

Patterns of Pollution

in
the



Hudson-Raritan Basin

By Robert U. Ayres and Samuel R. Rod

On the last day of 1985, New York City's North River Wastewater Treatment Plant officially opened. The city's 13th sewage plant, North River began treating 145 million gallons of (previously untreated) waste water per day when the primary system became fully operational in spring 1986. When Red Hook, the 14th plant, opens in 1987 to process 45 million gallons of sewage each day, fully 100 percent of the city's daily 1.6 billion gallons of waste water will receive at least primary treatment.

Eliminating the addition of 190 million gallons per day of raw sewage into New York Harbor is one example of the slow but steady progress being made in

cleaning up the rivers and coastal waters of the Hudson-Raritan basin (see Figure 1 on page 16). But with this progress arise many practical and policy-relevant questions concerning the anticipated benefits for the basin of physical and institutional actions, past and ongoing.

When can we expect to see measurable changes in the ambient levels of various pollutants in the river and estuary? What changes should we expect to see in the health of the estuarine ecosystem, and how quickly should the changes become apparent? In particular, can we expect recovery in important sports and commercial fish stocks in the river?

There is a growing data base on current pollution sources, environmental transport pathways, bio-uptake and

concentration processes, and toxic effects. It is therefore possible to characterize the state of the Hudson-Raritan basin fairly well from about 1970 onward. The National Oceanic and Atmospheric Administration, for example, has sponsored general overview projects to estimate the levels and sources of major pollutants from 1975 to 1980.¹

Basin History

Despite the recent attention to the region, historical information that is crucial to answering the preceding questions is still scarce. Polluting activities occur over decades. Furthermore, large natural systems generally respond



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Hudson River and Manhattan, 1895.

slowly to these perturbing influences and they recover slowly. Thus it is important to estimate the historical loadings into the basin of numerous toxic and nutrient pollutants resulting primarily from human activities. Better estimates of natural background levels are also needed.

Without historical background data it remains uncertain whether long-term population changes in commercial fish stocks are caused by changes in patterns of fishing (or overfishing), dredging and other physical disturbances, eutrophication, or toxic waste disposal. In view of the problem's complexity, it is particularly hard to attribute specific consequences to contaminants only recently monitored, like metals and pesticides.

For example, nearly all of the current loading into the Hudson River of some discontinued chlorinated pesticides (notably DDT) and polychlorinated biphenyls (PCBs) comes from past production, use, and disposal. Intensive chlorinated pesticide applications began replacing metal-based pesticide use in the late 1940s; PCBs were used and routinely discharged in large quantities in the region by the early 1950s. For heavy metals as well, a large portion of present river loadings apparently results from past activities and environmental accu-

mulations of various kinds. Significant use of arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc began in the Hudson-Raritan basin before 1900.

Unfortunately, systematic studies of concentrations of trace contaminants in the Hudson-Raritan basin did not appear until around 1964. At that time New York University began a survey of radionuclides, and later expanded it to

include trace metals and pesticides.² The New York City Department of Environmental Protection (DEP) began measurements of the metals on the U.S. Environmental Protection Agency's "priority pollutant" list only in 1973.³

Better estimates can be made of the historical fluctuations in sanitary treatment-related water quality measures such as the total and fecal coliform (bacteria) and the dissolved oxygen concentrations. DEP has records that show

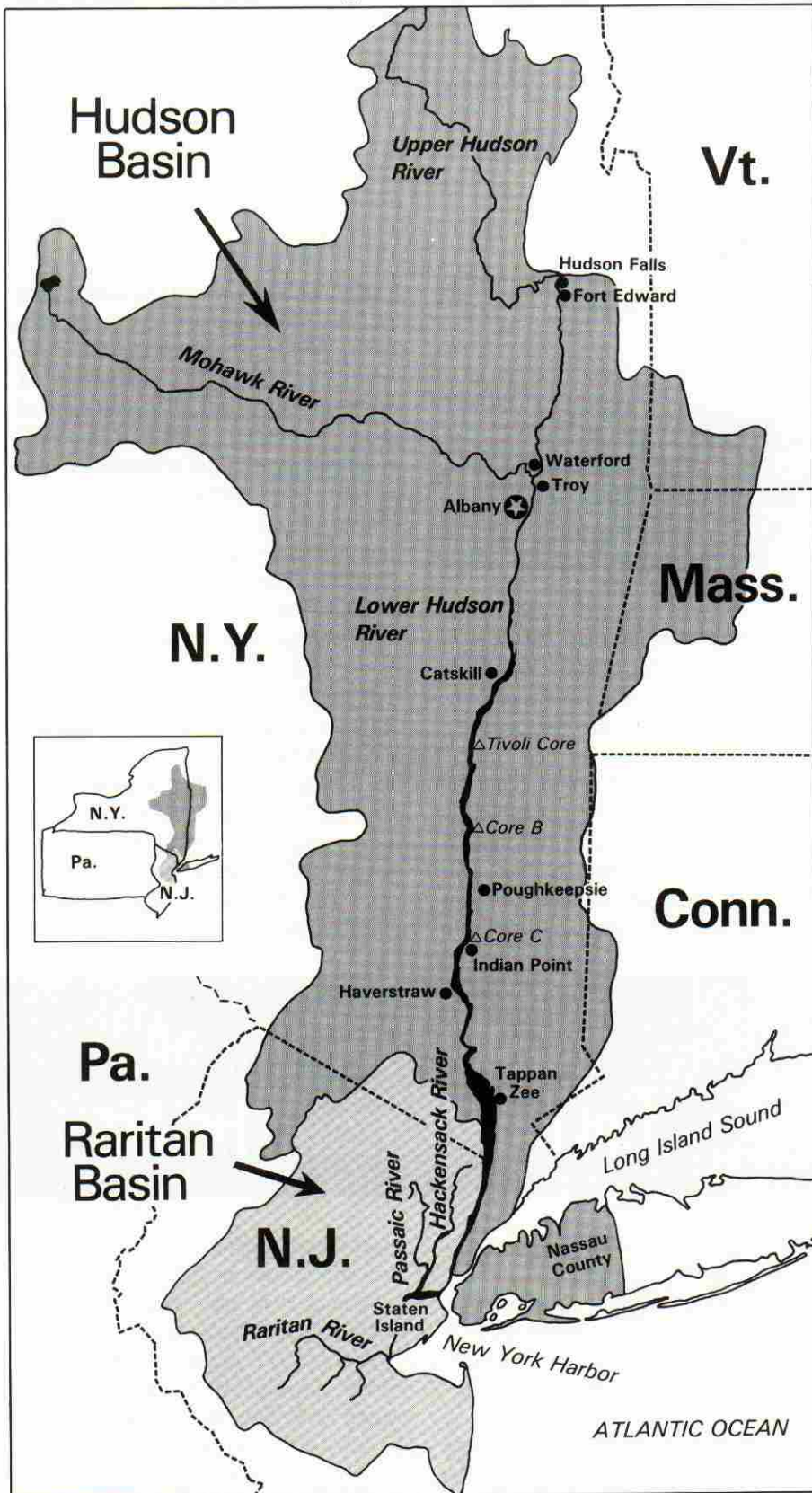
local dissolved oxygen concentrations decreased from almost 70 percent saturation in 1909 to below 40 percent in the late 1930s. Since then concentrations have been slowly increasing and reached about 70 percent saturation in 1983.⁴ Total and fecal coliform concentrations in New York Harbor increased from 1950 to 1960, leveled off until 1973, and then decreased. The use of chlorine to disinfect effluent in all New York City plants by 1973 is cited by DEP to be "correlating well with the observed improvements in the sanitary quality of the receiving waters."⁵

However, apart from a few measures such as those related directly to sewage treatment, no other data are to be found in administrative archives to reconstruct past, or historical, pollution loads and effects. Only recently has in-depth research on historical pollution in the Hudson-Raritan basin begun. There are

Reconstructing an Environmental History

two lines of approach. First, there is increasing activity in field collection and radionuclide dating of sediment cores—a kind of natural archive of environmental sinks. These cores offer the only widely distributed historical record of actual pollutant deposition. Second, there is some complementary investigation into the original sources of the historical pollutant loads that have left their traces in the basin's sediments (see box on page 19). The relationships be-

FIGURE 1. Hudson-Raritan drainage basin.



Note: Indicated are former PCB entry points at Hudson Falls and Fort Edward, sampling locations, and other landmarks. Western Long Island is not formally part of the basin but is included in the analysis as it drains into New York Harbor.

tween pollution sources and sinks (cores) will be an increasingly important topic for research in the coming years.

A first systematic and quantitative look at the complex and changing network of pollution sources and transport paths in the Hudson-Raritan basin since 1880 was completed last year.⁶ The purpose of the study was to provide data concerning the long-term relationships between commercial fish stocks and human activities in estuarine waters.⁷ Relying solely on recent empirical data was known to be inadequate, since fish populations respond to pollution trends on time scales of several decades.

The major contaminants studied fell into three categories of materials thought to pose the greatest present threat to the ecosystem or to humans:

- heavy metals—arsenic, cadmium, chromium, copper, mercury, lead, silver, and zinc;
- pesticides and herbicides—DDT, TDE, aldrin, lindane, chlordane, dieldrin, endosulfan, endrin, heptachlor, methoxychlor, and toxaphene; and
- other critical pollutants—PCBs, polynuclear aromatic hydrocarbons, oil and nitrogen, phosphorus, and total organic carbon.

The pilot historical pollution study was broken down into categories of pollutant sources and receptors (see Figure 2 on page 17), chosen, in large part, on the basis of the availability and reliability of the supporting quantitative data. The flows of materials from sources to the surface waters of the Hudson-Raritan basin were calculated by using the materials-balance methodology described in the box. For land uses, historical documentation resolved the region into four broad categories (see Figure 3 on page 39):

- developed land (urban and suburban, industrial, commercial, and residential) with separate sewage and storm-water conveyance;

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- developed land with combined sewage and storm-water conveyance;
- agricultural land (all crops and cultivation methods); and
- undeveloped land.

Pollutant Loadings

The pilot study using the mass-balance technique has generated a picture of the types and amounts of pollutants that reach the Hudson-Raritan basin. The origins of pesticide pollution, although the amounts are difficult to quantify, are generally clear. River loadings come almost entirely from run-off of recent applications and of undegraded residues of past applications (see Table 1 on page 18). PCB loadings come from two basic sources: nonpoint sources (sewage and run-off) and specific known industrial sources (see Table 2).

Historical patterns of metal emissions and run-off present a more complex picture because of the multiplicity of uses, sources, disposal methods, and transport pathways. Actual river loadings of metals from run-off are typically smaller than the mass of emissions from the primary sources (see Tables 3 and 4 on page 20). This is because a significant portion of the emitted contaminants is permanently retained on land. Exceptions, such as high cadmium and copper run-off, occur where large natural sources of metals exist or where particularly large past environmental accumulations (slag-heaps and landfills, for example) contribute to the pollution load through leaching.

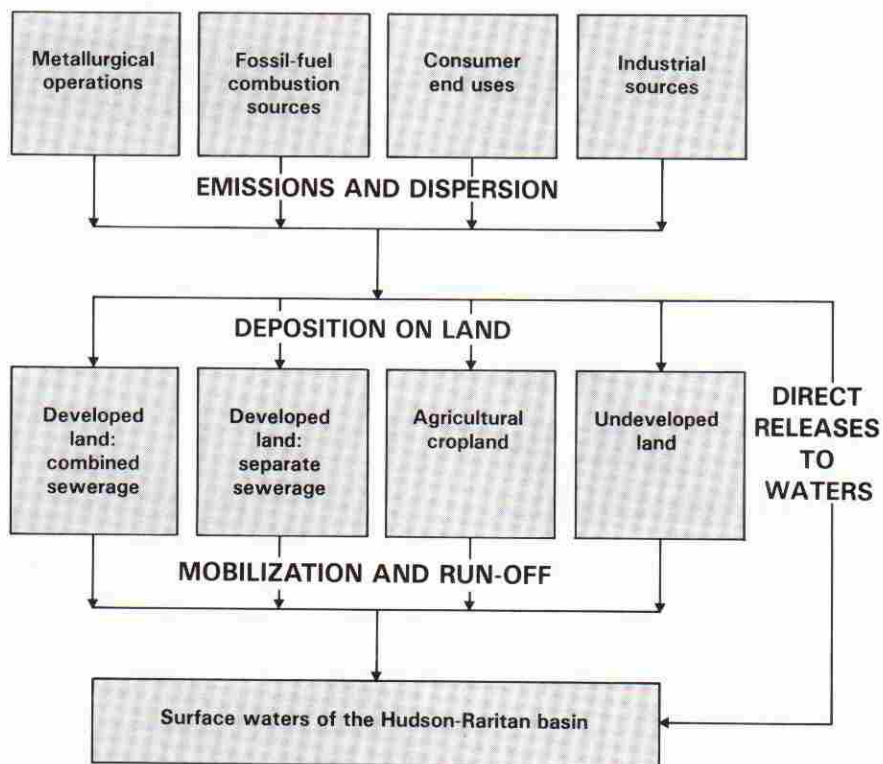
The histories of mercury and lead releases into the Hudson-Raritan basin provide instructive examples of the different source characteristics to be found among many toxic pollutants. Mercury and lead, both highly toxic metals, are judged by environmental scientists to be "high-priority" pollutants.⁸ They are also, at the moment, the only two metals that have been analyzed from Hudson basin sediment cores dated as far back as the 1800s. This direct environmental evidence is valuable in validating the metals' reconstructed emission and run-off trends.

Mercury

The approximately 60 metric tons of mercury emitted into the basin in 1980 came from sources in three major categories: intermediate industrial uses, biocide applications, and consumer end uses (see Figure 4 on page 40). Present industrial releases are mainly from losses of unrecycled catalysts and reagents; final consumer-related emissions are mostly from mercury in discarded hearing-aid and watch batteries, switches, and other electrical or electronic equipment (see Table 5 on page 41).

Widespread use of mercury-based fungicides for agricultural purposes began in the 1930s, peaked in 1956, and dropped sharply after 1968 as the dangers of mercury in the environment became apparent. Mercury was used as an antifouling agent in marine paint, as an antisliming agent in the paper industry, and as a fungicide for seed grain in the 1940s and 1950s. Interestingly, a cluster of small firms in northern New Jersey accounted for close to 60 percent of mercury-based national fungicide sales in the 1960s.⁹ Before World War II direct consumer uses were more significant. Mercury was used in mirrors,

FIGURE 2. Anthropogenic emission and transport of pollutants.



Metallurgical operations include iron and steel foundries; copper, lead, zinc, and other nonferrous metal primary and secondary refiners and smelters.

Fossil-fuel combustion includes all heat and power burning of coal, petroleum distillate fuels, and residual oil.

Consumer end uses include all end uses by consumers as distinguished from intermediate uses (emissions) in industrial processes.

Industrial sources include all losses from industrial plants and processes other than metallurgical operations and the burning of fossil fuels for heat or power. Also, industrial emissions refer only to pollutants released from the point of production, not those embodied as trace residues in final products. Chemical uses embodied in final products ultimately are released into the environment through the consumption of the products, and are therefore included in the end-use category.

Environmental Analyst

Job Order No.: 656071

Conducts research studies to develop theories or methods of abating or controlling sources of environmental pollutants, utilizing knowledge of principles and concepts of various scientific and engineering disciplines: Determines data collection methods to be employed in research projects and surveys. Plans and develops research models, using knowledge of mathematical, statistical, and physical science concepts and approaches. Identifies and analyzes sources of pollution to determine their effects. Collects and synthesizes data derived from pollution emission measurements, atmospheric monitoring, meteorological and mineralogical information, and soil or water samples. Prepares graphs, charts, and statistical models from synthesized data, using knowledge of mathematical, statistical, and engineering analysis techniques. Analyzes data to assess pollution problems, establishes standards and develop for control of pollution.

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TABLE 1
ESTIMATED PESTICIDE LOADING INTO THE HUDSON-RARITAN BASIN (metric tons per year)

YEAR	DDT	LINDANE	ALDRIN	CHLOR-DANE	DIEL-DRIN	ENDRIN	HEPTA-CHLOR	TOXA-PHENE
1980	1.9	0.08	0.001	2.8	0.005	0.001	0.025	0.020
1976	2.4	0.21	0.006	5.6	0.021	0.005	0.023	0.041
1971	3.5	0.28	0.010	8.5	0.030	0.007	0.026	0.050
1966	4.6	0.50	0.014	6.2	0.064	0.010	0.025	0.052
1964	4.7	0.64	0.010	5.5	0.066	0.010	0.023	0.054
1960	5.0 ^a	1.20	0.006	5.1	0.078	0.012	0.022	0.053
1955	3.4	2.00	0.003	4.4	0.067	0.011	0.019	0.053
1950	2.5	1.70	0.001	3.1	0.003	0.004	0.014	0.037
1945	1.1	0.10	—	0.2	—	—	—	—

^aPeak occurred in 1957 when forests were sprayed to control gypsy moths.

TABLE 2
ESTIMATED PCB LOADING INTO THE HUDSON-RARITAN BASIN (metric tons per year)

YEAR	SOURCES		TOTAL
	INDUSTRIAL ^a	SEWAGE AND RUN-OFF	
1980	1.0	1.5	2.5
1975	7.4	2.9	10.3
1973 ^b	15.0	4.0	19.0
1970	1.8	5.0	6.8
1960	1.8	2.0	3.8
1950	1.8	1.0	2.8
1940	0	0.5	0.5

^aLoading came from two electrical manufacturing plants (production losses) plus scouring of sediments behind Fort Edward Dam.

^bPeak occurred when Fort Edward Dam was removed.

medicines (some taken orally), thermometers, antiseptics, and as a preservative for felt hats. The antibacterial treatment of fur or wool with mercuric nitrate left the products with 2 percent to 3 percent mercury by weight. One-third of the mercury volatilized during the finishing of the hats; the remainder slowly dissipated to the air during the life of the hat.¹⁰

Until after World War II mercury fulminate was extensively used as a detonator for explosives. Beginning in the 1950s the major single use of mercury was in the manufacture of chlorine by

electrolysis. Several mercury-cell chlorine plants were located in northern New Jersey.¹¹

Compared with mercury emissions from consumer and manufacturer uses, mercury emissions from coal combustion and various metallurgical operations were minor. Mercury is a trace element in bituminous coal, which provided most of the power for industry, railroads, and residential heating, and virtually all of the electricity for the Hudson-Raritan basin between 1880 and 1950. By the 1950s the efficiency of electrostatic precipitators for smoke

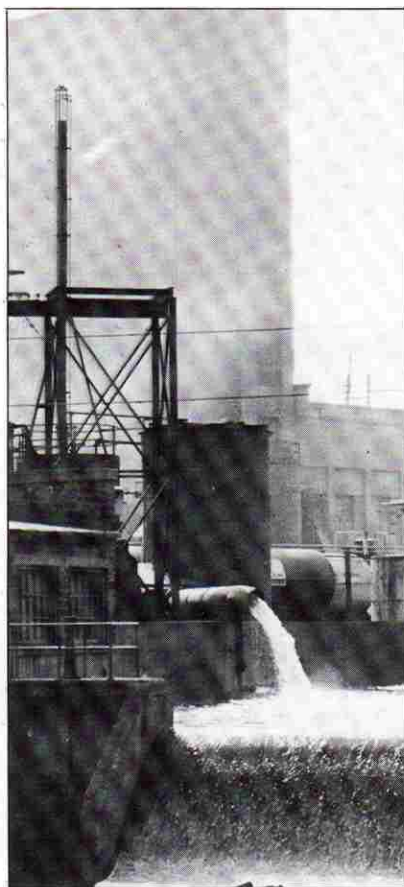
A Method for Reconstructing the History of Pollution Emissions

The method for piecing together historical patterns of pollution releases takes advantage of the available data that are most complete. Since very few direct measurements were made in the past (pollutants of current interest were usually unintended and unmonitored by-products of other activities), documentary evidence of releases is drawn mainly from the records of economic activity. The available data are integrated into a "routing" network for the flow of each pollutant, from raw materials through processing (with accompanying material losses), shipment of products, consumption, and finally to waste disposal.

Throughout the material cycle, the principle of conservation of mass is explicitly adhered to, so that the overall method is referred to as a mass-balance approach, balancing at each step amounts put into the system with amounts taken out.¹ Mass balancing helps to resolve or at least minimize the discrepancies that crop up while quantifying the complex movements of pollutants. Gaps in historical data, if they are relatively few, can be inferred from known values in the immediately surrounding network. The process is much like reconstructing a fossil skeleton, even though it may be missing a few bones.

In the pilot historical study of the Hudson region, the level of geographic resolution is fairly coarse. The breakdown of the material cycles (qualitative) is generally limited by the availability and reliability of the mass-balance (quantitative) data. For instance, "consumer end uses" of chemicals (in Figure 2 on page 17) could be subdivided into smaller subcategories.

The generalized procedures used to estimate certain chemical emissions into a river basin are straightforward. The total U.S. consumption of a chemical for a particular end use is multiplied by the fraction used by the state. The resulting state allocation is then multiplied by the fraction of the state population living in the river basin. Multiplying the basin allocation by an emission coefficient for each end use and summing over



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all end uses yields the total consumer-related emission of the chemical in the river basin.

A similar scheme applies to pollutants released through the burning of fuels. The total U.S. consumption of a fuel is multiplied by the fraction of fuel used by the state. The state fuel consumption is multiplied by the fraction of the state population in the river basin and by an emission factor for the pollutant of interest. The result is the total combustion-related emission of a pollutant in the river basin for a given fuel.

Some key consumption data are available only at the national level although some consumption patterns are regional. This is particularly critical in estimating the emissions of pollutants associated with agriculture. The U.S. use of an agricultural chemical is multiplied by the fraction used by the region and by

the U.S. use of the chemical by crop. The results are the chemical uses per crop in the region, assuming uniform planting, infestation, and other patterns. These quantities are divided by the acreages of the various crops in the region to yield chemical use per acre per crop in the region. These values are then multiplied by the acreages of crops in the river basin and summed to yield the total agricultural use of the chemical in the river basin.

Once released from the various sources, pollutants that do not enter surface waters directly are dispersed and deposited on land. Both the emission coefficients² needed for source calculations and the transport coefficients needed to quantify pollutant dispersion in the environment can be found in numerous published sources.

Pollutants on land, from both human activities and natural sources, are eroded and mobilized (transported) and finally enter the basin's surface waters as indirect run-off. Several environmental transport models are available to describe these processes. The pilot historical study used the Level I screening version of the U.S. Department of Agriculture's Surface Water Management Model.³

Pollutant run-off rates vary greatly with the particular use of land, so that changes in land use over time strongly influence pollutant loading from non-point sources into the rivers. For example, roughly 25 percent of the solids dislodged from some cultivated fields during storms actually reach the river, while for urban areas (largely paved) the run-off rate is frequently higher than 90 percent.

NOTES

1. R. U. Ayres, *Resources, Environment and Economics: Applications of the Materials/Energy Balance Principle* (New York: John Wiley & Sons, 1978).
2. Mass of pollutant released per unit mass of waste water, flue gas, or other effluent.
3. J. P. Heany, W. C. Huber, and S. J. Nix, *Storm Water Management Model: Level I, Screening Procedures*, Technical Report EPA-600/2-76-275 (Washington, D.C.: Environmental Protection Agency, 1976).

TABLE 3
ESTIMATED ANTHROPOGENIC EMISSIONS OF METALS IN THE HUDSON-RARITAN BASIN (metric tons per year)

YEAR	AR- SENIC	CAD- MIUM	CHRO- MIUM	COPPER	LEAD	MER- CURY	SILVER	ZINC
1980	680	50	880	1,100	9,600	60	60	7,900
1970	1,100	120	1,500	1,300	14,000	110	50	10,300
1960	960	100	1,700	1,000	12,500	60	40	8,800
1950	1,100	90	1,500	1,200	12,400	70	40	9,300
1940	1,700	80	1,600	1,400	12,200	70	20	8,600
1930	1,300	50	540	670	7,800	60	10	7,400
1920	830	60	660	890	9,700	50	10	5,800
1900	250	30	700	730	1,700	30	5	1,800
1880	60	10	160	240	50	30	1	540

TABLE 4
ESTIMATED LOADING OF METALS INTO THE SURFACE WATERS OF THE HUDSON-RARITAN BASIN (metric tons per year)

YEAR	AR- SENIC	CAD- MIUM ^a	CHRO- MIUM	COPPER ^a	LEAD	MER- CURY	SILVER	ZINC
1980	280	60	430	1,500	2,500	5	4.0	3,600
1970	440	140	750	1,700	3,500	9	3.3	4,700
1960	380	110	770	1,300	3,000	5	2.5	3,800
1950	420	93	660	1,500	2,800	5	2.3	3,800
1940	600	83	680	1,700	2,700	5	1.1	3,500
1930	850	47	210	740	1,600	4	0.7	2,700
1920	230	48	220	820	1,600	3	0.5	1,800
1900	64	18	210	610	250	2	0.2	490
1880	15	6	52	210	10	2	0.1	160

^aCadmium and copper river loadings from run-off exceed their anthropogenic emissions in recent times. Their usage and disposal patterns over time point to some leaching from past disposal sites. For copper there is also a significant contribution from erosion of natural copper in soil.

NOTE FOR TABLES 1-4: The river loadings for pollutants are summed over all land-use categories (see Figure 3) in the Hudson-Raritan basin. The river inputs are calculated as the metric tons of pollutant per hectare per centimeter of rainfall for each land use in a given year, multiplied by the area in hectares for that land use and by the annual rainfall. The release rates from the different land-use types actually vary dramatically. For metals, developed land with combined sewage and storm-water conveyance has a run-off rate about four times greater than the run-off rate of developed land with separate sewage and storm-water conveyance, about ten times greater than that of cultivated land, and roughly one hundred times greater than that of undeveloped land.

control had climbed above 90 percent, eliminating much of the coal-related mercury pollution.

Lead

Lead emissions reveal a different pattern over time (see Figure 5 on page 40 and Table 5). By far the biggest single source of lead in the environment since World War II has been the use of tetraethyl lead as an additive in automotive gasoline, a use that actually began on a small scale in the 1920s. Environmental

regulations begun in the mid-1970s have had a clear effect on lowering lead emissions from gasoline and other sources.

Before World War II lead found its way into the environment primarily as an ingredient in exterior paints. (Red lead is still widely used in anticorrosion paint for iron and steel.) As paint ages and weathers, the lead is released into the environment. The larger tonnages of metallic lead—used in automobile batteries, pipes, foils, soldering, sound-proofing, and radiation shielding—did

not actually result in significant losses to the environment except in secondary recovery processes.

In 1899 two refineries—Balbach Metals in Newark, New Jersey, and American Smelting and Refining Company (ASARCO) in Perth Amboy, New Jersey—accounted for 32.5 percent of the total of 222,000 metric tons of refined lead in the United States. Other Hudson-Raritan basin facilities also refined silver and lead, and some engaged in primary smelting as well. These and other metallurgical operations began closing or leaving the region in the 1930s and 1940s. The Balbach plant closed in the 1920s, but the ASARCO lead refinery operated until 1961. These refineries produced significant emissions of lead. Secondary lead recovery is still carried out in a number of small plants in the industrial areas of northern New Jersey and Staten Island.

Core Comparisons

The pilot historical analysis traces the routes of pollutants from their sources to surface waters. There have been other recent advances in techniques to assess pollutants in sediment cores taken from river beds, harbor floors, marshes, and wetlands. Such sediment cores have provided the only long-term historical record of pollutant deposition in the Hudson-Raritan basin. The trick is to find locations where the sediment records are undistorted by natural scouring, by deposition of large amounts of coarse debris, by channel dredging, or by numerous other types of disturbing conditions.

Researchers at the Lamont-Doherty Geological Observatory of Columbia University in the late 1970s performed what appears to be the first reliable core dating in the Hudson basin. They used radionuclide analysis of atmospheric fallout from nuclear weapons testing and of effluents from the Indian Point nuclear power plant (located on the Hudson River about 40 miles north of Manhattan).¹² At sampling sites with favorable conditions, the radioactive tracers can pinpoint sediment deposi-

(continued on page 39)

In balancing the pros and cons of instituting controls, it seems to me that the issue now boils down to one of values more than to information that science can provide. Those who believe that the pride in practicing good stewardship of the environment is worth the monetary costs can demonstrate the reality of adverse environmental effects. Those who insist that more needs to be known before controls are instituted do so because they are willing to take risks with the future environment in order to avoid near-term economic costs. The understanding we have achieved about surface-water acidification has taken 20 years, and details are still lacking on some key questions. It is unlikely that there will be a clear consensus on the questions concerning terrestrial systems in the next 5 or perhaps even 10 years. The clear consensus, however, is that waiting for more answers from scientific investigations will be accompanied by demonstrable environmental costs.

Patterns of Pollution

(continued from page 20)

tion for approximately each year since 1954, the first year there was measurable fallout. The record is very useful to mark the changes in deposition of chlorinated hydrocarbon pesticides, which became popular just before the 1950s. However, even longer sediment histories are needed to trace pollution from heavy metals, major uses of which in some cases go back to colonial times.

Recent radionuclide dating work using naturally occurring lead 210 (with a half-life of 22.3 years) appears to be able to extend the time horizon for core dating back before 1800.¹³ With this approach, cores have so far been dated from two marshes along the Hudson River (about river mile points 100 and 120).¹⁴

Although very few dated cores from the Hudson-Raritan basin exist today,

those that have been dated and analyzed for toxic pollutants reveal tantalizing clues about past pollution. By assessing pollutant deposition in an environmental receptor, or sink, they complement the historical analysis of pollution sources.

Three pollutant examples are presented here. The first (see Figure 6 on page 42) compares the historical input of PCBs into the Hudson-Raritan basin with PCB concentrations in two cores taken from the central Hudson basin (river mile points 52 and 89).¹⁵ As of yet there is no method for relating—with a high degree of confidence—the yearly amount of a substance released into the river to the substance's concentrations in sediments. Hence the comparison is limited to a qualitative look at the historical trends of PCB release from the source to the receptor.

The major historical sources of PCBs in the lower Hudson were two General Electric Company capacitor plants,

NOTES

1. E. Robinson, "Natural Emission Sources," in A. P. Altshuler and R. A. Linthurst, eds., *The Acidic Deposition Phenomenon and Its Effects. Critical Assessment Review Papers*, vol. 1, *Atmospheric Sciences* (Washington, D.C.: Environmental Protection Agency, 1984).
2. U.S. National Research Council, *Acid Deposition: Atmospheric Processes in Eastern North America* (Washington, D.C.: National Academy Press, 1983).
3. U.S. National Research Council, *Acid Deposition: Long-Term Trends* (Washington, D.C.: National Academy Press, 1986). Copies are available from National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.
4. The model used followed the work of F. Mosteller and J. W. Tukey, *Data Analysis and Regression: A Second Course in Statistics* (Reading, Mass.: Addison-Wesley, 1977).
5. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors*, AP-42, 3rd ed. (NTIS PB-275525), Supplements 1-7 and 8-14 (Springfield, Va.: National Technical Information Service, 1977).
6. The first four bulleted items represent the language of the report, the last two are paraphrases by the author.
7. U.S. National Research Council, note 2 above.
8. U.S. National Research Council, *Acid Deposition: Processes of Lake Acidification* (Washington, D.C.: National Academy Press, 1984).
9. J. R. Kramer and A. Tessier, "Acidification of Aquatic Systems: A Critique of Chemical Approaches," *Environmental Science & Technology* 16(1982):606A-615A.
10. U.S. National Research Council, note 2 above, 287-289.

FIGURE 3. Land use in the Hudson-Raritan basin.

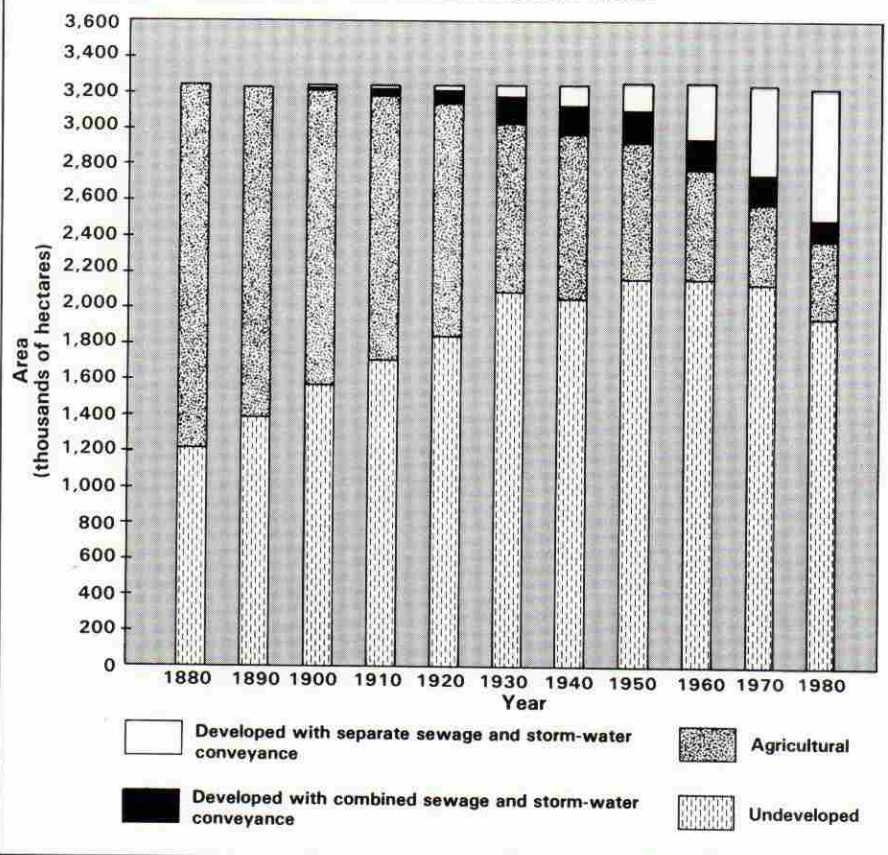


FIGURE 4. Annual mercury emissions in the Hudson-Raritan basin, 1880-1980.

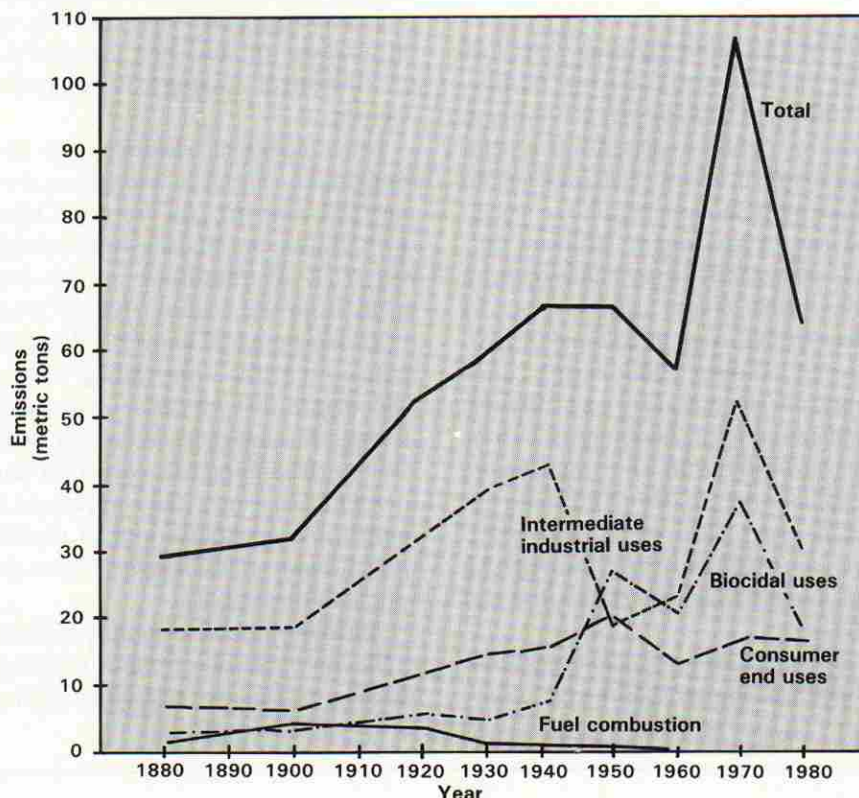
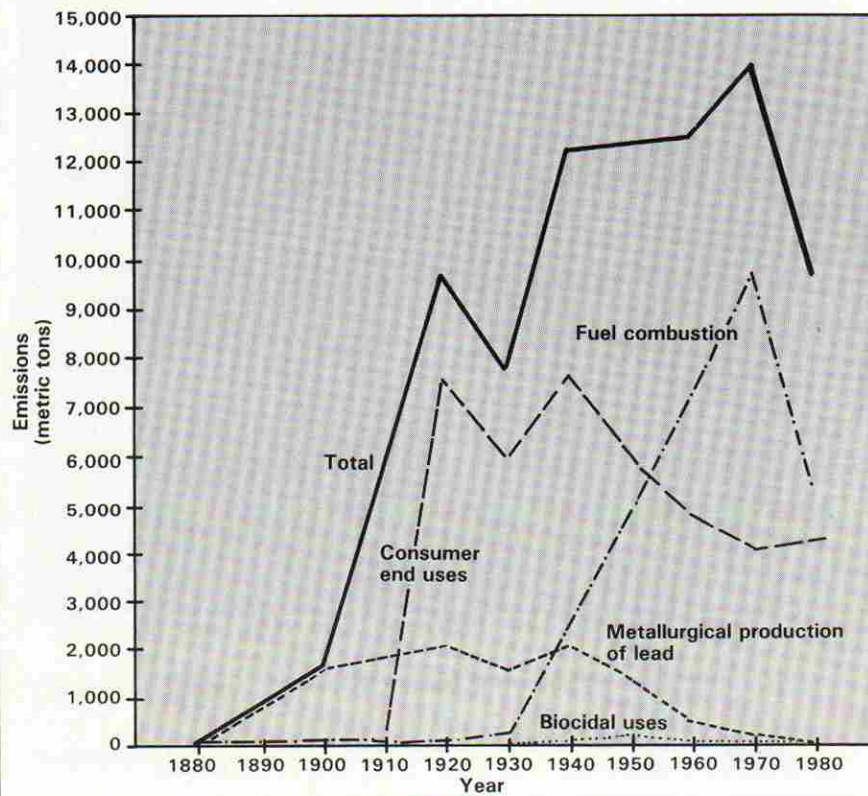


FIGURE 5. Annual lead emissions in the Hudson-Raritan basin, 1880-1980.



both upstream from Albany and well upstream from the core locations. Until 1973 most of the PCBs released were trapped in sediments behind the dam at Fort Edward, New York, between the General Electric plants and the core sites. In 1973 that dam was removed, resulting in a large inadvertent release of PCBs downstream. The benchmark year of 1973 revealed such a clear PCB peak on all records that it can be used as the reference point to normalize the curves for earlier and later years.

From 1960 to 1977 (the year the sample cores were taken) the profiles of both estimated releases and sediment deposition coincide, giving at least a qualitative feeling of confidence in the validity of the methods involved. At this time it is impossible to say why emissions of PCBs before 1960 do not seem to show up in the downstream sediments. Are releases from early periods overestimated? Were the early river inputs held up behind the Fort Edward dam? More research is needed to resolve these questions.

As well, estimates of historical mercury and lead run-off have been compared with estimates of mercury and lead deposition taken from the same core (from Tivoli marsh at river mile 100)¹⁶ that has been dated back to the early 1800s (see Figures 7 and 8 on pages 42 and 43). The year 1980 was selected as the benchmark for normalizing the plots because sharp coincident peaks do not exist in the metals data. Having normalized the two curves at 1980, the remainder of the historical profiles seem to match fairly well, given that the single core used could be susceptible to local effects while the run-off estimates are averaged over the entire Hudson-Raritan basin.

A Whole-Basin Perspective

Reliable information on past as well as present pollution is essential for understanding long-term environmental trends and for establishing technically sound policy for resource management in the Hudson-Raritan basin. The historical data are needed because significant fractions of current river loads

of many contaminants are actually delayed releases from past production, use, and disposal activities. It is clear that historical studies are important in identifying long-term relationships between human activities and conditions in the ecosystem. However, the relevance of the historical materials-balance approach to questions of river policy may need more discussion.

Many studies have already been performed on specific ecological niches in the Hudson-Raritan basin. The bulk of the work, though, has been on a micro-scale and has relied on large numbers of field measurements. While these studies are vital to understanding the complex relationships and mechanisms operating in the basin, they are conducted on a scale inappropriate for answering broader policy questions for the region as a whole. A different and more aggregated level of resolution is appropriate for research addressing regional policy issues.¹⁷

As examples, two recent studies have scrutinized pollution run-off from local urban and suburban watersheds at a resolution of a few hectares.¹⁸ As comprehensive as these studies were, they could not stand alone in terms of assessing pollutant loadings into New York Harbor because they neglected to consider the effects of several of the relevant sources, including the entire upper Hudson River and the drainage basins in New Jersey.

The historical materials-balance method is tailored to a whole-basin perspective; it is designed to help address broad policy questions.¹⁹ Supporting data (weather and point discharges, for example) for historical work and the level of detail of mass transport models are averaged on a whole-basin scale as well. But although basinwide policy-making employs macroscale models and data averaging, most of the parameters in the macroanalysis are likely to be derived from the microscale studies. Erosion, aerosol dispersion and deposition, averaged rainfall values, and other data are all derived from studies of small areas. Thus the large-scale analysis depends on fine-scale data and models.

TABLE 5
MAJOR USES OF METALS, 1880-1980

METAL	1880s-1920s	1930s-1950s	1960s-1980s
ARSENIC	Biocides agricultural ^a nonagricultural ^b Glass and ceramics	Biocides agricultural nonagricultural	Biocides nonagricultural agricultural
CADMIUM	Paint and pigment	Plating ^c Paint and pigment Alloys Photography and lithography	Plating Batteries Paint and pigment Plastic stabilizer
CHROMIUM	Paint and pigment Leather tanning	Paint and pigment Plating Tanning Alloys	Alloys and miscellaneous metallic uses Paint and pigment Plating Tanning Oil-drilling mud Wood preservative
COPPER	Metallic uses: architectural brass and alloys plumbing electrical Biocides agricultural	All metallic uses Biocides agricultural Catalysts Paint and pigment	All metallic uses Biocides agricultural Industrial fungicide Antifoul paint Wood preservative Catalysts
LEAD	Metallic uses: architectural plumbing soldering Paint and pigment Batteries	All metallic uses Batteries Paint and pigment Gasoline additive Biocides	All metallic uses Batteries Gasoline additive Paint and pigment
MERCURY	Medical ^d Biocides nonagricultural Electrical instruments Paint and pigment Wool and felt anti-bacterial agent Batteries Mirrors	Batteries Medical Electrical instruments Catalysts Biocides agricultural nonagricultural Dental alloys	Electrolytic chlorine products Antimildew and marine paint Batteries Electrical instruments Medical and dental uses Catalysts
SILVER	Silverware Jewelry Coinage Photography	Silverware Jewelry Photography Coinage Electrical equipment Soldering and brazing Mirrors	Photography Electrical equipment Silverware, coins, and jewelry Soldering and brazing Catalysts Batteries
ZINC	Galvanizing Metallic uses Paint and pigment Catalysts Brass and alloys	Galvanizing Metallic uses Paint and pigment Rubber vulcanizing Rayon processing	Metallic uses Galvanizing Paint and pigment Process chemical: rubber floor covering textiles photocopying Motor oil additive

Note: Uses are listed in order of decreasing amounts (metric tons per year) consumed during the time period.

^aBiocides (agricultural): Agricultural insecticides, herbicides, and fungicides

^bBiocides (nonagricultural): Pesticides for all nonagricultural applications excluding medical uses

^cPlating: Electroplating and related protective cover processes

^dMedical: Medical, dental, and pharmaceutical uses

RCRA and the Rivers

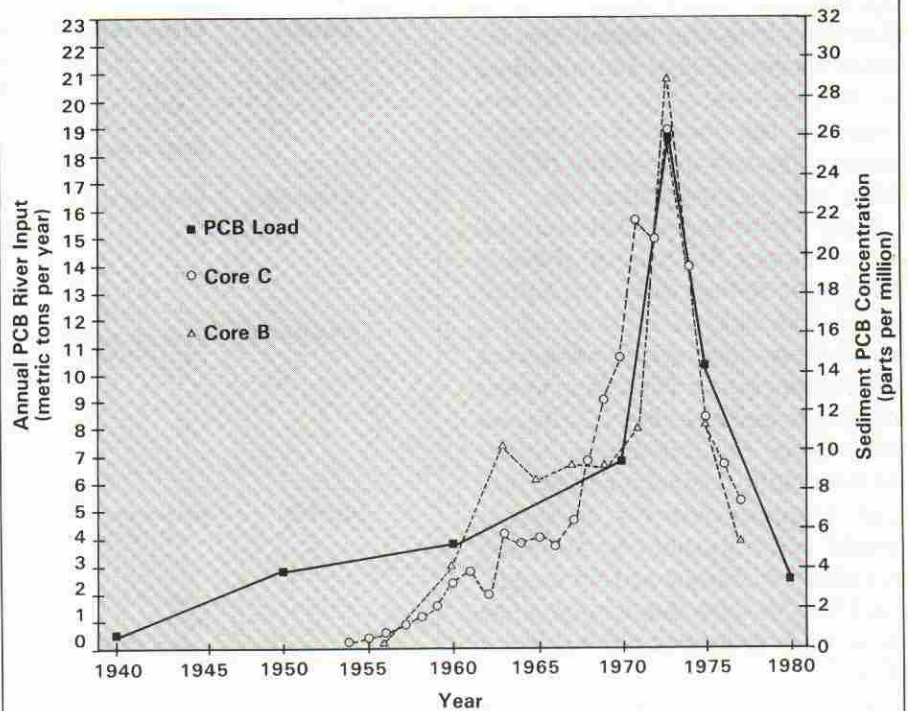
As one example of a regional policy issue, the results of the pilot Hudson-Raritan basin historical study can be applied to predict some effects of soon-to-be implemented environmental laws. The Hazardous and Solid Waste Congressional Amendments of 1984 (also known as the Resource Conservation and Recovery Act, or RCRA, reauthorization) will become law in September 1986. The new small-quantity generator rules will have widespread economic impacts on small businesses—from dry cleaners to motor freight terminals—in the Hudson-Raritan basin.²⁰ Those generating over 100 kilograms but less than 1,000 kilograms per month of any of the RCRA-listed hazardous materials will be subject to the reporting, shipping, and manifesting requirements now applied only to larger generators.

Will the new rules lead to significant improvements in the condition of the Hudson-Raritan basin and the health of its marine and human inhabitants? We can infer from basinwide historical evidence that for many specific pollutants the answer is yes. But for a few contaminants, such as PCBs and persistent pesticides, the new rules will not lead to significant improvements because their principal sources are not addressed by the regulations.

Levels of nearly all important pollutants have declined in New York Harbor under the environmental laws of the 1970s.²¹ The large generators of wastes appear to have been regulated about as far as is practical considering costs versus benefits. The next step in reducing pollution under the new laws may have to emphasize regulating the end uses of various pollutants. As shown by the materials-balance analysis, such uses are now the major sources of many critical contaminants.

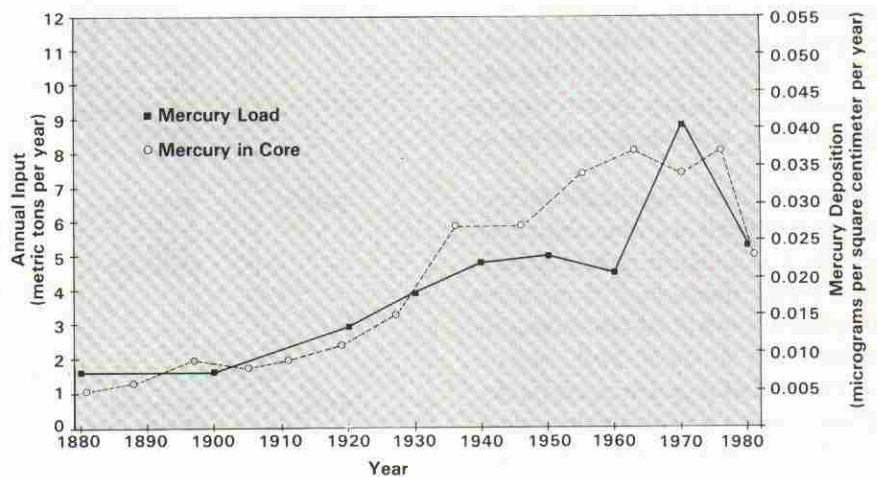
For the metals arsenic, chromium, mercury, lead, silver, and zinc, dissipative consumer end uses are now the dominant sources of river inputs. In addition, for cadmium and copper particularly and for the other metals to a lesser extent, natural metal sources and remobilization (from possible leaching

FIGURE 6. Comparison of historical Hudson-Raritan river loading with sediment concentration: PCBs.



Note: Lines linking point estimates are for clarity only. They should not be used for interpolation.

FIGURE 7. Comparison of Hudson-Raritan river loading with sediment concentration: Mercury.



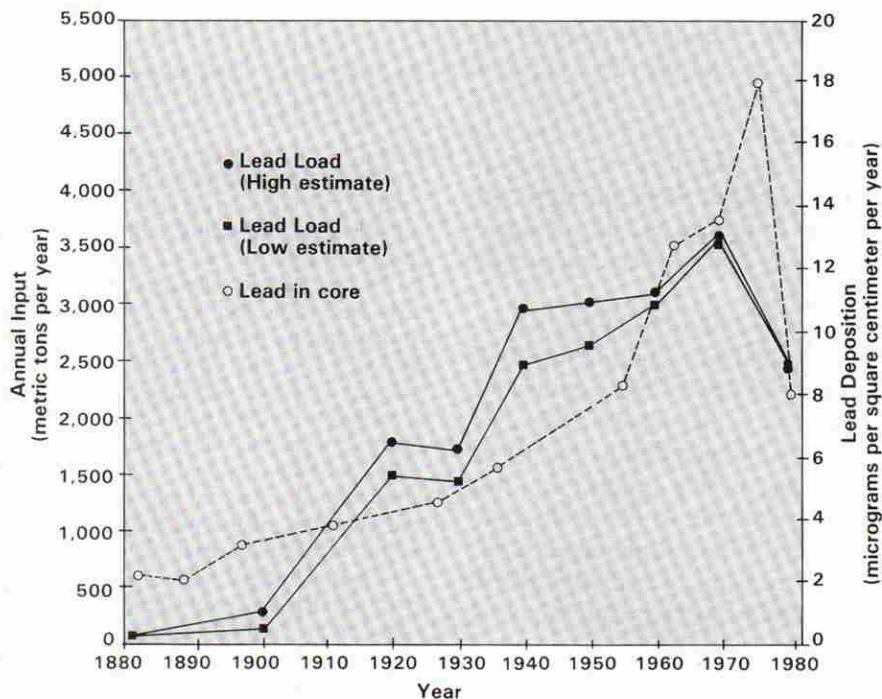
Note: Lines linking point estimates are for clarity only. They should not be used for interpolation.

and erosion of old disposal sites) of historical wastes may contribute large fractions into the river; these sources also remain unregulated.

For currently used pesticides, the new RCRA rules will probably lead to some

environmental improvements, but for pesticides applied in the past, residues of which contribute to current pollutant loads, the rules will have no effect. River loadings of persistent chlorinated pesticides can be seen to be decreasing,

FIGURE 8. Comparison of Hudson-Raritan river loading with sediment concentration: Lead.



Note: Lines linking point estimates are for clarity only. They should not be used for interpolation.

and will continue to decline. This is not, however, a result of the latest round of regulations. It is essentially attributable to outright bans on most uses of these pesticides in the 1960s and early 1970s. For certain other stable (metals) or persistent (PCBs) contaminants, a significant reservoir of potentially leachable material remains in slag-heaps or dump sites from past production, use, and disposal. In such cases visible improvements in the ecosystem from any new remedial actions may be slow to appear.

The historical materials-balance studies that have been performed so far reveal new insights about the complex network between old pollution sources and the ultimate fate of the contaminants released into the Hudson-Raritan basin. The high copper loadings, for instance, appear to be derived from bulk disposal of refinery slag. Current and historical source identification and emissions estimates, when compared with recent DEP measurements of copper concentrations in local water columns and sediments, point to areas

around Staten Island and in the Upper East River as likely locations of as yet unidentified copper smelting and refining slag-sites.

Still, more quantitative studies of long-term releases from present and past nonpoint sources are needed to fill in the tentatively sketched networks of pollution release and transport. Some new analytical tools are now in hand to make the job easier.

NOTES

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14. K. Stevenson, U.S. Geological Survey, Albany, N.Y., telephone conversation with authors, 12 March 1986, and W. R. Schell, School of Public Health, University of Pittsburgh, private communications with authors, February-March 1986.
15. PCB inputs for the basin are from Ayres et al., note 6 above. Core analysis is from Bopp et al., note 12 above.
16. Stevenson and Schell, note 14 above.
17. Joel S. O'Connor and David A. Flemer, "Monitoring, Research and Management: Integration for Decisionmaking in Coastal Marine Environments," in T. P. Boyle, ed., *Symposium on Monitoring in Aquatic Ecosystems* (Philadelphia: ASTM, in press).
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19. The contemporary pollutant study of Mueller, Gerrish, and Casey, note 1 above, and the historical pollutant reconstruction of Ayres et al., note 6 above, can be considered as two complementary data bases needed to address basinwide waste management policy.
20. Other businesses affected include: textile manufacturers, furniture manufacturers, printers, paper industries, cosmetic manufacturers, cleaning-product manufacturers, education and vocational shops, laboratories, chemical manufacturers, pesticide formulators, equipment repair shops, vehicle maintenance shops, construction companies, metal fabricators, leather-processing shops, wood preservers, and pesticide application services.
21. DEP, note 3 above.

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