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The Tainted River: A Review of Polychlorinated Biphenyl (PCB) Pollution in the Hudson River

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ABSTRACT

The Hudson River has been severely contaminated by polychlorinated biphenyls (PCBs) as a result of industrial pollution over several decades. Despite significant remediation efforts PCB contamination persists, posing ongoing risks to the river's ecosystem and nearby communities. This review explores the history of PCB pollution in the Hudson River, its environmental and human health impacts, and the effectiveness of past and present remediation efforts. While progress has been made, PCB levels remain alarmingly high in fish and sediments, especially in the Upper Hudson. The paper also highlights the challenges faced by vulnerable populations who continue to rely on the river in spite of advisories against consuming contaminated fish. In addition to examining past efforts, this review introduces emerging bioremediation technologies which offer promising, cost-effective alternatives to dredging. This paper addresses the shortcomings of current strategies and explores novel solutions, emphasizing the need for continued monitoring, public awareness, and investment in new technologies to restore the health of one of New York's most iconic waterways.

Introduction

The Hudson River is a 315-mile-long river in New York State that starts at Lake Tear of the Clouds in the Adirondack mountains and ends in Manhattan, New York City where it meets the Atlantic Ocean. The river was named after British explorer Henry Hudson, who navigated its waters looking for a northwest passage in 1609. In the eighteenth and nineteenth centuries, it served as a critical transportation route during the Industrial Revolution. Long before Henry Hudson, dozens of native American tribes lived along the banks of the river for thousands of years. Once a source of food for many communities and home to a thriving fishing industry, the river has transformed into a danger zone for wildlife and humans alike in the past few decades.[1] Today, the Hudson River remains vital to the region's biodiversity, recreational activities, and tourism, making its ongoing contamination an urgent environmental and public health concern.

Over the course of thirty years, General Electric (GE) dumped over a million pounds of polychlorinated biphenyls (PCBs) into the Hudson River from two manufacturing plants north of Albany, NY.[2,3] PCBs were used for fire prevention and insulation in the devices that GE manufactured, and their ability to withstand extremely high temperatures made them valuable in the production of electrical components such as transformers and capacitors. Defined by the Environmental Protection Agency (EPA) as "man-made organic chemicals consisting of carbon, hydrogen, and chlorine," PCBs have caused long-lasting environmental damage both in and around the Hudson. GE stopped using them when the use of PCBs was banned in 1977, but left behind a highly damaged river, which has remained contaminated to this day despite extensive cleanup efforts. PCB contamination in the Hudson remains a significant environmental and public health issue, with ongoing risks to aquatic life and communities reliant on the river's resources.

This review paper provides a comprehensive overview of the history of PCB pollution in the Hudson and its impact on the ecosystem, and highlights the ongoing challenges and emerging remediation technologies that hold the potential for more effective and sustainable solutions.

PCBs and the Health of the River

Composition and Uses of PCBs

PCBs are obtained from oil and tar, from which benzene is extracted, and then transformed into biphenyl, which is then chlorinated to polychlorinated biphenyl. The chemical structure is characterized by the presence of two aromatic rings on which there are 1 to 10 chlorine atoms. PCBs are characterized by very high chemical stability, low flammability, and resistance to thermal degradation. Due to these characteristics, they were widely used in industrial applications such as sealants, inks, carbon paper, paint additives, and in particular, refrigerants and lubricants in closed electrical equipment, such as electrical transformers and capacitors. PCBs are a "forever chemical" - they don't break down and can cycle between the air, soil, and water.

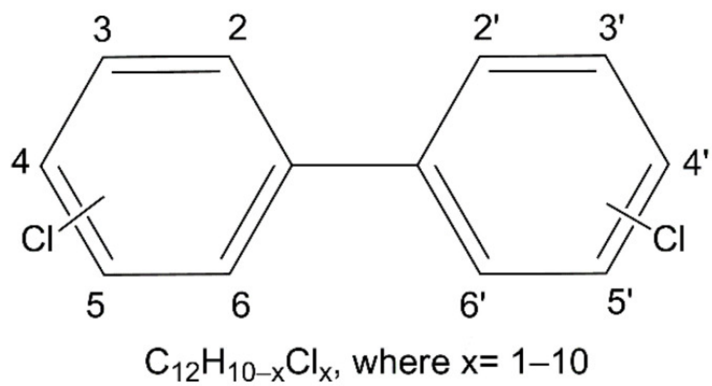

Figure 1. General structure and formula of PCBs. Chlorine atoms can replace hydrogens in different positions of the aromatic rings.[4]

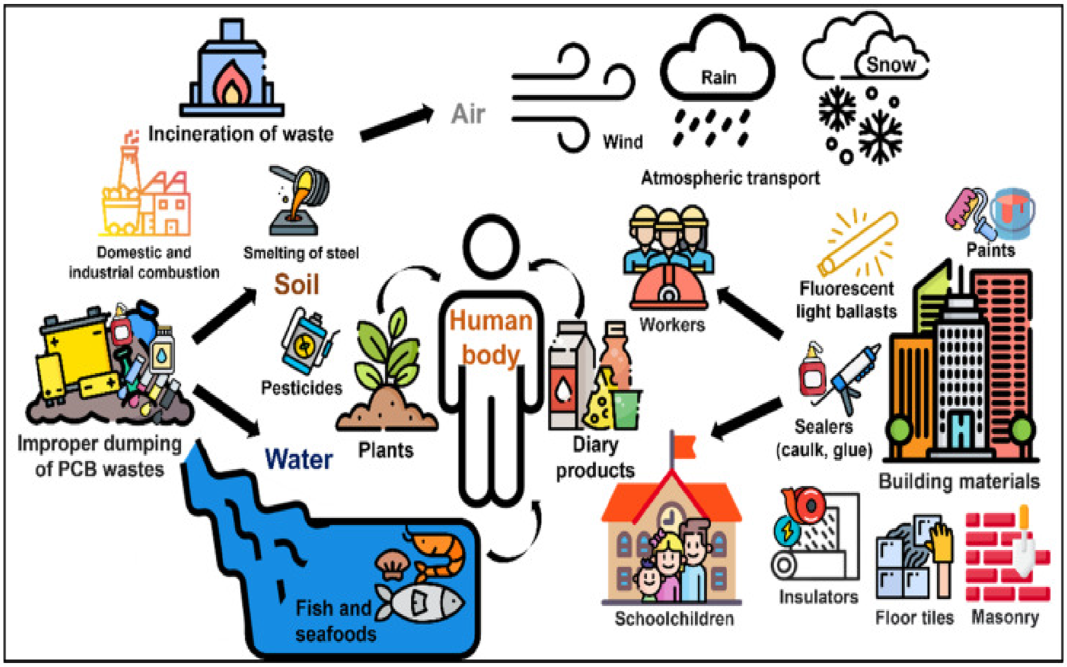

Figure 2. PCB sources and routes for human exposure.[4]

History of PCB Pollution in the Hudson

While PCBs were useful for industrial purposes, their stability and resistance to degradation have made them a persistent pollutant in the environment. From 1947 to 1977, General Electric dumped approximately 1.3 million pounds of PCBs into the Hudson River from its manufacturing plants in Fort Edward and Hudson Falls, NY impacting wildlife, the water and sediment, and residents living near the river. In 1969, PCBs were detected in fish swimming in the river. Following the removal of the Fort Edward Dam in 1973 and the subsequent flooding, much of the PCB-contaminated sediments moved downstream. In 1975, the New York State Department of Health (NYSDOH) began to issue advisories to limit eating fish from the Hudson River. The New York State Department of Environmental Conservation (NYSDEC) filed a lawsuit against GE for PCB pollution. By 1976, NYSDEC had banned all fishing in the Upper Hudson and most commercial fishing in the Lower Hudson. Between 1976 and 1984, the NYSDEC identified 40 “hotspots” with average total PCB concentrations over 50 parts per million (ppm). The manufacture and sale of PCBs were prohibited in 1977, causing GE to stop using PCBs. However, PCBs continued to pollute the river due to bedrock fractures at the Hudson Falls plant.[5]

Environmental and Health Impacts of PCBs

Human Health Risks

Numerous studies have highlighted the harmful effects of PCBs on human health. Exposure to high concentrations of PCBs has been associated with neurophysical and neurological deficits, dementia, immune system dysfunctions, cardiovascular diseases and cancer. Studies have indicated harmful effects on the thyroid function, as well as increasing the risk to women of giving birth to infants of low birth weight with high lifetime risk of many diseases.[6] The primary exposure route to PCBs for humans is the consumption of contaminated food, mainly fish and other seafood.

A secondary route for PCB exposure is inhalation of contaminated air. PCBs can be released into the air from water bodies such as rivers via evaporation.

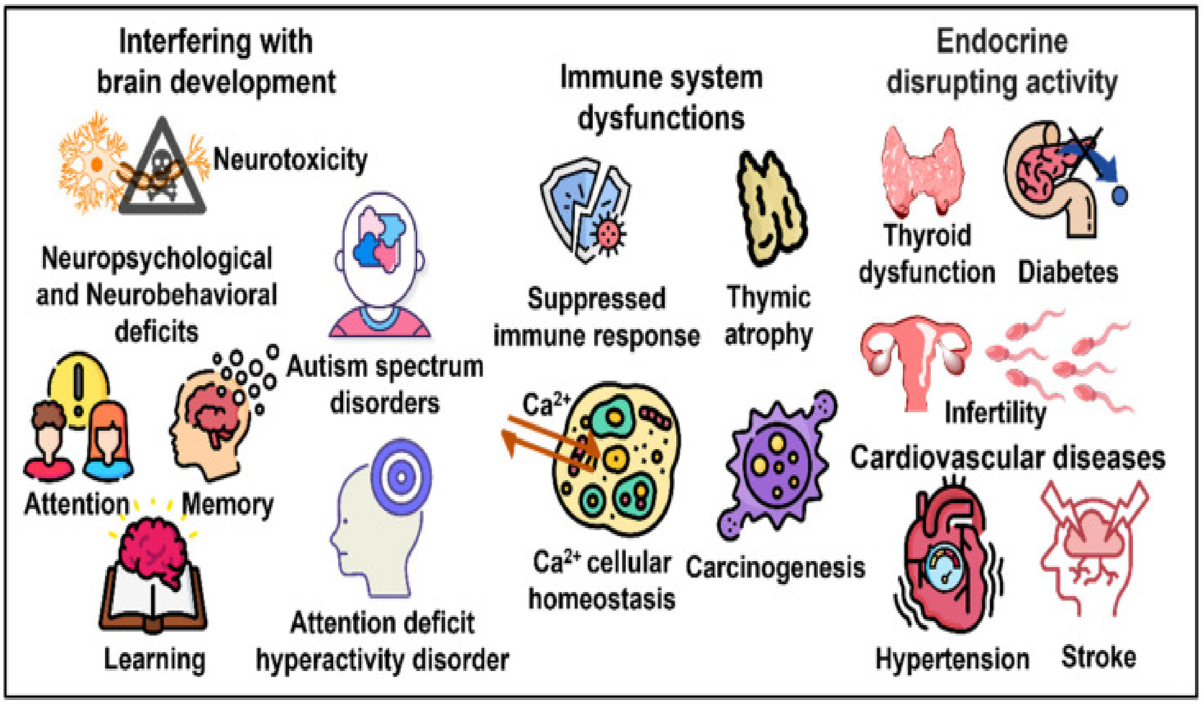

Figure 3. Representation of the main targets of PCBs with related disorders in humans.[4]

Bioaccumulation and Biomagnification of PCBs

PCBs build up in living organisms both via uptake from the environment (bioaccumulation) and along the food chain (biomagnification). The degree of PCB bioaccumulation over time depends on how quickly they are taken up and eliminated by the organism, and on the ability of the organism to break down PCBs. Biomagnification is a process in which a chemical compound accumulates through the food chain from lower concentrations in prey species to higher concentrations in predatory species. In humans, the concentration of PCBs in fatty tissues is over a hundred times greater than in the food they eat.[7,8]

PCBs in Hudson River Wildlife

A number of researchers have studied the impact of PCBs in Hudson River wildlife, including fish, mink, bullfrogs, snapping turtles and birds. Fish absorb PCBs directly from the water and are also exposed via ingestion of contaminated prey such as insects and smaller fish. Contaminated fish can, in turn, be eaten by birds, wildlife and humans. In the 1970s, several Hudson River largemouth bass fillets were contaminated at levels in excess of 2,000 ppm.[9] After 1977, when GE stopped direct discharges of PCBs to the river, PCB levels in Hudson River fish dropped considerably but since the early 1980s have generally remained stable at relatively high levels. Sampling results indicate that PCB concentrations in fish tend to be highest in the Upper Hudson downstream of the GE plants at Hudson Falls and Fort Edward, and generally decline with increasing distance down the river. The U.S. Food and Drug Administration (USFDA) does not permit the commercial sale of fish with PCB levels above 2 ppm, and the Environmental Protection Agency (EPA) has their remedial action objective (RAO) set at 0.5 ppm. Fish collected in the Upper Hudson between

2000-2008 were found to have PCB levels exceeding the EPA limit in approximately 75-90% of largemouth bass, smallmouth bass, brown bullhead and yellow perch fillet.[8] More recent studies have indicated that PCB contamination of fish has remained a persistent problem, despite extensive cleanup efforts.[10]

In another study, the concentration of PCBs was examined by analyzing the fat and muscle tissues of mallards, both upstream and downstream of the GE plants. It was found that the concentration of PCBs was significantly higher in muscle tissues of mallards living downstream, areas that were highly polluted by the GE plants, compared to those living upstream. Over 90% of the downstream ducks had PCBs in excess of levels recommended by the USFDA in poultry.[11]

Impact On Communities Surrounding the Hudson

The issue of PCB contamination in the Hudson River is not only an environmental crisis but also a clear example of environmental injustice. Marginalized communities, particularly low-income, immigrant, and minority groups, are disproportionately affected by the pollution. The bioaccumulation of PCBs in the Hudson and the subsequent ban on fishing wiped out a major source of food and subsistence for nearby communities – many of whom representing low income, immigrant and minority communities. Despite a multi-year initiative by the New York State Department of Health (NYSDOH) to warn anglers about the dangers of eating contaminated fish, consumption of fish from the Hudson has continued, particularly among certain socioeconomic groups. The results of one survey[12] showed that Latino anglers reported the highest rate of fish consumption (64%), followed by African Americans (41%). Over 60% of fish consumers with household incomes between 25K and 50K reported eating fish in quantities exceeding NYSDOH recommendations.

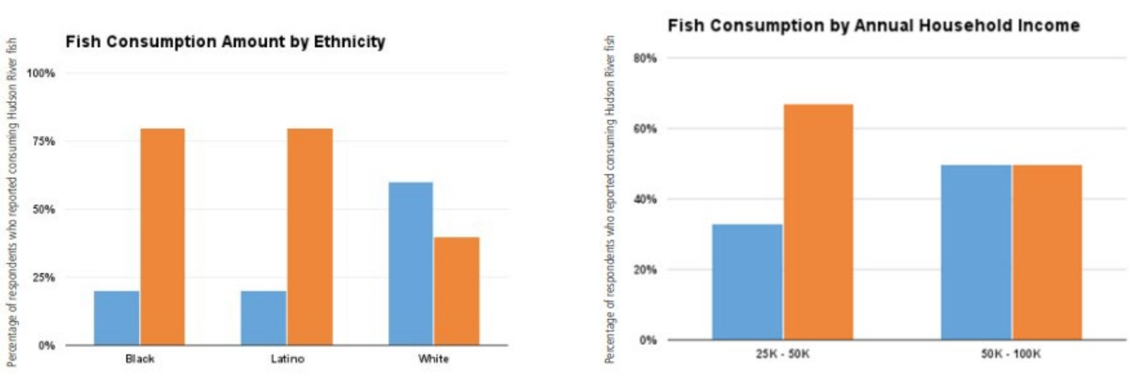

Figure 4. Current fish consumption trends by ethnicity and annual household income when compared to NYSDOH recommended portion size of 8 ounces.[12]

The awareness gap regarding the dangers of consuming fish from the Hudson River is particularly alarming among younger individuals, unlicensed fishers, and those with lower levels of education. A 2023 study found that the mean age of people who were unaware of the NYSDOH advisories were on the younger side (20s and 30s). There are many examples of specific demographics who were less likely to be aware of the "Do Not Eat" advisories. Of the unlicensed fishers, only 50% of them were aware of the advisories compared to the 82% of licensed fishers. People in the study who did not finish high school were overrepresented in the "unaware" or "not sure" categories.[12] This presents a strong need to raise awareness of PCBs in the Hudson, as they are harming marginalized communities simply because they are not familiar with the dangers. Public health initiatives need to be more targeted and culturally responsive, including outreach efforts in multiple languages, collaboration with community organizations, and the use of social media to reach younger audiences. Additionally, educational programs in schools and local community centers could help increase awareness around the risks associated with PCB exposure.

Remediation Efforts

Dredging and Monitoring the Hudson

The Hudson River's contamination with PCBs led to the designation of a 200-mile stretch as the largest Superfund site in the United States. In 2002, the EPA issued a Record of Decision (ROD) mandating the removal of PCB-contaminated sediment through targeted dredging.[1] Between 2009 and 2015, General Electric, under EPA supervision, dredged approximately 2.75 million cubic yards of contaminated sediment from a 40-mile section of the Upper Hudson River. Following this, habitat restoration efforts, such as the replanting of aquatic vegetation, were initiated. Although these actions reduced PCB levels in certain areas, the extent of contamination remaining in river sediments post-dredging has exceeded initial estimates, highlighting ongoing environmental risks.

The project has subsequently transitioned to a long-term monitoring phase, which involves regular assessments of water, sediment, and fish to evaluate the river's recovery. The EPA is required to conduct a study on the river every 5 years due to federal Superfund law, and as such announced in April 2022 that they were going to begin their third Five Year Review.[10] There are also organizations working to clean the Hudson that have made good progress. The Hudson River Natural Resource Trustees, for example, monitor the river regularly. The studies, tests, and cleanups on the river have mostly been conducted in the Upper Hudson River, and organizations like Riverkeeper have been pressing the EPA to expand to the lower part of the river. The Lower Hudson is a tidal estuary, unlike the Upper Hudson, which is freshwater and non-tidal. As such, it has different water flow patterns and ecological characteristics, and therefore may be impacted differently by PCBs. In the spring of 2023, the EPA began a long-awaited investigation of the Lower Hudson River under a 2022 agreement with GE.[15] GE is working with the EPA to sample water, fish and sediment from this part of the river and determine next steps once the evaluation is completed in 2025.

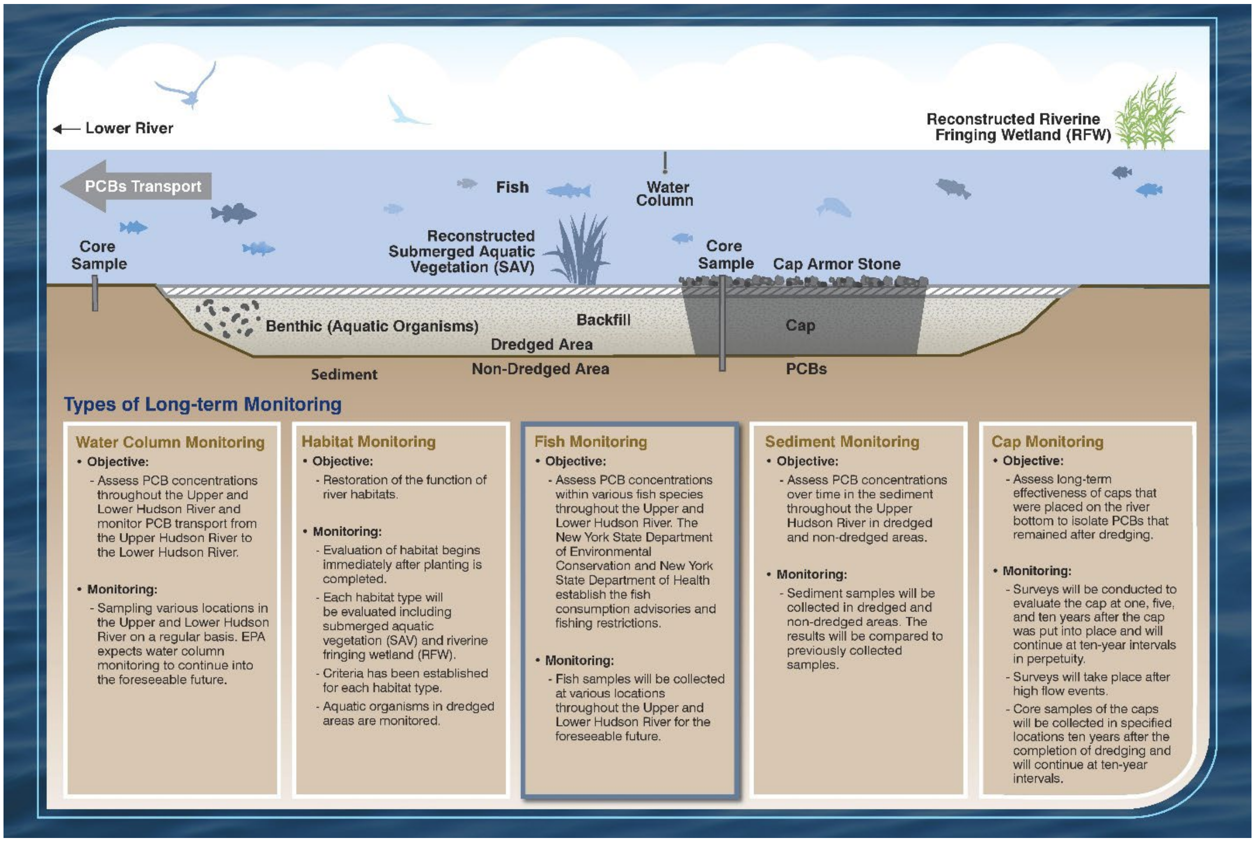

Figure 5. EPA long-term river monitoring program.[1]

Despite all the collective cleanup efforts to date, the river still poses risks to human health and the environment. Significantly more PCBs remain in the river sediment post-dredging than were originally estimated, and the EPA is now relying on institutional controls like fish consumption advisories to mitigate risks to human health.[10]

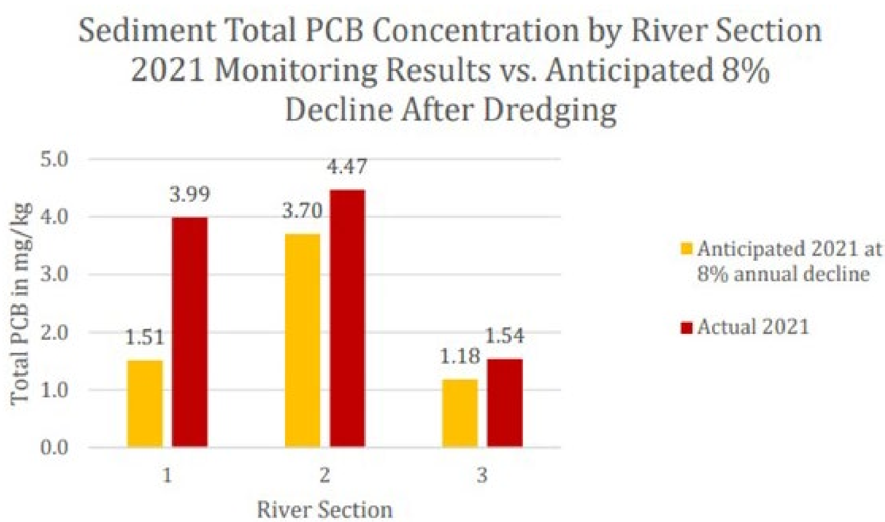

Figure 6. Total PCB Concentrations in Sediment by River Section: Sediment Sampling Results EPA Anticipated for 2021 Compared to the Actual Sediment Sampling Results Collected in 2021. The 8% rate of decay is the rate the EPA

anticipated in the 2002 ROD. The projected 8% rate of decay is based on data collected in 2016/2017 (first year after dredging) as the baseline year.[10]

Recent Technological Advances

In recent years, researchers have been developing lower cost solutions to the PCB contamination problem, relative to dredging. One such potential solution, developed at the University of Maryland, Baltimore County, uses activated carbon in the form of specialized pellets to bind to PCBs and reduce their bioavailability, or uptake by fish and other aquatic organisms. The technology can also be combined with microbes that break down PCBs, reducing their toxicity.[13]

Bioremediation methods include the use of specialized microorganisms to accelerate naturally existing biodegradation processes, which have shown significant potential as an economical and environmentally sustainable solution to PCB pollution. These microbes can be engineered to dechlorinate biphenyl rings utilizing either one of two degradative processes, aerobic degradation or anaerobic reductive dehalogenation, depending on the level of chlorination and the position of chlorine atoms on the biphenyl rings.[16] Genetically engineered microorganisms (GEMs), created using genetic engineering by modifying protein strains to overexpress the desired characteristics, have been shown to be effective and environment friendly. Suicidal-GEMs" (S-GEMs), a recent invention on recombinant DNA technology, can help to attain eco-friendly and potential bioremediation of polluted areas.[17]

These emerging bioremediation techniques have not yet been implemented to specifically address PCB pollution in the Hudson, but show significant potential as a long-term solution to the issue.

Conclusion

PCB contamination in the Hudson River, primarily due to industrial discharges by General Electric, has left a lasting impact on the river's ecosystem and the surrounding communities. Over decades, these toxic chemicals have caused significant harm to aquatic life and human health, with bioaccumulation in fish leading to increased risks for populations that rely on the river for food. Despite extensive remediation efforts, PCB levels remain alarmingly high in fish and sediments, and therefore continue to pose grave environmental and public health threats.

The remediation efforts undertaken to date, including dredging and habitat restoration, have reduced some contamination, but they have not eliminated the problem. Ongoing monitoring has revealed that the rate of recovery has been slower than expected. Further attention is needed to protect vulnerable populations, in particular marginalized communities who disproportionately suffer the effects of PCB exposure. The new investigation into the Lower Hudson presents an opportunity to extend the cleanup and address the contamination more comprehensively.

Looking ahead, continued monitoring, public awareness campaigns, and expanded regulatory measures are essential for safeguarding the health of both the river and communities that depend on it. Further research into innovative remediation technologies, such as bioremediation with genetically engineered microorganisms, could offer more sustainable and cost-effective long-term solutions. It is critical for policymakers, environmental agencies and industry stakeholders to collaborate on advancing cleanup efforts and investing in technologies that will permanently address the contamination. Raising awareness in affected communities, particularly through targeted outreach and education, needs to be a key priority in reducing exposure risks. Only with sustained commitment, investment, and innovative solutions can the Hudson River be fully restored for future generations.

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