHs from nonroad exhaust in the Watershed:

Lawn and Garden Equipment

- Promote the use of equipment that utilizes the best available air pollution control technology (e.g., catalytic converters), as well as equipment that does not require the combustion of PAH-releasing fuels. This could be done through an equipment changeout program or a regulatory phase-in of more efficient equipment.
- Provide incentives for low-emissions landscape design and maintenance, such as a program that recognizes landscapers that reduce their emissions during design and maintenance. This may include planting natural land cover or land cover that does not need to be mowed, as well as using no- or low-emission equipment.
- Inform the community of the emissions associated with yard care and of low-emission landscape alternatives such as moss or clover.
- Promote further development of non-PAH-releasing engine technologies (such as solar), potentially through federal and industry-funded research.

Construction and Commercial Equipment

- Consider the implementation of a statewide emissions control retrofit program that retrofits older equipment with pollution reduction technologies (similar to the NYC program explained above).
- Educate equipment owners on the importance of proper equipment maintenance measures, such as addressing the following maintenance issues: restricted air filters, improper engine timing, malfunctioning fuel injectors, defective air fuel controllers, poor fuel quality, and air intake manifold leaks.
- Reduce unnecessary idling of equipment, possibly by extending idling restrictions to nonroad engines and through the promotion of idling reduction technologies such as automatic shut-off devices.[124]

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[124] Visit the U.S. EPA's Clean Construction web site for case studies, http://www.epa.gov/cleandiesel/construction/casestudies.htm.

3.4. Petroleum Spills

Petroleum Spills: National Trends and Emission Factors

PAHs are a component of coal and are at least a trace component of all petroleum products. The percentage by weight of total PAHs (where total is defined as the sum of the 16 U.S. EPA priority PAHs, although many other PAHs are present) in selected products is as follows: creosote, 21%; asphalt, 19%; roof paint, 7%; No. 2 fuel oil, 1%; and Kuwaiti crude oil, 0.05% [59] [168] [169]. Creosote, asphalt, roof paint, and fuel oils are all distillation products of crude oil, and may be expected to have relatively consistent PAH compositions, depending on the source material (crude oil) used and the operating parameters of the refinery. The relative PAH content of natural gas, propane, ethane, and gasoline is low.[125]

The PAH content of crude oil can vary dramatically, depending on the source rock (i.e., marine- or terrestrial-derived organic deposits) and the thermal environment prevailing during oil formation. Petroleum deposits are created by the slow heating of organic matter–rich rock over millions of years (a process referred to by geologists as diagenesis). Crude oils with the greatest PAH content are formed from marine deposits and tend to be found primarily in the Middle East [171]. The PAH composition given for Kuwaiti crude oil (Table A.1) should therefore equal or exceed the PAH content of crude oils from most other sources.

Quantifying total annual releases of petroleum products from spills is difficult because it can be tricky to estimate the quantity of material spilled, while some spills are not reported at all. One estimate gives the total release of crude oil in waters nationwide to be about 8 million gallons per year [172]. Given a composition of crude oil of about 0.05% PAHs, crude oil spills on a national level may release about 14 tons of PAHs per year. Additional releases of oil into water may be caused by smaller, unreported spills, and by oil residues released to the water from shipping activities that include illegal sludge dumping and lightering.[126,127]

Petroleum Spills: Regional Releases

Releases to Water. A few "historical" spills of exceptional size have occurred in the Watershed and may continue to impact the Harbor today. One example is the Newtown Creek oil spill in Greenpoint, the northwesternmost community in Brooklyn. The spill along Newtown Creek, a historically industrial area with more than 50 refinery facilities along its shores by 1870, was first identified in 1979 by the U.S. Coast Guard (USCG) [175]. A subsequent investigation concluded that the area of the spill under parts of Greenpoint (including residential, commercial, and industrial properties) was in excess of 52 acres, and the total spill volume, as estimated in 1979, was approximately 17 million gallons of petroleum product. The spilled product is mostly located on top of the water table, in a layer ranging in depths of up to 20 feet, and continues to seep into Newtown Creek, a tributary of the East River [176]. Petroleum recovery measures have been taken, including a containment boom on Newtown Creek surrounding the seeping material and recovery wells, and it is estimated that 8.8 million gallons have been recovered. However, given the current size of the plume, it is possible the original volume estimated may have been low, or that recovery volumes may have been overestimated, or both [175]. Evidence points to Exxon/Mobil as the most likely responsible party, based on hydrocarbon forensics analysis, product thickness on the groundwater, the direction of groundwater flow, and the seeps originating at the bulkhead adjacent to their property. However, some analyses suggest that BP/Amoco has contributed significantly as well. In addition, there have been many aboveground and underground storage tanks (both commercial and residential) historically in the area; it is unknown how many of those may have leaked over the years. In addition to seeping petroleum, toxic vapors are being released. The New York State Department of Health has collected data on releases of toxic vapors from residential and commercial properties on top of the underground spill, and continue to assess the data collected [176].

Several lawsuits have been filed in an attempt to hasten the cleanup of spilled petroleum. Riverkeeper, along with local city council members, filed suit against Exxon/Mobil, and a group of neighborhood residents has also filed a lawsuit against Exxon/Mobil (as well as Chevron/Texaco and BP) [177].[128] More recently, the New York State Attorney General's Office filed a lawsuit against

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[125] Although PAHs are generally no more than trace components of light petroleum fractions, gasoline may contain up to 0.05% naphthalene. Nonoptimal refinery operation conditions may increase the PAH content of refined products [170].

[126] A report by the National Academy of Sciences estimates that worldwide 226,000 tons of oil sludge is dumped at sea every year [173]. The fraction of the sludge dumped in U.S. coastal waters is unknown.

[127] Lightering is when ships transfer their cargo to another vessel. As many as 75% of petroleum-bearing ships must transfer their cargo to barges before entering the harbor [174].

[128] It is estimated that approximately 50% of the petroleum product is underground, much of it under surrounding homes. Residents have complained of methane odor coming from their basements and that their property values are depreciating due to the contamination under their homes. Furthermore, there is concern that as efforts are made to stop the release of petroleum to Newtown Creek, product will seep further inland and contaminate more homes. [178]

Exxon/Mobil to force them to clean up the spilled petroleum and to restore Newtown Creek.

The overall impact of this spill on the Harbor is unclear. Sediment sampling in Newtown Creek reveals high concentrations of PAHs (80,100 ng/g in 1990s, two orders of magnitude greater than in Raritan Bay) [179]. The mass balance (see Appendix B) reports an overall net loss of contaminants from the Harbor to the Long Island Sound via the East River. Given the point at which Newtown Creek enters the East River, it is possible that oil from Newtown Creek would be transported to Long Island Sound more readily than if the creek entered the East River at a point closer to the Harbor. However, preliminary findings from an experiment that relied on injecting a gaseous tracer at Newtown Creek indicate that this substance moves into the Harbor in a short time span.[129]

In addition to historical spills in the New York/New Jersey Harbor, recent petroleum releases, ranging in magnitude and location, contribute to petroleum loadings to the Harbor (Table 3.18).

The USCG National Response Center (NRC) is one source for data on petroleum spills because they are a primary contact for petroleum spills, including any spill that creates a sheen on the water. After collecting initial spill data, the NRC distributes a release notice to responding parties (e.g., regional USCG responders, U.S. EPA, and state and local agencies). Based on 2004 USCG NRC data, there were approximately 800 reported petroleum spills in the Watershed.[130] Approximately 50% of the reported petroleum spills occurred at facilities, 35% from miscellaneous equipment (e.g., transportation and unknown equipment), and 15% from vessels [183]. Causes of the reported releases vary; however, the greatest reported known cause of incidents was equipment failure (Table 3.19).

It is difficult to estimate actual releases based on initial reporting data, because reports may have been made while material continued to spill and/or those making the report may not have been qualified to make accurate estimates of material released. Therefore, data documented in the USCG's Marine Information for Safety and Law Enforcement (MISLE) database were used to estimate releases. MISLE is a database of all reported spills from vessels, facilities, and miscellaneous activities, for which the USCG has

Table 3.18. Recent petroleum spills in the New York/New Jersey Harbor

Date	Location	Material released	Estimated amount released
2/13/2006	Arthur Kill, Middlesex, NJ	Crude oil	31,000 gallons
2/6/2006	Passaic River, NJ	Fuel oil	10,000 gallons
12/16/2005	Rahway River, NJ	Oil	80,000 gallons (oil and water)
Total spilled			**121,000 gallons**
Total PAHs[a]			**192 kg**

Sources: Waste News [180]; New Jersey Dept. of Environmental Protection [181]; Environmental Business & Legal Reports [182].
a Crude oil PAH concentration was used to calculate releases. See Table A.1.

Table 3.19. Reported causes of petroleum release to the Watershed region in 2004

	New York	New Jersey	NY & NJ
Source		**Percent of total**	
Dumping	3	2	2
Equipment failure	31	40	36
Natural phenomenon	1	2	2
Operator error	10	10	10
Transportation	3	3	3
Vessel sinking	2	1	2
Other/unknown	50	42	46

Source: U.S. Coast Guard National Response Center [183]

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[129] Basil Seggos, Riverkeeper, presentation to the NYC DEP Citizens Advisory Committee on Pollution Prevention, April, 2004.

[130] Spills are typically called in to the NRC and complete and/or accurate information is often not available at that time. In some cases, the amount released is reported as unknown.

Table 3.20. Petroleum releases and associated PAH releases to the Watershed, 2000–2004[a,b]

	2001	2002	2003	2004	Total (land and water)	Avg. release to water
No. of petroleum spills	9	132	76	33	273	59
Liters spilled	4735	41,605	88,361	3145	137,846	15,180
Total PAHS (kg)	**245**	**536**	**626**	**35**	**1441**	**70**

Source: U.S. Coast Guard [185].

a Petroleum materials included in calculations: fuel oils No. 2, No. 2D, and No .6; diesel; crude; misc. oil: lubricating and motor oil; jet fuel; waste oil; and unknown oil-like material.

b PAH release estimates are based on concentrations presented in Table A.1. For estimated PAHs releases by compound, see Table A.2.

filed a follow-up report; it is expected to have more accurate estimates of material released.[131] Data from spills that occurred between 2001 and 2004 were used to estimate average annual PAH loadings to the Harbor.[132] An estimate of PAHs released from total petroleum spills (land and water) and water only are provided (Table 3.20).[133]

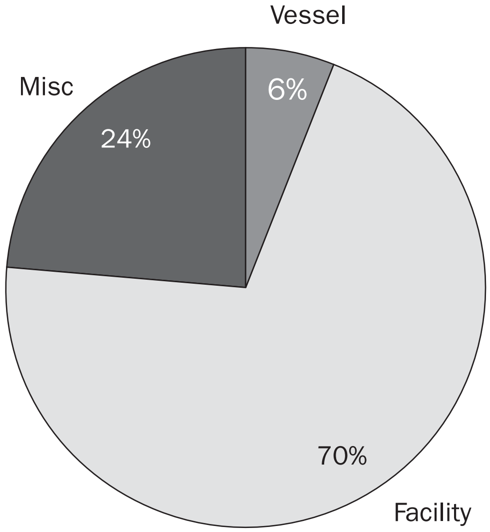
Based on the MISLE data, facility petroleum spills have been responsible for the largest average release of PAHs over the past four years, compared with all of the spill source categories reported in the MISLE database (vessel, facility, and miscellaneous) (Fig. 3.6.). This is similar to the USCG reported spill data described above. It is likely that facilities that are reporting petroleum releases include aboveground petroleum storage tanks that are typically located near a water body. These spills are primarily concentrated in the immediate Harbor area, although some spills occurred up the Harbor tributaries (Fig. 3.7).

Measures to Prevent Petroleum Spills

Some measures have been taken to identify and respond to petroleum spills. Under the Federal Water Pollution Control Act (FWPCA), the USCG NRC must be notified when a discharge of oil in a harmful quantity occurs. A harmful quantity is defined by 33 CFR 110.3 as any amount of oil that creates a sheen, film, discoloration, sludge, or emulsion upon or beneath the surface of the water or the adjoining shoreline. Releases of other nonoil materials, such as creosote, vegetable oils, cocoa butter, and soaps, are also regulated under the FWPCA [186]. The USCG ensures that all spills are met with some form of cleanup and remediation, although the remediation actions may not be documented. If the responsible party does not take action, the USCG will organize a cleanup and charge the responsible party up to three times the cost of cleanup [187].

Measures have also been taken to prevent petroleum spills. For example, Federal regulation 40 CFR Part 112 establishes requirements for spill prevention,

Figure 3.6. Estimated contributions of PAH releases from facilities, vessels, and miscellaneous activity in the New York/New Jersey Harbor, 2001-2004



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[131] The U.S. Coast Guard (USCG) spill protocol for reporting and follow-up are as follows:
Initial spills are reported to the NRC; the NRC collects initial data and distributes a notice to regional USCG facilities, U.S. EPA, or state agencies; depending on jurisdiction and spill characteristics, either one or more of the notified agencies will respond; all spills included in the MISLE database are those to which the USCG responded. The USCG jurisdiction includes all major water bodies of the NY/NJ Harbor including the following: Lower Bay, Jamaica Bay, Gravesend Bay, Sandy Hook Bay, Navesink River, Raritan Bay, East Rockaway Inlet, Coney Island Channel and tributaries south of the Belt Parkway on Long Island, Upper Bay, The Narrows, Gowanus Bay and Creek, Bay Ridge, Red Hook, Buttermilk, Arthur Kill, Kill Van Kull, Newark Bay, and the Hudson River [184].

[132] Only those spills whose cases have been closed are included in the MISLE database. There are approximately 6722 cases nationwide that are still open [185]. More complete data are not available at this time.

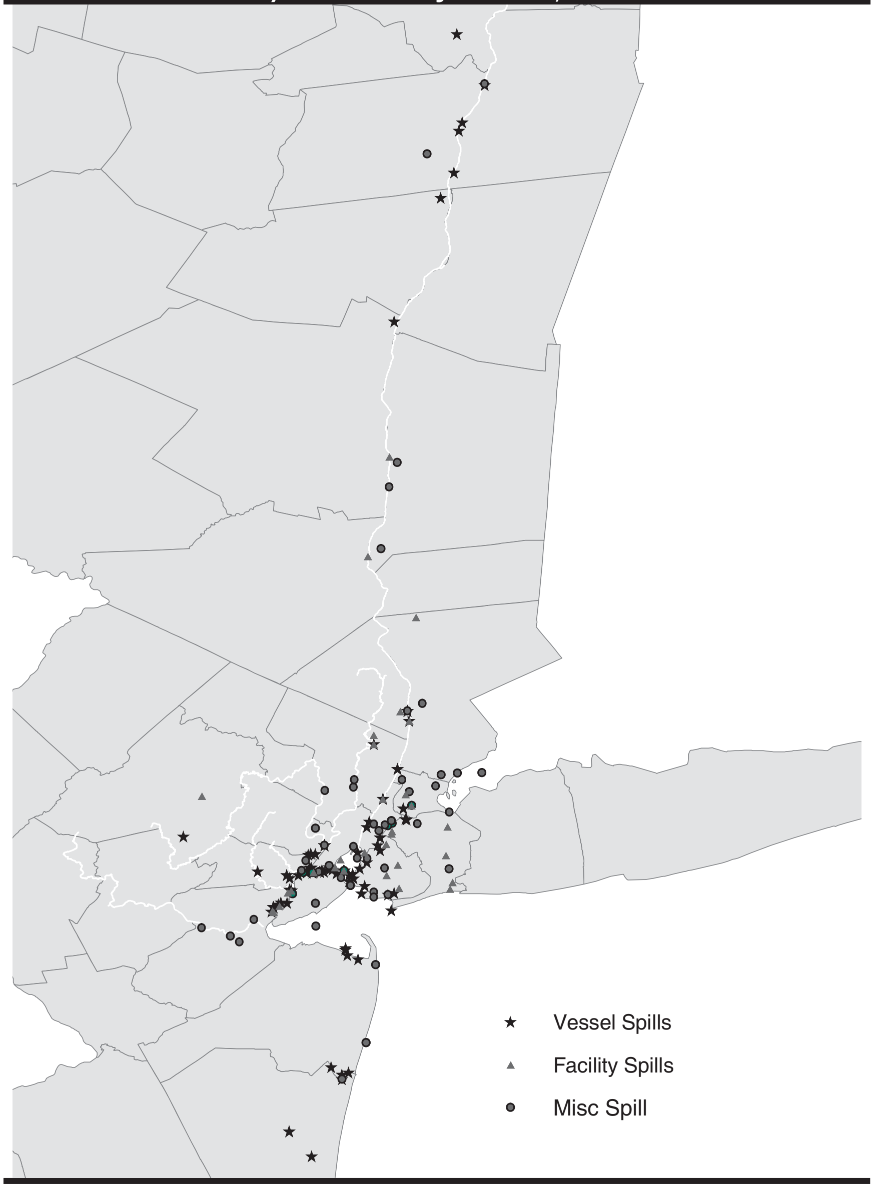
[133] Due to the lack of data on PAH concentrations for several types of oils spilled, it was assumed that some grades of oil have equivalent PAH compositions. Grades of petroleum included in our estimate include unknown oil-like, jet fuel, oil fuel No. 2, diesel oil, waste oil, miscellaneous lubricating oil, and miscellaneous motor oil.

control, and countermeasure (SPCC) plans that apply to owners or operators of facilities that drill, produce, gather, store, process, refine, transfer, distribute, use, or consume oil and oil products. Owners and operators are required to establish a SPCC plan that must be reviewed every five years and updated to reflect current spill prevention and control technology.[134] In addition, an owner or operator must conduct discharge prevention briefings for oil-handling personnel at least once a year to assure adequate understanding of the SPCC plan.

New York and New Jersey have also taken measures to prevent and respond to petroleum spills. In New York, petroleum spills of five gallons or more must be reported to the New York State Department of Environmental Conservation [188, 189]. In addition, aboveground storage tanks holding more than 10,000 gallons of petroleum or smaller tanks that could reasonably be expected to pose a threat to state waters are required to construct a secondary containment system, as specified under NYCRR Part 613. This would include dikes, curbs, liners, diversion systems, or any system that would contain spills from tank ruptures, overfills, vandals, and equipment failure. This rule also requires monthly inspection of tanks by the owner and more thorough ten-year inspection for all tanks larger than 10,000 gallons. The New Jersey Department of Environmental Protection has established individual reporting requirements based on spill condition, and encourages that all spills be reported to their spill hotline.[135]

Because most reported spills occurred at facilities and were caused by equipment failure, our recommendations center on preventing such incidents. Keep in mind that it is likely that many smaller spills go unreported and, collectively, may constitute a sizable contribution of PAHs to the Harbor.

Figure 3.7. Location of petroleum oil spills in the New York/New Jersey Harbor, 2000-2004



Source: U.S. Coast Guard Marine Information for Safety and Law Enforcement [MISLE] database.

The following are pollution prevention recommendations to reduce petroleum spills in the Watershed:

- Support a quick and thorough cleanup of the historical petroleum spill that continues to release oil into Newtown Creek.
- Consider strengthening the spill prevention control and countermeasures for facility and equipment operations, specifically in regard to equipment failure and maintenance.

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[134] As part of this plan, aboveground containers must be inspected on a regular schedule,e when material repairs are done, and when secondary containment is implemented.

[135] Spills reported to NYSDEC and NJDEP are logged electronically and are available for public review through either an online database (http://www.dec.ny.gov/chemical/8437.html) or by request (http://www.nj.gov/dep/opra/forminfo.html). Types of spills presented in these databases include, and are not limited to, spills at fuel delivery (i.e., residential and commercial), transportation facilities, containment sites, and during distribution of material.

- Increase employee spill prevention knowledge by organizing training for employees, with a focus on preventive maintenance and identifying signs of equipment failure.
- Data gaps and need for further research.
  - Some of the oil spill data available are based on reported or called-in information. Further information is needed on confirmed causes of releases to better target appropriate spill prevention measures.
  - Causes of vessel spills in the Harbor need to be evaluated and documented further. The causes of vessel spills reported to the U.S. Coast Guard National Response Center are often unknown.
  - A comprehensive list of PAH concentrations in various grades of petroleum products is needed.

3.5. Contaminated Sites

Contaminated Sites: National Trends and Emission Factors

PAHs are a contaminant in soil and groundwater at various sites across the country. In some cases, PAHs are the primary contaminant of concern, while at others PAHs may be present at concentrations slightly above background levels. Sites may become contaminated with PAHs through activities and misuse of materials previously described in this report. For example, petroleum and creosote spills or leaks are a source of contamination, as are improper disposal or dumping of such materials.

Contaminated sites are generally classified as contaminated based on their potential to release contaminants to the environment and their potential risk to public health. However, some sites may be classified as contaminated based solely on the quantity of the contaminant at the site [190]. PAHs at a contaminated site may reach the surrounding environment through soil erosion, wind transport of particle-bound PAHs, groundwater leaching, and volatilization and deposition. Once classified as contaminated, sites may be managed under Federal, state, or local jurisdiction. Currently, there are 564 Federal Superfund sites across the U.S. that have been identified as contaminated with PAHs [191].[136]

Contaminated Sites: Regional Sites

Federal Superfund Sites: There are a total of 51 Federal Superfund sites reported to be contaminated with PAHs in the Watershed, 37 in New Jersey and 14 in New York, respectively (Fig. 3.8, Table 3.21) [191].[137] Sources of contamination vary from site to site and, in some cases, within the site. One example of a Superfund site potentially releasing PAHs is the Federal Creosote site, a former coal tar wood treatment facility in Somerset County, New Jersey, approximately one-half mile south of the Raritan and Millstone Rivers. While the facility was in operation, excess creosote was discharged into unlined canals, which fed into two unlined lagoons. In the 1960s, after the facility was closed but prior to removal of creosote, 137 single-family homes and a mall were built on top of the site. It is estimated that 212,000 tons of creosote-contaminated soil were at the site. Thus far, river surface water and sediments are reported to be free of contamination [192] and cleanup has been completed on 15 acres of the site, from which approximately 200,000 tons of soil has been removed. Cleanup of the remaining 35 acres is ongoing [193].

Formerly Used Defense Sites: The U.S. Department of Defense (DOD) is responsible for the remediation of any formerly used defense sites (FUDS) that have been found to be contaminated as a result of activities administered by the U.S. DOD. This program, which is administered by the U.S. Army Corps of Engineers, addresses sites such as former NIKE missile sites. The NIKE sites, developed under a national program that was in place during the 1950s to the 1970s, were constructed to protect major metropolitan areas and strategic military installations from aerial attack. Operations and maintenance of missile batteries required the use, storage, handling, and disposal of solvents, fuels, hydraulic fluids, paints, and other materials, which sometimes resulted in contamination of subsurface soil and/or groundwater with petroleum hydrocarbons, among other compounds.

There are approximately 338 sites in New York and 112 sites in New Jersey eligible for the cleanup program. In the Watershed, there are 33 and 12 eligible sites in New York and New Jersey, respectively, most of which have been identified as having hazardous material. Although many sites have received preliminary investigations, budget constraints have delayed further investigation and remediation of contaminants at

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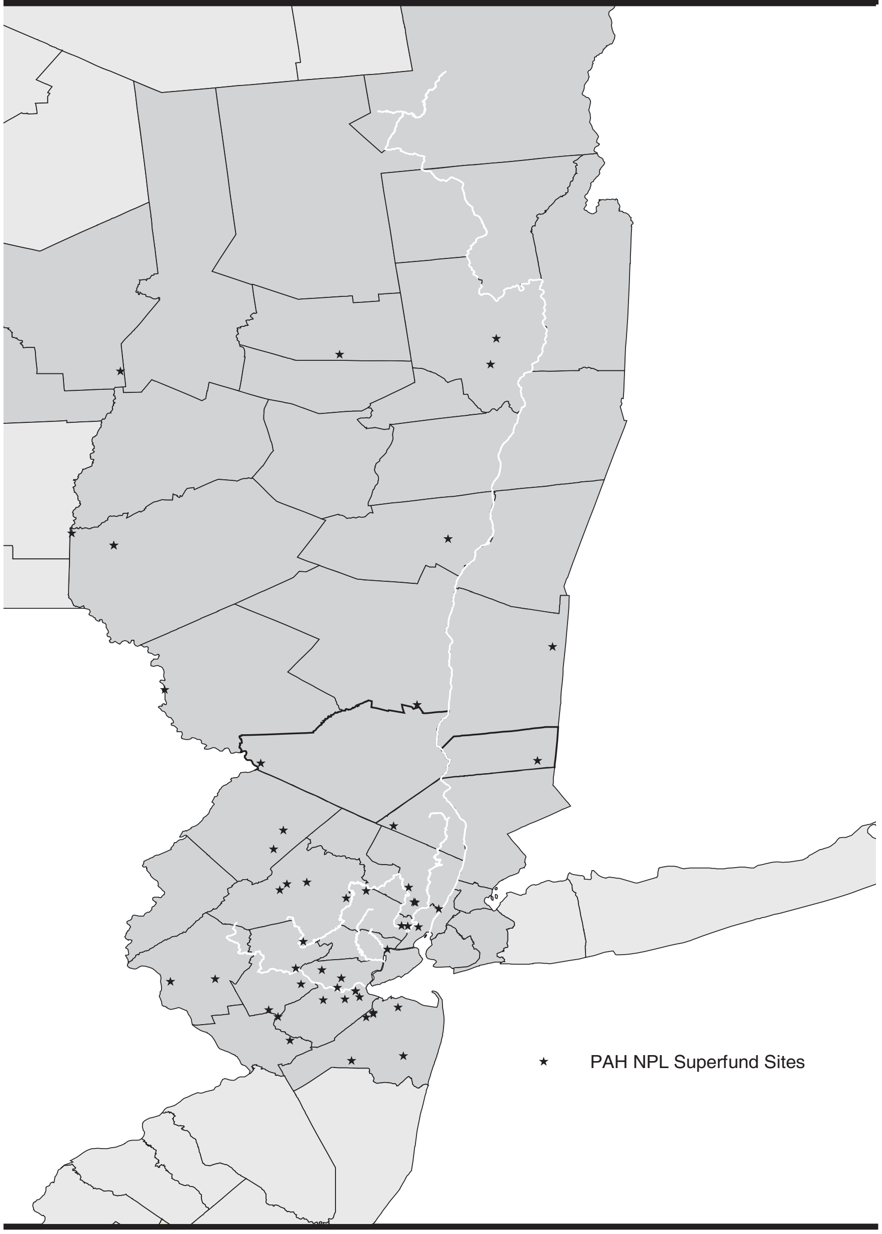
[136] This number was obtained from the U.S. EPA's National Priority List. It is possible that remediation has taken place at some of these sites. However, given that these sites are referred to as "Currently on the Final NPL" list, it is assumed that these sites are still contaminated.

[137] Statewide, there are 59 Federal Superfund sites contaminated with PAHs in New Jersey and 43 in New York [191].

Figure 3.8. PAH-contaminated Superfund sites in the Watershed



most of these sites. We were unable to obtain estimates of potential PAH contamination at the sites. However, because most of the sites are contaminated with fuel, it is likely that there are elevated levels of PAHs.

State Contaminated Sites: New York and New Jersey manage state contaminated sites, typically those sites that are not part of the Superfund program. One such group of state-managed sites is the former manufactured gas plants (MGPs). Manufacturing gas, a common source of energy in New York in the early-to-mid-1900s, has left a legacy of contaminated soils and water across the U.S., in New York and New Jersey specifically. Manufacturing gas from coal consists of primarily two processes: 1) a coal carbonization process in which coal is heated in closed ovens and kept from burning, harnessing and piping out the volatile constituents; and 2) a carbureted water–gas process, in which coal or coke is heated in a closed vessel into which steam and petroleum products are injected, causing the petroleum constituents to "crack," forming methane. A byproduct of both of these processes is a tar/water emulsion.[138] Over decades of operation, gallons of tar leaked from many storage and processing facilities, contaminating surrounding surface and subsurface soils as well as groundwater.

Although there are no MGPs currently operating in New York or New Jersey, evidence remains of their previous popularity. The New York State Department of Environmental Conservation reports that there are an estimated 300 former MGP sites in New York. Of these, remedial programs are either underway or scheduled to start at 194 of the sites (135 of which are in the Watershed, 24 in Manhattan alone) [194]. In New Jersey there are approximately 90 former MGP sites undergoing investigation and remediation. The list of former MGPs is not complete, and both states acknowledge the likelihood of additional unidentified sites owned by smaller and no longer existing utility companies.

In addition to MGP sites, there are other state PAH-contaminated sites. New York state reports 126 sites contaminated with PAHs (in addition to former MGPs) that are scheduled for remediation. It is unknown whether or how many contaminated sites exist in New York that are not considered to be under remediation.

New Jersey also has state sites contaminated with PAHs, although the exact number is unknown. One example is the Standard Chlorine Chemical Company in Kearny, New Jersey (this site is also on the U.S. EPA National Prior-

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[138] Additional byproducts are purifier waste composed of lime or wood chips treated with iron oxides.

Table 3.21. Sites contaminated with PAHs currently on the U.S. EPA Superfund Final National Priority List[a]

NPL site name	City	State	County
Quanta Resources	Edgewater	NJ	Bergen
Scientific Chemical Processing	Carlstadt	NJ	Bergen
Universal Oil Products (Chemical Division)	East Rutherford	NJ	Bergen
Curcio Scrap Metal Inc.	Saddle Brook	NJ	Bergen
Caldwell Trucking Co.	Fairfield	NJ	Essex
Diamond Alkali Co.	Newark	NJ	Essex
Syncon Resins	South Kearny	NJ	Hudson
PJP Landfill	Jersey City	NJ	Hudson
Myers Property	Franklin Township	NJ	Hunterdon
De Rewal Chemical Co.	Kingwood Township	NJ	Hunterdon
Fried Industries	East Brunswick Township	NJ	Middlesex
Chemical Insecticide Corp.	Edison Township	NJ	Middlesex
Kin-Buc Landfill	Edison Township	NJ	Middlesex
Jis Landfill	Jamesburg/S. Brunswick	NJ	Middlesex
Chemsol, Inc.	Piscataway	NJ	Middlesex
Evor Phillips Leasing	Old Bridge Township	NJ	Middlesex
Global Sanitary Landfill	Old Bridge Township	NJ	Middlesex
Atlantic Resources	Sayreville	NJ	Middlesex
Sayreville Landfill	Sayreville	NJ	Middlesex
Waldick Aerospace Devices, Inc.	Wall Township	NJ	Monmouth
Naval Weapons Station Earle (Site A)	Colts Neck	NJ	Monmouth
Bog Creek Farm	Howell Township	NJ	Monmouth
Lone Pine Landfill	Freehold Township	NJ	Monmouth
Burnt Fly Bog	Marlboro Township	NJ	Monmouth
Imperial Oil Co., Inc/Champion Chemicals	Morganville	NJ	Monmouth
Sharkey Landfill	Parsippany, Troy Hills	NJ	Morris
Dover Municipal Well 4	Dover Township	NJ	Morris
Rockaway Township Wells	Rockaway Township	NJ	Morris
Dayco Corp./L.E. Carpenter Co.	Wharton Borough	NJ	Morris
Asbestos Dump	Millington	NJ	Morris
Higgins Disposal	Kingston	NJ	Somerset
Montgomery Township Housing Development	Montgomery Township	NJ	Somerset
American Cyanamid Co	Bound Brook	NJ	Somerset
Higgins Farm	Franklin Township	NJ	Somerset
Metaltec/Aerosystems	Franklin Borough	NJ	Sussex
A. O. Polymer	Sparta Township	NJ	Sussex
Chemical Control	Elizabeth	NJ	Union
GCL Tie and Treating Inc.	Village of Sidney	NY	Delaware
Richardson Hill Road Landfill/Pond	Sidney Center	NY	Delaware
Sidney Landfill	Sidney	NY	Delaware
Sarney Farm	Amenia	NY	Dutchess
Johnstown City Landfill	Town of Johnstown	NY	Fulton
American Thermostat Co.	South Cairo	NY	Greene
Ludlow Sand & Gravel	Clayville	NY	Oneida
Carrol & Dubies Sewage Disposal	Port Jervis	NY	Orange
Brewster Well Field	Putnam	NY	Putnam
Ramapo Landfill	Ramapo	NY	Rockland
Malta Rocket Fuel Area	Malta	NY	Saratoga
Niagara Mohawk Power Corp.	Saratoga Springs	NY	Saratoga
Cortese Landfill	Village of Narrowsburg	NY	Sullivan
Hertel Landfill	Plattekill	NY	Ulster

Source: EPA Superfund National Priority List [191].

a The Harbor Project will provide further discussion on releases from contaminated sites via stormwater runoff in a forthcoming report.

ity Proposed Listing). The 24-acre site, located along the Hackensack River, formerly housed a chemical manufacturing facility whose operations included the production and refinement of naphthalene, the storage and packaging of 1,4-dichlorobenzene moth repellents and deodorizers, the production of dye carriers, and the processing of liquid petroleum naphthalene for the manufacture of mothballs and flakes, as well as several other manufacturing activities. There are several contaminated "hot spots" within the site, including two lagoons on the eastern portion of the property. The contaminated spots ultimately drain into the Hackensack River via three probable points of entry: a drainage pipe, a drainage ditch, and an overland runoff that flows directly from the property to the river. In 2002, the U.S. EPA sampled surface water from the outfall discharging to the Hackensack and found concentrations of naphthalene at 45 μg/kg.

3.6. Sources For Which Emission Factors Were Not Available

There are several sources of PAHs in the Watershed for which emission factors were not available, precluding the calculation of PAH releases (Table 3.22). It is possible that some of these sources are relatively significant sources of PAHs, and efforts should be made to develop a means for quantifying their potential contribution to total PAH releases. Some of the sources listed in this section have already been addressed under their source category and are listed here for reference.

Table 3.22. Sources of PAHs in the Watershed for which an emission factor was not available

Source/activity (discussed in this section)
Structural fires and vehicle fires
Asphalt pavement and roofs
Leaking underground storage tanks
Commercial charbroilers
Fire works
Campfires
Source/activity (discussed previously in this report)
Outdoor wood boilers
Brake dust
Nonroad tire wear
Used motor oil disposal and leakage from nonroad equipment

3.6.1. Structural and Vehicle Fires

Structural and Vehicle Fires: National Trends and Emission Factors

PAH emissions from structural and vehicle fires depend on combustion conditions and materials combusted. The paucity of data at this time on PAH emissions from structural fires precludes us from calculating PAH releases from this activity. In fact, in a paper submitted to Environment Canada, the authors were unable to find source testing information or emission factors for BAP and PAHs from structural fires [195].

There are several studies available that provide some information on the release of PAHs from structural fires. For example, one study calculated the concentration of PAHs in gaseous plumes from structural fires. However, these data do not allow us to calculate a PAH release rate. Another example is a study by Ruokojarvi et al. [196], in which various materials found in a typical structure were combusted and gaseous PAH samples were taken. These authors found total PAH concentrations to be high, 6 to 470 mg/m^3.[139] A study by the Swedish National Testing and Research Institute collated data on PAH emissions from the combustion of some of the most common types of building materials in houses, schools, and other occupancies [197]. The levels of emissions calculated were uncertain, but potentially provide an order of magnitude of emissions from various materials. Unfortunately, emission factors by compound were not provided, and regional fire activity data were not detailed enough to allow an emission estimate to be calculated.

Structural and Vehicle Fires: Regional Releases

With the data available, we are unable to estimate PAH emissions from structural fires at this time; however, it is possible that this is a significant source, given the activity level (Table 3.23).

Table 3.23. Structural fires in New York and New Jersey, 2001

	Number of fires
Watershed	
NY	32,334
NJ	3741
Total	**36,075**
Outside Watershed	
NY	4264
NJ	3094
Total NY+NJ	**43,433**

Sources: New York State Dept. of State, Office of Fire Prevention and Control [198]; Puskar [199]

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[139] Total PAH refers to the U.S. EPA 16 priority PAHs, excluding naphthalene.

3.6.2. Asphalt Pavement and Roofs

Asphalt Pavement and Roofs: National Trends and Emission Factors

Asphalt pavement is ubiquitous throughout the Watershed and is used to construct roadways and parking lots. Asphalt pavement contains aggregate (~95%) and petroleum-based asphalt binder (~5%), and the concentration of PAHs in the asphalt depends on the type of crude petroleum used to produce the binder. There is very little literature available on the concentration of PAHs in asphalt pavements. However, a report by Grosenheider et al. [200] provides an average concentration of PAHs in seven asphalts—10 mg/kg. This report also summarizes the findings of several studies that analyzed the concentration of PAHs in asphalt pavement leachate [201] [202] [203] [204]. In general, PAH concentrations in leachate were low, in some cases below the detection limit. None of these reports, however, account for PAHs that are volatilized from asphalt after it is installed.

Asphalt is also used to make roof shingles and to construct what are referred to as "built-up roofs."[140] A study conducted in Austin, Texas compared runoff from asphalt shingled roofs and metal roofs in similar environmental conditions, and found no difference in the concentration of particle-bound PAHs [205]. The authors conclude that asphalt roofs are not a source of PAHs to stormwater runoff.

Emission factors for PAHs released from asphalt pavement and roof shingles are not available at this time.

3.6.3. Leaking Underground Storage Tanks

Leaking Underground Storage Tanks: National Trends and Emission Factors

PAHs may be released to surrounding soil and potentially reach groundwater via leaking underground petroleum storage tanks. In the United States, there are approximately 660,000 federally regulated underground storage tanks, with approximately 25,000 tanks containing hazardous material (4%) and the remaining tanks holding petroleum [207]. These tanks may be located at service stations and convenience stores, as well as at private fleet and municipal garages. It was reported that in 2004 there were a total of 450,000 confirmed releases at these sites nationwide [208]. Many releases from underground storage tanks are the result of human error, oftentimes during material delivery. Under-

Figure 3.9. Registered underground storage tanks in New Jersey [206]

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[140] Built-up roofs (BURs) are typical of older, flat-roofed buildings. BURs consist of layers of reinforcing felt between either asphalt or coal tar bitumen, with a top layer of gravel that serves to hold the layers down and protect against UV damage. Recently, people have begun to apply reflective coatings to flat roofs, such as elastomeric coatings to reduce heat gain.

ground releases may be the result of corroded holding tanks and are often undetected, releasing unknown quantities of material.

Leaking Underground Storage Tanks: Regional Releases

Over the years, releases have been reported at underground storage tanks in New York and New Jersey that are regulated by the U.S. EPA (Table 3.24).[141] Based on data provided by the U.S. EPA's Corrective Measures Reports, the ratio of confirmed spills to active tanks has increased over the past five years for tanks registered in New York and New Jersey [208].

Releases to Land. Due to the nature of the reporting and the dearth of information, the quantity of material released cannot be estimated.[142] As indicated by Figure 3.9, tanks cluster around the Harbor, and spills from these facilities may be released directly to a waterway.

3.6.4. Charbroiling

Charbroiling: National Trends and Emission Factors

Commercial charbroiling or cooking of meat generates PAHs that either accumulate on the outer layer of grilled food or are released to the atmosphere. The quantity of PAHs generated and emitted to the atmosphere varies with food type and fat content. One study found that cooking "Western" food generated more total PAHs than did Chinese, Japanese, and fast food [211].[143] In a study conducted by Rogge et al. [212], total PAH emissions were reported for extra-lean hamburger (0.71 mg/kg) and regular hamburger (2.32 mg/kg).[144] In addition to commercial cooking, recreational barbecuing generates PAH emissions.

The South Coast Air Quality Management District identified commercial charbroiling as a significant source of particulate and hydrocarbon pollution, and in 1997 adopted a measure that requires chain-driven charbroilers to install devices such as catalytic oxidizers to reduce air pollution.[145]

3.6.5. Fireworks

Fireworks: National Trends and Emission Factors

Fireworks, used to mark private and public celebrations, are generally a seasonal source of PAHs. Fireworks are composed mostly of gunpowder, and the quantity of PAHs released depends on the firework design and chemical composition.

3.6.6. Campfires

Campfires: National Trends and Emission Factors

Campfires and bonfires are a type of uncontrolled combustion, and release PAHs to the atmosphere through incomplete combustion of wood and waste. Emissions from this source likely reflect seasonal variation of outdoor activities such as summer camping, and depend on the types of material combusted and combustion conditions.

Table 3.24. Federally registered tanks, releases, and cleanups initiated in New York and New Jersey, 2004

State	Active tanks	Releases	Cleanups
New Jersey	18,608	9383	5558
New York	30,161	19,621	17,324

Source: U.S. EPA [210].

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[141] The U.S. EPA maintains jurisdiction over those tanks that hold petroleum, waste oil, and hazardous substances. States maintain control over additional tanks that contain hazardous substances not regulated by the EPA, as well as hazardous waste and emergency spill tanks [209].

[142] The quantity of soil removed as a result of a spill is reported, not the quantity of material released. Reports for leaks in New York and New Jersey were either available in a case-by-case format or, in some instances, not available at all.

[143] Cooking of Western food includes grilling, broiling, roast, deep frying, smoking, and stewing.

[144] Where total PAH includes fluoranthene, pyrene, benzo[a]anthracene, benzo[k]fluoranthene, benzo[b]fluoranthene, benzo[a]pyrene, perylene and benzo[ghi]perylene.

[145] A catalytic oxidizer is a control device that burns or oxidizes smoke and gases from the cooking process into carbon dioxide and water by using an infrastructure coated with a noble metal alloy.

4. MINOR REGIONAL SOURCES OF PAHS

The following are considered minor PAH sources in the Watershed because they constitute, individually, 2% or less of the total emissions to their primary medium of release (air, water, and land). While these sources are considered minor, they still contribute to the overall releases of PAHs in the Watershed. Furthermore, these sources may be considered major sources to local environments and in other regions.

Most of the minor sources discussed in this section are combustion sources, with the exception of gasoline distribution (18% of total minor atmospheric releases; Table 4.1). The largest of the minor atmospheric sources is power generation, which makes up approximately 19% of atmospheric emissions from minor sources.

The following sections discuss emission estimates, relevant policy, and pollution prevention recommendations for the minor PAH sources in the Watershed; these sources are in the same order as in the previous section on major regional sources of PAHs.

4.1. Heating Fuel Combustion

4.1.1 Residential Fuel Combustion - Petroleum, Coal, Natural Gas, and Kerosene

Residential Fuel Combustion: National Trends and Emission Factors

Boilers, heaters, and stoves are all used to heat homes through the combustion of oil, coal, and natural gas, a process that generates PAHs. In 2001, approximately 80% of all British thermal units (BTUs)[146] consumed by the U.S. residential sector were from natural gas, and 16% were from oil. Coal combustion, a more prominent residential heating fuel in the 1960s (9% of residential energy consumption), currently comprises only slightly more than 1% of BTUs consumed in this sector [213]. Not all of the fuel consumed by the residential sector is used for heating[147]; however, space heating accounts for more than 70% of gas consumption and 90% of oil consumption in the U.S. residential sector [214].

The U.S. EPA has compiled PAH emission factors for residential boilers and furnaces that combust petroleum, natural gas, and coal (Table A.3) [215]. Residential combustion heating units are typically not equipped with pollution controls and rely on the complete combustion of fuel for pollution minimization. Therefore, none of the emission factors reflect equipment that uses any type of pollution control device.

Residential Fuel Combustion: Regional Releases

In the New York and New Jersey Watershed, 65% of homes reported to the 2000 Census that natural gas is their primary heating fuel, 35% use petroleum, and less than 1% use coal or wood [77]. This trend is reflected in the annual state residential fuel consumption (Table 4.2), in which over 60% of BTUs consumed by the residential sector in New York are from natural gas. To estimate fuel consumed in the Watershed, it was assumed that residential consumption of fuel is proportional to the percentage of homes that report using that fuel as their primary heating source.

Releases to the Atmosphere. PAH emissions from residential fuel combustion were calculated by applying the emission factors presented in Table A.3 to the quantity of fuel consumed in the region (Table 4.2). Although more BTUs of natural gas are consumed, our estimates identify oil combustion as a larger source of PAHs from this sector.

There are uncertainties with this estimate, since boiler and furnace efficiencies vary between households and emission factors are missing for several PAH compounds, including naphthalene.

Measures to Reduce Releases of PAHs from Residential Fuel Combustion

PAH emissions from these types of heating units are directly related to the type of feedstock combusted and to the efficiency of the unit. A boiler or furnace's efficiency is characterized by its Annual Fuel Utilization Efficiency (AFUE) rating, which compares the quantity of heat delivered to the home with the quantity of fuel that is supplied to the heating unit. The 1992 efficiency standards specify the following AFUEs: gas- and oil-fired furnaces, 78%; manufactured home furnaces, 75%; hot-water boilers, 80%; and steam boilers, 75% [214]. The U.S. Department of Energy is currently working on an update to the 1992 efficiency standards and has posted an Advanced Notice of Pro-

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[146] A British thermal unit (BTU) is the quantity of heat required to raise the temperature of one pound of water from 60°F to 61°F at a constant pressure of one atmosphere. Converting fuel, which is often reported in different units (i.e., barrels, billions of cubic feet [BCF], and tons), into BTUs allows data to be compared.

[147] Fuel may be used to heat homes, to power appliances such as cooking stoves, and to heat water.

Table 4.1. Summary of releases of PAHs from minor sources within the Watershed[a]

	PAH release in the Watershed		Emission factor/ratios applied		Level of regional activity
Source	**Quantity released (kg/yr)**	**Medium of release**	**Particle bound or gaseous**	**Uncertainty[b]**	**Uncertainty[c]**
Heating fuel combustion					
Residential	4500	A	Coal–P&G Gas–uk Oil–uk	E	II
Commercial	9000	A	Coal–P&G Gas–P&G Oil–P&G	Coal–E Gas–D Oil–E	II
Materials containing PAHs					
Naphthalene (mothballs)	267,000	A	G	C	III
Naphthalene (solvents)	2500	A	NA	NA	NA
Transportation					
Personal watercraft	1100	A	P&G	E	II
Vessels	600	A	P	E	II
Port-related activity	100	A	P	E	II
Locomotives	1300	A	P	D	II
Airplanes	70	A	uk	uk	II
Car washing	<1	W	P	uk	III
Uncontrolled combustion					
OB of household waste	1400–8000	A	P&G	C	IV
OB agricultural waste	1	A	uk	C	IV
Tire fires	9000	A	G	B	V
Industrial Sources					
Industrial fuel combustion	2700	A	Coal–P&G Gas–uk Oil–P&G	Coal–D Gas–D Oil–D&E	II
Refineries	1200	A/W	NA	NA	NA
Gasoline distribution	4000–20,200	A	G	B	IV
Power generation	12,500	A	Coal–uk Gas–G Oil–uk	Coal–uk Gas–D Oil–C	II
Incineration	1200–1600	A/L	uk	C	II
Steel production	200	A	uk	D	I
Cement production	3700	A	uk	E&D	I
Pulp & paper production	30	A	uk	D	II
Cigarette smoke	**160**	**A**	**uk**	**A**	**II**
Additional facilities reporting to the U.S. EPA TRI	**4000**	**A**	**NA**	**NA**	**NA**

A=air, L=land, W=water; G=gaseous; P=particle bound; NA= not available; OB= open burning; uk= unknown

[a] Sources are considered minor if they contribute 2% or less to total PAHs to their primary medium of release.

[b] The U.S. EPA rates emission factors in their AP-42 database of air pollutant emission factors, with ratings ranging from A to E (A being the best). The ratings give a general indication of the reliability or robustness of a factor. When emission factors were not rated by the U.S. EPA or another source, the same metrics used by the U.S. EPA to assign a rating were applied. See Appendix D for a description of rating metrics.

[c] A rating system similar to that used by the U.S. EPA was created to represent the uncertainty of activity levels used to estimate emissions. See Appendix D for a description of ratings.

Table 4.2. Residential fuel consumption and associated PAH emissions in New York and New Jersey

	Oil[a]		Natural gas		Coal		Kerosene	
	Barrels	Trillion BTUs	BCF	Trillion BTUs	Ton (short)	Trillion BTUs	Barrels	Trillion BTUs
Watershed								
New Jersey	6,625,000	39	154	160	315	0.03	286,840	2
New York	24,546,000	143	228	236	5635	1	1,607,165	9
Total	31,171,000	182	382	396	5950	1	1,894,005	11
Total PAH emissionsb (kg/yr)	**4100**		**100**		**300**		**20**	
Outside Watershed								
New Jersey	2,844,000	17	56	58	185	0.02	123,160	1
New York	11,956,000	70	148	153	7365	2	782,835	4
Total	**14,800,000**	**86**	**204**	**211**	**7550**	**2**	**905,995**	**5**
Total PAH emissions[b] (kg/yr)	**2000**		**100**		**400**		**10**	

BCF= billion cubic feet

Source: U.S. Energy Information Administration [75].

a Distillate fuel oil also referred to as No. 2 or No. 3 fuel oil.

b PAH emission estimates are based on emission factors presented in Table A.3.

posed Rulemaking.[148] Efficiency standards are established and enforced by the Federal government. However, in 2005, the Natural Gas Price Reduction Act was introduced; it would permit regions to establish and enforce their own efficiency standards in place of uniform national standards [216]. The Act would allow regions to implement stricter standards, possibly in areas where atmospheric emissions are of concern. However, a patchwork of standards would make compliance difficult for heating appliance manufacturers and distributors. At this time, the Act has not passed.

In addition to improving the efficiency of new boilers and furnaces, older units can be retrofitted with technology that improves fuel combustion conditions. For example, older units can be retrofitted with a catalyst that breaks apart fuel clusters, allowing fuel that would otherwise be trapped inside the cluster to combust.

The following are pollution prevention recommendations that reduce releases of PAHs from residential fuel combustion in the Watershed:

- Update national efficiency standards for residential heating units to reflect best available technology.
- Promote the use of high efficiency heating units (90% AFUE rating or greater), possibly through an incentive program.[149,150]
- Reduce fuel combustion (see earlier section Measures to Reduce Emissions from Residential Wood Combustion).

4.1.2. Commercial Fuel Combustion- Petroleum, Coal, and Natural Gas

Commercial Fuel Combustion: National Trends and Emission Factors

Commercial boilers are used to provide space heating for commercial establishments, multi-family residential buildings, medical institutions, and educational institutions. While multifamily buildings (apartment buildings) may technically be considered residential, given the size of the boiler needed to heat the space, they typically are categorized as commercial space. Commercial fuel combustion is prevalent throughout the U.S. and tends to concentrate in areas of dense industry and population. In 2003, approximately 90% of commercial fuel consumed in the U.S. was natural gas, most of which was consumed in office and educational facilities [217]. PAH emissions are associated with the combustion of fuels including wood waste, natural gas, coal, and oil—residual (No. 6) and distillate (No. 2).

The U.S. EPA compiled PAH emission factors for commercial boilers that combust petroleum, natural gas, and coal (Table A.3) [215]. There are several PAH

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148. For more information, see the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, http://www.eere.energy.gov/buildings/appliance_standards/residential/furnaces_boilers.html.

149. Energy Star provides a list of energy efficient residential furnaces, http://www.energystar.gov.

150. New Jersey's Clean Energy Program distributes financial incentives to eligible residents who exchange their old furnace for a furnace with a 90% AFUE rating or greater.

compounds for which there are no reported emission factors, making it difficult to calculate a comprehensive estimate of PAH emissions from this source. However, these emission factors are the best available at this time, and represent emissions testing results from uncontrolled boilers.

Commercial Fuel Combustion: Regional Releases

The commercial sectors in New York and New Jersey consume approximately 50% and 34% of total state BTUs, respectively [75]. In 2001, New York's commercial sector was reported to be the third largest fuel consumer (1303 trillion BTUs)[151] nationwide, preceded only by California and Texas [213]. Based on the quantity of BTUs consumed, natural gas is the primary fuel combusted in Watershed commercial boilers (Table 4.3).

Releases to the Atmosphere. PAH emission estimates are calculated by applying emission factors in Table A.3 to the quantity of fuel consumed by the commercial sector in the Watershed (Table 4.3). Due to the lack of emission factors for several PAH compounds it is difficult to conclude which fuel releases the most PAHs when combusted.

Measures to Reduce Releases of PAHs from Commercial Fuel Combustion

Similar to residential fuel combustion, commercial fuel combustion can be minimized by employing energy efficiency measures and practices. For example, the U.S. Green Building Council has established a Leadership in Energy and Environmental Design (LEED) program for commercial buildings, in which buildings that utilize sustainable design and construction practices are rewarded with a certification.[152]

Recommended pollution prevention strategies are as follows:

- Reduce fuel combustion (see Measures to Reduce Emissions from Residential Wood Combustion).
- Target energy efficiency measures towards office and educational facilities, the sites consuming the most commercial fuel.

Table 4.3. Commercial sector fuel consumption and associated PAH emissions in New York and New Jersey[a]

	Petroleum Distillate fuel (No.2) & residual fuel (No. 6)		Natural gas		Coal	
	No. of barrels	**Trillion BTUs**	**BCF**	**Trillion BTUs**	**Ton (short)**	**Trillion BTUs**
Watershed						
New York	12,991,000	77	187	194	54,540	1
New Jersey	1,852,000	11	67	69	1960	0.05
Total	**14,843,000**	**89**	**255**	**263**	**56,500**	**1**
Total PAH emissions[b] (kg/yr)	**6700**		**4**		**2300**	
Outside Watershed						
New York	11,067,000	66	160	165	46,460	1
New Jersey	1,927,000	11	70	72	2040	0.05
Total	**12,994,000**	**77**	**229**	**237**	**48,500**	**1**
Total PAH emissions[b] (kg/yr)	**3700**		**2**		**1300**	

Source: U.S. Energy Information Administration [75].

BTU=British thermal units; BCF= billion cubic feet.

[a] In addition to the fuel types listed, kerosene and liquid propane gas were consumed (5 trillion and 3 trillion BTUs in New York, and 7 trillion and 1 trillion BTUs in New Jersey, respectively) However, because no emission factor is available for either of these fuel types, they are not included in these estimates. Motor gasoline and electricity were also considered, and it is assumed that emissions estimates from consumption of these are captured in Section 3.3.1 Transportation and Section 4.5.3 Power Generation, respectively.

[b] PAH emission estimates are based on emission factors presented in Table A.3.

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[151] This value is the sum of all fuel types reported by the U.S. EIA in 2001 and includes coal, natural gas, kerosene, LPG, motor gasoline, distillate and residual fuel, wood and waste, and electricity. Not all of these fuel types are presented in Table 4.3.

[152] Areas of sustainable design addressed by the LEED rating system are site selection, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. The LEED rating system is available for new construction, existing buildings, commercial interiors, and core and shell projects. A residential home rating system is in development. For more information visit the U.S. Green Building web site, http://www.usgbc.org.

4.2. Materials Containing PAHs

4.2.1 Naphthalene Use

Naphthalene Use: National Trends and Emission Factors

The 1999 NEI data place consumer and commercial products containing PAHs as a dominant nonpoint source for total PAH emissions. The vast majority of emissions from production, processing, and use of products with PAHs come from one compound—naphthalene. In general, naphthalene is expected to be released in the greatest quantities from products containing PAHs because naphthalene has the highest vapor pressure and thus can volatize easily. Commercial products that may contain PAHs and release them to the atmosphere include some solvents, such as those used in the metal coating process and in paints. Some PAH-containing consumer products include dandruff shampoo and mothballs.[153] It was estimated in 1999 that naphthalene in the U.S. was consumed by the following end uses: phthalic anhydride[154] (59%), surfactant and dispersant chemicals (21%), insecticides (11%), and mothballs and miscellaneous purposes (9%) [60]. PAHs released to the air from products including mothballs would be expected to reach the Harbor by absorption into water from the atmosphere, or via wet or dry particle deposition after PAHs in the atmosphere adsorb onto soot particles. Emission of naphthalene via wastewater is also possible, although the water solubility of naphthalene is low and the volatility is high.

If it is assumed that 5% of annual naphthalene consumption (108,000 tons/yr in 1996 [60]) is used to produce mothballs, and that all of the naphthalene is eventually emitted to the atmosphere, the release of naphthalene could be approximately 5450 tons per year nationwide. The production of naphthalene-based moth repellent has declined over the years as a result of the availability of para-dichlorobenzene (p-DCB) and the increased use of synthetic fibers [218].[155]

Aromatic solvents used in the metal coating process can contain high concentrations of naphthalene, approximately 3% to 6% by weight [220].[156] During the paint coating process, which includes application and settling,[157] atmospheric emissions may be generated. Ninety-eight percent of the naphthalene used in this process must be contained (i.e., of the 100 parts of naphthalene entering the process, only 2 parts are allowed to be emitted) [220]. Many of these facilities utilize thermal oxidizers to destroy potential atmospheric emissions. Naphthalene-deficient/free coatings and solvents are available; however, these products may have formation and performance issues.

Naphthalene Use: Regional Releases

Mothballs

Releases to the Atmosphere. Data that can be used to quantify the consumption of mothballs in the Watershed region are not available. An estimate of naphthalene emissions from mothballs can be calculated by extrapolating from the national emissions data presented above (5450 tons/yr) based on Watershed population (Table 4.4). It is likely that this is an overestimate because most mothballs in use today are composed of p-DCB.

Table 4.4. Naphthalene released from mothball use, assuming all mothballs used annually are eventually emitted to the atmosphere[a]

	Percent of U.S. population[b]	Naphthalene[c] (kg/yr)
Watershed	4.9	267,000
Outside Watershed (NY & NJ)		239,800

Source: International Programme on Chemical Safety [59].

a Estimates extrapolated from national emissions data (5500 tons naphthalene mothballs/yr) based on population in the region.

b 2000 Census.

c Estimates assume that all the naphthalene in mothballs consumed in a year is emitted.

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[153] It was reported in 2002 that naphthalene is no longer used directly in tanneries, in the textile industry, and in the production of toilet deodorizers [60].

[154] The production of phthalic anhydride includes the oxidation and refining of a feedstock; in this case naphthalene o-xylene can also be used. It is expected that 100% of the feedstock is converted to product and that there are no processing emissions. The only emissions associated with this product are fugitive releases that occur when napthalene is transferred [215].

[155] Para-dichlorobenzene (p-DCB), an aromatic compound that contains a chlorine-substituted benzene ring, is used to make mothballs that smell similar to naphthalene mothballs. Exposure to p-DCB may cause irritation to the eyes, nose, and throat. The Department of Health and Human Services has determined that p-DCB may reasonably be anticipated to be a carcinogen; however, there is no direct evidence that it causes cancer in humans [219].

[156] Solvents may be added to paints to obtain the desired viscosity.

[157] Settling consists of baking the coated metal in an oven, allowing for an even film. Once the metal coating is done, a conveyer-like system transports the material to a quencher, where it is cooled with cold water.

Solvents

Releases to the Atmosphere. There are three metal-coating and fabricating facilities in New Jersey (none in New York), all of which are in the Watershed. Their naphthalene atmospheric emissions, as reported to the U.S. EPA's Toxics Release Inventory (TRI), are presented in Table 4.5.

Table 4.5. Naphthalene emissions from metal-coating and allied service facilities in the Watershed, as reported to the U.S. EPA's Toxics Release Inventory, 2005

Location of facility	Naphthalene (kg)	
	Fugitive	Stack
Watershed		
Middlesex	74	2200
Middlesex	119	168
Mercer	61	104
Total	**254**	**2472**

Source: U.S. EPA Toxics Release Inventory, 2005 [221].

Measures to Reduce Releases of PAHs from Products Containing PAHs

Although most mothballs (and all urine deodorizers) consumed today are manufactured with p-DCB instead of naphthalene, utilizing alternative products and practices will reduce the release of both naphthalene and p-DCB.

Moth larvae feed on natural materials such as wool, fur, and leather, as well as lint, dust, and paper. When clothing is placed in an air-tight container with mothballs, the naphthalene fumes can accumulate in a concentration that will kill moths and moth larvae. Although mothballs are often perceived as the only combatant, there are alternative products and practices that can be utilized to protect clothing from moths. Moth larvae are especially harmful to fabric stained with food, beverages, urine, and sweat. Removing stains and cleaning fabric regularly are practices that will help control moth damage. Other measures include placing clothes in a tightly sealed container, such as a vacuum-sealed plastic bag, and replacing mothballs with cedar chips, lavender, rosemary, or any other scent that will mask the smell of clothes [222].[158]

The following are pollution prevention recommendations to reduce releases of PAHs associated with mothball use in the Watershed:

- Educate consumers on alternative methods for repelling moths.
- Consider discontinuing the sale of naphthalene mothballs. This should be coupled with education on alternative, nontoxic methods, so as to discourage consumers from switching to toxic alternatives such as p-DCB.
- Data gaps.
  - A better understanding of the current mothball market is needed.

The U.S. EPA has made efforts to reduce the use of metal coatings containing naphthalene through their National Partnership for Environmental Priorities, in which voluntary partnerships are formed with public and private organizations to reduce the quantity of priority chemicals reported to the Toxics Release Inventory. Through this program, for example, Material Science Corporation was able to reduce the use of naphthalene by substituting for solvents and paints with naphthalene-free products provided by PPG Industries.[159,160]

The following are pollution prevention recommendations to reduce releases of PAHs from metal-coating facilities in the Watershed:

- Research and develop well-performing naphthalene-free metal-coating materials.
- Promote the use of low-naphthalene and naphthalene-free products through voluntary programs and outreach to the coatings industry.

4.3. Transportation

4.3.1. Nonroad Engine Exhaust

Personal Watercraft: National Trends and Emission Factors

Personal watercraft with inboard or outboard, two- or four-stroke, gasoline or diesel engines are also considered nonroad equipment.[161] Four-stroke marine

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[158] Masking the smell of clothes will not kill moths or their larvae; however, it will deter moths from laying eggs.

[159] For more information on the EPA's National Partnership for Environmental Priorities, visit http://www.epa.gov/epaoswer/hazwaste/minimize/partnership.htm.

[160] The following are additional manufacturers of low- or no-naphthalene solvents, with the reported naphthalene content in their solvents by percent weight: Advanced Aromatics (nondetect), Exxon (<1%), State Chemical Manufacturing Company (<1%), Citgo (0.047%), Ultra Scientific (0.3%), American Refining Group Inc. (0.4%), Accustandard Inc. (0.4%), Exxon/Mobil (0, 0.03%, 0.4%, and 0.7%), and Koch Chemical Company (0.7%) [223].

[161] This includes personal boats and other recreational watercraft such as jet skis.

engines have been found to release up to three times fewer PAHs than four-stroke engines, [164].

The emission fractions used to calculate PAH releases are those used in the MOBILE6 model. Both the emission fractions and activity level data are described in Section 3.3.4 in this report and are presented in TABLE A.3.[162]

Personal Watercraft: Regional Releases

It is estimated that personal watercraft activity releases over 1000 kg of PAHs every year to the Watershed (TABLE 4.6). It is likely that most of the emissions from watercraft deposit directly onto the water, given the close proximity of the engine to the water.

Table 4.6. Estimated PAH emissions from personal watercraft activity in the Watershed[a]

	Personal watercraft	
Watershed	**New York**	**New Jersey**
Total (kg/yr)	500	600

a Emission estimates based on emission fractions presented in Table A.3.

Measures to Reduce Releases of PAHs from personal watercraft activity

PAH emissions from watercraft activity are seasonal. In a study conducted by the National Oceanic and Atmospheric Administration (NOAA), PAH concentrations in water samples taken from Auke Lake in Alaska were found to be higher in summer months than in winter, corresponding to the increase in recreational boat use during those months [224].[163]

In 2007, the U.S. EPA proposed a new emissions control program that would reduce hydrocarbon emissions from spark-ignition motors (e.g., those used in watercraft) and would apply only to newly manufactured engines. This program would begin in 2011 and 2012, depending on engine size. Manufacturers will likely meet this regulation by using three-way catalysts and closed-loop fuel injection. An evaporative emissions control program has also been proposed for these engines.[164]

Available data do not allow us to clarify in what type of water body the estimated emissions were released (i.e., rivers, lakes, or ocean), which is important when trying to understand the impact of this activity on the Harbor. The use of watercraft in lakes and ponds will not impact the Harbor, but may have an impact on the local environment.

The following are pollution prevention recommendations to reduce releases of PAHs from watercraft activity in the Watershed:

- Educate the community on best management practices for engine maintenance, such as keeping engines well tuned, and limiting the time an engine is at full throttle.
- Educate the community on the differences between two-stroke and four-stroke engines such as emissions, purchasing cost, operating costs, maintenance costs, and performance,[165] as well as information on proper disposal of used motor oil from four-stroke engines.
- Promote the elimination of all unnecessary idling by encouraging marinas to adopt anti-idling policies.
- Consider restructuring boater registration fees so that older engine models or models that release more PAHs pay a premium.
- Establish a changeout program that facilitates the exchange of older engines for newer, less polluting engines.

4.3.2. Vessel and Port-Related Activity

Vessels and Port Activity: National Trends and Emission Factors

Many of the goods consumed in the U.S are brought into the country through various seaports. Vessels, tugboats, cargo moving equipment, trucks, trains, and other nonroad equipment all facilitate the movement of goods through the ports into the local economy, as well as release PAHs. PAH emissions from ports are primarily due to fuel combustion in engines in the aforementioned equipment.

Ships and vessels use diesel propulsion and auxiliary engines to move across the sea and in the Harbor.[166] While dwelling at berth, the propulsion en-

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[162] The type of data used to establish personal watercraft emission fractions is unknown; however, they appear to be the same as the nonroad emission fractions described in Section 3.3.4 of this report.

[163] Summer months include May through August. PAH concentrations in water were found to be seven times higher in June than in September.

[164] For more information, see the U.S. EPA web site, http://www.epa.gov/otaq/marinesi.htm.

[165] Generally speaking, the following are some of the differences between four- and two-stroke marine engines: four-strokes engines cost more upfront, are more fuel efficient, use more spark plugs, and require crankcase oil (including oil and filter changes), typically have more expensive repairs (due to the increase in components), are quieter, have cleaner exhaust, and are heavier than two-stroke.

[166] Although some vessels may use engines other than diesel, such as gas turbine, steam for propulsion, or steam turbine generators for auxiliary power, most marine vessel engines are diesel [225, 226].

gines are shut down, and the auxiliary engines and boilers are left running to provide electricity for hoteling activities such as the ship lights, heat, refrigerators, pumps, and equipment to discharge the cargo.[167] Emission factors for PAHs specific to vessel activity were not available. However, the U.S. EPA's Office of Transportation and Air Quality recommends applying the heavy-duty diesel vehicle (HDDV) emission fractions to PM_{10} emissions (see Section 3.3.1 VEHICLE EXHAUST) [228].

Emission fractions for nonroad equipment were used to estimate releases of PAHs from on-land port-related equipment (see Section 3.3.4 NONROAD ENGINE EXHAUST in this report).

Vessels and Port Activity: Regional Releases

The port of New York and New Jersey is the largest port on the East Coast of North America. It serves as a key gateway in the movement of imports and exports between the United States and international markets in Europe, Central and South America, Africa, and Asia. The port is a multi-dimensional cargo center, handling a full range of ocean-borne cargoes. The port handled approximately five million 20-foot–equivalent units; over 850,000 vehicle imports and exports; and almost 86 million metric tons of bulk and general cargo in 2006 [229]. The Port Authority of New York and New Jersey (PANYNJ) is the landlord for many of the region's port facilities, and the PANYNJ's tenants are the terminal operators. PANYNJ's facilities include The Port Newark/Elizabeth–Port Authority Marine Terminal complex (NJ), the Port Authority Auto Marine Terminal (NJ), Brooklyn Piers and Red Hook Container Terminals (NY), and Howland Hook Marine Terminal (NY). Private, non-PANYNJ facilities include the Global Container Terminal and several petroleum facilities in New York and New Jersey.

Releases to the Atmosphere. PAH emissions estimates were made by applying the HDDV emission fractions reported in TABLE A.1 to estimated PM_{10} emissions in 2000 [227, 230] (TABLE 4.7).[168,169] It is estimated that approximately 12% of ocean-going vessel emissions are released while the vessel is dwelling. Tug and assistant tugboats are the largest contributors of PAHs, most likely as a result of their constant activity.

The U.S. EPA's National Emissions Inventory estimates much larger annual PAH emissions from commercial marine vessels in New York and New Jersey (combined ~5000 kg in 1999). There is some uncertainty in both of these emission estimates, because both calculations applied the same emission fractions and the emission fractions are not specific to vessel diesel exhaust.

To estimate PAH emissions from nonvessel port activity, activities were categorized either as cargo handling equipment (CHE) or port-associated locomotive activity. Nonroad diesel emission fractions and locomotive emission fractions (see Sections 3.3.4 and 4.2.3 in this report) were applied to estimated CHE and locomotive PM_{10} emissions [231] (TABLE 4.8). Emission estimates address activities at port container terminals in Kings and Richmond Counties, New York; and Essex, Hudson, and Union Counties, New Jersey.

In addition to container terminals, there are private non-PANYNJ ports in the Watershed (e.g., petroleum terminals). We were unable to estimate release of PAHs from these ports due to lack of information.

Table 4.7. Estimated PAH emissions from ship and vessel activity in the New York/New Jersey Harbor[a]

	Bulk	Car carrier & Ro-Ro	Container ship	Cruise vessel	Tanker	Tug and assist tug	Misc.
Total (kg/yr)	50	30	170	4	61	305	2

Vessel categories: bulk=vessels that can carry granulated products (e.g., cement, sugar, coking coal), as well as bulky goods such as machinery, steel, palletized goods, and even livestock; car carrier/Ro-Ro=vessels that are outfitted specifically for the transport of cars, trucks, and other vehicles that can be rolled on and off; container ship=vessels that carry standard-sized, steel-reinforced containers; cruise vessel=vessels that transport passengers; tanker=includes vessels that carry crude oil and finished liquid petroleum products, sewage, water, liquefied petroleum gas, and fruit juice; tug and assist tug=tug vessels tow barges within the harbor, and assist tugs assist ocean-going vessels (OGVs) during docking, departing from berths, and in making some of the very tight turns that are required within the channels; misc.=vessels that could not be categorized.

a PAH emission estimates are based on emission factors presented in Table A.1.

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167. The highest dwelling requirements are typically those for cruise ships, due to their high passenger electricity demand [227].

168. Emission estimates account for vessel and ship activity in the following New York and New Jersey counties: Orange, Rockland, Westchester, Bronx, New York, Richmond, Kings, Queens, Nassau, Suffolk, Bergen, Hudson, Essex, Union, Middlesex, Monmouth, and Ocean.

169. This does not include governmental boat activity such as fire department and ferries. Estimated emissions from these sources are approximately 175 kg/yr.

Table 4.8. Estimate of PAH emissions due to port activity in the New York/ New Jersey Harbor[a]

	CHE at terminal[b]	Locomotive
Total (kg/yr)	100	10

a PAH emission estimates are based on emission factors presented in Tables A.1 and A.3.
b Cargo handling equipment (CHE) includes, but is not limited to, terminal tractor, rubber-tired gantry crane, container top loader, fork lift, nonroad vehicles, portable light set, generator, sweeper, bucket loader, and payloader.

Measures to Reduce Emissions from Vessels and Port-Related Activity

The U.S. EPA proposed a new emissions control program for all types of marine diesel engines below 30 liters per cylinder displacement. This includes marine propulsion engines used on vessels from recreational and small fishing boats to yachts, tugs, and Great Lakes freighters, and marine auxiliary engines ranging from small generator sets to large generators on ocean-going vessels [232]. Large vessel engines are being addressed under a separate U.S. EPA proposal, in which emissions standards would be set for very large marine engines used primarily for propulsion power on ocean-going vessels such as container ships, tankers, bulk carriers, and cruise ships. The proposed standards would apply only to engines on U.S.-flagged vessels; however, application to foreign-flagged vessels is being considered.

The following are pollution prevention recommendations to reduce the releases of PAHs from vessels and port-related activity:

Vessel Activity

- Establish a program that encourages the retrofitting or replacement of older diesel engines, specifically those associated with tugboats.[170]
- When feasible, require vessels to utilize the cleanest fuel available while traveling through and berthed in the Harbor.
- Consider establishing a low speed zone in the Harbor.
- Promote the use of electricity while at berth instead of diesel auxiliary engines and boilers.

Port-Related Activity

- Consider developing a port-wide retrofit program that retrofits older vehicles/equipment with atmospheric control devices.
- When feasible, replace older equipment with hybrid vehicles/equipment or vehicles/equipment that combust fuel that releases no or low PAHs.
- Reduce idling in rail yards by requiring the installation of Kim Hotstart or other anti-idling devices on locomotive engines and port equipment, while also enforcing existing state no-idling regulations.
- Data gaps.
  - Develop emission factors for marine vessel diesel engines, including both new and old engine models.

4.3.3. Locomotives

Locomotives: National Trends and Emission Factors

Rail transport is one of the more efficient modes of transport, offering a high transport-volume-to-fuel-consumption ratio. As commerce continues to grow, so will the transport of goods via rail. For example, rail transport of domestic goods grew 26% from 1996 to 2005 (in terms of ton miles traveled), and more domestic goods overall were reported to be transported by rail than by air or truck [233].

PAHs are released through locomotive engine emissions generated by the combustion of fossil fuels. Engines are either two-or four-stroke, with 70% of the locomotive fleet composed of two-stroke engines [133]. The U.S. EPA Office of Transportation and Air Quality provided PAH emission fractions for locomotives based on four tests of two-and four-stroke engines (Table A.3).

Locomotives: Regional Releases

There are several types of rail lines in New York and New Jersey, including commuter and passenger, line haul (cargo transport), and switch (in-yard transport). Rail is an important mode of transport in this region. In New Jersey alone, approximately 19 million gallons of fuel is used every year to power the rail sector [234].

Releases to the Atmosphere. Releases of PAHs were calculated by applying emission factors in Table A.3 to 2002 rail PM_{10} emissions provided by the New Jersey Department of Environmental Protection and the New York State Department of Environmental Con-

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[170] Examples of vessel atmospheric pollution control technologies include seawater scrubbing (reduces SOx and PM), selective catalytic reduction (reduces NOx), humid air motor (reduces NOx), and water emulsion (reduces NOx).

PORT POLLUTION REDUCTION INITIATIVES

Ports afford a conduit for the flow of goods into and out of the country. While this infrastructure is fundamental to the U.S. economy, these types of activities can have an impact on local and regional environments. However, some ports are already addressing these concerns with various green or sustainability initiatives, as demonstrated by the initiatives at the Port Authority of New York and New Jersey, and the Port of Long Beach, summarized below:

The Port Authority of New York and New Jersey: In 2005, the Port Commerce Department (PCD) finalized its environmental policy, which highlights its commitment to operate and maintain its facilities in ways that prevent pollution, conserve natural resources and energy, reduce the use of hazardous substances, minimize wastes, and have the least adverse impact on the environment. To achieve the goals of this environmental policy, PCD has been implementing various programs that include the following:

- **Air Quality:** Improving inland access–Building infrastructure that will provide environmentally beneficial alternatives to inland trucking (e.g., expanding ExpressRail to handle 1.5 million cargo containers annually. Electrification of port cranes–Replaced diesel-powered cranes with new electrical cranes. Gate modifications–Port tenants have installed electronic gates, relocated gates, and expanded gate hours to reduce truck delays and congestion. Replacement of yard equipment–Port tenants were able to achieve greater than 30% reductions in air emissions across a full spectrum of pollutants by modernizing cargo handling equipment. Retrofitting Staten Island Ferries fleet–Repowering of tugboats and retrofitting of Staten Island Ferries to offset emissions from the Harbor deepening project; benefits will go well beyond the duration of the dredging project. Use of alternative fuel–Using CNG in the central automotive fleet, while port tenants are using ultra-low sulfur fuel in off-road equipment and propane for some forklifts. Locomotive anti-idling device–NYCT installed Kim Hotstart anti-idling device on its newly rebuilt yard switcher locomotive.
- **Water Quality:** Contaminant Assessment and Reduction Program (CARP)–Assessing all sources of contaminants of concern in water, sediment, and biota within the NY Harbor estuary through data collection, sampling, testing, and modeling to evaluate contaminant levels in the Harbor. Modeling results will be used to predict the movement of contaminants through the Harbor and develop strategies for their reduction. Support research on Harbor restoration–Providing financial support to New York Academy of Sciences for its industrial ecology study, the New Jersey Marine Science Consortium, and the Institute of Marine Coastal Sciences. These research efforts work to determine sources of contaminants in the estuary and ways to prevent them from polluting the estuary, as well as provide key innovations needed to support marine industries and to strengthen efforts to protect marine and coastal environments. Ballast water initiative–In collaboration with NJ Sea Grant, published “Ballast Water” brochure to educate the maritime community about impacts of the introduction of invasive species into ports and harbors via ballast water, and about protective measures to exchange ballast water at sea before entering the port. Historic Area Remediation Site (HARS)–Clean, dredged material is used to remediate and cap a historically contaminated ocean dump site. Artificial reef and fish habitat–Excavated rocks from the Harbor deepening project used to create artificial reefs and fish habitat. Floor drain and catch basins inserts–Port tenants have voluntarily increased their use of floor drain and catch basins inserts that trap contaminants from runoff and rainwater.
- **Waste Minimization:** The Port and its tenants are undertaking a comprehensive recycling program that reduces waste stream and saves disposal cost.

- **Energy Conservation:** The Port Authority has deployed over 350 alternative fueled vehicles across all of its facilities. Port tenants also conserve fuel through their cargo handling equipment modernization efforts.
- **Harbor Restoration Initiatives:** Harbor Roundtable–Port Authority participates in the Harbor Roundtable, along with the states of New York and New Jersey, New York City, various Federal agencies, and environmental interest groups. The Roundtable's goals are to d evelop an environmental agenda for the Harbor, including restoration priorities and objectives to achieve a world-class estuary, and to advocate for the resources to accomplish it. Hudson-Raritan Estuary Study–Local sponsor, providing over 50% of funding for the Hudson-Raritan Estuary Environmental Restoration priorities and objectives to achieve a world-class estuary, and to advocate for the resources to accomplish it. Hudson-Raritan Estuary Study–Local sponsor, providing over 50% of funding for the Hudson-Raritan Estuary Environmental Restoration Study to determine restoration opportunities in the estuary. Hudson-Raritan Estuary Resources Program–Port Authority has committed $60 million to the states of New York and New Jersey to create the Hudson-Raritan Estuary Resources Program, whose goal is the purchase of property for public use and natural resource preservation.

Summarized from the Environmental Brochure, available at www.panynj.com/DoingBusinessWith/seaport/html/environmental_commit.html

Port of Long Beach, California: In 2005, the Port of Long Beach adopted a green port policy that addresses five environmental concerns: air pollution; water pollution; and sediment contamination; habitat protection and restoration; sustainable design and construction practices; and community involvement.The programs that have been implemented under this policy and relevant to this report are listed below:

- Air quality: Vessel speed reduction (green flag program)–Arriving and departing vessels are asked to reduce their speed to 12 knots starting 20 nautical miles from the breakwaters. Cold-ironing/auxiliary exhaust control–Port provides shoreside power at new and reconstructed container terminal berths and requires through lease language for selected vessels the use of that power or use of low-sulfur diesel. Diesel emission reduction–Port provides funding and technical support for the installation of pollution reduction technologies in cargo handling equipment. Locomotive replacement–Port provides funding for the replacement of locomotive fleet with cleaner locomotives (exceeding EPA and state emissions standards) equipped with idling controls. Clean construction–Port requires construction contractors to use clean diesel and diesel exhaust controls in construction equipment, electric dredging whenever possible, and newer, cleaner equipment. Fleet conversion–Program identifies opportunities to use alternate fuels and purchase cleaner vehicles and equipment, as well as install engine retrofits in Port's fleet. Carpool–Port provides pool vehicles for staff;.
- **Water quality:** Stormwater and dust control–Program identified undeveloped Port properties that pose potential impact to stormwater or emit fugitive dust and implements best management practices at those locations. Dredge monitoring–Port conducts water quality monitoring during dredging activities to detect adverse impacts of dredging. Long-term groundwater monitoring–Monitor known areas of groundwater contamination to ensure that it does not enter the harbor.
- **Community involvement:** Green port open house–Port holds an annual open house showcasing the green port programs. Tree project–Program focuses on planting mature trees in Long Beach.

Summarized from Port of Long Beach Green Port Quarterly Update 2005, available at www.polb.com/

servation (Table 4.9).[171] Releases of PAHs from rail activity are greater inside the Watershed than outside. This due in part to the rail transport of goods from ports within the Watershed, and to urban centers that provide employment to willing commuters.

Table 4.9. Estimated PAH emissions from locomotive activity in New York and New Jersey

	Watershed	Outside Watershed
Total (kg/yr)[a]	1300	1000

[a] PAH emission estimates are based on emission fractions presented in Table A.3.

Measures to Reduce Releases of PAHs from Locomotive Activity

The U.S. EPA has announced the intent to propose more stringent emission standards for all new locomotive engines [235]. The standards, which could apply in 2011, would require the use of advanced emissions control technologies, which are now feasible, given the low-sulfur fuel standards for nonroad engines. However, older engines are likely to emit more PAHs, and efforts should be made to address this issue.

The following are pollution prevention recommendations to reduce releases of PAHs from locomotive activity:

- Establish a voluntary incentive program that encourages the retrofitting of older diesel engines with new, more efficient engines.
- When feasible, require the use of anti-idling devices and the use of electric auxiliary engines when idling is necessary.
- Explore the feasibility (environmental and economic) of using alternative fuels (such as biofuels) and hybrid engines.[172]

4.3.4. Airplanes

Airplanes: National Trends and Emission Factors

In 2004, there were a reported 43 passenger airlines and 24 all-cargo carriers. Most of the commercial aircraft fleet is made up of single- and twin-piston engines. However, more fuel is consumed and emissions released by commercial jet transports that have two, three, or four engines.

PAHs are released through airplane engine emissions generated by the combustion of fossil fuels. The U.S. EPA derived PAH emission factors from 1979 data on PAH concentrations in exhaust particulate from a small gas turbine engine (Table A.3) [215]. Emission factors are presented in units of mass of pollutant per landing and takeoff (LTO) cycle, which consists of the following operating modes: approach, taxi/idle in, taxi/idle out, takeoff, and climb out.

Airplanes: Regional Releases

There are 13 airports in New York and New Jersey servicing certified air carriers, of which seven are in the Watershed (Table 4.10). If it is assumed that a departure is an equivalent to one LTO, then there were 503,632 LTO cycles in the Watershed in 2000 [236].

Releases to the Atmosphere. Emission estimates were calculated by applying the emission factors dis-

Table 4.10 New York and New Jersey aircraft departures

Airports	Total departures
New York	
Watershed	
John F. Kennedy	126,932
LaGuardia	134,577
Downtown Manhattan Heliport	1128
West 30th Street	150
Westchester County	9991
Albany County	20,119
Total–Watershed	**292,897**
Outside Watershed	
Rochester-Monroe County	26,390
Clarence E Hancock	19,764
Greater Buffalo International	29,675
Niagara Falls International	5
Long Island MacArthur	12,385
Total–Outside Watershed	**108,338**
TOTAL–New York	**381,116**
New Jersey	
Watershed	
Newark	230,854
Outside Watershed	
Atlantic City, NAFEC	4721
TOTAL–New Jersey	**235,575**

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[171] The NYSDEC estimates are projected from a 1990 inventory.

[172] The use of hybrid locomotives might be most appropriate in rail yards where trains are moving at low speeds and making frequent stops, providing an engine battery with opportunities to recharge.

cussed above to the estimated LTOs (Table 4.11). There is relatively high uncertainty in this estimate, given that emission factors are likely outdated and not available for most of the 16 U.S. EPA priority PAHs for which emission estimates are made throughout this report. Furthermore, the emissions from planes crossing over the Watershed, as well as military and cargo planes, are not included in this estimate.

Table 4.11. Estimated PAH emissions from airplane activity in New York and New Jersey[a]

	Watershed	Outside Watershed
Total (kg)	70	13

[a] PAH emission estimates are based on emission factors presented in Table A.3.

Measures to Reduce Releases of PAHs from Airplanes

Our estimates indicate that small quantities of PAHs are emitted from airplane activity in the Watershed; however, the emission factors used are incomplete and outdated. Given the high concentration of airports in the Watershed region, it is possible that this source is more significant than our estimates indicate.

The U.S. EPA recently amended their aircraft emission standards to bring them in line with international standards, specifically in regards to the United Nations International Civil Aviation Organization nitrogen oxide standards. Aircraft standards established by the U.S. EPA are enforced by the Federal Aviation Administration (FAA) of the U.S. Department of Transportation (DOT).

The following are pollution prevention recommendations to reduce releases of PAHs from airplane activity:

- Improve communications, navigation, surveillance, and air traffic management systems. This would help to minimize idling and taxiing time.
- Data gaps.
  - Develop improved emission factors that provide a more accurate picture of PAH emissions from this sector.

4.3.5. Car Washing

Car Washing: National Trends and Emission Factors

Daily driving activity generates brake dust and lubricating oils that adhere to a vehicle, both of which contain PAHs. Washing loosens and releases this material from the vehicle. Contaminants are then transported via wastewater and, depending on the type of facility, are released into the environment.

There are generally three classifications for carwashing establishments: 1) permanent facilities that discharge wastewater to a treatment facility; 2) permanent facilities that discharge wastewater to ground or surface waters; and 3) temporary operations that discharge wastewater to ground or sewer systems (e.g., carwashing fundraisers, people washing their vehicles at their homes).

Car Washing: Regional Releases

There are numerous permanent carwashing facilities in the Watershed. These facilities differ in their level of activity and in how they treat their wastewater For example, some facilities treat and recycle their water on site, while others release water directly to the sewer or surface waters. The wastewater treatment practices at permanent facilities that discharge wastewater to the municipal sewer system are not currently consolidated, and would require abundant resources and time to gather. Therefore, we have not estimated releases from permanent carwashing facilities releasing to a municipal sewer system. It is possible, however, that PAH emissions to wastewater treatment plants from this type of carwashing facility are relatively low, due to the economic benefits of treating and recycling water on site.

We were able to identify permanent facilities that discharge wastewater to the ground or to surface waters in the Watershed, based on reported State Pollutant Discharge Elimination System (SPDES) permits. There are 15 carwashing facilities in the New York Watershed that have SPDES permits, with a cumulative wastewater capacity of 21,000 gallons of wastewater per day [237]. In New Jersey it was determined that only one carwashing facility releases its wastewater to the ground and surface waters; it has a reported capacity of 2000 gallons of wastewater per day [237, 238].[173] These types of facilities are generally allowed

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[173] New Jersey has discouraged the practice of discharging wastewater to ground and surface waters by classifying these types of facilities as industrial and by enforcing the associated fees and regulations. Those businesses not discharging to a treatment facility have been encouraged to recycle all of their wastewater [238]. The only facility discharging to ground or surface water is a self-service washing station in Passaic County.

to discharge 15 mg of oil and grease per liter of water released.

We are unable to account for releases from temporary carwashing facilities, because permits generally are not required.

Releases to Water and Land. If it is assumed that facilities holding SPDES permits are operating at capacity and are releasing grease and oil at the discharge limit, then an estimated one-half ton of oil and grease is released to ground and surface waters from carwashing facilities every year. Assuming that the PAH concentration of the oil and grease is similar to that of used motor oil (Table A.1), 0.7 kg of PAHs are released every year from this source. It is possible, however, that these facilities are operating below or above capacity. In addition, we have not estimated releases of PAHs from all types of carwashing facilities.

4.4. Uncontrolled Combustion

Uncontrolled combustion is a general source category that includes all unenclosed combustion in the ambient environment. Typical activities include combustion of agricultural waste, household garbage, and tires, as well as forest fires. Open burning, as this activity is frequently referred to, often takes place under poor combustion conditions (i.e., insufficient mixture of fuel and air, and low temperatures), producing soot and particulate matter that are visible as a smoke plume.

Given the complete lack of emissions control devices, open burning is an important source of PAH releases to the atmosphere in some regions. However, it is very difficult to quantify PAH releases accurately, because the variable combustion conditions make it difficult to develop an accurate emission factor.

4.4.1. Open Burning of Household Waste

Open Burning of Household Waste: National Trends and Emission Factors

Open burning of household waste often takes place in a barrel in the backyard, hence the bestowing of the name "backyard barrel burning." Barrel burning is more common in rural areas, where it is not always prohibited, waste collection services are sometimes absent, and education on its health, safety, and environmental impacts may be limited. The Federal government does not regulate open burning; however, some states have established local regulations and, in several cases, have banned the practice [239].[174]

The emission factors in Table A.3 were developed by the U.S. EPA and were derived from an average of tests conducted in a laboratory simulation of barrel burning [240]. The laboratory testing included the combustion of waste from an avid recycler and a nonrecycler,[175] with emissions from the nonrecycler approximately twice as high as emissions from the average recycler per kg of material burned [242].

Open Burning of Household Waste: Regional Releases

Several estimates have been made of the proportion of the rural population in New York that burns household waste. A survey conducted by St. Lawrence County Planning Office in New York found that 48% of rural households burn trash in some capacity [243]. In Otsego County, New York it was estimated that approximately 30% of residents burn garbage, while other polls indicate that 24% of rural residents burn garbage [244]. These estimates are for specific regions within the Watershed and do not necessarily represent overall activity for the entire region. The U.S. EPA summarized surveys from several states; based on their findings, between 8% and 30% of the garbage generated by a particular population is combusted in an uncontrolled environment.[176]

The quantity of waste generated varies from household to household. However, a report by the U.S. EPA estimated that, on average, 3.28 pounds of waste is generated per person per day, not including noncombustible items and yard debris [246]. Table 4.12 provides an estimated range of the number of people burning waste outdoors and the quantity of waste combusted. Communities with local bans on open burning are not included in our calculations.

The State of New Jersey banned open burning in 1956 and established fines of approximately $10,000; therefore, compliance is widespread.[177] For the purposes

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[174] The following states have banned open burning: California, Washington, New Mexico, Wisconsin, Louisiana, Arkansas, Mississippi, Alabama, Georgia, North Carolina, Maryland, Delaware, Connecticut, Massachusetts, Vermont, New Hampshire, and Maine [239]. New York and New Jersey also have bans with exemptions.

[175] Materials combusted in the PAH emissions laboratory test included paper milk cartons and drink boxes; plastic resins–HDPE #2, PVC #3, LDPE #4, PP #5, PS #6, mixed #5; wood; ceramic plates and cups; metal cans; and nonferrous aluminum cans, copper wire and pipe, and batteries [240].

[176] This range is based on several U.S. surveys summarized by the U.S. EPA [245]: Illinois: 40% of people burn 63% of waste (i.e., 25% of all waste). Other polls summarized indicated the percentage of people that admitted burning, but not the percentage of waste that they burned: Minnesota, 28%; Ontario, 24%; Northeast, 12%; California, 18%; St Lawrence County, NY, 48%. If in all cases 63% of the waste is burned, we obtain a range of roughly 8% to 30 %.

[177] Source: New Jersey Administrative Code Title 7, Chapter 27, Subchapter 2.

of estimating emissions, it is assumed that no open burning of household waste takes place in New Jersey.

Releases to the Atmosphere. Table 4.12 presents PAH emission estimates made by applying the emission factors in Table A.3 to the estimate of material combusted. There is some uncertainty in this estimate, given that there is not a consensus on the number of people actively burning waste and that actual emissions will vary with feedstock and combustion conditions.

Measures to Reduce Releases of PAHs from the Combustion of Household Waste

The State of New Jersey has issued general control and prohibition rules for open burning activities, with exemptions and allowances. For example, one- and two-family dwellings are exempted from the statewide ban. These households, however, may be subject to local and/or county regulations. In addition, permits may be issued for certain open burning activities, such as prescribed burning, and burning of orchard prunings, culling material, and infested plant life.[178] Open burning activities in New Jersey are deemed to be scant. However, data to validate this claim are not available.

New York has also implemented a ban on burning, with considerable exceptions. This rule is outlined in the New York State Department of Environmental Conservation's regulation 6 NYCRR Part 215 Open Fires, which indicates that unless otherwise permitted, no person shall burn garbage, refuse at a refuse disposal area, rubbish generated by land clearing or construction debris, on-site disposal of industrial or commercial rubbish, salvage material, or on-site disposal of rubbish generated by residential activities. However, towns with a population of less than 20,000 are exempt from the open burning of household waste. The burning of toxic, explosive, or dangerous materials may be permitted if it is deemed that there is no safe or economical way in which to dispose of the material. Open burning is also regulated under fire codes adopted three years ago, Part 307.2.2, and is prohibited if it causes smoke, odor nuisances, or objections.

Some communities in New York have established partial or total bans on open burning, while others are making efforts to minimize open burning activity. For example, Otsego County decided to educate residents about the dangers of open burning rather than pass a ban, and towns in Washington and Saratoga have passed some local open burning regulations.[179]

Legislation has been proposed to ban open burning statewide (Senate Bill S2961). This bill does not only propose a ban on open burning of solid waste, it would also establish an infrastructure for distributing material describing the health and environmental impacts of open burning. However, property rights groups and farming communities have expressed and continue to express opposition [252].

The following are pollution prevention recommendations to reduce releases of PAHs from the uncontrolled burning of household waste (summarized from Muñoz et al.[253]):

- Educate the rural community (particularly public officials and local agencies) on the hazards associated with open burning, as well as on current regulations.
- Reduce waste by increasing recycling rates through improved management and col-

Table 4.12. Estimated household waste combustion and associated releases of PAHs in New York[a]

	Rural population in NY[b] (million people)	Waste burned[c,d] (million tons/yr)	PAH emissions (kg/yr)
Watershed	0.9–1.3	0.03–0.2	1400–8000
Outside Watershed	1.3–2.1	0.05–0.3	2100–12,900

a Emission estimates are based on emission factors in Table A.3.

b Based on rural population data provided by the 2000 U.S. Census and people in towns with <20,000 inhabitants. Both population values are adjusted for communities that have local bans on open burning, which include Oneida, Herkimer, Westchester, and Rockland Counties, a town in Delaware County, and towns in Putnam County that have garbage service.

c Assuming an average of 543 kg of waste generated per person per year (kg/yr/person) [246].

d Assuming that between 8% and 30% of rural refuse is burned in uncontrolled fires.

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[178] When other options are not available, burning may be authorized with a permit on a case-by-case basis for infested plant life, prescribed burning, emergencies, dangerous material, herbaceous plant life and hedgerows, orchard prunings and cuttings, land clearing, and other special situations.

[179] The following towns and counties have generally prohibited open burning of garbage (although combustion of other materials, such as plant materials, or recreational fires may be allowed): Oneida and Herkimer Counties; town of Charlton, Saratoga County [247]; Colonie, Albany County [248]; Owasco, Cayuga County [249]; Kortwright, Delaware County; and three towns in St. Lawrence County. The sanitary codes for Westchester and Rockland Counties prohibit open burning [250, 251]. It should be noted that this is not a comprehensive inventory of towns and municipalities prohibiting open burning in New York.

lection infrastructure, and through the establishment of recycling centers in rural communities that do not have such services. Consider providing incentives for recycling (e.g., deposits on materials returned, or coupons for local retailers).[180]

- Provide waste collection to areas not currently serviced.
- Increase producer responsibility for packaging waste.
- Consider prohibiting open burning statewide in New York.

4.4.2. Open Burning of Agricultural Waste

Open Burning of Agricultural Waste: National Trends and Emission Factors

Agricultural communities utilize open burning as an economical way in which to dispose of crop cover, land clearings, animal carcasses, and containers, and to inhibit pest infestations. Open burning activities vary from farm to farm. Some farmers may burn crop cover only; others may include household refuse and farming waste, such as pesticide and nursery containers, seedling trays, mulch and fumigation films, greenhouse covers, and dairy bags (all of which are often polyethylene plastic). Some farmers burn when they feel there are no other options, whereas others incorporate burning into their seasonal practices.

PAHs are generated through the incomplete combustion of biomass, animal carcasses, and plastics [254]; the relative PAH concentrations depend on the material combusted and combustion conditions (e.g., wind, fire temperature). Given the unknown mixtures of materials combusted in agricultural fires, it is difficult to estimate PAH emissions from this source. One approach is to estimate potential PAH releases associated with the combustion of specific materials. Table A.3 provides emission factors for the combustion of agricultural plastic films composed primarily of polyethylene and carbon black [215].

Open Burning of Agricultural Waste: Regional Releases

It is estimated that approximately 760,000 metric tons of plastics are used nationally in agricultural production every year, of which approximately 2% (~12,000 tons/yr) is consumed in New York state [255].[181] It is estimated that 50% of the plastics used are burned in piles without an air curtain,[182] and the remaining materials are recycled, buried on site, landfilled, or incinerated at a regulated facility [255]. Based on agricultural sales in each county, approximately 26% of the combustion activity takes place in the New York Watershed (1668 tons of plastic per year).

Stubble burning is most prominent on the West Coast and in the Central Plains. Therefore, it is assumed that stubble burning does not take place in any significant amount in New York, and emissions are not calculated for this activity [254]. It is also assumed that no open burning takes place in New Jersey, given the statewide ban and heavy fine.

Releases to the Atmosphere. The emission factors in Table A.3 were applied to the estimated plastic combusted by the New York state agricultural industry (~ 6000 tons) to estimate PAH emissions from agricultural plastic combustion (Table 4.13). There is uncertainty in this estimate, given that the emission factors applied do not represent all agricultural plastics, including those that have remnants of material that could increase PAH releases, such as containers for petroleum-based pesticides. In addition, there are several PAH compounds for which there was not an emission factor, including naphthalene, which is often the major PAH in combustion emissions.

Table 4.13. Estimated releases of PAHs from combustion of agricultural plastics in New York[a,b]

	PAHs (kg /yr)
Watershed	1
Outside Watershed	3

[a] Emission estimates based on emission factors presented in Table A.3.
[b] Agricultural open burning activity in the Watershed is extrapolated based on agricultural sales in each county (the Watershed is ~26% of statewide activity).

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[180] Philadelphia residents (~2500 households) are participating in a pilot program in which residents are rewarded with coupons depending on how much they recycle (up to $25/month). Each participating resident is given a recycling bin equipped with technology that allows the garbage collector to weigh and record how much material is recycled. This information is managed online, and participants can log on to the web site to view what they have earned. The system was designed by RecycleBank, http://recyclebank.com/.

[181] Estimates of New York state's consumption are based on the percentage of total New York agricultural receipts reported [254].

[182] An air curtain is a portable or stationary combustion device that directs a plane of forced air into a curtain around a pit where the plastic (or other material) is burning. Air curtains are used as a means to improve combustion conditions [215].

Measures to Reduce Releases of PAHs from Open Burning of Agricultural Waste

Although estimated emissions from uncontrolled combustion of agricultural waste (plastics specifically) are relatively small, this may still be a significant source, given the uncertainty of the emission factor and the additional toxins that are released during combustion (e.g., dioxins). Although New York state has a partial ban on open burning (see previous section), agriculture is exempt from this regulation. It is assumed that no open burning of agricultural plastics takes place in New Jersey, due to that state's ban.

Several issues must be addressed simultaneously to successfully reduce emissions from open burning, including waste generation, recycling, and education. Although the agricultural community should be targeted, several of the recommendations presented below are also relevant to communities that combust household waste.

The following are pollution prevention recommendations to reduce releases of PAHs from open burning of agricultural plastics (summarized from Muñoz et al. [253]):

- Educate farmers on the hazards associated with combusting agricultural plastics, including the potential contamination of nearby crops and livestock.
- Create and distribute curriculum to rural schools that addresses the hazards of open burning and provides examples of alternative practices.
- Increase opportunities for recycling plastics by providing regular or semiregular collection of plastics and/or by placing collection centers in rural areas not currently served by plastic collection services; these services could be financed by plastic producers and/or farmers.
- Investigate options to increase markets for recyclable materials.
- Consider prohibiting open burning statewide.

4.4.3. Tire Fires

Tire Fires: National Trends and Emission Factors

In 2005, approximately 87% of the 299 million scrap tires generated were reused in the economy [256], while the remaining 13% (39 million) were stockpiled or landfilled. Tire stockpiles, often found at auto wrecking and salvaging lots, provide a breeding ground for insects and rodents, and an opportunity for tire fires to occur.

PAH emissions from burning tires are related to the tire burn rate. Tires combusting at a slower burn rate (i.e., smoldering tires and the combustion of shredded tires) generate more PAHs than tires combusting at a faster burn rate (i.e., large tire fires, and combustion of whole tires). In addition to the release of PAHs, tire fires may generate carbon monoxide (CO), sulfur oxides (SO), oxides of nitrogen (NO), volatile organic compounds (VOCs), dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls (PCBs), and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium. The U.S. EPA provides emission factors based on laboratory simulations of open burning of tires [257] (Table A.3). The emission factors are an average of three burns in which tires of various sizes were combusted.

Tire Fires: Regional Releases

It is estimated that New Jersey generates approximately 8.4 million waste tires every year [258]. Of the waste tires generated, approximately 7 million are either recycled or disposed of as solid waste [258], leaving approximately 1 million tires unaccounted for.[183] Most of the tires that are recycled are sent to out-of-state handling facilities primarily in Pennsylvania and New York. New Jersey has implemented a tire cleanup program, although there are still 18 tire piles in the state containing 3.5 million tires. Five of these sites are in the Watershed region and contain an estimated 570,000 tires [258].[184] Based on inspection summary reports provided by the New Jersey Department of Environmental Protection, over the past three years there have been no tire fires within the Watershed and only one fire within the entire state that consumed approximately 100,000 tires.[185,186]

New York generates approximately 18 to 20 million waste tires annually. Although most of the scrap tires generated are either disposed of in landfill or recycled, 8% are estimated to end up in stockpiles [261]. The 2004 New York State Stockpile Abatement Plan reports that there are 95 tire stockpiles, at which an estimated 29 million tires are stored

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[183] Unless otherwise mandated for recycling in a county, scrap tires in New Jersey may be disposed of legally as solid waste [258, 259].

[184] The number of waste tires in piles throughout New Jersey continues to change as a result of the tire cleanup fund created by the tire tax implemented in 2004; therefore, this number may quickly become outdated.

[185] On December 28, 2004, there was a tire fire in Cumberland County, NJ in which approximately 100,000 tires burned [260]. Cumberland County is not in the Watershed.

[186] Site inspection summary reports can be found by visiting http://datamine.state.nj.us/dep/DEP_OPRA/.

[262].[187] There have been 21 reported stockpile fires since 1989, 10 of which occurred between 1994 and 1998 [261, 263]. Averaged over the past 16 years, approximately 158,000 tires are consumed annually in New York Watershed tire fires, and 72,000 in fires outside the Watershed (1.5% and 0.4% of tires stockpiled, respectively).

Although there have been no tire fires reported in the New Jersey Watershed within the last three years [260], an upper bound estimate of the tires that have the potential to burn in the New Jersey Watershed was calculated by applying New York's Watershed tire fire rate (1.5%) to the stockpiled tires. A summary of piles, stockpiled tires, and an estimate of tires burned in the Watershed is presented in Table 4.14.

Releases to the Atmosphere. It is difficult to estimate annual emissions from tire fires, given their sporadic nature. However, based on the data provided, an estimate of potential PAH emissions associated with tire fires can be made.

Table 4.14 presents the estimated potential release of PAHs due to tire fires in and outside of the Watershed in New York and New Jersey. Estimates are based on the estimated volume of tires consumed in fires annually and the emission factors in Table A.3. The estimated PAH release is driven by naphthalene and acenaphthylene, which comprise almost 50% of the overall emission estimate.

Measures to Reduce Releases of PAHs from Tire Fires

Reducing the number of tires stockpiled will reduce the number of tires available to be consumed in fires. Finding ways to divert tires to end markets is one way to reduce the prevalence of stockpiled tires. Nationally, tire-derived fuel is estimated to be the largest consumer of scrap tires (52%),[188] followed by civil engineering applications (16%), ground rubber applications (12%),[189] landfill disposal (14%), export (2%), and a small amount used in agricultural and miscellaneous applications [256]. A new end market for scrap tires is electric arc furnaces. The carbon and steel content of scrap tires can be extracted, recycled, and used as raw materials to manufacture steel [256].[190] Although recycling rates have increased nationally over the years, there are still relevant market barriers and concerns with using scrap tires in certain end-use applications (Table 4.15).

The Rubber Manufacturers Association 2005 Scrap Tire Report calls for Alabama, Michigan, New York, and New Jersey to establish an aggressive scrap tire abatement program (these four states collectively contain 67 million scrap tires). New York and New Jersey were ranked 33rd and 35th, respectively, for scrap tire management performance; however, New Jersey was ranked fifth for most improved.

Another way to reduce the number of scrap tires is to reduce the number of scrap tires generated. This

Table 4.14. Tire piles and estimated PAH emissions from tire fires in New York and New Jersey

State	No. of sites	No. of tires	Estimated no. of tires burned annually[a]	Total PAH emissions[b] (kg/yr)
Watershed				
NJ[c]	5	570,000	8700	8500
NY	44	10,620,500	158,800	500
Total	**49**	**11,190,500**	**167,500**	**9000**
Outside Watershed				
NJ	13	1,927,500	7600	3900
NY	50	18,370,000	72,300	400
Total	**63**	**20,297,500**	**79,900**	**4300**

Sources: New Jersey Dept. of Environmental Protection [258]; New York State Dept. of Environmental Conservation [262].

a It is assumed that New Jersey has the same tire fire rate as in New York (1.5% within the Watershed and 0.4% outside the Watershed).

b Emissions estimates are based on emission factors in Table A.3.

c All of the New Jersey tire piles in the Watershed are currently on the 2004 NJDEP cleanup list [264].

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[187] Four of the sites identified each hold over one million tires [262].

[188] In the U.S., tires are used to fuel cement kilns (53 million/yr), pulp and paper mills (26 million/yr), electric utilities (24 million/yr), industrial boilers (17 million/yr), and dedicated tire-to-energy facilities (10 million/yr) [265]

[189] Crumb tires can be used in asphalt–rubber hot mix (rubber-modified asphalt) resurfacing and in slurry sealants, both of which provide added protection to highways, potentially extending the paving cycle.

[190] Passenger and truck tires are approximately 15% (wt) steel [266].

Table 4.15. Scrap tire end markets—barriers and concerns

Application	Description	Market barrier
Reuse and retread	Tires with useful tread life may be reused and retreaded. There is a strong export market for tire reuse.[a]	A,D
Tire-derived fuel	Tires can be used as a substitute for coal. Tires are often more affordable than coal and offer a higher BTU content.	A,B
Crumb rubber	Tires are chipped or broken down into small pieces and used in the manufacturing of various products, including the following: asphalt, molded products, mats and playground covers, speed bumps, carpet pads, and soil amendments.	A,C,D
Civil engineering	Whole or half tires may be used to construct wall barriers, leachate collection systems, artificial reefs, slope stability/erosion controls, and road base, as well as in the manufacture of railroad ties and speed bumps.	A,D
Electric arc furnaces	The carbon and steel content in scrap tires can be used as raw materials to make steel.	E
Products	Tires can be used in the manufacture of various products, including shoes, bags, sports fields, and carpets. Tires can also be added to other materials to make composites that can be used in products such as railway ties and car insulation.	D,C

A: High collection and transportation costs.
B: Toxic air emissions from combustion.[b]
C: Public health concerns (i.e., off-gassing/volatilization of contaminants).
D: Perception of products, with recycled content being inferior to products made with raw materials.
E: New to the market.
Source: California Integrated Waste Management Board [267].

[a] Due to performance concerns, tires are typically made with virgin material; however, mixing 5% to 15% recycled rubber into the mix is perceived as advantageous, creating better mixing properties and reduced curing times [222].

[b] Although facilities that consume tires for fuel may have air pollution control devices that reduce emissions, other facilities choose not to combust tires, taking a precautionary approach to potentially unknown emissions and the inability to properly prevent their release [268, 269].

can be done by reducing vehicle transport and by proper tire maintenance. (See Section 3.3.2 Vehicle Tire Particulate and Motor Oil Leaks in this report for more information on measures to reduce tire wear.) Reducing the generation of scrap tires has the potential to harm end-use markets; however, because not all scrap tires are currently recovered, this may not yet be of primary concern.

Most tire pile abatement efforts are made at the state level, although under Section 7003 of the Federal Resources Conservation and Recovery Act, the U.S. EPA has the authority to use enforcement tools to decrease environmental conditions that present “imminent and substantial endangerment to health or environment,” including scrap tire stockpiles. The U.S. EPA Region 5 office recently distributed a scrap tire cleanup guidebook. The guidebook was developed as a resource for solid waste managers across the U.S. and provides insights on how to design a scrap tire cleanup program.[191]

In 2003, New York passed an act (Title 19 of Article 27 of the Environmental Conservation Law) that established a tax of $2.50 on each new tire sold until 2010. The act also requires tire service facilities to collect waste tires from customers, prohibits the burial of waste tires, and establishes provisions for an abatement plan for all noncompliant waste tire stockpiles by 2010. Similar to New York, New Jersey passed P.L. 2004, c.46 in June 2004, establishing a tire fee of $1.50 per tire that will be used to fund scrap tire pile cleanup efforts.[192] All tire piles in the New Jersey Watershed are on the 2004 cleanup list.

Currently, there are no large-scale scrap tire markets in New York and New Jersey. However, recently, New York and New Jersey have promoted several engineering initiatives, including the substitution of gravel for tire chips in septic system trenches (NJ) and the use of waste tire–derived aggregate for landfill primary leachate collection and removal systems (NY) [270, 271].

The following are pollution prevention recommendations to reduce the release of PAHs from tire fires:

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[191] The Scrap Tire Cleanup Guidebook can be found at http://www.epa.gov/reg5rcra/wptdiv/solidwaste/tires/guidance/.

[192] Prior to this, New Jersey did not have a dedicated source of funding for scrap tire management and stockpile remediation [258].

- Educate drivers on how to extend the useful life of their tires by maintaining proper tire pressure and tire rotation, and by avoiding excessive acceleration and braking.
- Increase the scrap tire end-use market by establishing procurement programs for scrap tires (such as for city- or state-sponsored construction projects), by promoting the manufacture of tire products that do not harm people or the environment (e.g., through leaching or volatilization of contaminants), and by identifying appropriate uses of retreaded tires (e.g., some retreaded tires can be safely used on school buses, fire trucks, and other emergency vehicles).[193]
- Establish easy and convenient tire pickup programs for do-it-yourselfers and "mom and pop" auto shops. Consider establishing a tire take-back program at tire retailers and/or vehicle retailers (similar to the used motor oil recycling requirements in New York and New Jersey, see Section 3.3.3 IMPROPER DISPOSAL OF USED MOTOR OIL in this report) and funded by tire manufacturers.
- Consider creating a deposit system for tires that are returned to a recycling facility.

4.5. Industrial Sources

4.5.1. Industrial Fuel Combustion

Industrial Fuel Combustion: National Trends and Emission Factors

Industrial boilers are used widely in manufacturing, processing, mining, and refining, primarily to generate process steam, electricity, or to heat space at a facility. Utility boilers are typically larger than industrial and commercial boilers, and are therefore characterized in Section 4.5.3 POWER GENERATION. Similar to commercial fuel consumption, PAH emissions are associated with the combustion of fuel, including wood waste, natural gas, coal, oil residual (No. 6), and oil distillate (No. 2). Based on data reported by the U.S. Energy Information Administration for 2002, New York and New Jersey were the 15th and 24th largest industrial sectors, respectively, based on fuel consumption (together ~3% of all U.S. industrial fuel consumption) [213].

Table 4.16. Industrial fuel consumption and associated PAH emissions in New York and New Jersey[a]

	Petroleum							
	Distillate fuel (No. 2)		Residual fuel (No. 6)		Natural gas		Coal	
	Barrels	Trillion BTUs	Barrels	Trillion BTUs	BCF	Trillion BTUs	Ton (short)	Trillion BTUs
Watershed								
New York	1,699,200	10	880,100	6	48	50	1,518,500	41
New Jersey	1,898,500	11	468,000	3	67	70	4700	0.08
Total	**3,597,700**	**21**	**1,348,100**	**9**	**115**	**120**	**1,523,200**	**41**
Total PAH emissions[b] (kg/yr)	**1000**		**800**		**<1**		**900**	
Outside Watershed								
New York	1,281,800	7	663,900	4	37	38	1,145,500	31
New Jersey	535,500	3	132,000	1	19	20	1300	0.02
Total	**1,817,300**	**10**	**795,900**	**5**	**56**	**58**	**1,146,800**	**31**
Total PAH emissionsb (kg/yr)	**600**		**500**		**<1**		**700**	

BTU= British thermal unit, BCF= billion cubic feet.

Source: U.S. Energy Information Administration [75].

a In addition to the fuel types listed, kerosene, liquid propane gas, lubricants, and asphalt and road oil were consumed (1, 6, 6, and 40 trillion BTUs in New York and 3, 19, 10, and 66 trillion BTUs in New Jersey, respectively); however, because emission factors are not available for any of these fuel types, they are not included in the table. Motor gasoline and electricity were also consumed, and it is assumed that emissions estimates from these are captured in Section 3.3 Transportation and Section 4.5.3 Power Generation, respectively.

b PAH emission estimates are based on emission factors presented in Table A.3.

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193. Tire debris sometimes found along the highway is often identified as the result of a tire that has been retreaded; however, driving on underinflated tires causes the tread to separate from the tire [177].

The U.S. EPA [215] compiled PAH emission factors for industrial boilers that combust petroleum, natural gas, and coal (Table A.3). All of the emission factors are an average of test results, with the number of tests conducted varying with fuel type. All of the emission factors presented, except for coal, represent emissions testing results from uncontrolled boilers. Similar to commercial boiler emission factors, there are several PAH compounds for which there are no reported emission factors, making it difficult to calculate a comprehensive estimate of PAH emissions from this source. However, these emission factors are the best available at this time.

Industrial Fuel Combustion: Regional Releases

Industrial fuel consumption in the Watershed was estimated by extrapolating from state consumption data based on the percentage of manufacturing facilities in the Watershed reported to the Census in 2002. Based on reported BTU consumption, natural gas is the primary fuel type consumed by the industrial sector in the Watershed (Table 4.16).

Releases to the Atmosphere. PAH emissions were estimated by applying emission factors in Table A.3 to the estimated fuel consumption (Table 4.16). Given the lack of emission factors for several PAH compounds it is difficult to say which fuel type releases the greatest quantity of PAHs.

Measures to Reduce Releases of PAHs from Industrial Fuel Combustion

The most energy intensive industries are aluminum, agriculture, chemical, forest products, glass, and steel. Motors to power pumps, fans and blowers, air compressors, and many other mechanical devices consume energy as part of the industrial process.

Measures that reduce emissions from industrial fuel combustion center on energy efficiency, air pollution control technologies, and identifying alternative products that are less energy intensive. Recent technologies allow boilers and furnaces to operate at higher temperatures while using less energy, creating a more efficient combustion environment. Variable-speed motors also reduce fuel consumption by matching motor output with energy necessary for the task.

Given the diversity of industrial equipment and function, our recommendations will remain general in nature.

The following are pollution recommendations to reduce releases of PAHs from industrial fuel combustion:

REDUCING ENERGY CONSUMPTION THROUGH MATERIAL CHOICE

Choosing products or materials that are less energy intensive to manufacture will reduce releases of PAHs associated with a particular industry. Below are several examples of ways to reduce energy consumption through material choice:

- **Concrete** is produced from water, aggregate, and cement. Cement is an energy (and water) intensive material. By replacing cement in concrete with fly ash (a byproduct of coal-burning power plants), blast furnace slag (a byproduct of metal production), or silica fume (a byproduct of silicon and ferrosilicon alloy manufacturing), the overall embodied energy of concrete can be reduced. In addition, raw aggregate material can be replaced with recycled material, such as crushed material from a demolished building.
- **Aluminum, steel, and glass** industries can reduce overall energy consumption by utilizing recycled material. In addition, consumers can choose recycled or salvaged materials over new/raw materials that require additional energy to extract and manufacture.
- **Lumber** industries can reduce energy consumption by air drying lumber instead of kiln drying.

- When feasible, reduce fuel consumption by using variable-speed motors and by minimizing opportunities for heat loss.
- Confirm that the best available air pollution control technologies are being used, and establish an equipment in-service program to identify equipment that might be failing or not performing correctly.
- Identify alternative products that are less energy intensive to manufacture; products may be identified through life-cycle analysis.
- Encourage the manufacture of products that use recycled materials, reducing the energy required when using raw materials.

4.5.2. Petroleum Processing, Fuel Refining and Gasoline Distribution

Nationally, major industrial processes that release PAHs via coal or petroleum processing, distribution and use include coal coking,[194] coal conversion, petroleum refining, and oil and gas distribution.

Coal Conversion: National Trends and Emission Factors

In coal conversion (also referred to as coal gasification and coal liquefaction), coal energy is transformed into gaseous or liquid forms. Coal gasification was an important source of combustible gas in the U.S. at the turn of the 20th century (resulting in significant releases of PAHs to the environment, see Section 3.5 CONTAMINATED SITES), and continues to be important source of fuel in other parts of the world. However, modern developments in the discovery and transport of natural gas have substantially decreased the need for coal gasification in the U.S. There are currently three major coal conversion plants in operation in the United States that are in North Dakota, Louisiana, and Tennessee [272].

Coal Conversion: Regional Releases

There are no active coal conversion/gasification facilities in the Watershed or on the East Coast [272].

Petroleum Refining: National Trends and Emission Factors

Petroleum refineries release PAHs to the environment via atmospheric emissions and wastewater. In general, the two refining processes that are associated with the largest atmospheric releases of PAHs are process heaters and catalytic cracking units.[195] Atmospheric emissions data depend on the type of fuel being refined, the refining plant design, and the location and method of sample collection.

Wastewater from refineries consists of cooling water, process water (such as water from wet scrubbers), sewage water, and stormwater. Wastewater is treated on site and then either discharged to a wastewater treatment facility or to surface waters or groundwaters; in the latter cases, a National Pollution Discharge Elimination System permit is required [273].

There are limited emissions factor data available for refineries; therefore, atmospheric and wastewater emissions reported to the U.S. EPA Toxics Release Inventory (TRI) are presented in this report.

Petroleum Refining: Regional Releases

New Jersey has a total of six oil refineries, with three located along the Delaware River and three located in the Watershed. One of the facilities in Middlesex County has downstream capacity only and does not distill any oil.[196] The combined distillation capacity of the other two facilities in the Watershed is 335,000 barrels per calendar day, although one of the facilities was reported idle in a report published by MACTEC Federal Programs, Inc. [274]. New York state currently does not have any oil refineries, and relies partly on New Jersey for its petroleum supply needs.

Releases to the Atmosphere. A complete set of PAH emission factors for refineries was not available. Therefore, we present emissions reported to the U.S. EPA's TRI (TABLE 4.17). PAHs are reported as total PAHs (naphthalene is reported separately).

There is uncertainty in the TRI data, primarily due to the method used to collect data. Participating facilities must self-report their emissions, which are often estimated. Although efforts have been made to educate the industrial community on reporting procedures, additional quality control may increase the reliability of data.

Releases to Water. The oil refining facilities in the Watershed treat their wastewater on site, discharge to ground and surface waters, or release to a municipal utility authority [238]. There are two facilities in New Jersey that report to the U.S. EPA's TRI that they discharge water to ground or surface waters (TABLE 4.17), one of which has a permit to discharge 0.9 million gallons of treated wastewater per day to Woodbridge Creek [275]. The discharge to ground or surface water is permitted a daily average total petroleum hydrocarbon concentration of no more than 15 mg/L [238]. The other facility in the Watershed discharges wastewater to a municipal utility authority and is permitted to discharge 50 mg of oil and grease per liter of water per day [276].

Gasoline Distribution: National Trends and Emission Factors

A gasoline distribution network includes activities such as shipping, piping, trucking, rail transport, storage, and service station distribution. For the purpose of es-

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[194] Coal coking is the distillation of bituminous coal into a carbon material called coke.

[195] Cracking units are used to produce gasoline cracking feedstock composed of atmospheric or vacuum gas oils. It is the combustion of the coke used to regenerate the catalyst during this process that is the primary source of PAH emissions [215].

[196] Downstream capacity refers to a facility that produces gasoline and other fuel products by processing intermediates in a fluid catalytic cracking unit [274].

Table 4.17. U.S. EPA 2005 Toxics Release Inventory emissions for petroleum refineries in the New Jersey

Facility	Refining capacity (barrels/ calendar day)	Process type	Stack emissions (kg)		Fugitive emissions (kg)		Total atmos. PAH (kg)	Surface water & groundwater releases (kg)
			Total PAH	Naphthalene	Total PAH	Naphthalene		Naphthalene
Watershed								
Middlesex[a]	—	FCC	38	16	126	69	249	NR
Middlesex[b]	80,000	AD, VD	NR	3	NR	18	21	NR
Union	255,000	FCC, AD, VD, CR, CH, FSD	2	309	NR	500	811	155
Total	**335,000**		**40**	**328**	**126**	**587**	**1081**	**155**
Outside Watershed								
Gloucester[c]	49,500	AD, VD	1	1	NR	297	299	NR
Gloucester	150,000	AD, VD, FCC, CR, CH	NR	NR	NR	NR	NR	NR
Gloucester	160,000	AD, VD, TC,FCC, CR, CH	105	704	NR	NR	809	3
Total	**359,500**		**106**	**705**	**NR**	**297**	**1108**	**3**

AD=atmospheric distillation, CH=catalytic hydrotreating, CR=catalytic reforming, FCC=fluid catalytic cracking, FSD=fuel solvent de-asphalting, VD=vacuum distillation [274].[197] NR=not reporting.

Source: U.S. EPA Toxics Release Inventory, 2005 [221].

a Downstream capacity only, using refined intermediates to produce gasoline.

b This facility produces asphalt only and stores and transfers petroleum products [274].

c 2003 TRI data—2005 data not available.

timating releases of PAHs, gasoline distribution activities have been divided into four phases: 1) In transit—releases occur when vapors are expunged from the delivery tank via vapor expansion and contraction, and when residual vapors or displaced vapors that have been captured and piped back into the delivery tank escape. 2) Stage I—releases occur when vapors in empty tanks are displaced by gasoline being loaded into the tanks. 3) Stage II—releases occur when vapor in a vehicle (e.g., a car) tank is displaced by gas being filled into the tank. 4) Tank breathing—gasoline vapors evaporate from the storage tank and from lines going to the pumps during transfer of gasoline. There are several factors impacting releases from gasoline distribution, including vapor pressure of fuel, technologies and techniques used to load and unload fuel, and tank characteristics (e.g., color, design). Emissions can be controlled through the use of several devices, including vapor recovery and collection or destruction systems; closed vapor balancing systems; internal and external floating roof tanks; and control systems on service station equipment and/or on board automobiles.

The U.S. EPA has published gasoline distribution emission fractions for the filling and "breathing" of underground storage tanks, for in transit trucks, and for vehicle refueling (Table A.3). The emission fractions are presented as a fraction of total VOC emissions. It is estimated that total PAHs comprise 0.05% of gasoline VOC emissions, where total PAHs refers to

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[197] Atmospheric distillation consists of heating crude oil in a heat exchanger and furnace to about 750° F, then feeding the oil into a vertical distillation column, where most of the feed is vaporized and separated into its various fractions; the lighter fractions condense and are collected towards the top of the column. Catalytic hydrotreating utilizes catalysts, in the presence of substantial amounts of hydrogen under high pressure and temperature, to react the feedstocks and impurities with hydrogen, removing impurities such as sulfur, nitrogen, oxygen, halides, and trace metals. Catalytic reforming uses catalytic reactions to process typically low-octane gasolines and naphthas into high-octane aromatics (including benzene). Fluid catalytic cracking uses heat, pressure, and a catalyst to break larger hydrocarbon molecules into smaller, lighter molecules. Vacuum distillation separates the heavier fractions from the atmospheric distillation unit by distilling the petroleum at very low pressure.

the sum of U.S. EPA 16 priority PAHs (see Table 1.2, excluding perylene) [277].[198]

Gasoline Distribution: Regional Releases

New York and New Jersey annually consume approximately 6 billion and 4 billion gallons of gasoline, respectively [278]. Watershed gasoline consumption was extrapolated from state data, based on population.

Releases to the Atmosphere. The U.S. EPA rules require the use of pollution prevention methods (e.g., improving seals on storage tanks, inspecting equipment for leaks) and the use of controls; therefore, an emission fraction associated with balanced submerged filling is used to estimate Stage I PAH emissions.[199] New Jersey requires Stage II controls for all facilities with a storage capacity of greater than 2000 gallons, while New York state requires Stage II (or vehicle fueling) emissions controls only at facilities in the New York City metropolitan area and at facilities in lower Orange County that have an annual throughput greater than 120,000 gallons. Because only a portion of the Watershed is in the NYC metropolitan area, a range of emission estimates is provided for Stage II service station activities.[200] Estimated PAH emissions are presented in Table 4.18.

Measures to Reduce Releases of PAHs from Petroleum Refining and Gasoline Distribution

Currently, PAH emissions from petroleum refining facilities reported to the U.S EPA TRI are relatively small. However, a report published by the Mid-Atlantic Regional Air Management Association indicates that refining facilities are likely incorrectly estimating and reporting their atmospheric emissions [274]. The report also finds that reported emissions do not correlate directly to size of facility, and that, although activity and operation vary between facilities, it is possible that this variation in emissions is a result of inconsistency in reporting methodologies. For example, emission estimates may not correctly estimate emissions from flares and other nonroutine operations.[201]

The U.S. EPA recently changed their emissions reporting requirements for facilities reporting to the TRI. The changes expand eligibility for TRI reporters to use Form A, a more simplified form than reporting Form R. Form A can be used for certain chemicals of greater concern, such as PBTs, when there are no releases or other disposal, and no more than 500 pounds of other water management (e.g., recycling or treatment). In general, Form A serves as a certification that a particular chemical is used at above-reporting thresholds, and can be used by the public as an indication that the facility manages a range of waste (e.g., 0–500 lbs). Form R provides more details about releases (e.g., total quantity of releases to air, water, and land) and other waste management (e.g., on- and off-site recycling, treatment, combustion for energy recovery), including atmospheric releases of PAHs.

The following are pollution prevention recommendations to reduce releases of PAHs from petroleum refining:

Table 4.18. Estimated PAH emissions from gasoline distribution activities within the Watershed[a]

	Watershed	Outside Watershed
Emission Source	Total PAHs[b] (kg/yr)	
Truck in transit[c]	100	100
Stage I—filling of underground storage tank, controlled	500	200
Stage II—service station displacement loss[d]	1800–18,000	900– 9900
Storage tank breathing	1600	800
TOTAL	**4000–20,200**	**2000–10,100**

a PAH emission estimates are based on emission factors presented in Table A.4.
b Total PAHs include the U.S. EPA 16 priority PAHs (see Table 1.2, excluding perylene), although it is likely that naphthalene is the only PAH released.
c Includes transport of fuel to service station and the transport of vapor back to terminal.
d Estimate is a range of releases from controlled and uncontrolled releases.

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[198] It is likely that naphthalene is the only PAH compound released.

[199] Submerged filling refers to a filling method in which the fill pipe extends almost to the bottom of the cargo tank. Liquid turbulence is controlled significantly during submerged loading, resulting in much lower vapor generation than in alternative filling methods such as splash loading.

[200] Stage II regulations in New York and New Jersey do not apply to marine and airplane fueling activities.

[201] Flaring is the combustion of excess gases that may be produced during refinery startup and shutdown and may otherwise be released directly to the atmosphere.

- Make documentation on facility practices and emission estimates available so that agencies and the public can check completeness of reporting.
- Conduct site visits to confirm that reporting is reasonably correct, and conduct testing when warranted.
- Promote and enforce the use of best available control technologies for all refineries, especially for catalytic cracking facilities.

New York and New Jersey have both established regulations to reduce emissions from gasoline distribution. As previously mentioned, New York state, under 6 NYCRR Part 230, requires vapor collection systems on tanks at gasoline dispensing sites whose annual throughput exceeds 120,000 gallons (~328 gallons/day). This regulation also requires Stage II vapor collection systems for gasoline dispensing sites in lower Orange County and in the New York City metropolitan area.[202] New Jersey, similar to New York, requires vapor control systems for stationary storage tanks that have a maximum capacity of 2000 gallons or greater, and has Stage II vapor control requirements for dispensing operations, as stipulated in Rule 7:27-16.3. Exemptions are made for the fueling of marina vehicles and aircraft in both New York and New Jersey regulations.

The following are pollution prevention recommendations to reduce releases of PAHs from gasoline distribution:

- Reduce demand for gasoline through vehicle efficiency, development of non-PAH-releasing fuels, and reduced vehicle use (see Section 3.3. TRANSPORTATION for more recommendations on how to reduce vehicle and gasoline use).
- Extend Stage II emissions control requirements to all vehicle fueling facilities, including facilities in upstate New York.
- Remove the exemption for marine vehicle and aircraft fueling in New York and New Jersey.

4.5.3. Power Generation

Power Generation: National Trends and Emission Factors

Another industrial activity releasing PAHs is the combustion of fossil fuels in the power generating process. However, modern emissions control devices have substantially decreased atmospheric releases of PAHs from this source. For example, baghouse and electrostatic precipitators are effective at controlling particulate-phase PAHs, and scrubbers are often used to compress and control PAHs in the gas phase (see Section 4.5.4 INCINERATION for more information on air pollution control devices).

Although atmospheric control devices capture PAHs, they do not destroy them, and PAHs can accumulate in trapped residues. A common example of this is the lime spray dryer used at coal-fired power generating facilities, where sulfates and particulates including PAHs are captured by a fine (dry) spray of slaked lime injected to the scrubber [279]. PAHs accumulate in the trapped fly ash; however, the concentration is generally lower than the regulatory target or background soil concentration [280]. TABLE A.3 shows PAH concentrations averaged from four samples of LSD ash (a mixture of fly ash, lime, and trapped sulfates) from a spreader stoker boiler coal-fired power generating plant equipped with a dry lime scrubber pulse jet baghouse [279].

Atmospheric emission factors depend on the type of feedstock (i.e., coal, oil, or natural gas), the design of the facility, the type of emissions control devices utilized, and the type and placement of the exhaust sampling device. Emission factors are provided in TABLE A.3 for a coal-fired power plant in Taiwan [281], and natural gas and oil-fired plants in the U.S. [215].

Power Generation: Regional Releases

There are 41 power generation facilities in the New York/New Jersey Harbor Watershed region: 18 in New Jersey and the remaining 23 in New York [282] [283] (TABLE 4.19). Most of the facilities consume a combination of fuels, including coal, natural gas, oil, and kerosene, although most of the facilities combust gas in some capacity. There are 19 coal-fired power plants in New York and New Jersey, with only four in the Watershed.

Releases to the Atmosphere. PAH emissions were calculated by applying the emission factors shown in TABLE A.3 to reported fuel consumption (TABLE 4.19). Of the three types of fuels combusted at power generating facilities in the Watershed, it is the combustion of natural gas in total that releases the largest quantity of PAHs every year, followed by coal and oil. The comparatively large releases of PAHs from natural gas combustion are likely due to the number of natural gas–fired power plants

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[202] Stage II vapor collection systems may be required in upstate New York in the future (6 NYCRR Part 230).

in the Watershed, and not necessarily because electricity produced by natural gas releases more PAHs on a per kilowatt-hour basis. In fact, based on our release estimates, oil produces the largest quantity of PAHs per kilowatt-hour of electricity produced, followed by coal and then natural gas.[203]

All of the coal facilities utilize electrostatic precipitators at some or all of their coal burning plants [285]. This is consistent with the emission factors used to make the estimates. Data obtained on atmospheric emissions controls for the remaining power generating facilities are incomplete; however, some form of emissions control was reported for over half of the facilities [285].

According to the U.S. EPA TRI, 15 electric utility facilities in the Watershed reported releasing 500 kg of PAHs in 2005, approximately 4% of our release estimates.

Releases to Land. Particulate matter that moves up the stack and collects in air pollution control devices is called fly ash (to differentiate it from ash left behind in the combustion chamber, called bottom ash). This ash is landfilled or reused in other materials; for example, as a substitute for cement used in manufacturing concrete.

The quantity of PAHs found in coal-fired power plant fly ash was estimated by assuming that 30% of coal combusted remains as ash and applying the concentrations presented in Table A.3 (Table 4.20).

Measures to Reduce Releases of PAHs from Power Generation

There are several ways to reduce releases of PAHs from power generation. One of the easiest is to employ energy efficiency measures in homes and offices. These include the use of energy efficient lighting, appliances, and technology. Measures that reduce energy loads at certain times of the day can be particularly beneficial. For instance, there are generally three types of electrical generating operations: 1) base load units that operate to meet minimum energy demand, and thus operate constantly; 2) load-following units that operate at low levels during the night and then increase to meet daytime demand; and 3) peak units that operate only during times of peak demand. Eliminating or minimizing the operational demand of peak units can reduce fuel combustion and, consequently, PAH emissions from this source.

Another approach is to use alternative energy sources, such as solar power and wind power, or distributed energy systems. Distributed energy technologies consist primarily of energy generation and storage systems placed at or near the point of use, reducing energy lost during transmission. Technologies include fuel cells and microturbines; fuels include natural gas, hydrogen, solar power, biomass, and wind.

Table 4.19. Estimated PAH atmospheric emissions due to power generation in New York and New Jersey

	Coal (Tons)	Natural Gas (TCF)	Oil- Residual and Distillate (Barrels)
Watershed			
New York			
(23 facilities)	1,236,000	143,702,500	14,959,600
New Jersey			129,500
(18 facilities)	1,036,800	98,074,500	
Total	**2,272,800**	**241,777,000**	**15,089,100**
Total PAH emissions[a] (kg/yr)	**1300**	**10,700**	**500**
Outside Watershed			
New York	7,701,800	125,983,500	10,119,500
New Jersey	1,522,400	6,630,200	26,200
Total	**9,224,200**	**132,613,700**	**10,145,700**
Total PAH emissionsa (kg/yr)	**5200**	**5800**	**400**

TCF= thousand cubic feet

Source: U.S. Energy Information Administration [286, 287].

a PAH emission estimates are based on emission factors presented in Table A.3.

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[203] In general, emissions of PAHs per kWh of electricity produced were calculated by converting kWh per unit of fuel consumed, as reported in the EIA Electric Power Annual 2000, to kWh/BTU and dividing by the total PAH emission factors(lbs PAH/BTU) used to estimate PAH emissions [284]. The kWh per unit fuel used is an average, because energy produced per fuel unit varies with BTU content.

Table 4.20. Estimated PAHs in fly ash generated at coal-fired power generating facilities in New York and New Jersey[a,b]

	Watershed	Outside Watershed
Total PAHs (kg/yr)	24	99

a It is assumed that 30% of the coal combusted remains as ash.
b PAH emission estimates are based on emission factors presented in Table A.3.

The following are pollution prevention recommendations to reduce releases of PAHs from power generation:

- Promote the use of "clean" alternative sources of energy, including within government agencies and government-related facilities. Establish procurement guidelines requiring facilities that receive public funding to purchase a certain percentage of their power from alternative, non-PAH-releasing energy sources.[204]
- Explore the feasibility of alternative energy systems such as distributed energy systems (e.g., combined heat and power systems).[205]Reduce electricity demand during peak periods by promoting energy efficiency measures (e.g., energy efficient lighting, appliances, and technology; policies that require commercial and retail facilities to keep their doors closed when using air conditioning).
- Improve pollution controls on new and existing facilities.

4.5.4. Incineration

The incineration process consists of combusting solid, semisolid, liquid, or gaseous materials in an attempt to reduce waste volume. Historically, incineration activities have been a significant source of atmospheric emissions, emitting such compounds as hydrocarbons, sulfur oxides, nitrous oxides, chlorides, and carbon monoxide (CO). It was reported that in 1940, 2202 thousand tons of CO were released in the U.S. from incineration processes. Over the years, however, regulations governing emissions have changed, beginning in the 1960s with the formulation of particulate standards for all incinerators [289]. Since then, additional emission standards have been established, and utilization of some form of air pollution control device to meet these standards has become the norm. As a result of these changes, yearly CO emissions were reduced to 413,000 tons by 1998, 66% less than in 1940 [290].

Organic compounds, including PAHs, can be controlled through proper plant design and operation of the combustor, and by using air pollution control devices (APCDs). APCDs may be utilized either alone or collectively, and include fabric filters, electrostatic precipitators, and dry scrubbers [291]. Table 4.21 provides a brief overview of each of these pollution control systems. In general, PAHs are captured by controlling emissions of PM, acid gas, sulfur dioxide, or nitrous oxide. Residual emissions of PAHs in facilities with modern APCDs are small, and depend on type of material being burned, type of facility, combustion conditions, and type of emissions control devices in place. Therefore, emissions of PAHs from incineration processes are difficult to estimate.

In a typical incineration process, approximately 30% of the incinerated waste is retained in the ash [293]. Ash materials are generally divided into two categories: heavy material that remains at the bottom of the incinerator chamber ("bottom ash"), and light ash that escapes up the stack and is captured by air pollution control devices ("fly ash"). Typically, PAH content is much higher in bottom ash [294]. Ash materials may be disposed of in municipal landfills or, depending on their organic compound and metal content, may be used to make building materials or roads in a process known as beneficial reuse. Given the volume of ash generated from all incineration processes combined (~4 million tons of ash per year in New York and New Jersey),[206] beneficial reuse is an attractive option, although a careful analysis must be performed to ensure contaminants will not leach from the finished materials

Regulated Medical Waste Incineration: National Trends and Emission Factors

On average, hospitals generate approximately 26 pounds of waste per bed per day. The type of waste generated is heterogeneous, and is highly dependent on the origin (e.g., laboratories, hospitals,

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[204] One hundred percent of the electricity used to power the floodlights and torchlight at the Statue of Liberty will be wind power generated in Pennsylvania and West Virginia. The U.S. General Services Administration, responsible for running government buildings, states that because they buy in bulk, there will be no increase in cost [288].

[205] Combined heat and power (CHP) systems generate electricity and useful thermal energy in a single, integrated system. The thermal energy recovered in a CHP system can be used for heating or cooling.

[206] This estimate is based on a 30% ash generation rate and includes the following combustion activities: coal combustion, hazardous waste incineration, sewage sludge incineration, municipal waste incineration, and medical waste incineration.

Table 4.21. Summary of emissions control technologies utilized at industrial facilities

Technology	Pollutant controlled	Description	Cleaning mechanism
Fabric filter (FF, a.k.a. baghouse)	PM, metals	Pollutants are removed by passing flue gas through a porous fabric bag. Several filter bags make up one compartment, with several compartments to a complete fabric filter system. PM is collected through inertial impaction and accumulates into a filter cake.	Reverse air is blown through the filter bag, causing the bag to collapse and drop the filter cake. A pulse jet system uses compressed air that is pulsed through the inside of the filter bag until the filter cake falls off.
Electrostatic precipitators (ESP)	PM	Flue gas flows through a series of high-voltage discharge electrodes and ground metal plates. Negatively charged ions attach to PM, causing the charged particles to fall.	Particles are collected on ground plates and are removed by cleaning the plates.
Dry scrubbers	Acid gas, CDD/CDF (in combination with ESP or FF)	Sorbent is pneumatically injected into a reaction vessel or a section of flue gas duct downstream of combustor. Alkali in sorbent reacts with HCL, HF, and SO2 to form alkali salts, calcium fluoride, and calcium sulfate.	Solid reaction products and unreacted sorbent are collected with either an ESP or FF.
Wet scrubber[a]	Acid gas, SO2	Flue gas is passed over a liquid spray, jet, or layer of calcium-, sodium-, and ammonium-based sorbents (typically limestone) that react with the SO2 in the flue gas.	A sludge is produced that must be treated before disposal.
Selective catalytic reduction (SCR) and noncatalytic reduction	NOx	An ammonia-based reducing agent reacts with NOx to produce N2 and water. SCR works at a lower temperature because a catalyst is used.	

CDD=chlorinated dibenzo-para-dioxin, CDF=chlorinated dibenzofuran, NOx=nitrogen oxide, PM=particulate matter, SO2=sulfur dioxide
Source: U.S. EPA [291].
a Source: International Energy Agency and Clean Coal Centre [292].

health facilities). However, the typical composition of waste is 55% paper and cardboard, 10% water, 30% plastics, and 5% miscellaneous [295]. Some medical waste, referred to as “red bag waste,” is infectious and must be incinerated or otherwise sterilized to prevent the potential spread of disease. It is estimated that approximately 15% of total hospital waste is red bag waste; however, some hospitals treat up to 90% of their waste as red bag waste, due to the lack of standard waste separation practices [296]. For example, a study conducted by Waste Tec in 1991 found that through proper sorting, recycling, and use of nondisposable materials, red bag waste could potentially fall to 5%.

Emission factors for two medical waste incinerators are given in Table A.3 [297]. The emission factors were taken from a mechanical grate and a fixed grate facility that combusted blood, sharps, isolation wastes, and pathological and animal wastes.[207] Emissions control devices for both incinerators included an electrostatic precipitator and a wet scrubber placed in series.

Regulated Medical Waste Incineration: Regional Releases

In New Jersey, there are 30 medical waste generators that treat their own regulated medical waste (RMW) [298]; generators that do not treat their own waste

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[207] Mechanical grate refers to an incinerator facility design that allows waste to be rearranged during the incineration (akin to stirring the embers in a fireplace) versus a fixed grate facility where the waste bed cannot be moved during the process.

ship it out of state for treatment. Five of the regulated treatment facilities that treat their own waste are authorized to incinerate their waste, while the remaining generators use alternative methods, such as microwave/grinders, chemical/grinders, or autoclave/grinders. The five incineration facilities, all of which are in the Watershed, have a combined incineration capacity of approximately 3000 tons per year (TABLE 4.22.) [299].[208] Based on the information provided by the New Jersey Department of Environmental Protection, all but one of the facilities utilizes some form of air pollution control device to control emissions. The fifth facility is reported to meet the emission limits without air pollution controls. There are currently no commercial RMW treatment facilities in New Jersey.

New York generates approximately 200,000 tons of RMW annually, and has 30 transfer, treatment, and disposal facilities permitted to operate, with a combined throughput capacity of 96 tons per day (~35,000 tons/yr) [300]. Currently, there are no operating medical waste incineration facilities in New York.

Releases to the Atmosphere. A range of PAH emissions was calculated by applying the emission factors in TABLE A.3 to the New Jersey incineration facility capacity (TABLE 4.22). There is uncertainty in this estimate, given that emission factors are based on the combustion of specific materials in a particular combustion environment, and that actual material combusted and combustion environment will vary with each facility.[209]

Releases to Land. PAH concentrations in fly ash and bottom ash from medical waste incinerators are not available.

Measures to Reduce Releases of PAHs from the Incineration of Regulated Medical Waste

There are two ways to reduce the incineration of regulated medical waste: 1) reduce material discarded, and 2) utilize alternative treatments such as autoclaving.[210]

The following are pollution prevention recommendations to reduce releases of PAHs from the incineration of regulated medical waste:

- Reduce material discarded by educating employees on proper waste sorting practices.
- When appropriate, consider using reusable equipment.
- Consider the use of alternative treatments, such as autoclaving.

Municipal Solid Waste Incineration: National Trends and Emission Factors

Most facilities burning municipal solid waste (MSW) recover heat and generate energy, and are referred to as waste-to-energy facilities (89 in the U.S. [305]). There are three types of municipal solid waste inciner-

Table 4.22. Estimated PAH atmospheric emissions due to medical waste incineration in New Jersey

County	APCD[a]	Capacity (tons/yr)
Mercer	FF/WS	708
Passaic	SNCR/WS/ESP	725
Somerset	None[b]	454
Union	DS/DC[c]	454
Union	WS/FF	725
Total tons		**3065**
Total PAH emissions[d] (kg/yr)		**100–300**

APCD= air pollution control device, DC=dust collector, DS=dry scrubber, ES=electrostatic precipitator, FF=fabric filter, SNCR=selective noncatalytic reduction, WS=wet scrubber.

a Source: Olson [302].

b Source: Subash [303].

c Source: Romano [304].

d PAH emission estimates are based on emission factors presented in Table A.3.

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[208] These facilities may incinerate material other than medical waste or below capacity; therefore, actual medical waste incinerated may be less than the reported value.

[209] The NJDEP defines medical waste as any solid waste generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining to or in the production or testing of biologicals [301]. The exact amount and composition of medical waste being burned at each individual facility is unknown.

[210] An autoclave is a strong, pressurized, steam-heated vessel used for sterilization. Material that is autoclaved is then landfilled.

ation technologies: refuse-derived fuel,[211] modular,[212] and mass burn.[213] The prevalent design of large-scale municipal waste-to-energy is mass burn. Approximately 70% of municipal waste incineration capacity is provided by mass burn facilities, and it is estimated that over 50% of all new units will be mass burn [215] [280]. Most of the mass burn refractory wall combustors in use today were built in the 1970s and 1980s, and typically use electrostatic precipitators (ESP) to reduce PM emissions.

Atmospheric PAH emissions are generated when incomplete combustion of organic materials evolves from the waste. In general, PAH emissions can be minimized by creating a combustion environment with adequate oxygen, temperature, residence time, and turbulence [215]. The U.S. EPA obtained data from the Integrated Waste Services Association to develop PAH emission factors [215]. Although 16 PAHs were targeted in the data, naphthalene was the only compound detected in samples from all facilities (6.06E-06 lb naphthalene/ton of material incinerated).[214]

Table A.3 provides PAH concentrations in MSW incinerator bottom ash from four moving grate facilities in Sweden [306]. These samples were analyzed for PAHs after aging in open containers for four years. Despite the aging step, the data from this study were determined to be more complete than from any other study available for bottom ash from MSW incineration, and the PAH concentrations by compound are similar to (and usually greater than) the fragmentary data available in four other studies.

Municipal Solid Waste Incineration: Regional Releases

There are ten MSW incineration facilities in New York and five in New Jersey, with a total of five facilities in the Watershed (Table 4.23) [305]. For facilities in New Jersey, it was assumed that annual combustion is equal to 85% of annual capacity.[215] Actual combustion volumes were reported for New York. All of the facilities employ multiple air pollution control technologies.

Releases to the Atmosphere. PAH emissions were estimated by applying emission factors in Table A.3 to facility capacity (Table 4.23).

Releases to Land. Assuming that 30% of the material incinerated is retained in ash, approximately 609,000 tons of ash is generated annually in the Watershed from municipal solid waste incineration (946,000 tons in the rest of New York and New Jersey). The estimated PAH content in the ash generated is presented in Table 4.23.

Most of the ash generated in New York and New Jersey is landfilled. In New Jersey, some of the ash is blended with dredged soils and cement kiln dust, and sent to Pennsylvania for mine reclamation or alternative daily cover for landfills.[216]

Measures to Reduce Releases of PAHs from MSW Incineration

MSWI emissions are regulated under 40 CFR Part 60, in which emission standards are established in subparts Ca and Ea for the following: PM, tetrachorinated through octachlorinated dibenzo-p-dioxin/chlorinated dibenzofurans (CDD/CDF), hydrogen chloride (HCl), sulfur dioxide (SO_2), nitrogen oxide (NOx) (subpart Ea only), and carbon monoxide (CO). Standards for mercury (Hg), lead (Pb), cadmium (Cd), and NOx (for subpart Ca) are being considered for new and existing facilities [280]. There are no standards for PAH included in this regulation.

One way to reduce emissions from MSW incineration is to decrease the amount of waste generated. However, this is not the trend in our region. In New Jersey, municipal solid waste has increased from approximately 8 million tons in 1995 to approximately 9 million tons in 2003 [301]. In contrast, the recycling rate has decreased from 45% in 1995 to 33% in 2002, leaving a larger quantity of material to be landfilled, incinerated, or exported out of state for management [301]. At this point, a current published estimate of municipal solid waste generated in New York is not available; however, data provided by the New York State Department of Environmental Conservation indicate that the quantity of material incinerated in the state over the past six years has increased slightly (by ~ 2%) [307]. Incineration in the New York Watershed reached its peak in 2001, while incineration in the entire

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[211] A refuse-derived fuel system entails the shredding of nonrecyclable material that is combusted for energy on site or transported off site to be used as fuel in a boiler that also burns fossil fuel [305].

[212] Modular systems combust mixed waste in a smaller furnace and are typically assembled where needed [305].

[213] Mass burn systems combust mixed waste in a large furnace that is dedicated to producing energy from waste [305].

[214] Emission factors from facilities with different combinations of air pollution control devices were not found to be significantly different, and, therefore, were averaged.

[215] Annual capacity = daily capacity × 365 days × 85%. It is estimated that typical annual throughput capacity is 85% [305].

[216] For more information, see G. Muñoz et al. [253].

state was at its highest in 2004. Since reaching its reuse/recycling goal of 42% by weight (12 million tons recycled) in 1997, there have been no reports published by the New York Department of Environmental Conservation estimating MSW generation and recycling rates [308].[217]

The following are pollution prevention recommendations to reduce releases of PAHs from MSW incineration:

- Reduce waste generation (see MEASURES TO REDUCE EMISSIONS FROM OPEN BURNING OF HOUSEHOLD WASTE, WASTE MINIMIZATION).
- Data gaps.
  - Update New York State data on recycled and composted materials.

Sewage Sludge Incineration: National Trends and Emission Factors

The incineration of sewage sludge, typically in a multiple-hearth furnace (MHF) or fluidized bed (FB), is another source of PAH emissions to the atmosphere and to land via the disposal of ash generated from the combustion process. Sludge, a byproduct of wastewater treatment, is composed of organic compounds that release PAHs when combusted. Naphthalene is the PAH most commonly reported from emissions testing at sewage sludge incinerators (SSI), and is the driving force of the emission factors presented in TABLE A.3 [[309], as cited by the U.S. EPA [215]]. These emission factors are averages from tests conducted on three different multiple-hearth furnaces, all of which were equipped with wet scrubbers. A complete set of emission factors for FBC was not avail-

Table 4.23. Waste-to-energy facilities in New York and New Jersey, and associated PAH releases[a]

State	County	Technology	Air pollution control technology	Annual capacity (tons)
Watershed				
NJ	Essex	MBWW	SDA/ESP/CI/SNCR/WESPHIX	759,939
NJ	Union	MBWW	SDA/FF/SNCR/CI	405,301
NY	Dutchess	RWW	DSI/FF	136,548
NY	Washington	MBWW	SDA/ESP/CI	140,025
NY	Westchester	MBWW	SDA/FF/SNCR/CI	588,077
Total				**2,029,890**
Total PAH emissions (kg/yr)				**10**
Total PAHs in -bottom ash (kg/yr)				**1000**
Outside Watershed				
NJ	Camden	MBWW	SDA/ESP/CI	295,532
NJ	Gloucester	MBWW	SDA/FF/SNCR/CI	161,839
NY	Suffolk	MBWW	SDA/FF/SNCR/CI	126,094
NJ	Warren	MBWW	SDA/FF/NOX/CI	194,515
NY	Nassau	MBWW	SDA/FF/SNCR	846,766
NY	Suffolk	MBWW	SDA/FF/SNCR/CI	288,236
NY	Suffolk	RWW	DSI(hydrated lime/tesisorb)/FF	130,161
NY	Niagara	MBWW	SDA/FF/SNCR/CI	3378
NY	Onondaga	MBWW	SDA/FF/SNCR/CI	727,496
NY	Oswego	MCU	SDA/FF/CI	322,608
Total				**3,155,215**
Total PAH emissions (kg/yr)				**10**
Total PAHs in bottom ash (kg/yr)				**1500**

MBWW=mass burn, water wall; MCU=modular combustion unit; RWW=rotary water wall combustor.
CI=activated carbon injection; DSI=dry sorbent injection; ESP=electrostatic precipitator; NOX=nitrogen oxide control device; SNCR=select noncatalytic reduction for nitrogen oxides control; FF=fabric filter; SDA=spray dryer absorber (same as dry scrubber); WESPHIX=fly ash stabilization.
Sources: Kiser and Jannes [305]; New York State Dept. of Environmental Conservation [307].
a Estimates of PAHs in bottom ash are based on concentration factors presented in Table A.3.

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[217] New York set this goal in 1987 and achieved it in 1997 [301]. Since then, no new goal has been set.

able; however, available emission factors for naphthalene alone (1.94E-01 lb/ton of dry sludge) indicate that emissions from this type of incinerator may be higher than those from MHFs [215].

Sewage Sludge Incineration: Regional Facilities

Of the 24 in-service sewage sludge incineration facilities in New York and New Jersey, 14 are in the Watershed. Combined, these facilities process approximately 48,000 tons of material every year (Table 4.24); approximately 74,000 tons are processed in the rest of New York and New Jersey. Most of the incinerators in use within the Watershed are FBC (65%), with the remaining MHF.

Releases to the Atmosphere. An emission factor for FBC is not available; therefore, it is assumed that all sewage sludge incinerated releases the same amount of PAHs as a MHF. An estimate of PAHs released is calculated by applying the emission factor previously presented to the quantity of sludge incinerated every year (Table 4.24).

The lack of emission factors brings uncertainty to this estimate. Over half the material incinerated is combusted in a FB, a combustion unit for which an emission factor was not available.

Releases to Land. PAH concentrations for ash from sewage sludge incinerators are not available.

Measures to Reduce Releases of PAHs from Sewage Sludge Incineration

Atmospheric emissions from sewage sludge incineration can be addressed through investigation into further air pollution control technologies.

Recommendations are as follows:

- Optimize combustion conditions by maintaining relatively high combustion temperatures and adequate oxygen concentrations throughout the combustion process.
- Confirm that the best available air pollution control technologies are being used.
- Data gaps.
  - A complete list of air pollution control technologies used at facilities in the Watershed should be made available to the public.
  - Emission factors for FBC facilities should be developed.

Hazardous Waste Incineration: National Trends and Emission Factors

Hazardous waste (HW) material is generated by various industries and entities such as manufacturers, wholesale trade companies, certain universities, hospitals, and certain government facilities. It is estimated that between 1.5 and 3 million tons of hazardous waste is incinerated every year in the United States [296]. PAH emissions from this source are caused by incomplete combustion of feedstock (in this case, hazardous waste material). The quantity of PAHs released will vary greatly with the mixture of material being incinerated and, in some cases, may result in very low PAH emissions.

The U.S. EPA provides emission factors based on a study conducted by Johnson et al. [309], in which various types of hazardous wastes were combusted in different combustion configurations equipped with scrubbers and baghouse air pollution control devices (Table A.3). The characterization of the material incinerated was not available; therefore, estimates will be uncertain. Another caveat is the absence of an emission factor for naphthalene. In a study by Trenholm et al. [311], the concentration of naphthalene in the exhaust gas of a hazardous waste incinerator was found to be 100 times greater than that of the other two reported compounds, pyrene and fluoranthene.

Hazardous Waste Incineration: Regional Releases

The quantity of nonaqueous hazardous waste managed in New York increased slowly from 1995 to 2000. In 2000, New York treated 940,522 tons of hazardous waste, of which 97,950 tons were incinerated (68,000 tons more than in 1995).[218] Although, on average, 30% of HW generated in the state is exported, New York is a net importer of nonaqueous hazardous waste, most of which comes from Canada [312]. There are seven hazardous waste incineration (HWI) facilities in New York, of which four are within the Watershed**.**

There are three HWI facilities in New Jersey, with one located within the Watershed. Combined, these three facilities incinerate approximately 10,200 tons of hazardous waste per year, including approximately 200 tons at the facility in the Watershed [313, 314]. Table 4.25 provides facility characteristics, including available combustion technology, type of waste incinerated, and air pollution controls.

The amount of hazardous material incinerated at the facilities in the New York Watershed is not avail-

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[218] Fluctuations may be due to specific projects. In 2000, 236,673 tons of waste was generated and managed on site in New York state at one facility undergoing a hazardous waste remediation project [312].

Table 4.24. Sewage sludge incinerators in New York and New Jersey, and associated PAH atmospheric emissions

State	County	Incinerator	No. of units	APCDs[a]	Sludge combusted (DMT/yr)
Watershed					
NJ	Monmouth	FB	1	TS/VS/WESP	1897
NJ	Bergen	FB	1	VS/IT	2358
NJ	Somerset	FB	1	VS/TS/WESP	4320
NJ	Morris	FB/MH	1	VS/TC/WESP	3869
NJ	Morris	MH	2		4780
NJ	Mercer	MH	2		7634
NJ	Passaic	MH	2	VS/cooler/WESP	1314
NY	Dutchess	FB	1	VS/IP	658
NY	Herkimer	FB	1		694
NY	Oneida	FB	3	VS/IT	6227
NY	Warren	FB	1		2286
NY	Albany	MH	1		5523
NY	Albany	MH	1		2995
NY	Saratoga	FB	1		3543
Total					**48,097**
Total PAH emissions[b] (kg/yr)					**100**
Outside Watershed					
NJ	Atlantic	MH	2	AB/VTV/TS	12,746
NJ	Gloucester	FB	1	VS/TS	13,291
NY	Cayuga	MH	1		2986
NY	Erie	MH	3		13,546
NY	Erie	FB	2		3086
NY	Nassau	FB	1	VS/ITS	600
NY	Monroe	MH	3	WS	21,769
NY	Suffolk	MH	2		1998
NY	Erie	MH	2	VS	2134
NY	Jefferson	FB	1	VIS/TI	1457
Total					**73,613**
Total PAH emissions[b] (kg/yr)					**100**

APCDs=air pollution control device, DMT=dry metric tons, FB= fluidized bed, IT=impingement tray, MH=multiple hearth, TS=tray scrubber, VS=ventury scrubber, WESP=wet electrostatic precipitator.

Source: Roufaeal [310].

[a] We have identified air pollution control devices for half of the facilities, but have been unable to find data on the remainder.

[b] PAH emission estimates are based on emission factors presented in Table A.3.

able; therefore, it was assumed that activity in the Watershed is proportional to the number of facilities in the Watershed (~59,000 tons in the New York Watershed). Activity data are available for the facility in the New Jersey Watershed, and emission estimates were made based on these data.

Releases to the Atmosphere. PAH emissions were estimated by applying emission factors in Table A.3 to the quantity of waste incinerated (Table 4.25). If it is assumed that emissions from naphthalene alone are two orders of magnitude greater than emissions from fluoranthene (as found by Trenholm et al. [311]), then 133 kg of naphthalene alone is released annually in the New York and New Jersey Watershed region. In total, approximately 140 kg of PAHs may be released in the Watershed.

As previously mentioned, the characteristics of the waste incinerated greatly influence the quantity of PAHs released. The unknown composition of material incinerated combined with uncertainty in the emission factors leads to uncertainty in this estimate.

Releases to Land. PAH concentrations in ash from hazardous waste incinerators currently are not available.

Measures to Reduce Releases of PAHs from Hazardous Waste Incineration

The following are pollution prevention recommendations to reduce releases of PAHs from hazardous waste incineration:

- Reduce the quantity of material incinerated by establishing waste minimization plans at facilities generating hazardous waste, and by promoting the use of alternative/nonhazardous materials through purchasing policies and green chemistry.[219]
- Optimize combustion conditions by maintaining relatively high combustion temperatures and adequate oxygen levels throughout the combustion process.
- Further research.
  - Develop improved emission factors that measure all PAHs, including naphthalene, and that consider the combustion of different types of hazardous waste.

4.5.5. Metal Production

Aluminum Production: National Trends and Emission Factors

The production of metals, including aluminum and steel, has been a major contributor to PAHs releases in the recent past. One study published in 1996 reported that 860 tons/yr of total PAHs were released in the U.K. by an industrial process called anode baking, a step in the aluminum-making process [316]. This figure represents more than one-third of the total PAHs released from all sources that year in the U.K. Air emission factors for aluminum production are quite high: one report cites values of 0.005 to 0.015 kg/ton for benzo[a]pyrene and 0.3 to 0.5 kg/ton for total PAHs [59]. However, it is likely that modern technological developments have substantially decreased total and specific releases of PAHs from aluminum production.

Table 4.25. Hazardous waste incinerators in New York and New Jersey, and associated PAH atmospheric emissions

State	County	Combustor	Waste type	APCDs
Watershed				
NJ	Hudson	Incinerator	Liquid	LEWS, WQ
NY	Albany	Lightweight aggregate kiln	Liquid, solid	C, HE, FF, HEWS
NY	Albany	Lightweight aggregate kiln	Liquid, solid	LEWS, WQ
NY	Saratoga	Incinerator	Liquid	WQ, LEWS, IWS
NY	Saratoga	Incinerator	Liquid, solid, sludge	WQ, LEWS, IWS
Tons of hazardous waste incinerated				**59,200**
Total PAH emissions[a] (kg/yr)				**7–140**
Outside Watershed				
NJ	Gloucester	NA	NA	None[b]
NJ	Gloucester	NA	Liquid	WQ, HEWS, LEWS
NY	Monroe	Rotary hearth	Sludge	WQ, LEWS, HEWS, WESP
NY	Monroe	Rotary kiln	Liquid, solid	WQ, HEWS
NY	Niagara	Liquid injection	Liquid organics, wastewater, fuel oil	QC, LEWS, IWS
Tons of hazardous waste incinerated				**49,200**
Total PAH emissions[a] (kg/yr)				**12–260**

APCDs=air pollution control devices, C=multiclone, FF=fabric filter, HE=heat exchanger, HEWS=high-energy wet scrubber, IWS=ionizing wet scrubber, LEWS=low-energy wet scrubber, WHB=waste heat boiler, WQ=wet quenching.

NA: not available.

Sources: New York State Dept. of Environmental Conservation [312]; U.S. EPA [313]; M. Gerchman, pers. Comm. [314]; New York State Dept. of Environmental Conservation [315].

a PAH emission estimates are based on emission factors presented in Table A.3. Range represents emission estimates with and without the naphthalene estimate.

b Meets air quality standards without controls. (M. Gerchman, pers. Comm. [314]).

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[219] Green chemistry is an effective pollution prevention approach that focuses on reducing, recycling, or eliminating the use of toxic chemicals by finding alternative ways to reach the same scientific goals.

Casting of metals, including aluminum die casting, may also be a source of PAH emissions, but specific emission factors are not available.

Aluminum Production: Regional Releases

There are no primary aluminum production facilities in the Watershed. There is one known primary aluminum facility in northern New York, outside of the Watershed, whose emissions may have a transboundary affect on the Watershed. However, at this point no emission estimates have been made. There are six secondary aluminum plants in the Watershed, with a production capacity of approximately 264,000 tons per year [317]. Two of these facilities process "clean" scrap, and it is likely that associated emissions are due to fuel combustion, a PAH release that is captured in the Industrial Fuel Combustion section of this report.

Steel Production: National Trends and Emission Factors

Production of steel is also associated with releases of PAHs to the atmosphere. The available data [281] indicate, once again, that emissions of naphthalene dominate emissions of all other PAH compounds released to air. The steel manufacturing process consists primarily of taking iron produced in a blast furnace and converting it into steel in a basic oxygen furnace (BOF). This process can be broken down into the following steps: 1) pig iron is manufactured from sintered, palletized, or lumped iron ores using coal coke[220,221] and limestone in a blast furnace; and 2) pig iron is fed to a BOF with scrap metal, fluxes, alloys, and high-purity oxygen to manufacture steel. PAH emissions are linked to the combustion of coal coke and potentially oily materials in the pig iron feed.

Electric arc furnaces (EAFs)—which also release PAHs through the combustion of coal coke and, in some cases, coal—are used to produce iron products from a combination of used and raw materials (e.g., steel scrap, pig iron, coke or coal, limestone). This process is referred to as secondary production because the product is not composed entirely of raw materials. The EAF contains three carbon electrodes, whose extreme heat causes carbon reduction of the metal and iron oxides, resulting in the formation of a ferroalloy. This material is then poured into a cast or mold.

Table A.3 provides PAH emission factors for steel production and related processes [281]. In each case, the oxygen concentration was approximately 20% and the emissions control device in place was a baghouse.

Casting, another component of the steel sector, is also a source of PAHs. Casting foundries are characterized by the gray, white, malleable, or ductile metal castings they produce. Casting consists of melting metal in a cupola, and to a lesser extent in an EAF, and then injecting the molten material into cavities of a mold made of sand, metal, or ceramic material.[222] PAH emissions from this source are most closely associated with molding, casting, and shakeout of the metal, and are a function of the type and quantity of organic binder used to produce the casting molds [215]. These fugitive emissions are controlled with local hooding or building ventilation systems that are ducted to a control device.

The emission factors in Table A.3 represent an average of two testing programs at a single cupola gray iron foundry [318] [319] (as cited by the U.S. EPA [215]). The cupola tested was equipped with an afterburner and a baghouse.

Steel Production: Regional Releases

There are three known electric arc furnace facilities in New York and New Jersey: one outside the Watershed in Cayuga County, New York, and two within the Watershed in Middlesex County, New Jersey [320]. Combined, the two facilities within the Watershed produce 1.2 million tons of steel per year (Table 4.26) [321]. All of the facilities in the Watershed are equipped with baghouse air pollution control technology on their melt stacks and are considered to use Best Available Control Technology by the U.S. EPA [322]. This is consistent with the emission factors used to calculate emissions. The newer of the two mills, in addition to using baghouse technology, applies a preheating mechanism to their feedstock, providing extended gas combustion time [323].

There are at least 22 iron and steel casting facilities in the Watershed.[223] Based on reported monthly melt,

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[220] Coal coking is a process to convert certain types of coal into a substance called coke. Certain types of coal coking facilities require the combustion chamber to be opened intermittently to add more coal; this is likely to be when most PAHs are released to the atmosphere. Air emissions factors for coal coking are 0.2 mg/kg of coal for benzo[a]pyrene and 15 mg/kg coal for total PAHs [59]. There are no coking facilities in the Watershed.

[221] The sintering process consists of first mixing iron-bearing materials with coke or coal fines, limestone fines, water, and other recycled dusts (e.g., blast furnace flue dust). The prepared feed is then distributed evenly onto a continuous traveling grate, at which point the coke is ignited. After the coke has been ignited, the traveling strand passes over windboxes, where an induced downdraft maintains combustion and creates high temperatures (2400 to 2700°F [1300 to 1500°C]), fusing the metal particles into a porous clinker that can be used as blast furnace feed [215].

[222] Approximately 70% of all castings are made with the use of a cupola furnace, although the use of EAFs is increasing [215].

[223] In the Watershed there are 39 additional casting facilities that cast other materials such as copper and bronze.

approximately 36,000 tons of iron and steel was cast in 2002 by these companies [324]. In addition to the lack of casting data for four of the foundries, it is possible that this estimate includes casting of materials such as copper and bronze, as well as iron and steel.

There are no known blast furnaces, basic oxygen furnaces, or coal coke ovens in the Watershed.

Releases to the Atmosphere. PAH emissions were estimated by applying emission factors in Table A.3 to reported production (Table 4.26).

The emission factor used to estimate PAH emissions from casting is for iron casting. Available annual melting data did not allow any discrimination between material that was iron and that which was steel; therefore, it is assumed that iron and steel casting have a similar emission rate. Total estimated emissions were approximately 1 kg of PAHs per year. Data are not available on the air pollution control devices utilized at these facilities.

Measures to Reduce Releases of PAHs from Steel Production

Emissions from this sector are relatively small and may not be a significant source of PAHs to the Harbor.

- The following are pollution prevention recommendations to reduce releases of PAHs from steel production:
- Optimize combustion conditions by maintaining relatively high combustion temperatures and adequate oxygen levels throughout the combustion process.
- Evaluate maintenance and performance of pollution control devices.

4.5.6. Cement Production

Cement Production: National Trends and Emission Factors

Concrete, a material used in construction and building, consists of a sand/stone aggregate mixed with cement and water. The cement acts as a binding agent that enables the formation of concrete. Manufacturing cement is by far the most energy intensive process in the making of concrete, and concrete is considered one of the more energy intensive construction materials overall. Making cement requires the heating (also known as pyroprocessing) in large kilns of starting materials that include calcium carbonate, iron, and silicon oxides. The product of this process is called clinker and is mixed with gypsum to produce cement. Clinker is composed of limestone and pozzolans, materials that react with calcium hydroxide and alkali to form compounds possessing cementitious properties.

The combustion of fuel to heat the kilns is believed to be the primary source of PAH emissions, although some facilities may use raw materials containing organic compounds that may combust during pyroprocessing, releasing PAHs [215]. Fuel burned in kilns may be a combination of natural gas, oil, and coal. Some plants supplement their fuel consumption with waste solvents, chipped rubber, tires, or hazardous waste.

Table 4.26. Steel production facilities in New York and New Jersey, and associated PAH atmospheric emissions[a]

County	APCD	Production (tons/yr)
Watershed		
Middlesex, NJ	Baghouse on melt-shop stacks	647,000
Middlesex, NJ	Baghouse preheater[a]	556,000
Total		**1,203,000**
Total PAH emissions[b,c] (kg/yr)		**200**
Outside Watershed		
Cayuga, NY[d]		500,000
Total PAH emissions[b] (kg/yr)		**100**

APCD= air pollution control device

Source: H. Scardoelli (pers. comm.) [321].

[a] Scrap is loaded on a conveyer and transported to the furnace. Furnace exhaust is sent back over scrap, allowing for heat exchange as well as additional time for the combustion of gases.

[b] PAH emission estimates are based on emission factors presented in Table A.3.

[c] Total includes electric arc furnace and cupola/casting emissions.

[d] Source: Nucor Corp., http://www.nucorauburn.com/Aboutus.htm (accessed August 10, 2005).

Table 4.27. Cement facilities in the Watershed region

State	County	Kiln type	Pollution control technology	Fuel	Clinker (tons/yr)
NY	Warren	Dry	Baghouse on clinker cooler, electrostatic precipitator on kiln	Oil	600,000
NY[a]	Greene	NA	NA	NA	NA
NY	Albany	Wet	Baghouse dust collectors, electrostatic precipitator on kilns	Coal, coke, and oil[b]	1,600,000
NY	Greene	Wet	Electrostatic precipitator on kilns	Coal and oil[c]	591,026
TOTAL					**2,791,026**
Total PAH emissions[d] (kg/yr)					**3700**

NA= Not available.

Sources: D. Malone (pers. comm.) [326]; N. Jarry (pers. comm.) [327]; J. Brenchley (pers. comm.) [328].

a This facility imports clinker to make cement and does not use a kiln.

b During operation at this facility, a combination of coal and coke are used; during start-up and preheating, oil is used as well.

c This facility may use up to 20% chipped tires, gas, and nonhazardous waste (e.g., paper, wood)

d PAH emission estimates are based on emission factors presented in Table A.3.

The U.S. EPA provides emission factors, presented in Table A.3, for wet and dry kilns [215].[224] The emission factors are derived from samples taken at wet and dry kilns that utilized atmospheric pollution control technology, including an electrostatic precipitator and a baghouse.

Cement Production: Regional Releases

There are four cement plants in the Watershed, all of which are in New York state (two wet and one dry kiln; Table 4.27) [325]. Three of these plants produce clinker, while the fourth facility imports clinker from its sister plant a few miles away. The three plants producing clinker feature an integrated clinker and kiln system, and utilize either a wet or dry kiln process. Combined, these plants produce almost three million tons of clinker annually [326] [327, 328], approximately 3% of total U.S. production.

Releases to the Atmosphere. PAH emissions are estimated by applying emission factors in Table A.3 to annual clinker production (Table 4.27). In regard to pollution control devices, the emission factors are fairly appropriate, given that all of the facilities utilize some sort of control similar to the facilities used to calculate the emission factors. However, there is some uncertainty in these estimates, specifically in regards to fuel use and emission factors.

Only one of the cement facilities reported total PAH emissions (of 77 kg/yr) to the U.S. EPA's 2005 Toxics Release Inventory; however, it is unclear whether this is from cement production or other material production.

Measures to Reduce Releases of PAHs from Cement Production

In 2002, the U.S. EPA established Maximum Available Control Technology emission standards for cement kilns [329].

As mentioned, fuel combustion is believed to be the primary source of PAH emissions. Waste materials, such as tires and hazardous waste, are sometimes used as fuel in cement plants, raising concerns about associated emissions. PAH emissions associated with controlled combustion of tires were found to be similar to those from conventional fossil fuels [330]; however, emissions were shown to increase during disrupted combustion cycles, indicating that actual emissions may fluctuate.

The following are pollution prevention recommendations to reduce releases of PAHs from cement production:

- Evaluate PAH emissions caused by the combustion of supplementary fuels such as hazardous waste and tires, and determine whether their use should be discontinued.
- When appropriate, substitute for cement in concrete with lower-energy materials (see also Section 4.5.1 Industrial Fuel Combustion) such as fly ash,[225] slag,[226] and less common substitutes (e.g., silica fume and rice hull ash[227]).

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[224] Wet kilns (kilns that process wet clinker) use more fuel and require a longer kiln than the dry kilns. In the past, wet grinding and mixing technologies were perceived to provide more uniform material; however, all new kilns since 1975 use the dry process [215].

[225] Fly ash is a type of pozzolan, created as a byproduct of coal combustion. Slag is a byproduct of both iron and steel production.

[226] Several groups, such as the U.S. Green Building Council and the AIA Committee on the Environment, recommend use of fly ash to reduce the embodied energy of concrete and to divert material from the waste stream.

[227] Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys in electric arc furnaces. The smoke that results from furnace operations is collected and sold as silica fume. Rice hulls (or rice husks) are the protective layer of rice that is removed during the milling process. When power plants burn rice hulls, the ash can be collected and used as a substitute for cement.

4.5.7. Pulp and Paper Production

Pulp and Paper Production: National Trends and Emission Factors
PAH emissions associated with the pulp and paper industry are primarily due to three types of processing facilities: chemical recovery furnaces, lime kilns, and power boilers. It is estimated that approximately 85% of pulp production in the U.S. consists of Kraft pulping, a process that involves the cooking or digesting of wood chips in sodium sulfide and sodium hydroxide. Kraft pulping also includes an evaporation recovery process that recovers the spent sodium sulfide, and it is during this process that PAHs may be generated and released.

Emission factors for Kraft pulping activity are provided by the U.S. EPA [215] (TABLE A.3). The PAH emissions associated with lime kilns and power boilers are linked to the combustion of fuel and are addressed in Section 4.5.1 INDUSTRIAL FUEL COMBUSTION.

Pulp and Paper Production: Regional Releases
There are 36 pulp and paper manufacturing facilities in the Watershed, of which seven are reported to produce pulp [331]. Only one of those facilities is reported to utilize the Kraft pulping process, and is reported to produce 320,000 tons of pulp per year.

Releases to the Atmosphere. It is estimated that approximately 11 kg/yr are released from Kraft pulping facilities in the Watershed (TABLE A.3). There were two facilities in 2005 that reported releases of PAHs to the U.S. EPA's TRI. Collectively, they reported atmospheric releases of approximately 30 kg of total PAHs.

Emissions from this process are relatively small, although unlike the emission factor, the Kraft facility in the Watershed is not equipped with any atmospheric pollution controls.

4.6. Cigarette Smoke

Cigarette Smoke: National Trends and Emission Factors
Smoke generated from the combustion of cigarettes and other tobacco products contains PAHs. Although most concerns with cigarette smoke center on human health risks, environmental tobacco smoke (ETS), or second-hand smoke, does contribute to atmospheric pollution. Recently, smoking bans have been passed in several states, including New York and New Jersey, forcing more and more smokers outside. Although it is likely that this will not have a significant impact on the Harbor, it is another activity that contributes to atmospheric PAHs.

The U.S. EPA provides cigarette smoke PAH emission factors that reflect exhaled smoke and sidestream smoke (smoke from the burning cigarette) (TABLE A.3).

Cigarette Smoke: Regional Releases
The New York State Department of Health and the New Jersey Department of Health and Senior Services report that 22.3% and 18.4% of each state's adult population, respectively, are smokers [332] [333]. The Centers for Disease Control and Prevention reports that, on average, smokers consume 16.8 cigarettes per day [334].

Releases to the Atmosphere. Emission estimates were made by extrapolating from estimated state cigarette consumption, based on the percentage of smokers in the population within the Watershed (reported in the 2000 Census) and applying the emission factors previously discussed (TABLE A.3). It is estimated that approximately 160 kg of PAHs are released per year from people smoking cigarettes.

4.7. Facilities Reporting to U.S. EPA's Toxics Release Inventory

Several classifications of facilities that report PAH emissions to the U.S. EPA's Toxics Release Inventory have not been discussed. Many of these source categories have only one facility in the Watershed, with the exception of asphalt paving mixtures and blocks (TABLE 4.28). Individually, these facilities release comparatively smaller quantities of PAHs than some of the other sources discussed in this report; however, collectively the total atmospheric releases from these sources are relatively large.

4.8. Natural Sources

4.8.1. Petroleum Deposits

Petroleum Deposits: National Trends and Emission Factors
PAHs may be released to water and land via natural mechanisms, including seeps of natural petroleum deposits. No data are available to quantify the magnitude of this source nationally.

Petroleum Deposits: Regional Releases
There are no petroleum deposits in New Jersey. While there have been reports of seeps and exploration in the region, none of the reports have proven true nor explorations successful [335]. In New York,

Table 4.28. PAH emissions from facilities in the Watershed reporting to the U.S. EPA's Toxics Release Inventory, 2005[a]

	No. of facilities reporting releases	Atmospheric releases, total PAH (kg)
cyclic crudes and intermediates	1	2914
prefabricated metal buildings	1	671
pharmaceutical preparations	1	277
plastics materials and resins	2	87
asphalt paving mixtures and blocks	5	48
industrial inorganic chemicals	1	38
adhesives and sealants	1	15
manufacturing industries	1	12
medicinals and botanicals	2	5
leather tanning and finishing	1	5
Total	**16**	**4072**

a Includes only facilities not previously mentioned in this report. Reported TRI PAH emissions for activities previously discussed can be found in their appropriate sections.

however, there are several petroleum deposits, all of which are in western New York. Natural gas can be found in greater abundance than oil throughout the state, although no commercial quantities of oil or gas have been found in the eastern region of New York for some time [336]. Therefore, this source is not considered significant to the New York/New Jersey Watershed region.

4.8.2. Volcanoes

Volcanoes: National Trends and Emission Factors

Other natural sources of atmospheric emissions are volcanoes. While it is difficult to find an estimate of the total quantity of PAHs released via volcanism, one source reported annual emissions of benzo[a]pyrene via volcano eruptions to be 1.2 to 14 tons per year [59].

Volcanoes: Regional Releases

There are no active volcanoes in or near the Watershed, and transboundary deposition is estimated to be negligible.

4.8.3. Forest Fires

Forest Fires: National Trends and Emission Factors

Nationwide, the major natural source of PAH releases to the air is forest fires. Natural fires have been releasing PAHs into the environment since long before human civilization existed. However, today many fires are set deliberately or carelessly by humans (perhaps as many as 75% of the fires in New York and New Jersey [337-340]).Therefore, forest fires are both a natural and an anthropogenic source. One estimate places total releases of PAHs in the United States to be just under 20,000 tons/yr [341] for the total land area of the United States (2.3 billion acres or 161,923 sq km [342]), or approximately 100 kg/km^2 each year. In 1999, the U.S. EPA estimated that forest fires in the U.S. result in emissions of 990 tons/yr of benzo[a]pyrene alone [63].

It is difficult to estimate accurately the quantity of PAHs released from forest fires, as emissions will vary with fuel type (wood, grass, or brush), age of material, moisture content, and the presence of pesticide and herbicide residues. The U.S. EPA provides emission factors for the combustion of pine-tree material, which represents the average emission of the flaming and smoldering phase of a fire (Table A.3) [240].

Forest Fires: Regional Releases

There are two classifications of forest fires: wild and prescribed. Wildfires are accidental and may be started by natural phenomena, such as lightning, or by human negligence, such as by the dropping of lit cigarettes or by campfires that have not been thoroughly extinguished. On average over the past five years, approximately 1400 acres of forest have been consumed by wildfires in the Watershed region [337] [338].[228] Prescribed fires are intentionally ignited, typically by Federal or state agencies, under circumstances relating to hazardous fuel load in forests and to habitat improvement [340]. Based on re-

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[228] New York wildfire data (acres consumed) for 2000-2004 was provided for the entire state; therefore estimates were made based on the percentage of fires (number of fires) in New York Department of Environmental Conservation regions 3, 4, and 5 in 2004.

ports published by the National Interagency Fire Center, approximately 2400 acres of forest were consumed in 2004 by prescribed fires in the Watershed (TABLE 4.29).[229]

Releases to the Atmosphere. PAH emission estimates were made by applying emission factors to acres consumed in Watershed forest fires (TABLE 4.29). Although data indicate more acres of forest are consumed in prescribed fires in the Watershed, less forest material is consumed per acre than in wildfires. This results in more PAH emissions from wildfires.

There is uncertainty in this estimate because the composition and density of trees in the New York and New Jersey forests are not necessarily similar to those used to calculate the emission factor, and because actual combustion conditions willimpact PAH formation.

Table 4.29. Wildfire and prescribed fire activity in New York and New Jersey, and associated PAH atmospheric emissions[a,b]

	Wildfires			Prescribed fires		
State	**No. fires**	**No. acres**	**Material consumed (tons)**	**No. fires**	**No. acres**	**Material consumed (tons)**
Watershed						
New York	149	986	9841	12	162	589
New Jersey	387	428	4270	44	2247	8155
Total	**536**	**1414**	**14,111**	**56**	**2409**	**8744**
Total PAH emissions[c] (kg/yr)	**400**			**300**		
Total Watershed PAH emissions (kg/yr)	**700**					
Outside Watershed						
New York	70	630	6292	6	104	376
New Jersey	868	2362	23,574	143	12,407	45,022
Total	**938**	**2993**	**29,865**	**149**	**12,510**	**45,398**
NY & NJ	**1572**	**4407**	**43,976**	**205**	**14,920**	**54,142**
Total PAH emissions[c] (kg/yr)	**700**			**2200**		

Sources: D. Brooks (pers. comm.) [337]; B. Plante (pers. comm.) [338]; J. Smith (pers. comm.) [340].

a Fire data are averages of fires from 2000 to 2004.

b It is assumed that 10 tons of material is consumed per acre in wildfires and 3.6 tons per acre in prescribed fires [343].

c Emission estimates are based on emission factors presented in Table A.3.

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[229] Prescribed fire data was provided for the entire state. Estimates for the quantity of forest consumed in prescribed fires within the Watershed were made by applying the percentage of reported wildfires in the Watershed to the state prescribed fire data.

APPENDIX A: EMISSION FACTOR AND RELEASE BY PAH COMPOUND TABLES

Table A.1. Emission factors for major sources of PAHs to the Watershed

		Wood stoves				Coal tar sealants		On-road vehicles				
PAH compound	**Fireplace**[a]	**Conventional**	**Noncatalytic**	**Catalytic**	**Creosote (AWPA -P1)**	**Product**[b]	**Yields**[c]	**LDGV, HDGV, LDGT, & motorcycle**	**LDDV & LDDT**	**HDDV**	**Tire wear**	**Used motor oil**[d]
	mg/kg fuel	**mg/kg fuel**			**mg/kg**	**mg/kg**	**µg/m²**	**g/gPM10**			**mg/kg**	**mg/kg**
Naphthalene	8.2	130.63	65.32	84.37	90,000	1,889.47	2.14	8.80E-02	3.66E-03	1.29E-03	NR	268.67
Acenaphthylene	6.6	96.16	14.51	30.84	3,000	220.74	NR	3.99E-03	9.71E-04	3.40E-05	NR	0.00
Acenaphthene	0.6	4.54	4.54	2.72	61,000	1,117.51	NR	NR	NR	NR	NR	0.67
Fluorene	2.8	10.89	6.35	6.35	0	1,291.40	2.23	1.47E-03	3.81E-04	4.51E-05	NR	16.33
Phenanthrene	6.8	35.38	53.52	22.18	0	10,228.60	57.46	2.46E-03	1.06E-03	5.15E-05	11.8	65.33
Anthracene	1.7	6.35	4.08	3.63	22,000	2,734.94	6.23	8.21E-04	1.82E-04	3.40E-05	nd	13.00
Fluoranthene	3.5	9.07	3.63	5.44	68,000	8,762.02	252.10	8.83E-04	5.36E-04	2.02E-05	11.1	467.67
Pyrene	3.2	10.89	3.63	4.54	60,000	6,124.49	195.98	1.21E-03	6.89E-04	3.59E-05	54.1	416.00
Benz[a]anthracene	0.8	9.07	0.45	10.89	5,000	2,989.08	71.47	9.95E-05	4.81E-05	3.68E-05	nd	48.67
Chrysene	0.7	5.44	4.54	4.54	15,000	2,993.44	173.27	9.95E-05	5.70E-05	6.44E-06	8.2	NR
Benzo[b]fluoranthene	0.3	2.72	1.81	1.81	8,000	2,802.63	NR	1.18E-04	7.84E-05	1.01E-05	nd	10.33
Benzo[k]fluoranthene	0.2	0.91	0.45	0.91	3,000	1,981.36	NR	1.18E-04	7.84E-05	1.01E-05	nd	6.00
Benzo[a]pyrene	0.6	1.81	2.72	1.81	5,000	2,791.76	95.22	9.95E-05	4.45E-05	1.20E-05	3.9	17.00
Perylene	0.0	NR	0.91	NR	1,000	NR	NR	NR	NR	NR	nd	NR
Dibenz[a,h]anthracene	0.1	0.00	1.81	0.91	1,000	794.75	21.04	NR	1.78E-06	NR	NR	8.33
Benzo[g,h,i]perylene	0.3	1.81	9.07	0.91	0	1,648.78	NR	2.49E-04	5.34E-05	8.28E-06	nd	33.33
Indeno[1,2,3-CD]pyrene	0.4	0.00	0.91	1.81	1,000	1,577.33	NR	7.46E-05	2.14E-05	9.20E-07	NR	3.67
Source:	[70]	[68]	[68]	[68]	[344]	[345]	[1]	[131]	[131]	[131]	[146]	[153]

Table A.1. Cont. Emission factors for major sources of PAHs to the Watershed

PAH compound	Off-road			Petroleum			
	Two-stroke gasoline[e]	Four-stroke gasoline[e]	Diesel[e]	No. 2	Kuwait crude	No. 6	Lubricants and motor oils
		g/gPM10			µg/g		Avg wt %
Naphthalene	4.00E-06	9.07E-02	4.60E-04	4000	400	NR	0.059
Acenaphthylene	7.50E-05	4.12E-03	8.40E-05	NR	NR	NR	NR
Acenaphthene	NR	NR	NR	NR	NR	NR	NR
Fluorene	2.39E-04	1.51E-03	1.00E-04	3600	50	NR	NR
Phenanthrene	2.08E-04	2.54E-03	2.60E-04	429	26	482	0.0079
Anthracene	6.70E-05	8.50E-04	4.30E-07	37	3	240	0.0022
Fluoranthene	2.67E-04	9.10E-04	1.70E-05	41	5	23	0.0038
Pyrene	3.18E-04	1.24E-03	2.90E-06	1	2	90	0.01
Benz[a]anthracene	3.40E-05	1.00E-04	7.10E-07	2	7	196	0.0063
Chrysene	2.10E-05	1.00E-04	1.90E-06	1	3	44	0.0035
Benzo[b]fluoranthene	1.60E-05	1.20E-04	4.90E-07		0	22	NR
Benzo[k]fluoranthene	1.40E-05	1.20E-04	3.50E-07	NR	NR	NR	NR
Benzo[a]pyrene	2.90E-05	1.00E-04	3.50E-07	NR	1	NR	0.0017
Perylene	NR	NR	NR	1	3	NR	0.00035
Dibenz[a,h]anthracene	1.00E-06	NR	2.90E-09	NR	NR	NR	NR
Benzo[g,h,i]perylene	1.16E-04	2.60E-04	1.90E-07	NR	NR	NR	0.0028
Indeno[1,2,3-CD]pyrene	3.50E-05	8.00E-05	7.90E-08	NR	NR	NR	0.004
Source:	[131]	[131]	[131]	[168]	[168]	[346]	[169]

HDDV=heavy-duty diesel vehicle, LDDT=light-duty diesel truck, LDDV=light-duty diesel vehicle, HDGV=heavy-duty gasoline vehicle, LDGT=light-duty gasoline truck, LDGV=light-duty gasoline vehicle, NR=not reported, nd=not detected

a Emission factors are the mean of three burns under controlled conditions similar to domestic fireplaces for seasoned hardwood (mainly beech)

b Average of 9 samples.

c Average of 7 samples.

d Average of 40 samples of used crankcase oil. Samples were taken directly from gasoline vehicle crankcases and from used motor oil storage tanks. Motor oil generated in diesel fueled vehicles may exhibit different concentrations of PAHs.

e The nonroad classification includes both stationary and mobile nonroad vehicles, including but not limited to snowmobiles, lawnmowers, off-road motorcycles, carts, generators, construction machinery, and commercial equipment.

Table A.2 Estimated emissions from major sources of PAHs in the Watershed, by compound.

	Residential wood combustion				Creosote-treated wood				Transportation	
PAH compound	Fireplace	Conventional	Catalytic	Noncatalytic	Marine pilings	Railroad ties	Utility poles	Coal tar sealed surfaces[a]	Vehicle exhaust	Tire wear
					kg/yr					
Naphthalene	4175	76,132	49,155	9410	340	161,255	67,589	2–14	80,097	NA
Acenaphthylene	3360	56,041	17,971	2091	13	3,786	1587	NR	3677	NA
Acenaphthene	305	2643	1586	653	258	62,844	26,341	NR	0	NA
Fluorene	1426	6344	3700	915	0	0	0	2–15	1432	NA
Phenanthrene	3462	20,619	12,923	7711	0	0	0	57–380	2399	376
Anthracene	866	3701	2114	588	124	8,243	3455	6–41	818	nd
Fluoranthene	1782	5287	3171	523	387	31,613	13,250	250–1666	884	354
Pyrene	1629	6344	2643	523	338	22,150	9284	194–1295	1222	1724
Benz[a]anthracene	407	5287	6343	65	14	492	206	71–472	180	nd
Chrysene	356	3172	2643	653	41	547	229	172–1145	109	261
Benzo[b]fluoranthene	153	1586	1057	261	22	314	132	NR	137	nd
Benzo[k]fluoranthene	102	529	529	65	8	118	49	NR	137	nd
Benzo[a]pyrene	305	1057	1057	392	14	196	82	94–629	121	124
Perylene	NA	NA	NA	131	0	0	0	NR	0	NA
Dibenz[a,h]anthracene	51	NA	529	261	1	12	5	21–139	0	nd
Benzo[g,h,i]perylene	153	1057	529	1307	0	0	0	NR	243	NA
Indeno[1,2,3-CD] pyrene	204	NA	1057	131	1	12	5	NR	70	nd
Total	**18,737**	**189,801**	**107,005**	**25,680**	**1,559**	**291,582**	**122,215**	**869–5795**	**91,526**	**2840**

Table A.2, Cont. Estimated emissions from major sources of PAHs in the Watershed, by compound

PAH compound	Transportation, Cont.			
	Leaking motor oil	Improper disposal of used motor oil (all methods of disposal)	Nonroad engine exhaust	Petroleum spills to water[b]
	kg/yr			
Naphthalene	976	1460	24,926	37
Acenaphthylene	0	0	1605	NA
Acenaphthene	2	4	0	<1
Fluorene	59	89	1271	15
Phenanthrene	237	355	2443	5
Anthracene	47	71	295	
Fluoranthene	1698	2541	662	1
Pyrene	1511	2261	722	2
Benz[a]anthracene	177	264	72	4
Chrysene	0	0	62	2
Benzo[b]fluoranthene	38	56	52	<1
Benzo[k]fluoranthene	22	33	49	<1
Benzo[a]pyrene	62	92	63	<1
Perylene	0	0	0	1
Dibenz[a,h]anthracene	30	45	1	<1
Benzo[g,h,i]perylene	121	181	211	<1
Indeno[1,2,3-CD]pyrene	13	20	64	1
Total	**4993**	**7472**	**32,500**	**70**

[a] Estimated ranges are based on Mahler et al. [14] yields and assume that yields are constant for every rain event throughout the year and that annual consumption may represent one-fifth of actual sealed surface areas.

[b] Estimated petroleum releases include releases of the following: fuel oils No. 2, No. 2D, and No. 6; diesel; crude; misc. oil—lubricating and motor oil; jet fuel; waste oil; and unknown oil-like material. Due to incomplete PAH concentration data, some materials were assumed to have PAH concentrations similar to that of others

Table A.3. Emission factors for minor sources of PAHs to the Watershed

	Combustion of residential heating fuel			Combustion of fuel in commercial boilers				Personal watercraft[d]				
PAH compound	Bituminous/ sub-coal boilers and furnaces	No. 2 oil furnace	Natural gas furnace	Distillate fuel (No.2)[a,b]	Residual fuel (No. 6)[a,c]	Natural gas[a]	Coal[a]	2-stroke Gasoline	4-stroke Gasoline	Diesel	Diesel trains	Airplanes
	g/kg	lb/1000gal	lb/ 10^{12}BTU	lb/ MMBTU	lb/MMBTU	lb/MMCF	lb/ton		g/g PM10		g/g PM10	mg/LTO[e]
Naphthalene	NR	NR	NR	5.00E-05	2.12E-04	1.75E-05	1.05E-02	4.00E-06	9.07E-02	4.60E-04	2.59E-03	NR
Acenaphthylene	NR	NR	NR	NR	7.40E-07	4.99E-06	NR	7.50E-05	4.12E-03	8.40E-05	4.36E-04	NR
Acenaphthene	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	3.70E-05	NR
						NR						
Fluorene	NR	NR	NR	NR	3.50E-07		NR	2.39E-04	1.51E-03	1.00E-04	1.55E-04	NR
Phenanthrene	1.60E-02	1.00E-03	9.79E-02	NR	5.10E-07	6.24E-07	1.62E-02	2.08E-04	2.54E-03	2.60E-04	6.11E-04	47.8
Anthracene	1.60E-02	NR	NR	NR	NR	NR	NR	6.70E-05	8.50E-04	4.30E-07	1.04E-04	3.62
Fluoranthene	5.00E-03	3.93E-03	5.13E-02	1.91E-08	1.90E-07	4.37E-07	1.38E-02	2.67E-04	9.10E-04	1.70E-05	7.81E-05	37.1
Pyrene	5.00E-03	1.42E-03	6.53E-02	1.79E-08	2.60E-08	1.87E-06	1.39E-02	3.18E-04	1.24E-03	2.90E-06	1.14E-04	43.2
Benz[a]anthracene	4.00E-03	5.44E-04	1.10E-01	5.51E-05	NR	NR	7.39E-03	NR	NR	NR	1.66E-05	NR
Chrysene	4.00E-03	NR	1.21E-02	NR	1.40E-07	NR	1.23E-03	NR	NR	NR	1.29E-05	3.08
Benzo[b]fluoranthene	NR	NR	1.21E-02	NR	2.00E-08	NR	NR	1.60E-05	1.20E-04	4.90E-07	6.90E-06	NR
Benzo[k]fluoranthene	4.00E-03	NR	1.21E-02	NR	NR	NR	NR	1.40E-05	1.20E-04	3.50E-07	5.40E-06	NR
Benzo[a]pyrene	NR	1.92E-05	8.39E-02	5.96E-09	NR	NR	9.97E-03	2.90E-05	1.00E-04	3.50E-07	2.70E-06	1.24
Perylene	NR	7.53E-06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Dibenz[a,h]anthracene	3.00E-03	NR	4.43E-02	NR	NR	NR	1.40E-03	1.00E-06	NR	2.90E-09	NR	NR
Benzo[g,h,i]perylene	NR	5.02E-05	1.35E-01	NR	NR	NR	2.69E-03	1.16E-04	2.60E-04	1.90E-07	3.40E-06	1.62
Indeno[1,2,3-CD]pyrene	2.00E-03	NR	6.53E-02	NR	NR	NR	NR	3.50E-05	8.00E-05	7.90E-08	2.70E-06	NR
Source:	[215]	[215]	[215]	[215]	[215]	[215]	[215]	[131]	[131]	[131]	[133]	[215]

Table A.3. Cont. Emission factors for minor sources of PAHs to the Watershed

PAH compound	Open burning			Industrial boilers[h]				Power generating facilities				
	Household waste	Agricultural plastics[f]	Tires[g]	Distillate fuel (No. 2)[a,b]	Residual fuel (No. 6)[a]	Natural gas[b]	Coal	Coal-fired[i]	Natural gas–fired[j]	Residual oil–fired[k]	Oil No. 6 –fired[l]	Liquid spray dryer ash
	mg/kg	µg/kg	mg/kg	lb/MMBTU		lb/MMCF	lb/ton	µg /kg	lb /MMBTU			mg/kg
Naphthalene	11.36	NR	815.9	5.00E-05	2.12E-04	4.24E-06	NR	470.00	4.75E-05	1.21E-05	2.67E-06	0.010
Acenaphthylene	NR	NR	861.3	NR	7.40E-07	NR	NR	14.30	1.85E-08	9.22E-09	NR	NR
Acenaphthene	0.64	NR	290.3	NR	NR	NR	NR	10.10	4.57E-05	1.02E-07	4.55E-07	NR
Fluorene	2.99	NR	260.5	NR	3.50E-07	NR	NR	4.41	1.45E-07	3.15E-08	2.55E-08	NR
Phenanthrene	5.33	42.23	237.5	NR	5.10E-07	2.52E-07	1.68E-05	8.17	1.80E-07	1.08E-07	2.45E-08	0.006
Anthracene	1.3	4.23	56.3	NR	NR	NR	3.60E-06	1.12	1.25E-08	1.43E-08	8.73E-09	0.004
Fluoranthene	2.77	210.07	338.7	1.91E-08	1.90E-07	8.69E-07	4.80E-05	3.89	5.02E-08	2.55E-08	9.41E-09	0.005
Pyrene	3.18	131.04	33.8	1.79E-08	2.60E-08	1.97E-07	3.80E-06	14.60	4.75E-08	3.17E-08	8.42E-09	0.003
Benz[a]anthracene	1.51	33.57	82.2	5.51E-05	NR	NR	NR	0.84	NR	1.02E-07	NR	0.005
Chrysene	1.8	36.08	70.8	NR	1.40E-07	NR	NR	1.58	1.45E-08	1.75E-08	NR	0.004
Benzo[b]fluoranthene	1.86	21.94	69.4	NR	2.00E-08	NR	6.20E-04	6.05	NR	3.65E-08	NR	NR
Benzo[k]fluoranthene	0.67	8.13	74.3	NR	NR	NR	6.20E-04	2.03	NR	3.65E-08	NR	NR
Benzo[a]pyrene	1.4	24.65	84.8	5.96E-09	NR	NR	2.80E-07	8.64	NR	9.22E-09	NR	NR
Perylene	0.27	NR	1.1	NR	NR	NR	NR	3.74	NR	NR	NR	NR
Dibenz[a,h]anthracene	1.3	NR	66	NR	NR	NR	2.40E-05	12.3	NR	2.47E-08	NR	NR
Benzo[g,h,i]perylene	1.27	32.43	51.6	NR	NR	NR	8.00E-08	1.47	NR	6.95E-08	NR	NR
Indeno[1,2,3-CD]pyrene	NR	25.37		NR	NR	NR	5.60E-06	0.664	NR	6.25E-08	NR	NR
Source:	[240]	[215]	[257]	[215]	[215]	[215]	[215]	[281]	[215]	[215]	[215]	[279]

Table A.3. Cont. Emission factors for minor sources of PAHs to the Watershed

	Incineration					Steel production		Cement production				
PAH compound	General medical waste, mechanical grate	Special medical waste, fixed grate	Municipal solid waste bottom ash	Multiple-hearth sewage sludge furnace	Hazardous waste	Electric arc furnace	Iron cupola	Wet kiln[m]	Dry kiln[n]	Kraft pulping furnace[o]	Cigarette smoke	Combustion of pine trees
	µg/kg		mg/kg	lb/ton	lb/ton	µg/kg feedstock	lb/ton cast pipe	lb/ton		kg/ ton pulp produced	kg/ cigarette	mg/kg
Naphthalene	21,102	66,093	0.424	3.20E-03	NR	128	1.68E-07	9.66E-04	1.70E-03	1.60E-02	NR	NR
Acenaphthylene	2,168	1,634	0.119	8.02E-09	5.41E-06	9.44	6.10E-08	5.18E-04	NR	1.30E-03	NR	NR
Acenaphthene	81	740	0.016	4.16E-07	7.21E-06	2.4	1.15E-07	7.84E-05	1.20E-04	8.00E-06	NR	NR
Fluorene	87	461	0.038	8.82E-06	1.34E-05	3.7	7.93E-08	3.02E-04	1.90E-05	1.05E-04	NR	NR
Phenanthrene	492	9367	0.295	8.82E-05	1.01E-04	3.37	3.94E-06	6.01E-04	NR	2.80E-03	2.6E-09	4.96
Anthracene	472	3297	0.069	1.60E-07	1.16E-05	0.412	3.57E-07	1.63E-04	NR	2.00E-04	7.6E-10	4.96
Fluoranthene	83	1128	0.121	1.24E-04	4.97E-05	0.84	1.96E-05	2.17E-04	8.80E-06	3.45E-04	9.5E-10	3.36
Pyrene	52	411	0.127	3.61E-06	2.81E-05	2.47	1.44E-05	1.61E-04	NR	1.65E-04	1.00E-09	4.64
Benz[a]anthracene	98	549	0.040	1.24E-06	6.01E-06	0.079	7.70E-06	7.24E-05	4.3E-08	4.80E-05	2.7E-10	6.32
Chrysene	12	121	0.051	1.44E-05	1.01E-05	0.259	3.80E-06	1.32E-04	1.6E-07	1.95E-05	6.7E-10	6.32
Benzo[b]fluoranthene	19	182	0.042	1.40E-07	NR	1.18	2.80E-06	3.21E-06	5.6E-07	1.45E-05	5.4E-10	NR
Benzo[k]fluoranthene	32	55	0.015	1.22E-06	NR	0.622	2.37E-06	NR	1.5E-07	4.00E-06	NR	NR
Benzo[a]pyrene	64	270	0.026	1.02E-06	2.00E-06	4.03	3.85E-07	2.73E-05	1.3E-07	2.90E-06	NR	.740
Perylene	54	87	NR	6.01E-08	6.01E-07	5.01	NR	NR	NR	NR	NR	NR
Dibenz[a,h]anthracene	30	290	0.005	NR	1.20E-06	2.7	4.82E-07	3.21E-06	6.3E-07	3.40E-06	NR	2.54
Benzo[g,h,i]perylene	21	239	0.022	8.02E-08	4.21E-06	0.254	3.18E-06	3.21E-06	7.8E-08	6.00E-06	NR	1.70
Indeno[1,2,3-CD] pyrene	2	158	0.021	2.00E-07	3.81E-06	0.444	3.15E-06	4.51E-06	8.7E-08	2.10E-06	NR	.430
Source:	[297]	[297]	[306]	[309] (as cited in [215])	[309] (as cited in [215])	[347]	[318] [319] (as cited in [215])	[215]	[215]	[215]	[215]	[240]

a Tests were conducted on uncontrolled boiler technology.

b Emission factors represent an average of both industrial and commercial boiler test results.

c Emission factors for commercial boilers were not available; therefore, an industrial boiler emission factor was used.

d Watercraft engines include inboard and outboard motors for boats and jet skis.

e LTO = Landing-to-takeoff cycle

f Emission factors represent a burning condition in which the plastic is piled and ignited. Burns conducted with a forced-air current resulted in lower PAH emission factors.

g Represents the average of three open burning simulations.

h An average of several test results. Number of tests varies with fuel type.

i Emission factor from a power plant in southern Taiwan equipped with an electrostatic precipitator burning bituminous coal in 8% oxygen.

j Emission factor from a utility boiler equipped with a flue gas recirculation.

k Emission factor from a utility, industrial, and commercial boiler dataset. This represents the highest emission factor in the range.

l Emission factor from an uncontrolled utility boiler.

m With electrostatic precipitator.

n With fabric filter.

o Emission factors are from a direct contact evaporator Kraft recovery furnace with dry-bottom electrostatic precipitator.

Table A.4. Emission factors for gasoline distribution

Emission source	VOC (lb/1000 gal of gasoline)
In transit	
Vapor-filled truck	.055
Gas-filled truck	.005
Stage I: Filling underground storage tank	
Submerged filling	7.3
Splash filling	11.5
Balanced submerged filling of tank	.3
Stage II: Service station	
Displacement losses—uncontrolled	11
Displacement losses—controlled	1.1
Tank breathing	1

VOC=volatile organic compounds
Source: Eastern Research Group [277]

APPENDIX B: SUMMARY OF MASS BALANCES ON SELECTED POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN THE NY/NJ HARBOR ESTUARY

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Prepared for the "Industrial Ecology, Pollution Prevention and the NY/NJ Harbor" Project of the New York Academy of Sciences.

Summary

A mass balance for 14 PAHs was constructed using data primarily from the Contaminant Assessment and Reduction Project (CARP) [2], the Regional Environmental Monitoring and Assessment Program (R-EMAP) [3], and the New Jersey Atmospheric Deposition Network (NJADN) [4]. The goal of the mass balance was to understand the flux of PAHs entering and leaving the harbor.

Later in this chapter, we will compare our fate and transport analysis of primary emissions estimates with the results of the mass balance. Here we present a summary of the mass balance results. The mass balance considers inputs of PAHs from tributaries, atmospheric deposition, wastewater treatment plant discharges, combined sewer overflows (CSOs), stormwater runoff, and oil spills (Table B.1).

The mass balance also considers outputs of PAHs via advection of dissolved or suspended sediment-bound PAHs out into the coastal Atlantic Ocean or Long Island Sound, volatilization of dissolved PAHs into the atmosphere, and removal of sediment-bound PAHs via disposal of dredged sediments outside the NY/NJ Harbor (TABLE B.2). Aerobic degradation in surficial sediments were taken into account, as were storage/accumulation of sediment-bound PAHs in the NY/NJ Harbor.

Most inputs and losses to the Harbor could be calculated within about a factor of two. The two notable exceptions were oil spill inputs and losses due to aerobic degradation, which are, at best, order of magnitude estimates. For this reason, they are listed in TABLE 4 as maximum estimates. Both of these processes primarily affect the low molecular weight PAHs (MW < 200, although fluoranthene could be included in this group). As a result, the mass balance is nearly complete for the high MW PAHs, those with MW >250 g/mol (benzo[a]pyrene and below), because

Table B.1. Loadings of PAHs to the NY/NJ Harbor in kg/yr. PAHs listed in order of increasing molecular weight

	Rivers											
	Hudson		NJ tribs		Atmospheric deposition		Wastewater		CSOs		Runoff	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
PAH compound	kg/yr											
Naphthalene	744	772	79	236	0	0	300	1752	0	874	0	917
Acenaphthene	32	37	6.0	18	0	0	58	119	1.9	17	21	234
Fluorene	22	63	4.0	12	177	483	102	195	14	44	57	213
Phenanthrene	124	131	96	288	541	1531	148	281	60	204	213	909
Fluoranthene	113	196	183	548	132	427	70	114	35	353	334	1684
Pyrene	94	297	147	441	75	284	145	216	34	288	355	1336
Benz[a]anthracene	56	98	59	176	5.8	40	28	44	5.6	110	85	568
Chrysene	105	131	121	362	16	75	46	70	21	211	206	1059
Benzo[a]pyrene	77	80	90	270	7.2	32	17	32	9.3	148	114	782
Perylene	33	103	28	84	2.0	10	5.2	10	3.7	37	21	220
Benzo[b+k]fluoranthene	141	179	210	630	27	105	43	77	32	320	283	1606
Benzo[ghi]perylene	58	87	92	275	13	62	18	32	13	133	171	710
Indeno[1,2,3-cd]pyrene	48	78	87	261	19	83	16	27	11	120	99	639
Dibenz[a,h]anthracene	3.8	13	13	38	2.1	8.8	7.9	15	1.9	28	25	146
Total	**1651**	**2265**	**1215**	**3639**	**1017**	**3141**	**1004**	**2984**	**242**	**2887**	**1984**	**11,023**

their inputs due to oil spills are small and their aerobic degradation potential is minimal (TABLE B.3). For PAHs with MW < 250 g/mol, aerobic degradation could be significant.

The high MW PAH inputs to the system are dominated by stormwater runoff, which contributes on average approximately 50% of the total load to the Estuary. Additional stormwater sampling to confirm the importance of the stormwater load is warranted. The mass balance implies, however, that controlling PAH levels in the Estuary will require the implementation of strict stormwater management plans. The relative loadings of the high MW PAHs are remarkably constant, with average percentage loadings (± standard deviation) of 51±3% from stormwater, 20±3% from the New Jersey tributaries, 9.4±1.5% from the Hudson River, 9.2±0.4% from CSOs, 6.0±3.8% from atmospheric deposition, and 4.6±2.3% from wastewater.

Losses of high MW PAHs from the Estuary are driven by their association with sediments. Typically, a majority of all losses are the result of dredging, and a significant portion of the mass that enters the Harbor remains stored in the sediments. The losses of high MW PAHs are again remarkably similar, with average percentage losses (±standard deviation) of 55±6% lost to dredging, 22±6% flushed out to the Bight, 14±6 flushed out to the Long Island Sound via the East River, and 9±7% volatilized.

Again, because the mass balance is nearly complete for high MW PAHs, these conclusions are relatively certain. In contrast, the conclusions to be drawn about low MW PAHs are less certain. Loads of fluorene and phenanthrene are dominated by atmospheric deposition, comprising about 45% of the total load (excluding oil spills). It is unclear whether these two PAHs are representative of the lower MW PAHs in general. If they are, it suggests that the atmosphere could be a major source of naphthalene and acenaphthene as well. Relatively few measurements exist of acenaphthene in ambient air. One study observed less than 0.01 μg/m3 acenaphthene in outdoor samples from Taiwan [348]. This level would result in an atmospheric deposition load of less than 225 kg/yr, which could make atmospheric deposition the largest source of acenaphthene after oil spills. A recent review of airborne naphthalene concentrations [349] suggests that urban concentrations of naphthalene could be on the order of 1 μg/m3. This level would result in atmospheric deposition (mostly via gaseous absorption) of ~300 kg/yr, a level that is smaller than many other loadings, but not insignificant. Especially in light of the fact that sediment toxicity in the Harbor is thought by some to result primarily from narcosis due to low molecular weight PAHs (B. Brownawell, pers. comm.), it is important to determine whether atmospheric deposition or oil spillage is the primary source of these compounds to the Estuary.

Losses of low MW PAHs are dominated by volatilization (>30% of total), although sedimentation and dredging are also important for phenanthrene and acenaphthene. It is possible that aerobic degradation is a significant loss process for some low MW PAHs.

Table B.2. Losses of PAHs from the NY/NJ Harbor in kg/yr. PAHs listed in order of increasing molecular weight

	Tidal exchange				Dredging		Volatilization	
	Raritan Bay		East River		Raritan Bay		East River	
	Low	High	Low	High	Low	High	Low	High
PAH compound	kg/yr							
Naphthalene	118	156	–291	–162	44	103	2061	6433
Acenaphthene	11	13	36	41	20	67	63	146
Fluorene	26	31	17	23	15	64	1242	3192
Phenanthrene	188	204	44	75	166	402	112	666
Fluoranthene	385	411	67	120	251	867	82	493
Pyrene	214	237	98	150	294	1046	114	406
Benz[a]anthracene	86	90	92	121	145	682	46	120
Chrysene	145	233	82	120	175	691	16	89
Benzo[a]pyrene	137	145	102	137	208	821	6.9	18
Perylene	87	90	103	156	118	380	21	56
Benzo[b+k]fluoranthene	204	208	111	183	326	1140	23	61
Benzo[ghi]perylene	105	112	12	43	72	247	12	33
Indeno[1,2,3-cd]pyrene	120	128	39	74	41	247	9.6	25.1
Dibenz[a,h]anthracene	24	27	12	20	41	102	12	36
Total	**1850**	**2085**	**524**	**1101**	**1916**	**6859**	**3820**	**11,774**

Table B.3. Sums of inputs and losses of PAHs from the NY/NJ Harbor in kg/yr. Losses do not include aerobic degradation, which is listed separately

	Inputs		Outputs		Sediment accumulation	Aerobic degradation	Oil spill inputs
	Low	High	Low	High	Median	Max	Max
PAH compound	kg/yr						
Naphthalene	1156	3131	2014	6610	82	7273	3021
Acenaphthene	120	365	166	304	37	1613	0.00036
Fluorene	377	918	1338	3348	38	2643	2674
Phenanthrene	1194	3223	818	1655	308	9283	398
Fluoranthene	872	3282	1389	2495	604	2198	1729
Pyrene	851	2792	1468	2586	748	2270	34
Benz[a]anthracene	243	1023	805	1449	436	1440	21
Chrysene	516	1885	889	1605	472	1611	47
Benzo[a]pyrene	315	1329	1025	1693	572	135	11
Perylene	94	460	599	952	271	148	5.1
Benzo[b+k]fluoranthene	737	2884	1456	2385	794	347	0
Benzo[ghi]perylene	365	1285	377	611	176	134	0.00042
Indeno[1,2,3-cd]pyrene	281	1197	353	618	144	129	0.45
Dibenz[a,h]anthracene	54	242	169	264	81	35	0
Total	**7175**	**24,016**	**12,866**	**26,575**	**4763**	**29,259**	**7941**

APPENDIX C: SUMMARY OF FATE & TRANSPORT OF PAHS FROM SOURCES TO HARBOR

This report is focused on understanding sources of PAH pollution in the New York/New Jersey Harbor and developing pollution prevention strategies to mitigate harmful impacts of PAHs to the Harbor. Our metric in evaluating and prioritizing PAH pollution sources is the quantity of PAHs from the source that reach Harbor waters. To evaluate different PAH sources in terms of impact on Harbor waters, the transmission potential from initial point of release to Harbor waters was estimated for each PAH compound, in each medium (air, land, and water), from each county in the region. Sources of PAHs that do not have a high potential to reach the Harbor are not unimportant and may still have a significant impact on their local environments. This section summarizes the fate and transport analysis performed for this report. Additional details are expected to be available in a future publication. Information can now be obtained from Leslie Shor.[230]

C.1. FATE AND TRANSPORT CONCEPTUAL MODEL

High molecular weight PAHs are predominantly found in the environment attached to particles (aerosols, suspended sediment, or soil and sediment), while low molecular weight PAHs are found in both particle-bound and free molecular forms [16]. PAHs move in the environment via flowing air or surface water; however, gaseous PAHs in the atmosphere may travel great distances before returning to the earth's surface. Aerosol-bound PAHs generally travel shorter distances, and, if they are deposited onto impervious surfaces, have a high potential to reach the Harbor. Primary emissions and atmospheric fallout onto pervious land surfaces, however, have a low potential to reach surface waters. As illustrated in FIGURE C.1, the two main factors controlling transmission of PAHs to Harbor waters are 1) proximity of the primary emission to the Harbor, and 2) medium of release. Key location/medium combinations are shown toward the lower right of the figure: these sources involve primary emission near the Harbor, directly into surface waters or onto impervious land surfaces. This conceptual model is consistent with the mass balance (APPENDIX B), which demonstrates that direct inputs from the atmosphere to the Harbor surface are relatively minor, since most PAHs reach the harbor via stormwater and tributaries. The equations and assumptions are listed in the next section.

C.2. FATE AND TRANSPORT MODEL ASSUMPTIONS: ATMOSPHERIC EMISSIONS

A1. All atmospheric emissions instantaneously partition between gas and particulate phases in proportion to the measured relative concentration of gas versus particulate forms as reported in published monitoring data for the Watershed area (Table C.1.)

A2. Gaseous PAHs (only) are subject to atmospheric reactions assuming a first-order rate law, published first-order rate constants (Table C.2.), a hydroxide concentration of 3 ´ 106 molecules/cm3, for 5 hours (the time to travel approximately 50 miles at annual regional wind velocity).

A3. Gaseous PAHs are well mixed within a 50-mile radius surrounding the core Harbor area, and partition via gross gas absorption to surface water in proportion to measured fluxes for the region (Table C.3.). Rain dissolution is neglected.

A4. Particle-bound PAHs are deposited via wet and dry deposition back onto their source counties.

A5. Atmospheric fallout of particle-bound PAHs lands on pervious or impervious surfaces in proportion to the relative pervious/impervious land surface area ratio for that county (Fig. C.2.).

C.3. FATE AND TRANSPORT MODEL ASSUMPTIONS: LAND EMISSIONS

L1. Transmission to the Harbor of all PAHs on pervious land surfaces is zero. (Therefore, implicitly, transmission to the Harbor of all PAHs via groundwater is zero.)

L.2. Transmission to the Harbor of all PAHs on impervious land surfaces is 90%, consistent with other studies [350] [351] [352] [353].

---

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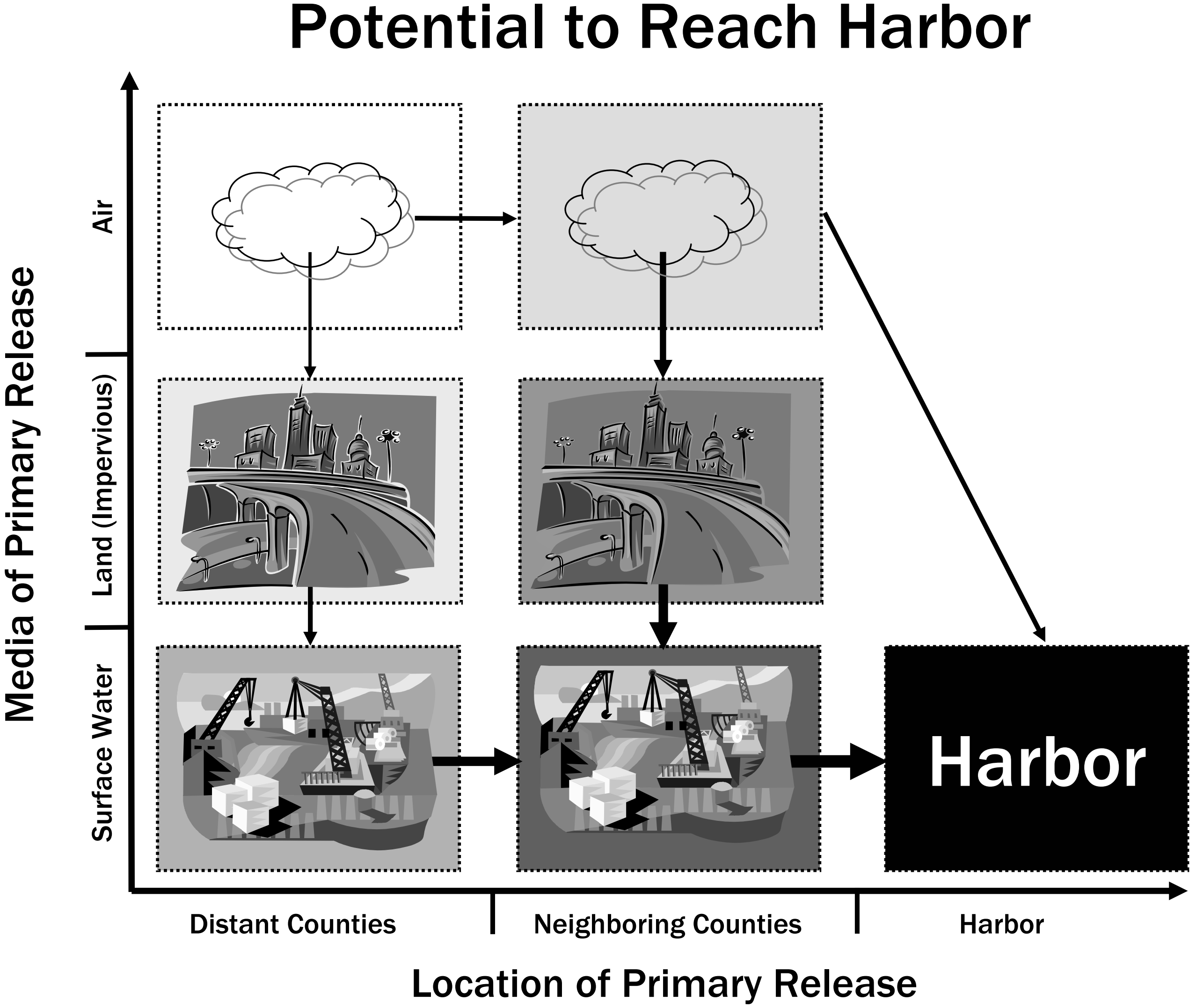
Figure C.1. Conceptual model showing potential of different PAH sources to reach the Harbor



Darker boxes in the grid indicate highest relative potential to reach the Harbor. Key transmission routes are indicated with arrows; darker and broader arrows reflect highest transmission efficiency.

C.4. FATE AND TRANSPORT MODEL ASSUMPTIONS: WATER EMISSIONS

W1. Transmission of stormwater to surface water is 100% in municipal separate storm sewer system (MS4) areas and 14% in CSO areas, based on the reported incidence of overflow events in the region (Fig. C.2.).

W2. Only tributary inputs from the Hudson, Raritan, and Passaic Rivers are included.

W3. PAHs in surface water are instantaneously partitioned in the county of emission (primary water emission, primary land emission and runoff, or atmospheric deposition and runoff) between freely dissolved, dissolved organic carbon (DOC)-bound, and suspended sediment-bound forms, assuming linear partitioning, Koc = 0.41 Kow, and concentrations of 2 mg/L DOC and 30 mg/L suspended sediment that is 20% organic carbon (Table C.4.).

W4. Transmission of dissolved, DOC-bound, and suspended sediment-bound PAHs is given by

Equation C.1.

$$\%T = \%aq\left(e^{-kt}\right) + \%ss\left(\frac{h - \frac{d\,w_s}{v}}{h}\right) + \%doc$$

Where

%aq, %ss, %doc = PAH content in aqueous phase vs. sorbed to solids or DOC

k = first-order aqueous net removal rate (volatilization, photoxidation, and biodegradation combined)

t = residence time (d)

h = river depth (m)

d = distance along river from county center (m)

ws = net particle settling velocity (m/d)

v = mean river flow velocity (m/d)

assuming

W4.1. Freely dissolved PAHs (only) are subject to removal from processes including biodegradation, volatilization, and photoxidation according to a first-order rate law and a lumped rate constant taken from published studies (Table C.7) during transport time to the Harbor.

W4.2. Suspended sediment-bound PAHs settle according to a linear net suspension/resuspension settling velocity of 1 m/day (Tables C.6. and C.7).

W4.3. Transmission of DOC-bound PAHs is 100%.

W4.4. River depth and flow rates are given in Tables C.6. and C.7.

Transmission values for each PAH and county are given in Table C.8. and Table C.9.

W5. "The Harbor" includes the water column of the entire land surface covered by water downstream from the head of tide of all major Harbor tributaries (Hudson, Passaic, Raritan, Elizabeth, Rahway, and Hackensack Rivers), including all of Newark Bay, Arthur Kill, the East River, and Jamaica Bay. We do not consider fate and transport within this region.

Table C.1. Measured atmospheric PAH data for three sites in New Jersey, from the New Jersey Atmospheric Deposition Network project. Data provided by Lisa Rodenburg (pers. comm.)

	Site			
	Jersey City (urban)	New Brunswick (urban)	Chester (suburban)	Estimated % gas
Percentage (%) of total PAHs in gas (vs. aerosol) phase				
Naphthalene	nr	nr	nr	99
Acenaphthylene	nr	nr	nr	99
Acenaphthene	nr	nr	nr	99
Fluorene	99.1	98.2	99.5	99
Phenanthrene	98.0	97.7	98.3	98
Anthracene	90.7	92.3	87.9	90
Fluoranthene	86.8	83.9	86.4	85
Pyrene	80.3	77.5	76.4	78
Benz[a]anthracene	4.2	5.1	4.3	4
Benzo[b+k]fluoranthene	1.1	2.4	0.5	1
Benzo[a]pyrene	1.6	4.7	0.7	2
Perylene	1.1	nr	nr	1
Dibenzo[a,h+a,c]anthracene	0.5	2.0	3.3	2
Benzo[g,h,i]perylene	0.4	2.5	0.2	1
Indeno[1,2,3-cd]pyrene	0.4	2.1	0.6	1
Total PAH concentration (ng/m^3)	**29.3**	**13.9**	**6.5**	
Total suspended particle concentration (mg/m^3)	**59.0**	**45.3**	**33.2**	

nr = not reported

Table C.2. Percent removal of PAHs by hydroxide radical reaction in time intervals corresponding with travel distances of 15, 50, and 150 miles, assuming a wind speed of 5 m/s (11 miles/h) and a first order rate law and degradation rate, K_e [day^{-1}], from Simick et al. [354]

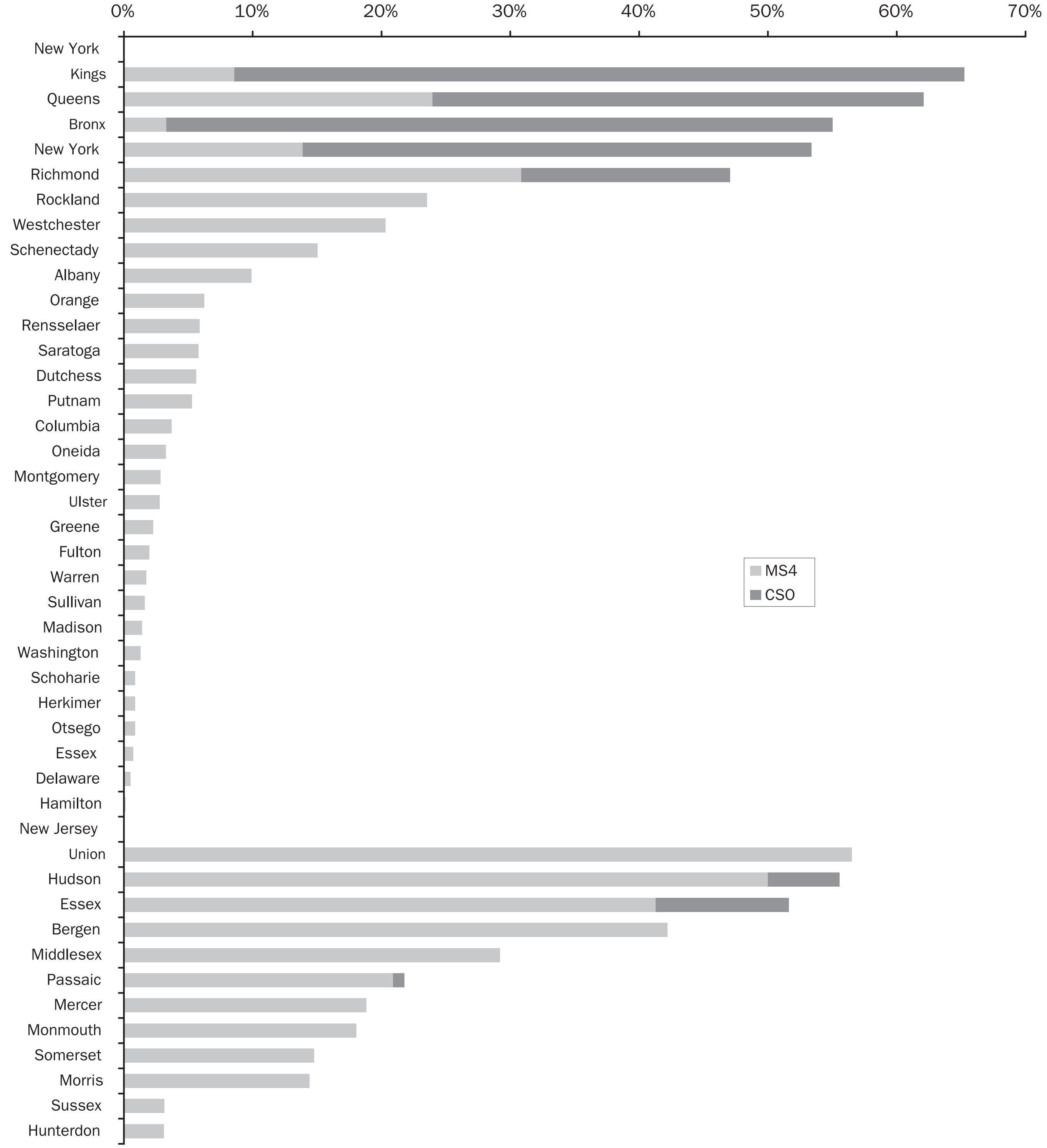
Time (days)	Travel distance (miles)	Percent removal					
		Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene
		k_e = 0.8/d	k_e = 0.5/d	k_e = 0.4/d	k_e = 0.35/d	k_e = 0.35/d	k_e = 0.5/d
0.06	15	5	3	2	2	2	3
0.2	50	14	9	7	6	6	9
0.6	150	36	23	21	18	18	24

Table C.3. Transmission factors by compound and inputs of gaseous PAHs via gross gas absorption to surface waters of the New York/New Jersey Harbor

PAH compound	Gross gas absorption estimated in mass balance kg/yr	Total atm (gas) gaseous emissions kg/yr	Transmission factor Percent	Estimated gas absorption in Harbor kg/yr
Naphthalene	nr	71,641.63	2.29	1638.48
Acenaphthylene	nr	13,605.65	2.29	311.17
Acenaphthene	nr	6878.29	2.29	157.31
Fluorene	321.03	14,036.75	2.29	321.03
Phenanthrene	989.73	41,629.12	2.38	989.73
Anthracene	42.63	5651.18	0.75	42.63
Fluoranthene	224.97	16,788.45	1.34	224.97
Pyrene	133.95	9752.16	1.37	133.95
Benz[a]anthracene	0.77	113.74	0.67	0.77
Chrysene	3.92	45.66	8.59	3.92
Benzo[b]fluoranthene	4.59	6.39	71.80	4.59
Benzo[k]fluoranthene	nr	3.74	71.80	2.69
Benzo[a]pyrene	0.33	11.54	2.87	0.33
Perylene	0.07	0.36	20.20	0.07
Dibenz[a,h]anthracene	0.03	3.14	1.10	0.03
Benzo[ghi]perylene	0.19	7.08	2.68	0.19
Indeno[1,2,3-CD]pyrene	0.25	3.02	8.18	0.25
Total	**1722.45**	**180,177.89**	**0.96**	**3832.10**

Data for some compounds were not available, so transmission factors for naphthalene, acenaphthylene, and acenaphthene were assumed to be equal to that for fluorene; similarly, transmission of benzo[k]fluoranthene was assumed to be equal to that of benzo[b]fluoranthene.

Figure C.2. Percent of impervious land surface in 2001 and the sewer system servicing that area in each Watershed county



Land cover data provided by NOAA. Sewer system service area was determined by identifying those municipalities with MS4 permits and by contacting municipal sewerage authorities.

Table C.4. Calculated partitioning of PAHs between aqueous phase, suspended sediment (SS)-bound, and DOC-bound phases (assuming SS 30 mg/L, 20% carbon; DOC 2 mg/L)

PAH compound	Log K_{ow}	SS K_d (L/kg)	% aqueous	% SS	% DOC
Naphthalene	3.37	192	99	0.6	0.2
Acenaphthylene	4.07	963	96	2.8	0.9
Acenaphthene	4.03	879	97	2.5	0.8
Fluorene	4.18	1241	95	3.5	1.2
Phenanthrene	4.57	3047	89	8.1	2.7
Anthracene	4.54	2843	90	7.7	2.6
Fluoranthene	5.22	13,609	65	26	9
Pyrene	5.18	12,411	67	25	8
Benz[a]anthracene	5.91	66,652	27	55	18
Chrysene	5.91	66,652	27	55	18
Benzo[b]fluoranthene	6.5	259,307	8.8	68	23
Benzo[k]fluoranthene	6.84	567,301	4.2	72	24
Benzo[a]pyrene	6.5	259,307	8.8	68	23
Perylene	6.5	259,307	8.8	68	23
Dibenz[a,h]anthracene	7.19	1,270,030	1.9	74	25
Benzo[g,h,i]perylene	6.85	580,516	4.1	72	24
Indeno[1,2,3-CD]pyrene	7.66	3,748,123	0.0	75	25

Table C.5. Selected value and literature ranges for combined aqueous-phase PAH removal half life, with corresponding rate constant (data from Mackay et al. [16])

	Selected value		Literature range	
PAH compound	K (day^{-1})	Days	Fast (d)	Slow (d)
Naphthalene	0.0693	10	3	550
Acenaphthylene	0.0693	10	43	60
Acenaphthene	0.0693	10	0.1	13
Fluorene	0.0693	10	32	60
Phenanthrene	0.0693	10	0.4	59
Anthracene	0.0693	10	0.4	5.0
Fluoranthene	0.0693	10	0.9	160
Pyrene	0.0231	10	0.03	4.2
Benz[a]anthracene	0.0231	30	0.04	2.1
Chrysene	0.0231	30	0.2	68
Benzo[b]fluoranthene	0.0231	30	0.4	30
Benzo[k]fluoranthene	0.0231	30	0.2	21
Benzo[a]pyrene	0.0231	30	0.04	0.5
Perylene	0.0231	30	nd	nd
Dibenz[a,h]anthracene	0.0069	30	0.3	33
Benzo[g,h,i]perylene	0.0069	100	590	650
Indeno[1,2,3-cd]pyrene	0.0693	100	nd	nd

nd=not determined

Table C.6. Hydrogeologic parameters for the Hudson River (Farley [355]) as far north as Rensselaer County, assuming that depth and velocity for the upper counties of the Hudson equal those in Rensselaer County

County	Distance (mi)	Depth (ft)	Velocity (mi/d) Fast (1/6)	Velocity (mi/d) Slow (5/6)	Residence Time (d) Fast (1/6)	Residence Time (d) Slow (5/6)	Settle height (d) Fast (1/6)	Settle height (d) Slow (5/6)	SS %T
Essex	171	20	21.0	8.3	12.5	32.4	12.5	32.4	2
Warren	130	20	21.0	8.3	10.7	27.7	10.7	27.7	4
Washington	112	20	21.0	8.3	10.9	28.3	10.9	28.3	3
Saratoga	85	20	21.0	8.3	8.4	22.0	8.4	22.0	5
Schenectady	84	20	21.0	8.3	7.4	19.5	7.4	19.5	6
Rensselaer	63	20	21.0	8.3	8.4	22.0	8.4	22.0	6
Albany	53	20	21.0	8.3	6.9	18.1	6.9	18.1	7
Columbia	31	15	15.6	6.1	6.6	17.5	6.6	17.5	7
Greene	29	15	15.6	6.1	5.5	14.6	5.5	14.6	10
Ulster	10	33	4.0	1.5	2.5	6.7	2.5	6.7	31
Dutchess	10	33	4.0	1.5	2.5	6.7	2.5	6.7	31

Table C.7. Hydrogeologic parameters for the two primary New Jersey tributaries. River velocity and depth (shown in gray background) were assumed

Passaic River	Veloc. (mi/d)	Avg. meas. dist. (miles)	Res. time (days)	Settle height (ft)	Depth (ft)	SS %T
Passaic	8.2	4.9	0.60	0.60	15	73
Morris	8.2	21.4	2.61	2.61	15	65
Somerset	8.2	42.4	5.16	5.16	15	56

Raritan River	Veloc. (mi/d)	Avg. meas. dist. (miles)	Res. time (days)	Settle height (ft)	Depth (ft)	SS %T
Somerset	8.2	3.2	0.39	0.39	15	74
Mercer	8.2	26.5	3.23	3.23	15	63
Hunterdon	8.2	30.8	3.76	3.76	15	61
Morris	8.2	50.0	6.10	6.10	15	52

Table C.8. Transmission rates for PAHs in surface water

County	Essex	Warren	Washington	Saratoga	Schenectady	Rensselaer	Albany	Columbia	Greene	Ulster	Dutchess
Res time–low flow (d)	32.4	27.7	28.3	22.0	19.5	22.0	18.1	17.5	14.6	6.7	6.7
Res time–high flow (d)	12.5	10.7	10.9	8.4	7.4	8.4	6.9	6.6	5.5	2.5	2.5
SS transmission (%)	2	4	3	5	6	6	7	7	10	31	31
Transmission rate (%) by compound											
Naphthalene	15.9	20.2	19.6	27.5	31.6	27.4	34.1	35.2	41.6	66.4	66.4
Acenaphthylene	16.2	20.4	19.9	27.6	31.6	27.5	34.0	35.1	41.4	66.1	66.1
Acenaphthene	16.2	20.4	19.8	27.6	31.6	27.5	34.0	35.1	41.4	66.2	66.2
Fluorene	16.4	20.5	20.0	27.6	31.5	27.6	34.0	35.1	41.3	66.0	66.0
Phenanthrene	17.0	21.0	20.5	27.8	31.5	27.7	33.9	34.9	40.9	65.3	65.3
Anthracene	17.0	21.0	20.5	27.8	31.5	27.7	33.9	34.9	40.9	65.4	65.4
Fluoranthene	19.8	23.1	22.7	28.5	31.5	28.5	33.3	34.1	39.1	62.7	62.7
Pyrene	19.6	22.9	22.5	28.5	31.5	28.4	33.3	34.1	39.3	63.0	63.0
Benz[a]anthracene	33.8	36.3	36.0	39.6	41.1	39.6	41.9	42.3	45.3	64.3	64.3
Chrysene	33.8	36.3	36.0	39.6	41.1	39.6	41.9	42.3	45.3	64.3	64.3
Benzo[b]fluoranthene	29.2	31.1	30.9	33.4	34.5	33.4	35.0	35.3	38.0	58.5	58.5
Benzo[k]fluoranthene	28.1	29.8	29.6	31.9	32.8	31.9	33.3	33.6	36.2	57.1	57.1
Benzo[a]pyrene	29.2	31.1	30.9	33.4	34.5	33.4	35.0	35.3	38.0	58.5	58.5
Perylene	29.2	31.1	30.9	33.4	34.5	33.4	35.0	35.3	38.0	58.5	58.5
Dibenz[a,h]anthracene	27.5	29.1	29.0	31.1	32.0	31.1	32.5	32.7	35.3	56.4	56.4
Benzo[g,h,i]perylene	29.3	30.9	30.7	32.8	33.7	32.8	34.1	34.4	36.9	57.4	57.4
Indeno[1,2,3-cd]pyrene	27.7	29.2	29.1	31.1	32.0	31.2	32.4	32.7	35.2	56.3	56.3

Table C.9. Net PAH transmission via New Jersey counties

	To Passaic			To Raritan			
County	**Passaic**	**Morris**	**Somerset**	**Somerset**	**Mercer**	**Hunterdon**	**Morris**
Residence time (days)	0.6	2.6	5.2	0.4	3.2	3.8	6.1
% SS transmission	73	65	56	74	63	61	52
Transmission rate (%) by compound							
Naphthalene	95.9	83.5	69.9	97.4	80.0	77.1	65.5
Acenaphthylene	95.9	83.6	70.1	97.4	80.1	77.2	65.7
Acenaphthene	95.9	83.6	70.1	97.4	80.1	77.2	65.6
Fluorene	96.0	83.6	70.1	97.4	80.1	77.2	65.7
Phenanthrene	96.0	83.8	70.4	97.4	80.4	77.5	65.9
Anthracene	96.0	83.8	70.3	97.4	80.3	77.5	65.9
Fluoranthene	96.3	84.7	71.4	97.6	81.3	78.5	66.9
Pyrene	96.3	84.6	71.3	97.6	81.2	78.4	66.8
Benz[a]anthracene	97.4	88.9	78.2	98.3	86.3	84.1	74.2
Chrysene	97.4	88.9	78.2	98.3	86.3	84.1	74.2
Benzo[b]fluoranthene	97.1	87.6	75.5	98.2	84.6	82.1	71.0
Benzo[k]fluoranthene	97.1	87.2	74.8	98.1	84.2	81.6	70.2
Benzo[a]pyrene	97.1	87.6	75.5	98.2	84.6	82.1	71.0
Perylene	97.1	87.6	75.5	98.2	84.6	82.1	71.0
Dibenz[a,h]anthracene	97.0	87.1	74.5	98.1	84.0	81.4	69.8
Benzo[g,h,i]perylene	97.1	87.4	75.1	98.1	84.4	81.9	70.6
Indeno[1,2,3-cd]pyrene	97.0	87.0	74.4	98.1	84.0	81.3	69.7

APPENDIX D: UNCERTAINTY RATING DEFINITION

U.S. Environmental Protection Agency Emission Factor Rating

A. Excellent. Factor is developed from A- and B-rated source test data taken from many randomly chosen facilities in the industry population. The source category population is sufficiently specific to minimize variability.

B. Above average. Factor is developed from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with an A rating, the source category population is sufficiently specific to minimize variability.

C. Average. Factor is developed from A-, B-, and/or C-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category population is sufficiently specific to minimize variability.

D. Below average. Factor is developed from A-, B-, and/or C-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source population.

E. Poor. Factor is developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population.

Source: U.S. EPA [240]

Activity Rating

The following rating system was used to apply a level of uncertainty to the regional activity levels used to estimate PAH emissions. The system is modeled after the U.S. EPA's emission factor rating system, previously defined.

I. Data are reported and represent desired activity. Data are expected to represent activity in the Watershed region only, and represent activity within the last three years. Activity data are expected to be complete.

II. Data are reported and represent desired activity. Data are extrapolated from state data, based on another known factor, and represent activity from more than three years ago.

III. Data are from an activity expected to represent desired activity. Data are expected to represent activity in the Watershed region only, and represent activity within the last three years.

IV. Data are from an activity expected to represent desired activity. Data are extrapolated from state or national data, based on another known factor, and represent activity from more than three years ago. Dataset is not expected to be complete.

V. Data do not necessarily represent desired activity, but are a known factor.

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